UNIVERSITY OF FORESTRY
FACULTY OF FOREST INDUSTRY

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ФАКУЛТЕТ ГОРСКА ПРОМИШЛЕНОСТ

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INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN
INNO 2022
3–5 October 2022, Hotel Rila, Borovets, Bulgaria

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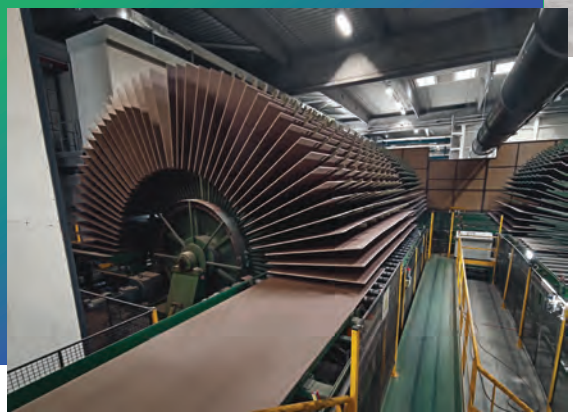
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•Since its establishment, BBCWFI has put great effort into increasing the quality of professional education in Bulgaria as a long term, sustainable solution to the trained personnel shortage.

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Единадесетата международна научно-техническа конференция ИНОВАЦИИ В ГОРСКАТА ПРОМИШЛЕНОСТ И ИНЖЕНЕРНИЯ ДИЗАЙН се провежда с подкрепата на ФНИ, в рамките на Договор № КП-06-МНФ/10 от 20.07.2022 г.
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NATURAL WOOD STAIN IN THE DESIGN FOR CHILDREN

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ABSTRACT

Colour is an important and indispensable part of man's material environment. Thousands of years humans have sought technologies to extract dyes from various natural sources and use them for colouring. In the process of industrial development, artificial dyes were rapidly and massively entering the market and natural pigments are forgotten, losing their attractiveness. Nowadays there is a reviving in colouring with natural materials. Old recipes are being searched for and discovered, different natural ingredients are being experimented with, the possibilities of use unexplored and unknown raw materials are being a subject of research. The most popular fields, where these researches are useful, are fabric dyeing, tinting paints and plasters, Easter eggs and cooking. Wooden materials could also be treated with natural pigments derived from vegetable, animal or mineral sources. The report discusses the background to the research and development of natural dyeing techniques and their applicability in the context of design for children's environments. The research results presented are about the possibilities of achieving colourfulness using natural sources. An analysis is made of the functional, aesthetic qualities, health aspects of natural pigments and their importance in contemporary design.

Key words: colorfulness using natural sources, natural dyeing techniques, natural pigments.

ОЦВЕТЯВАНЕ НА ДЪРВЕН МАТЕРИАЛ С НАТУРАЛНИ ПИГМЕНТИ ЗА ЦЕЛИТЕ НА ДИЗАЙНА ЗА ДЕЦА

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РЕЗЮМЕ

Цветът е важна и неизменна част от материалната среда на човека. Хилядолетия наред хората са търсели технологии за извличане на багрила от различни природни източници и са ги ползвали за оцветяване. С развитието на индустриите, бързо и масово навлизат изкуствените оцветители, а естествените пигменти са позабравени и губят своята атрактивност. В днешно време интересът към багренето с естествени материали се възражда. Търсят се и се откриват стари рецепти, експериментира се с различни натурални съставки, проучват се възможности за приложение на неизследвани и непознати суровини. Най-голяма популярност тези търсения намират в областта на багренето на тъкани, тонирането на бои и мазилки, също така на великденски яйца и в кулинарията. Дървените материали също подлежат на третиране с естествени пигменти, извлечени от растителни, животински или минерални източници. В доклада се разглеждат предпоставки за проучване и развитие на техниките за естествено боядисване, както и приложимостта им в контекста на дизайна за детска среда. Посочват са резултати от изследване на възможности за постигане на цветност при използване на природни източници. Анализират се функционалните, естетически качества, здравословни аспекти на естествените пигменти и актуалността им в съвременния дизайн.

Ключови думи: боядисване с естествени материали, натурални пигменти, естествени багрила.

УВОД

Хилядолетия наред хората са оцветявали различни материали, използвайки съществуващите в природата пигменти. С тези средства те са постигали невероятни като качество и устойчивост цветове, както и разнообразни и хармонични колоритни комбинации. Днес, интересът към природните оцветители се възражда и специалисти в различни области на дизайна и изкуствата се обръщат към тези стари технологии, търсейки естествени и безопасни източници на цветове.

Като изключително значим може да се определи стремежът за използване на безвредни оцветители в изделията и средата, предназначени за деца. Това е област в съвременния дизайн, в която естествените пигменти, с всички техни положителни качества биха намерили уместно приложение. Макар и не много популярни, а все още като бутикови изделия в малка серийност, се разработват и предлагат играчки и мебели от дърво, оцветени с природни багрила.

Още преди да навлязат в употреба изкуствените оцветители, палитрата на традиционния бит е била впечатляващо богата. Хората са познавали и разполагали с разнообразен набор от естествени багрила, които са се намирали в близката природна среда. За оцветители са използвали средства с различен произход: растителен, животински, минерален. Цветовете, получени при тониране с естествени багрила, са с явни предимства пред добитите от изкуствени, синтетични бои – природните пигменти не са токсични, не замърсяват околната среда, не създават здравословни проблеми, а в някои случаи дори имат лечебни, профилактични, антиоксидантни и антимикробни свойства. Освен това цветовите тонове се отличават с мекота и дълбочина, а с времето придобиват патина, която ги прави още по-приятни. Съвременните ботанически проучвания показват, че по-добрият художествен ефект на цветовете, добити от естествени материали, се дължи на сложния състав на багрилното вещество, което взема участие при боядисването с естествени багрила, докато при използването на синтетични бои се работи с химически чисти вещества.

В миналото най-често са се боядисвали текстилни материи и влакна от вълна, памук и коприна. Известни са различни способи за извличане на багрилното вещество от естествени суровини. За закрепител на цветовете са употребявали най-често материали с друго предназначение и произход като: кал от точило; ковашка сгур; винена утайка; оцет; урина; разсол от кисело зеле (зелев сок); крушев сок; отвара от корени на щавел (Rumex obtusifolius); готварска сол; пепел от царевични кочани, бреза, овес и други. В по-ново време те биват заменени от стипца, син камък (меден сулфат), сачка (зелен камък), кезап (азотна киселина), зачия (сярна киселина). Технологите на боядисване с естествени бои изискват натрупването на опит, познания и умения. За правилното протичане на процеса имат значение много фактори, важна е всяка подробност, в кой етап какъв съд се ползва, какви са свойствата и състава на водата, с която се прави извлека и мн. др.

Най-достъпни са багрилата с растителен произход. Добиват се от треви, цветя, дървета, зеленчуци, плодове, семена, но от точно определени техни части, в определен етап от развитието им. Извлечени чрез изваряване с вода, кисели или алкални разтвори, тези багрила са способни да оцветяват различни видове материали като текстил, кожи, дървесина, хартия и

други. Полученият цвят зависи много от материала, който се оцветява и неговия състав. Подготовката за добиване на желания цвят започва още със събирането на растенията. За целта се избира периодът, в който пигментът им е най-интензивен. В повечето случаи, с цел ефективно освобождаване на багрилното вещество, растенията се употребяват пресни, което създава затруднения от сезонен характер. Според вида на технологията, частите на растението се използват направо или се подлагат на предварителна подготовка – ситно накълцване, счукване, киснене, варене или ферментиране. Най-често използваният вариант за извличане на пигмента е няколкочасово изваряване на растенията във вода. Всеки от основните цветове се променя зависимост от боядисвания материал, вида и времетраенето на процеса, ползвания закрепител и тъй нататък.

В различните части на света, дори в отделните населени места, използваните растения, като материал за получаване на багрилни вещества, не са били еднакви. Според това какво им предоставя природата, сезона на годината и натрупания опит, хората са разполагали с различен набор от продукти. В стремежа си към прилагане на устойчиви техники, дизайнерите няма нужда да търсят надалеч багрила за своите проекти. Българската природа е разнообразна и богата на растителен свят, а много растения могат да се открият като храни или подправки в пресен, сушен, замразен или консервиран вид в магазините. В известна степен са запазени и старите познания за естественото багрене. Изучаваните и използвани *багрилни растения* в различни области на страната са много, и въпреки, че те са използвани предимно за багрене на тъкани, изследването им за приложение върху дървесина представлява интерес. В литературни и интернет източници са посочени разнообразни варианти за извличане на багрила:

Жълт цвят – цвят на млечок (Asklepias), кори на киселица (Malus sylvestris), листа или стъбла на сърпец (Serratula bulgarica), пожълтели есенни листа на черница и пипер (Capsicum annuum), листа на праскова и кайсия, цветове на жълта лайка (Anthemis tinctoria), корени на лапад, цветове или стъбла на вратига (Tanacetum vulgare), листа и стъбла на кукуряк (Helleborus), цветове на жилавика (Genista), камшица (Tagetes) и лютиче (Ranunculus), клончета от смрека – хвойна (Juniperus communis), люспи на кромид лук, корени и клонки на смрадлика (Cotinus), листа от бреза, бутрак (Bidens tripartita), еньовче (Galium), огнивче (Anagallis arvensis), кисел трън (Berberis vulgaris);

Червен цвят – корени на бояджийски брош (Rubia tinctorum), кора от корен на айважива (Alkanna tinctoria), цветове от риган (Origanum vulgare), цвят от червено мушкато, сухи жълти листа от киселица (Malus sylvestris), лишей от камениче (Rubus saxatilis), корен на червено цвекло, плодове от дива череша (Prunus avium), опадали есенни листа от трепетлика (Populus tremula), цвят от червена ружа (Malva alcea), плодове от дървовиден бъз (Sambucus), дръжки и корени от киселец, ашик боя/винобой (Phytolacca decandra), кори от глог (Crateagus monogyna) и други;

Розов цвят – цвят от липа, багулник/блатна трева (Ledum palustre) и други;

Оранжев цвят – при смесване на жълт и червен, както и от цвят на невен, листа от кромид лук, оранжев минзухар, тичинки на кърпикожух/мразовец (Colchicum) и други;

Кафяв цвят – зелени черупки от плод на орех (Juglans regia), кори на глог, листа от дюла и мушмула, корени на здравец, клончета от синя слива, бръшлян и други;

Зелен цвят – цветове и листа на сърпец (Serratula bulgarica), стъбла и листа от коприва, кори от млад дъб, клончета на зеленика (Vinca major), листа от чемерика (Radix Veratri lobeliani), мъх, листа и стъбла на зелениче (Vinca minor), стебла и листа от много други богати на зелен пигмент растения;

Син цвят – най-разпространеното естествено синьо багрило е индигото, добивано в Индия чрез ферментация от растенията Indigofera tinctoria и Indigofera suffruticosa. В България за багрене в синьо са ползвали: цветове от метличина (Centaurea cyanus), цветове от цикория (Cichorium intybus), цвят на омразниче/обикновена ралица (Consolida regalis), градинска лобода (Atriplex hortensis), багрилно сърпиче (Isatis tinctoria), домашно червено вино, и други.

Черен цвят – кори на: смрадлика (Cotinus), мъждрян (Fraxinus ornus), ела и елша, стъбла и листа от лютивец/водно пиперче (Persicaria hydropiper), сърпица (Isatis indigotica) и други.

За *багрила с животински произход* най-често са били използвани пигменти от дребни насекоми от типа на щитоносните въшки – кошенил/кохинил и кърмъз (Dactylopius coccus), също така и главоноги мекотели от семейство сепия (Sepiidae). Технологията на изличане на багрилното вещество е сходна с тази на растителните багрила.

Минералните бои се добиват от почвата и скалите, смята се, че техните пигменти са най-трайни:

Охра – тя е сред най-старите багрила, известни на човечеството, използвани от хиляди години. Ползват се естествено оцветени глини;

Син – ултрамаринът се получава от минерала лапис лазурит (Lapis Lazuli). Той е скъпоценен камък и съответно е на много висока цена. Поради тази причина, преди навлизането на синтетичните багрила, този специфичен син цвят е бил достъпен само за висшите слоеве на обществото.

Част от *минерални оцветители* обаче, са повече или по-малко *опасни*, а някои дори и *силно токсични*. Сред тях са:

Син – кобалтовите пигменти са извличани от относително редкия метал кобалт, съдържащ се в никеловите руди;

Жълт, оранжев, червен – кадмиевото жълто се е добивало от тежкия метал кадмий. Хромовото жълто, оранжево и червено са от групата на евтините природни пигменти, направени от оловен хромат.

Цинобър – получен от живачен сулфид. Над 1000 години този минерал е най-използвания метод за получаване на червен цвят;

Бял – оловни карбонати.

Като оцветители са били използвани и някои други широко достъпни материали, като например сажди, пепел и тиня.

В съвременните градски условия, набавянето на различните диворастящи растения е сравнително трудна задача. За сметка на това целогодишното наличие на разнообразни плодове, зеленчуци и подправки дава възможност за извличането на оцветители от достъпни на пазара продукти. Най-масовото, достъпно и атрактивно приложение на багренето с естествени бои днес е боядисването на великденски яйца. В тази посока могат да се открият редица насоки и рецепти за постигане на цвят:

Жълто – отвара от корени от куркума;

Оранжево – отвара от червен пипер, шафран;

Червено – сок от червено цвекло, малини;

Синьо – извлек и сок от листа на червено зеле;

Зелено – извлек и сок от спанак, рукола и други листни зеленчуци и подправки;

Пурпурно – сок от капина, синя боровинка, плодове от дървесен бъз;

Охра и кафяво – отвара от черен чай, кафе, какао.

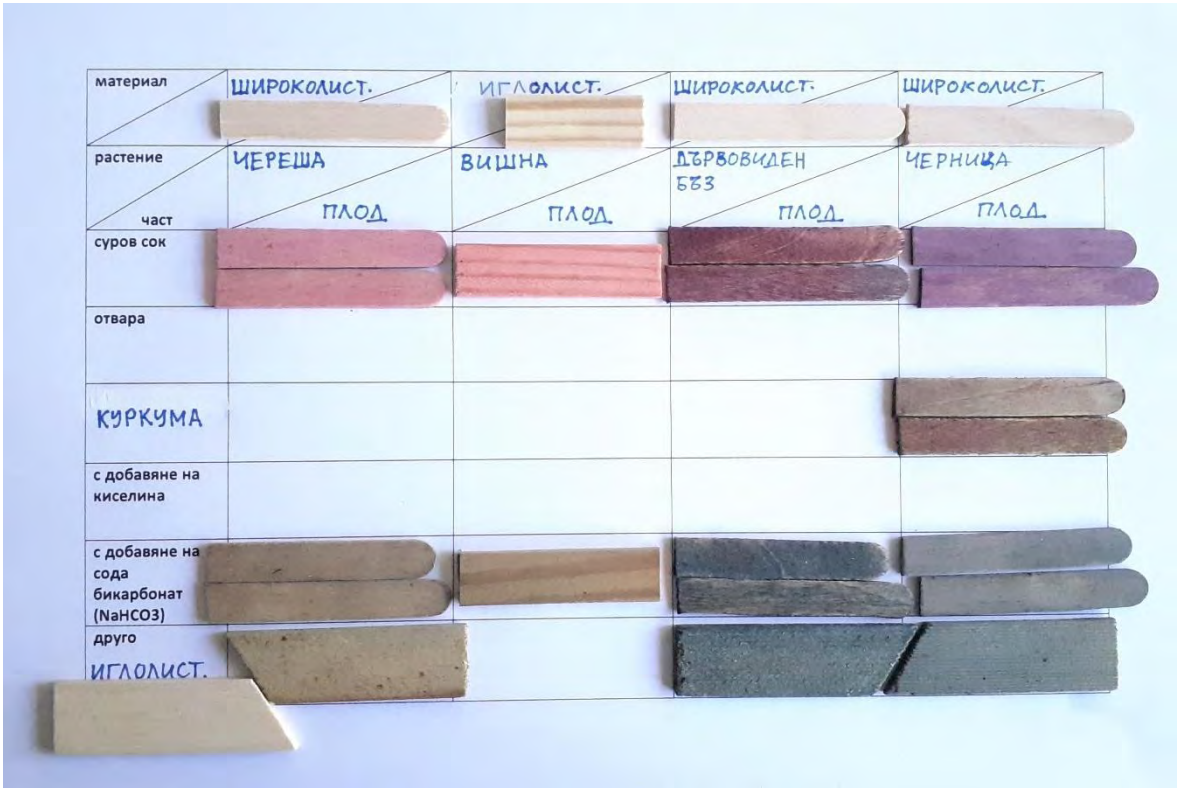
Любопитно е да се проучи оцветяващия ефект на тези и други лесно достъпни растителни субстанции. Целта на извършения експеримент е изследване и документиране на багрилните качества върху дървения материал. В приложените работни таблици са показани мостри от получените резултати, като са описани условията за постигането им. С цел максимална обективност на цветовете, фотосите не са подлагани на обработка (фиг. 1 – 7).



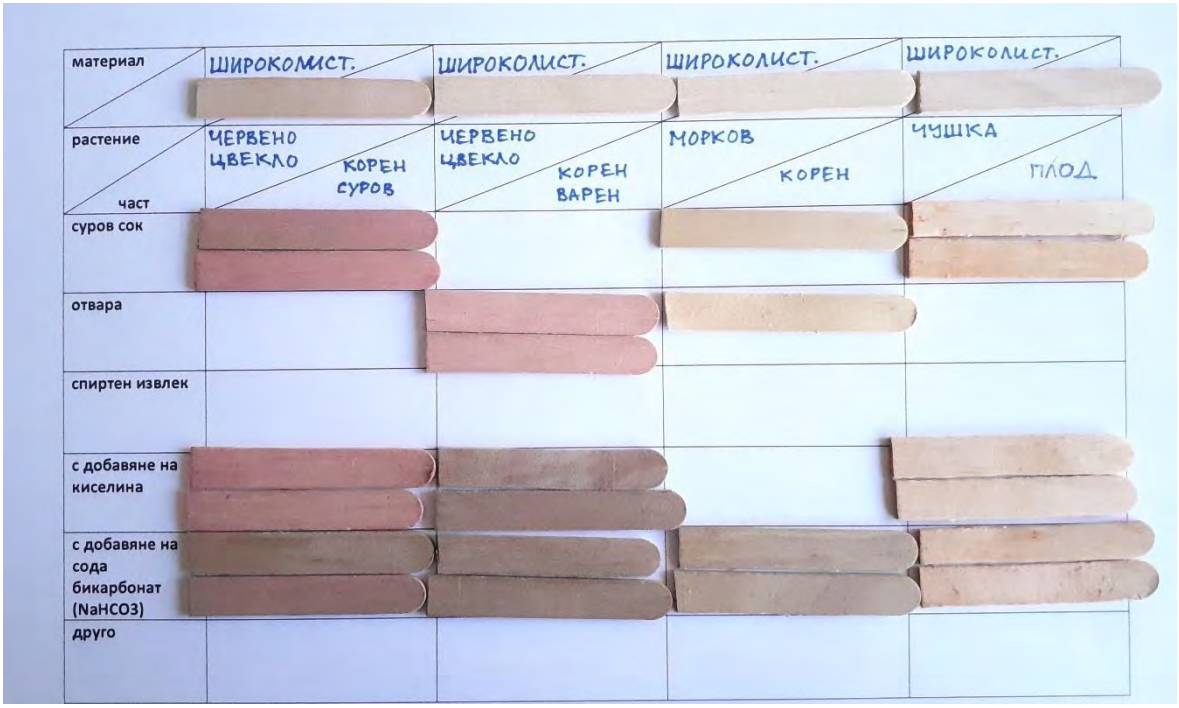
Фигура 1: Използвани са: замразени плодове, техника на нанасяне – чрез потапяне



Фигура 2: Използвани са: шипка – сушена, кйсия – прясна, касис – замразен, техника на нанасяне – чрез потапяне



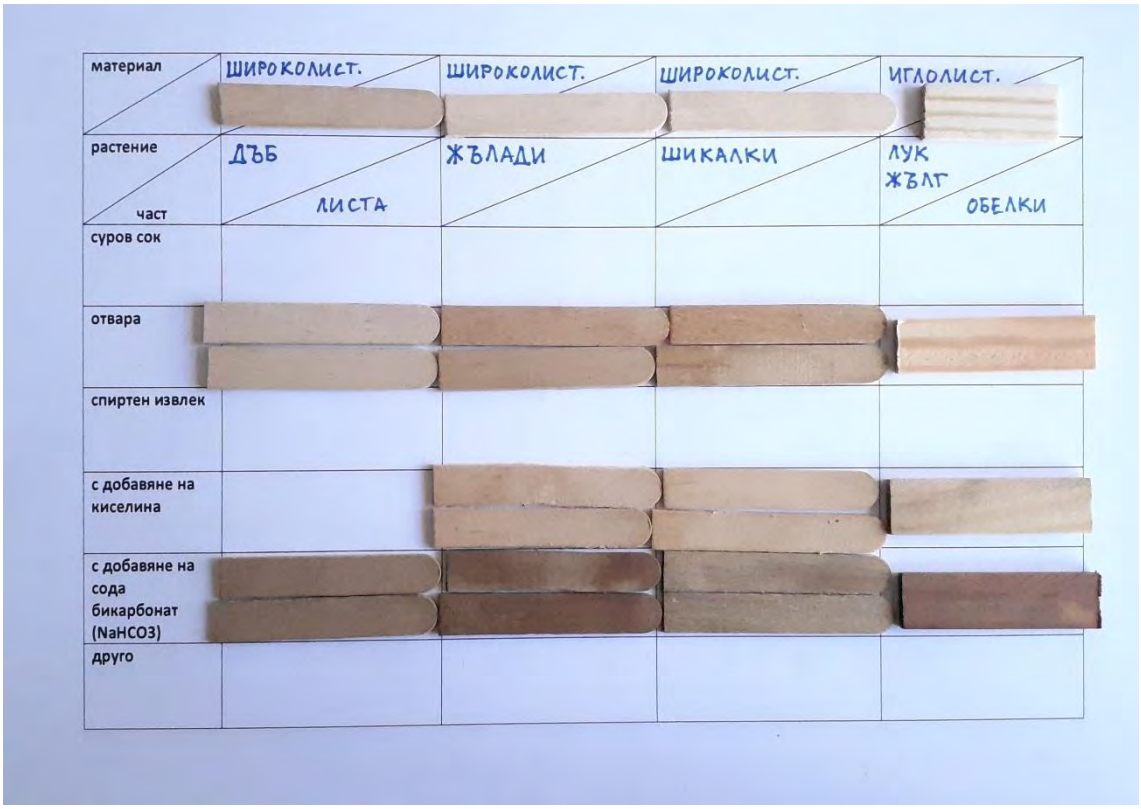
Фигура 3: Използвани са: пресни плодове, техника на нанасяне – чрез потапяне



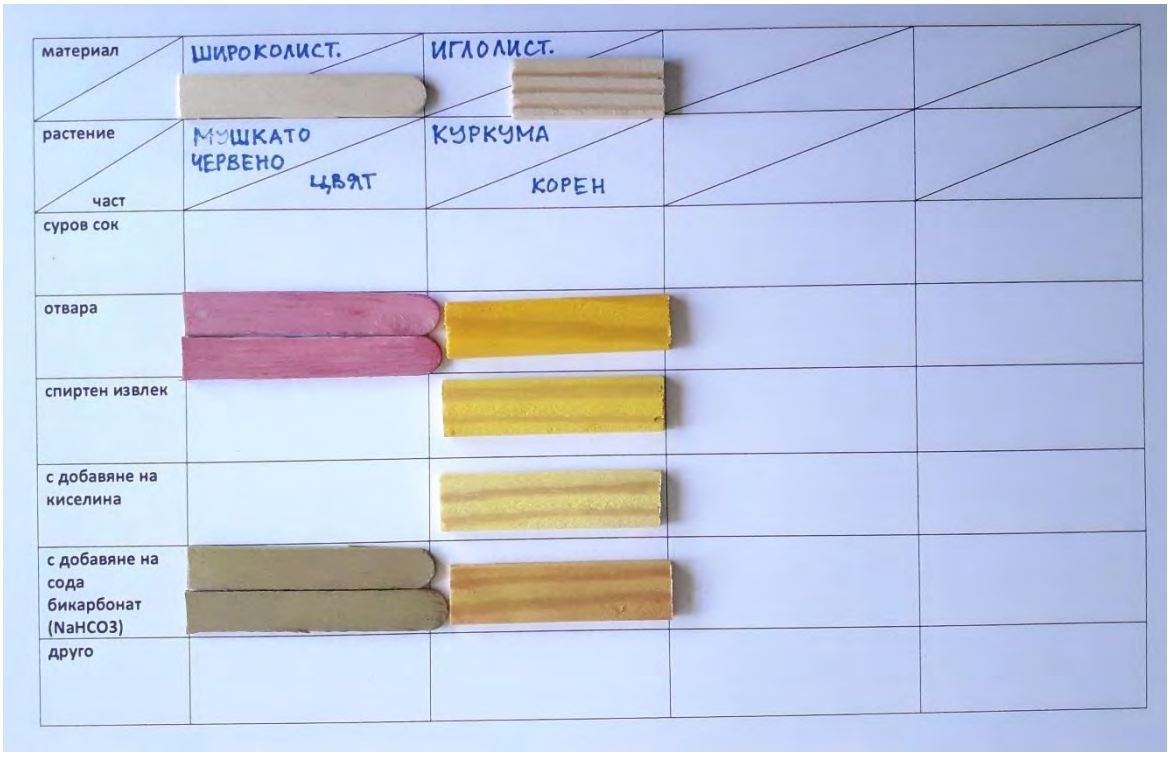
Фигура 4: Използвани са: пресни плодове, техника на нанасяне – чрез потапяне



Фигура 5: Използване са: пресни листа, спирулина на прах, техника на нанасяне – чрез потапяне



Фигура 6: Използвани са: пресни листа (м. юни), зрели жълади и шикалки, сушени люспи от лук, техника на нанасяне – чрез потапяне



Фигура 7: Използвани са: мушкато прясно, техника на нанасяне – чрез потапяне куркума на прах, техника на нанасяне – чрез четка



Фигура 8: Цветове, получени от плодове



Фигура 9: Цветове, получени от подправки



Фигура 10: Цветове, получени от листа

Естествените пигменти проникват в дървесината и оцветяват велатурно, подчертавайки структурата на материала и естествената му красота. Така дървесината се използва във връзка с естествения й вид и качества. По този начин децата могат да придобият по-обективна представа за реалността и взаимовръзката предмет, материал, цвят. Освен това ще имат възможност да развият тази фина чувствителност към хармонията и естетиката в цветността, която е характерна за природата и естествената среда, а в съвремието се притъпява от свръх стимулирането на сетивните възприятия.

Въпреки положителните качества на стественото оцветяване на дървесината е необходимо да се отчете, че този процес е доста по-трудоемък, бавен, в много случаи е по-скъп и с по-непредвидим резултат, от ползването на готови продукти за оцветяване. На този етап едва ли би бил приложим в идустриалното производство. Интересно решение в контекста на устойчивите подходи предлага Ерин Фрюктел-Деаринг /Erin Freuchtel-Dearing/. Тя разработва серии от изделия, които са оцветени с пигменти, добити чрез минимална обработка от широко достъпни растителни видове, които се използват в съвременната

кухня – плодове, зеленчуци и подправки (фиг. 8 – 10). Разбира се този тип производство е трудно да придобие масовост и да задоволи потребностите от игрови средства, както като количество, така и като разнообразие в глобален план. Ерин Деаринг намира решение във възможността всеки по-сръчен родител или възрастен да възпроизвежда нейните образци. В книгата си „Natural wooden toys“ тя предлага съвети, принципи, модели, рецепти за естествено багрене, с помощта на които да се даде възможност за популяризиране на натурално боядисаните дървени играчки, като част от предметния свят на много повече деца, отколкото би могло да обхване производството в едно или група от предприятия.

ЗАКЛЮЧЕНИЕ

Децата, обитавайки средата, влизат в много по-пряк и активен контакт с нея отколкото възрастния човек. Това поставя пред дизайнерите голямата отговорност да преценяват стриктно безопасността и полезността в изделията за деца, да подбират количеството и вида стимули. Редица са предимствата при употребата на натуралните цветове и естествените оцветители, както са много и недостатъците от използването на изкуствените. Възможностите за извличане на багрила, дори в условия далеч от природата – в големия град са много. Осъзнавайки това, съвременните дизайнери не само се възхищават на постиженията, достигнати със старите технологии, но и черпят опит и вдъхновение от тях, стремейки се да ги доразвият в контекста на съвременните потребности и изисквания.

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WOODEN TOYS IN A CHILD'S WORLD

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ABSTRACT

Childhood is an important period of every person's life. It is a period that also provides significant importance to character development and entrenching human values in a child. It's about the foundations of character, personal qualities, sensual, moral, aesthetic norms and limits – an inseparable part of our personal, professional and social realization. This significant stage is intense, colourful, full of impetuosity, curiosity and fantasy. Since antiquity, the toy has been the child's constant companion, main tool in games and entertainment, in getting to know and transition into adulthood. That helps child to resolve complex and emotional problems in life.

The report traces the stages in the development of wooden playthings in relation to their functionality, subject matter, form-building, colouring, manufacturing and production technologies. The topic is explored in terms of product design, trends and the place of these toys in the context of the contemporary child. It exposes the importance and timelessness of the wooden toy in the child's world.

Key words: design of children's environment, wooden toy.

ДЪРВЕНАТА ИГРАЧКА В СВЕТА НА ДЕТЕТО

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РЕЗЮМЕ

Детството е този важен период от живота на всеки човек, в който се полагат основите на характера, на личностните качества, на чувствените, морални, естетически норми и граници, на реализацията – житейска, професионална, обществена. Този значим етап е интензивен, пъстър, изпълнен със стремителност, любопитство и фантазия. Още от древността играчката е била неизменен спътник на детето и основно средство в игрите и забавленията, в опознаването и навлизането в света на възрастните, при справянето със сложни житейски и емоционални проблеми.

Докладът проследява етапи в развитието на средствата за игра от дървен материал във връзка с техните функционалност, тематика, формоизграждане, оцветяване, технологии на изработка и производство. Темата се изследва от гледна точка на продуктовия дизайн, тенденциите и мястото на тези играчки в контекста на съвременното дете. Показва се значимостта и непреходността на дървената играчка в света на детето.

Ключови думи: дизайн за детска среда, дървени играчки.

Играта и играчките са били и до днес са основни средства за опознаване на света, за изучаване и развиване на умения за реализиране на различни социални, житейски и професионални роли.

В най-ранната история на човечеството децата са се занимавали с предмети, които са били достъпни за тях – пръчки,

камъчета, листа, плодове, шишарки, костилки и ядки, кости, прешлени, перца, а също така и животинки.

Постепенно тези дадени от природата елементи били дооформяни и придобивали по-конкретна образност и роля, най-често свързана със социален статус и дейности от ежедневието – лов, земеделие, отглеждане на децата, бит.

Интерес представлява и етапът на обучение в занаят на младите чираци. В грънчарството, но вероятно и в другите занаяти децата чираци са се учели и упражнявали върху изработката на умалени модели на истинските занаятчийски произведения. За това говорят находки с нетолкова прецизна и сръчна изработка. Така децата от една страна са били обучавани чрез симулативна игра, а от друга – са създавали предмети подходящи за игра.

Веществени свидетелства за съществуването и развитието на дървените играчки има сравнително малко, поради характера на самия материал, поддатливостта му на гниене, горене, унищожаване от гъбички и вредители. Тъй като дървесината може да се обработва сравнително по-лесно и с по-примитивни средства от метала, костта, камъка, може да се съди, че постиженията при дървените играчки във функционално, естетическо и конструктивно отношение, едва ли са отстъпвали на тези, които се наблюдават при играчки от друг твърд материал.

В Древен Египет играчката вече е била обект на специално внимание. Открити са образци със сложна конструкция като напр. крокодил и котка, чиито усти се отварят, кончета с колелца. По-ранните играчки са единични фигури на животни или хора, но в последствие се усложняват и пресъздават различни ситуации – човек, яздещ кон, слуга мелещ с хромел, куклен театър с кукли, кукла със собствен гардероб от тоалети. Още тогава е имало кукли с подвижни крайници, както и механични играчки, задвижвани с връвчица. Играело се и на различни настолни игри, както и с дървени пумпали и топки (изработени от косми и треви). Благодарение на добрите условия за съхранение, в египетските гробници са запазени дървени изделия за игра (фиг. 1 – 5).



Фигура 11: Механична играчка, дърво



Фигура 12: Конче на колела, дърво



Фигура 13: Дървени птица, кон с ездач



Фигура 14: Игра, 1550–1295 пр.н.е.



Фигура 15: Игра

В древна Гърция на новородените са подарявали дрънкалки, чиято роля била да предпазва детето от всякакво зло и уплаха (фиг. 6).

Гърците са осъзнавали, че играта има отношение към психическото здраве на децата, физическото и психическо развитие. Платон е развивал идеята, че професионалната нагласа се възпитава още с играта. В тези ранни култури периодът на детството е бил чувствително по-кратък от този на днешните деца. Те са имали възможност да играят до 10 – 14 годишна възраст, предимно на игри подготвящи ги за тяхната социална и професионална роля и реализация. Дори децата на по-заможните притежавали малко играчки, според някой източници те получавали една при раждането си още една на 10 годишна възраст. Момичетата се занимавали с кукли и кукленски къщи (фиг. 7). Преди да се омъжат дарявали своите кукли на богиня (най-често на Артемида). Момчетата са играели със фигурки на животни, колесници, пумпали. С възмъжаването момчетата се разделяли със своите астрагали (ашици) (Серафимова-Лазарова 2000).



Фигура 16: Дрънкалка теракота, V в. пр.н.е



Фигура 17: Кукли, теракота



Фигура 18: Конче, теракота

Известно е, че в Сарди, столицата на Лидия, е имало планово производство на играчки.

В Рим се изработвали кукли с подвижни ръце и с кукленско обзавеждане, коне с ездачи и колесници, които можели да се отделят (фиг. 9 – 11). Децата търкаляли обръчи със звънчета.

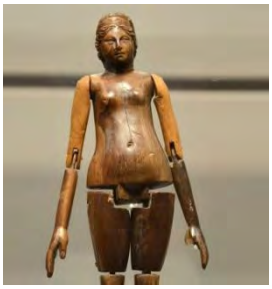




Фигура 19: Конници, дърво



Фигура 20: Кукли, теракота, кост



Фигура 21: Кукла, дърво

Въпреки находките и информацията от различни източници да свидетелстват за специализирана изработка на играчки в различни райони и епохи, то по-голямата част от децата са притежавали играчки, изработвани в семейството. Майките и бабите са правели играчки от плат, вълна, прежда, царевични листа и кочани, глина

и т.н., бащите и дядовците са майсторели играчки от дърво, камък, кост.

През Ренесанса култът към Дева Мария и Младенеца определя и ново отношение към детето, грижата за неговото възпитание и образование. Връх в развитието на играчките в този период са кукленските къщи. Първоначално те били кукленски стаи, после къщи с 2 – 3 помещения, но в последствие прерастнали в модели на цели многоетажни сгради с всички стаи в тях. Затваряли се като шкафове, които отвън изобразявали фасадата на сградата. Къщите представлявали почти буквално пресъздаване в мащаб на реална жилищна среда, понякога копие на истинската (фиг. 12 и 13). Изработката им била изключително сложна и скъпа. С направата им се занимавали не само майсторите на играчки. Били ангажирани истински мебелисти, паркетаджии, стъклари, производители на метална и керамична посуда, шивачи и модисти за облеклата и текстилните аксесоари и т.н. Конструкцията, архитектурните елементи, мебелите в по-голямата си част са били изработвани от дървен материал. Притежанието на кукленска къща е било въпрос на престиж и не малко фамилии са влагали цели състояния и са се разорявали в стремежа си да поръчат такова изделие (Серафимова-Лазарова 2021).



Фигура 22: Къща за кукли, XVII век



Фигура 23: Къща за кукли, Англия, 1705



Фигура 14: Серийна изработка на играчки, Германия, края на XVIII – нач. на XIX век

От XVIII век започва интензивното развитие на изработката на детски играчки като самостоятелен занаят. Началото е в Холандия и Германия. В Нюрнберг занаятчиите – грънчари, стругари наред с другата продукция започнали да правят играчки, които продавали. В Оберамергау, стругарите, изработващи олтари за църкви, в домашни условия майсторяли дървени купи и паници, но към асортимента добявили и играчки. В Берхестгаден, където се основава първата занаятчийска организация на майсторите на

играчки, целите семейства са били ангажирани в процеса на производство на изделията от дърво. Лятото са събирали материала, изсушавали са го, през зимата са изработвали играчките, а през пролетта по пазари и панаири са ги продавали. Моделите стават все по-осъвършенствани и разнообразни. Малките семейни работилници постепенно се развили в манифактури и предприятия. Най-разпространени били фигурките на дървени животни, човечета, войници.

Характерно за производство в тези райони е, че играчките са били оформяни предимно с помощта на струг. При изделията, които са изградени от ротационни форми това е логично, но майсторите са разработили и технология за бързо и качествено тиражиране на фигурки, най-често животински, чрез струговане. За целта са изработвали широк ринг с профил, отговарящ на желания силует (фиг. 14). След това той е нарязван на множество радиално разположени филийки. Получените фигурки са дооформяни по-детайлно ръчно с помощта на ножове и длета. Технологията позволява бързо и евтино производство, което е конкурентноспособно в световен мащаб.

Търсенето и производството бързо се разрастват. През XVIII век на Германия се е дължало 2/3 от европейското и 1/2 от световното производство на играчки (фиг. 15) (Серафимова-Лазарова 2000).

В южна Полша и Чехия също традиционно са изработвани играчки от дърво. В Полша има запазени оръжия и кончета – на колелца или за „яздене“, свирки, датирани в периода XIII – XVI век, с които са си играели и придобивали бойни умения подрастващите момчета (фиг. 17 – 18).



Фигура 24: Играчки от Ерцгебирге, Германия, началото на XX век



Фигура 25: Дървени играчки, Чехия



Фигура 26: Играчки оръжия, Полша, XIII – XVI век



Фигура 27: Играчки кончета, Полша, XIV – XV век

През XVIII – XIX век и в тези райони традиционното семейно изработване на играчки прераства в манифактури, оформят се занаятчийски центрове (фиг. 16).

В началото на 19 век играчките започват да стават по-детайлни, по-сложни и реалистични. Дотогава цветовете са постигани с естествени багрила. Пигментите са били с растителен, животински или минерален произход. През XIX век започва откриването и въвеждането на оцветители, получени по химичен път. Новите бои бързо навлизат и в производството на играчки, като отварят богати възможности за оцветяване и декориране на изделията.

Фигурките се предлагат не само единично, но и като част от игрални комплекти. Такива комплекти са били изработвани и по-рано, но в този етап започват да стават по-достъпни и разпространени. Някои от тях са свързани с религиозното възпитание на децата – особено привлекателни са били „Ноевите ковчези“, включващи фигурки пресъздаващи мъжки и женски екземпляри на животни от цял свят, събиращи се в кораба на Ной (фиг. 19 – 20). Също така, интерес е представлявала и сцената на Рождество, пресъздадена във вид на серия персонажи. Тези играчки са имали възпитателен и образователен аспект, но в същото време са отговаряли на потребностите и интереса на децата за сюжетно ролеви и познавателни игри.

Разпространявали са се и различни модели домашни куклени театри. Развивали са се и дървените возила – влакчета, камиони, автомобили, като особено ценени били тези, в които може да се поставят човешки фигурки. Също така са проектирани и изработвани играчки с механизми, които силно впечатлявали децата.



Фигура 28: „Ноев ковчег“, Германия, 1850



Фигура 29: „Ноев ковчег“, Ерцгебирге, Германия, 1860

В Русия дървената играчка първоначално е представлявала сноп от пръчки, които са грубо дооформяни, за да получат някакъв характер. С времето в различните региони се развиват различни школи. На север са характерни дялани от един къс дърво фигури на коне, птици, човечета, лодки. Те наподобяват древните идули и изследователите предполагат, че точно такъв е техния произход. Обикновено са с конично тяло и грубо дялано плоско лице (фиг. 21). В Нижний Новгород, където дървообработването е било силно развито, изкусни дърводелци, строители на дървени къщи, кораби, майстори на лъжици, посуда, вретена, започнали да изработват и играчки с много голяма прецизност и високи художествени качества (фиг. 22). В едни от руските школи преоб-

ладавали пищно декорирани с цветни орнаменти изделия, в други като Богородската школа са използвали фино датайлно резбоване от дървесина на бреза и трепетлика (фиг. 23). Разработвали и модели на механични играчки, изобразяващи дървари, ковачи, земеделци, а мечките са били едни от най-характерните персонажи.



Фигура 30:



Фигура 31: Края на 19 – началото на XX век



Фигура 32: Ковачи, Богородско, Русия

В края на XIX век се появява и матрьошката – стругована куха кукла от две части, която се отваря и вътре се крие следваща, по-малка, но сходна по форма и цвят фигура, която на свой ред също съдържа друга още по-малка фигура и т.н.

След Първата световна война започва конкурентно на дървените играчки, помасово разпространение на по-евтини метални и оловни фабрично тиражирани изделия, тъй като тяхната изработка позволява технологичност и в по-голяма степен машинен производствен процес. Освен, че са с по-ниска цена и са достъпни, те позоляват по-буквално пресъздаване на натурата и с това печелят почитатели.

В началото на XX век се формират два иновативни педагогически методи, разработени от Мария Монтесори и Рудолф Щайнер. Подходът и целта на играта в тях са доста различни, но и в двете методики дървената играчка има водеща роля за развитието и обучението на децата. Монтесори системата въвежда нови модели на „работа“ на децата, изискващи проектирането на специални дидактични материали, които са без аналог дотогава.

През XX век проектирането на дървените играчки вече е обект на дейността не само на занаятчиите и майсторите, но и на дизайнери, получили специално художествено и техническо образование. Висшето училище по строителство и художествено конструиране Баухаус, което оказва дълбоко влияние в развитието на графичния, промишления дизайн и архитектурата, дава своето отражение и върху идеологията на детската играчка. Модернистичните влияния са пренесени и върху веществената среда за деца (фиг. 24 – 26). Баухаус ясно осъзнават силната роля на дизайна като средство за моделиране и възпитание на младото поколение. В проектираните играчки те влагат стилистиката на модернизма, като обръщат особено внимание на естетическото възпитание и развиването на конструктивни и комбинативни умения (фиг. 26). Залагат на формоизграждане базирано на основните категории форми, модулното проектиране, гещалт психологията, теорията на композицията. Въпреки, че школата Баухаус работи и с различни нови за времето си материали и технологии, от при-

мерите може да се види, че дървеният материал е останал предпочитан в изделията за деца, използва се масив, но също така и иновативните гъвкави шперплатни плочи (фиг. 25).

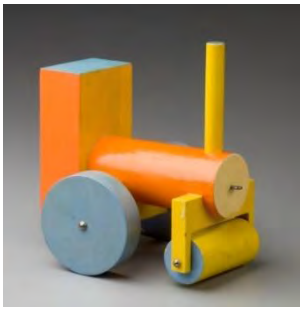


Фигура 33 и 25: Петер Келер, люлка за бебе и стол, 1922 – 23



Фигура 34: Алма Зийдхоф Бушер, конструктор, 1923

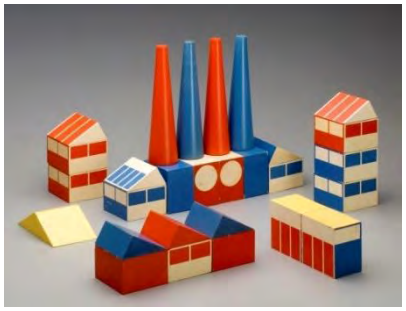
До масовото разпространение на пластмасите през втората половина на XX век, дървената играчка е в период на интензивно развитие. Проектирани са образци, които като функция, конструкция, формоизграждане, естетика се разграничават от народната играчка. Дизайнът на дървени изделия за деца е обект на специален интерес и целенасочени търсения, достигнали до изключително високи разултати, върху които стъпва проектирането и оформлението на пластмасовите модели (фиг. 27 – 30, дизайнер: Ладислав Сутнар, Чехословакия) и (фиг. 31 – 32 и 34).



Фигура 35: Парен локомотив, 1924



Фигура 36: Товарен камион, 1927



Фигура 37: Конструктор, 30-те години на XX век



Фигура 38: Серия животни, около 1930-та



Фигура 39: Кай Бойсен



Фигура 40: Кай Бойсен, скиор, 1940



Фигура 41: Кай Бойсен, животни, 40-те – 60-те години на XX век



Фигура 42: Александър Жирар, 1952

След Втората световна война, с навлизането на пластмасата, дървесината, металът, керамиката, папиемашето са изместени от новия технологичен и евтин материал, даващ нови и различни възможности пред производителите на играчки. Емблематичен пример за успешен преход от дървените към пластмасовите изделия за деца е една от най-големите и просперириращи фирми – Lego (фиг 35).



Фигура 43: Дървени играчки на фирма LEGO, 1932 – 1960

Постепенно интересът към дървените играчки намалява (въпреки, че никога не изчезва) и за известен период от време те се превръщат по-скоро в сувенирна и колекционерска стока. Може да се каже и че в този период се наблюдава по-бавно развитие на дървената играчка като масова стока. Характерно е по-скоро възпроизвеждане на образци типични за различни школи на народното творчество, класически модели, ретро изделия.

Дървената играчка е с древна и богата история. Играчката е продукт на направление в занаятите и дизайна, което най-бързо и убедително отразява новите тенденции, промените в нагласите и търсеното от страна на потребителите. Това определя нейното динамично развитие. Играта на децата винаги неподправено и обективно е пресъздавала и отразявала живота. Във всеки един момент от развитието си играчката може да служи за изследване на обществените, културните, политически, териториални, икономически и др. промени. Много сведения за живота, постиженията и бита на хората от миналото са известни именно благодарение на запазените умалени модели – играчките.

В последните десетилетия се наблюдава засилен стремеж към използване на естествените материали и употребата им в

дизайна за деца, провокиран от една страна от грижата за запазване на природните ресурси и биологичното разнообразие, и от друга – от желанието за здравословен начин на отглеждане и възпитание на децата.

Интересът към дървената играчка се възражда, като я превръща отново в значим фактор за развитието и забавлението на децата. Това връщане на сцената на детските игри довежда до интензивно й развитие.

Дървената играчка притежава редица предимства, които са оценени от съвременните потребители. Специфичните качества на дървесината като – топлота, ниско тегло, здравина, натуралност, биологична разградимост, естетическа стойност, разнообразие на структури и цветове, печелят децата и техните родители. Различните методи на обработка и прилагането на класически и нови технологии, възможността за изграждане на разнообразни конструктивни решения и богатство на подходи към формоизграждането привличат интереса на съвременните дизайнери.

Освен изброените качества, дървената играчка притежава редица предимства, които също са в интерес на децата. Тя щади тяхното здраве, възприятия и психика, въздейства активно посредством своята структура, натурална цветност, тактилен контакт. В повечето случаи дървените играчки притежават условна образност. При тях конструкцията е проста, видима и логично вписана във формоизграждането. Преобладават натурални неинтензивни цветове. Детайлите се използват като средство за акцентиране на най-важните елементи, разкриващи характера на образа. Дървените играчки, обикновено не работят на батерия, нямат вградени светлинни или звукови ефекти. Детето по-често не получава всичко на готово, а бива провокирано да вложи мисъл, въображение, действие. Тези играчки не оставят детето пасивен участник или наблюдател, а го въвличат в един непосредствен творчески и игрови процес. Активните деца, нямат нужда от получени наготово стимули, напротив колкото е по-опростена играчката, толкова повече възможности дава тя на играещия. Изградените образи чрез загатване на основни белези, а не чрез буквално пресъздаване на натурата, стимулират развитето на комуникативни умения и речта при децата. На децата се налага да разговорят повече в желанието си да обяснят предназначението на играчката или правилата на дадена игра.



Фигура 44: Играчка за бебе



Фигура 45: возило



Фигура 46: Комплект за игра



Фигура 47: Возило



Фигура 48: Комплект за игра



Фигура 49: Детска кухня



Фигура 50: Количка за кукла

Атрактивността на съвременните дървени играчки се дължи и на тяхното голямо разнообразие. Разработват се и се предлагат модели, обхващащи всички възрастови групи от изделия за новородени до игри, подходящи за младежи и възрастни (фиг. 36 – 45). Съвременните дизайнери, които проектират дървени играчки е необходимо да притежават и влагат в тях оригинално мислене, присъщо на младото поколение и да подхождат към дизайна с много любов и разбиране, за да получат резултати, едновременно привлекателни и полезни за презадоволените днешни деца (Воденова 2019).



Фигура 51: Конструктивна игра



Фигура 52: Милер Гудман, мозайка, 2009



Фигура 53: Конструктор

Богатството от видове играчки и игри, изпълнени от дървен материал също е изключително голямо. Разработват се както класически модели, така и изключително модерни като формоизграждане и стилистика играчки, повлияни от минимализма и скандинавския дизайн, отразяващи най-нови влияния в дизайна. Въпреки изявеното отражение на модерните тенденции, при дървената играчка ясно личи приемственост и наслагване в исторически и регионален план.

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PROCEEDINGS OF ELEVENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE "INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN" – INNO 2022, 3-5 OCTOBER, HOTEL RILA, BOROVETS, BULGARIA, PP. 31–40

CHANGES IN THE BANKING SPACES' FUNCTIONAL SCHEMES IN BULGARIA: 1990 – 2020

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ABSTRACT

The focus of the study is to investigate the changes happening in the banking spaces' functional schemes and how digitalization influences the process. The functional zones of a banking office are clearly listed and defined. Through an inductive method of analysis, the investigation tracks the floor-plan arrangement's changes of banking spaces in Bulgaria, that have been created between 1990 and 2020. Alongside this, the study monitors the level of implementation of technological solutions in the banks' physical environment. As a result, the conclusion of the study outlines a clear correlation between digitalization and the changes in the functional schemes of the bank spaces.

Key words: bank spaces, functional scheme, digitalization, technological solutions.

ПРОМЕНИ ВЪВ ФУНКЦИОНАЛНИТЕ РЕШЕНИЯ НА БАНКОВИЯ ОБЕКТ В БЪЛГАРИЯ: 1990 – 2020

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РЕЗЮМЕ

Фокусът на доклада е да изследва промените във функционалните решения на банковия обект и как дигитализацията повлиява на този процес. Изведени и ясно дефинирани са функционалните зони на банковия офис. Чрез индуктивен метод на анализ се проследяват промените в планови схеми на банкови обекти в България, проектирани и реализирани между 1990г. и 2020г. Паралелно се проследява и внедряването на технологични решения във физическата среда. Изводите от направеното проучване очертават ясна взаимовръзка между дигитализацията и промените във функционалните схеми на банковите обекти.

Ключови думи: банков обект, функционална схема, дигитализация, технологични решения.

УВОД

Функцията на Банката като институция в исторически план е свързана със сигурност, поверителност и ефективност на съхранение на пари и ценни книжа (Jebran, 2012, Кисляков и Вълков, 2020). Съответно интериорните пространства на нейните офиси, които са външното лице и физическият компонент в комуникацията с клиентите, са приемани от посетителите като студени, неприветливи и респектиращи, създаващи усещане за неприкосновеност и класово различие. От последното десетилетие на XX-ти век досега, обаче, се наблюдава радикална промяна в проектирането на банковите обекти. Интериорните пространства се „отварят“ към външния свят посредством нови планови решения на офисите, възникват нови функционални единици и отпадат други.

На база наблюдаваните процеси, няколко въпроса се поставят на дневен ред – какви са измененията в решенията на интериорния дизайн на банковите офиси и дали причините за тях са дигитализацията и внедряването на технологични решения (Кисляков, 2020). Целта на този доклад е да изследва хронологично промените на банковите обекти и да анализира причините за промените, които се наблюдават. За обект на изследване са взети банкови обекти, разработени на територията на България, проектирани през последните 30 години.

БАНКОВИТЕ ОБЕКТИ

В контекста на дефиниране на банковия обект съществуват три основни групи (Кадинов, 2010):

- Банкови обекти за клиенти;
- Банкови обекти за административно управление;
- Банкови обекти за съхранение на пари.

Докато банковите обекти за административно управление и тези за съхранение на пари са главно ориентирани към функционирането на банката като компания, то банковите обекти за клиенти са тези, които са физическото място на среща между клиент и банка. Съществуват два вида банкови обекти за клиенти (Majaski, 2022):

- Банкови обекти за търговия на банкови услуги, т.нар. „corporate banking" или бизнес банкиране, за корпоративни клиенти, и
- Банкови обекти за търговия на банкови услуги на дребно, т.нар. "retail banking", които оперират директно с крайни клиенти.

Предлаганите услуги за бизнес банкиране обикновено се извършват в офисите на административното управление на банката, където клиентите – от малки и средни предприятия до големи международни компания, оперират с големи суми пари и активи. Интериорните пространства на тези помещения в повечето случаи не са достъпни за крайните физически клиенти на банката. За разлика от тях, банковите обекти за търговия на банкови услуги на дребно, т.нар. „retail" банкови офиси, са тези, които представят външното лице на банката пред света и където всъщност се предлагат услуги за широката публика на ежедневна база. За тяхната успешна работа основно значение има подходящата планова схема, както и наличието на определени функционални зони, подредени в удобна за ползване последователност.

ФУНКЦИОНАЛНИ ЗОНИ НА БАНКОВИЯ ОБЕКТ.

На база проведени проучвания на функционални схеми на банкови обекти, проектирани и изпълнени от 1990 – 2020 г. на територията на България, се открояват следните основни функционални зони:

1. Зона вход банков обект за клиенти.

Зона вход банков обект клиенти осигурява оптимална връзка с клиентския салон. Обикновено се намира на фасадата към по-оживената улица, като в зависимост от плановата схема може да бъде разположен централно или в единия край на фасадата. Задължително изискване е той да осигурява достъпна среда за населението, включително за хората с увреждания посредством рампи с наклон до 5% (чл.16 (1) т.2) и/или подемна платформа (чл.17 (1)) (Наредба №4/01.07.2009 г.).

2. 24-часова зона за самообслужване.

24-часовата зона за самообслужване обикновено се разполага в зоната между входа за клиенти и клиентския салон – в

зоната на винд-ванга. В по-редки случаи се проектира като отделно помещение с отделен вход. Необходими изисквания към него е да осигурява защита на клиента, докато извършва сам банкови услуги. 24-часовата зона обикновено е окомплектована с банкомати за теглене и внасяне на пари, както и монитори с touch-screen екрани за допълнителни банкови услуги.

3. Клиентски салон.

- Зона за изчакване.

Зоната за изчакване на клиенти се разполага на удобно място в клиентския салон така, че да осигурява оптимална зрителна връзка между клиент и служители. Оборудвани са с меко сядане – столове или кресла, а в последните години – и дивани, за да осигурят максимален комфорт на клиента.

- Зона служители.

Служителите в банковия обект оперират на два вида работни места: *работни бюра* с плот на кота +0,72-0,75 м и в зоната на *касовия възел*. Подвижното обзавеждане (бюра, корпусни мебели, столове за служителите) в клиентския салон е разположено според плановата схема (обикновено в предната част на салона) като са обособени зони за конкретни видове обслужване. Всяко работно място за служител е оборудвано минимум с едно бюро 150/80/75 см, работен стол 45/45 см, както и 1–2 работни стола 45/45 см (или кресла 50/50см) за клиенти. За разлика от тях, *зоната на касовия възел* обикновено е изнесена максимално навътре в банковия салон. Всяко едно работно място каса изисква работен плот за клиента – обикновено на височина +0,90 м до +1,10 м, както и работно място за служител с работен плот на +0,72–0,75 м, оборудвано с необходимата техника за банкови услуги и парични трансакции.

- Зона консултации.

Зоната за консултации обикновено е разположена с пряк достъп до клиентския салон. Към нея се причисляват помещения за лични (конфиденциални) разговори, както и заседателните зали. В зависимост от квадратурата на банковия обект площта на зоната на консултации варира, както и обзавеждането й. В най-честите случаи мебелите включват заседателна маса (кръгла с d=min 80 cm или правоъгълна с размери = 80/140 min) със столове за минимум 4 човека, както и е осигурено оборудване и техника за презентации – проектори, видеостена, монитор.

- Помещения за работа с големи суми пари / VIP каса.

VIP касите също са разположени в непосредствена близост до клиентския салон, като са оборудвани с броячни машини и машини за проверка на пари. Обикновено са пряко свързани с касовите възли така, че пътят на парите да е един. Помещението е защитено с противокоршумно стъкло според EN356 стандарт за остъкляване – P1A-P8B, осигуряващ устойчивост на силови действия (EN 356).

- Стая на управител и заместник управител банков обект.

Помещението на управителя също се разполага с пряк достъп към клиентския салон. В повечето случаи преградата между помещенията е структурно остъкляване, оборудвано със щори или димиращо стъкло за осигуряване на самостоятелност при конфиденциални разговори. Помещението разполага с работно бюро мин 180/80 см, въртящ се стол с подлакътници, 2–3 посетителски стола, шкафове за документи.

4. “Back” офис – помещения без достъп на клиенти в служебна зона.

Помещенията, които обслужват служителите на банковия обект или са свързани с пътя на парите и осигуряване на сигурността им, се намират в „back" офиса – или задния офис, където клиентите нямат достъп. Обслужващите помещения са:

- Санитарен възел – тоалетна с мивка. Помещението отговаря на изискванията на Наредба №4 за проектиране, изпълнение и поддържане на строежите в съответствие с изискванията за достъпна среда за населението, включително за хората с увреждания;
- Зона за почивка и гардеробно;
- Кухненски възел;
- Склад;
- Архив.

Степента на конфиденциалност и изискванията към тях налагат посочените по-долу помещения да попадат извън обхвата на настоящия доклад:

- Трезори: банкови и граждански;
- Охрана и видеонаблюдение.
- Техническо помещение – сървъри и RACK.

МЕТОДИКА НА ИЗСЛЕДВАНЕТО

За да се проследят промените във функционалните решения, наблюдавани в банковите обекти, се използва индуктивен подход на анализ на примери (10 бр. банкови обекти в България) от периода 1990–2020, които служат за събиране на емпирични данни и знания. На база проведеното проучване чрез създадена аналитична матрица се достига до изводи, изведени в таблици (Табл. 1 и Табл. 2), които отразяват измененията в плановите схеми на банковите обекти. С цел изследване на хипотезата, че дигитализацията и внедряването на технологиите са в основата на тези промени, отново в отделна таблица е проследено навлизането на технологиите в банковите обекти.

ГЕНЕРИРАНЕ НА АНАЛИТИЧНА МАТРИЦА ЗА ИЗСЛЕДВАНЕ НА ПРИМЕРИТЕ.

Изследването на примери е с цел събиране на емпирични данни и знания, на базата на които да се направят общи изводи за процесите и трансформациите на банковия обект. Проучените банкови обекти са разглеждани хронологично от гледна точка на функционално зониране, взаимовръзки между служители и клиенти на банковия обект, както и внедряване на технологични решения. За да има универсалност на изводите е необходимо унифициране на изследването чрез прилагане на критерии, които да направят сравними различните примери. За целта изследването се осъществява чрез аналитична матрица, която съдържа няколко основни части:

- Основни данни за изследвания банков обект, в това число наименование, година на проект и реализация, местоположение;
- Изследване на банковия обект в план по функционални зони и взаимовръзки между отделните зони, изображение на плановата схема на банковия обект;
- Изследване на банковия обект от гледна точка на внедрени вътре технологии;
- Обобщение и генерални изводи за изследвания обект.

ИЗСЛЕДВАНЕ НА ПРИМЕРИ ОТ БЪЛГАРИЯ В ПЕРИОДА 1990 – 2020 ГОДИНА.

Примерите, подбрани за изследването в настоящия доклад, са на база направени проучвания, интервюта, посеще-

ния на обекти, личен опит и архив на архитектурни студиа. Банковите обекти, разглеждани в изследването, са значими, тъй като всеки от тях представя особени характеристики и промени от гледна точка на функционално зониране и показват нивото на внедряване на технологии в тях. Те са различни по квадратура, местоположение и градски контекст, но представат напълно промените, които се наблюдават през последните 30 години в банковия обект, на периоди през 3–5 години.

РЕЗУЛТАТИ

За да установят промените във функционалните зони на банковите обекти, изследването използва планови схеми на 10 банкови обекти, проектирани и реализирани в периода 1990–2020 г., съдържанието на които е представено в Таблица 1. Фигури 1–4 демонстрират етапи в прехода от статична и фиксирана в пространството планова схема на банковите обекти (Фиг. 1) към нова отворена такава, която позволява пространството да се възприема като единно и гъвкаво.

ФУНКЦИОНАЛНА СХЕМА НА БАНКОВИТЕ ОБЕКТИ.

От функционална гледна точка промените в интериорните пространства са ориентирани към създаване на усещане за уют, достъпност и комфорт на ползване на банковите обекти. Плановите схеми позволяват по-лесна ориентация и обслужване на клиентите в банковите обекти от входа до напускането му. Отделните функционални единици преливат една в друга като границата помежду им се губи при липсата на каквито и да било прегради.

24-часовата зона за самообслужване набира все по-голямо значение при проектирането на банковия обект. С навлизането на интернет и технологиите в началото на XXI век, се наблюдава разполагането на банкомат за теглене на пари непосредствено до входа. С течение на времето се осигурява 24-часов достъп до тази зона като се обособява определено помещение (обикновено в рамките на виндванга между входа и клиентския салон), достъпът до което се извършва със сканиране на клиентската дебитна или кредитна карта. В последните години, благодарение на дигитализацията (виж Таблица 2) и технологичните решения за банковия сектор, се наблюдава внедряването на високотехнологични банкомати с повече функции, touch-screen екрани за информация, както и зони за видео-разговори с банкови консултанти. Така 24-часовата зона става основен елемент на новите банкови обекти, тъй като позволява на клиента да се самообслужи, т.нар. „self-service”.

Условията за самообслужване са и водещо изискване при проектирането на клиентския салон в последните години. Това явление (виж Таблица 1) се наблюдава в изискванията за проектиране на банкови обекти на „Уникредит Булбанк“ АД, на „ОББ“ – част от КВС Груп, както е и било заложено в заданието при разработката на „Офиса на бъдещето“ на „Банка ДСК“ АД (Младенов, 2021, Асенов, 2021). Зоните за изчакване присъстват като неизменен компонент в банковите обекти – удобни кресла и мека мебел осигуряват комфорта на клиента.

Таблица 1: Резултати от изследването: Функционални зони на банковия обект.

	Банков обект	РДСК -4, филиал Иван Вазов, София	Банков офис "ТБ – Средец", София	"ТБ – България инвест" – Алианц, Со-	Офис на БПБ – клон Варна	Офис на ДСК – клон Пловдив	ДСК – клон Васил Левски, Пловдив	Алианц Банк – клон София	"Уникредит Булбанк" – Бургас, Branch of the future	Офис на бъдещето ДСК – клон София	Офис на ОББ – клон Гурко, София
	Година проект-реализация	1990	1996	2002	2004	2006	2008	2012	2014	2016	2020
Б.1.	Вход с винд-ванг	•	•		•	•			•		•
Б.2.	24-часова зона за (само)обслужване				•	•	•	•	•	•	•
Б.3.	Клиентски салон										
Б.3.1.	Зона за изчакване	•	•	•	•	•		•	•	•	•
Б.3.2.	Зона служители		•	•	•			•	•		•
	работни места – бюра на кота +0,72-0,75м от КГП			•••	••••	••••	••••	••••	••••	••••	•••••••••
	Касов възел – гишета и каси (неподвижно обза-веждане)	••••••••••••••	••••••••••••••	••••	••••	••••	••••	•	•		•
Б.4.	Зона за консултации				•						
	Заседална зала		•	•	•	•					
	Помещения за конфиденциални разговори			•	•	•		•		•	•
Б.5.	Помещение за работа с големи суми пари / VIP каса				•		•				
Б.6.	Стая на (зам.) управи-тел на банка	•	•	•	•	•			•		•
Б.7.	Други помещения										
Б.7.1.	салон инспектори и счетоводители	•	•	•		•					
Б.8.	**"ВАСК" офис**										
Б.8.1.	Санитарен възел	•	•	•	•	•	•	•	•	не е налична информа-ция	не е налична информация
Б.8.2.	Зона за почивка /гардеробно	•	•	•	•	•	•		•		
Б.8.3.	Кухненски възел			•	•	•	•				
Б.8.4.	Архив	•	•	•	•	•	•				
Б.8.5.	Трезори	•		•					•		
Б.8.6.	Броячно	•	•								
Б.8.7.	Охрана		•	•		•	•	•			
Б.8.8.	Техническо помещение – сървър / RACK			•	•	•	•		•		
Б.8.9.	Склад		•	•				•	•		

Таблица 2: Резултати от изследването: Дигитализация и внедряване на технологии в банковия обект.

	Банков обект	РДСК -4, филиал Иван Вазов, София	Банков офис "ТБ – Средец", София	"ТБ – България инвест" – Алианц, София	Офис на БПБ – клон Варна	Офис на ДСК – клон Пловдив	ДСК – клон Васил Левски, Пловдив	Алианц Банк – клон София	"Уникредит Булбанк" Бургас, Branch of the future	Офис на бъдещето ДСК – клон София	Офис на ОББ – клон Гурко, София
	Година на проект-реализация	1990	1996	2002	2004	2006	2008	2012	2014	2016	2020
Г.	**ВНЕДРЯВАНЕ НА ТЕХНОЛОГИИ**										
Г.1.	компютри за служители			•	•	•	•	•	•	•	•
Г.2.	АТМ (банкомат)			•	•	•	•	•	•	•	•
	24-часова зона за самообслужване				•			•	•	•	•
Г.3.	Други технологични решения								•	•	•
	видео екрани								•	•	•
	таблети									•	•
	touch-screen екрани								•	•	•
Г.4.	зона за видео-консултации									•	•
Г.5.	Видео-консултации с call-center								•	•	



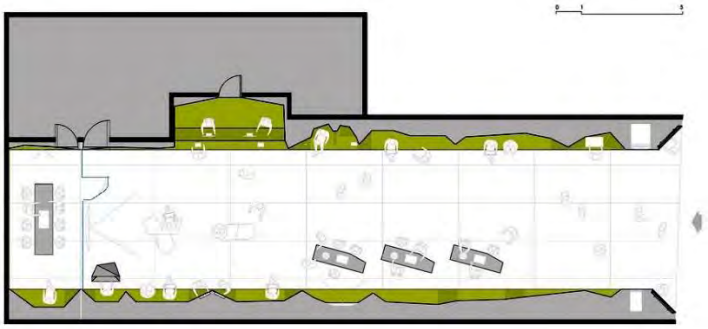
Фигура 1: План РДСК-4, филиал Иван Вазов („Дикански и партньори“ ООД)



Фигура 2: План Банков офис БПБ – Варна, („Дикански и партньори“ ООД)



Фигура 3: План Банков офис Алианц – клон София, („Дикански и партньори“ ООД)



Фигура 4: Планова схема Банков офис ДСК – клон София (DA Architects, 2016)

В допълнение към тях са интегрирани в интериора и технологични устройства, които да задържат вниманието на посетителя, докато изчаква да бъде обслужен, или дори в някои случаи – да има възможността изцяло да получи необходимата му информация без да се налага да чака съдействие от банков служител. Такива устройства са таблети, touch-screen екрани, вградени в масите за изчакване, както и модули за видеоконсултации (виж Таблица 2). Като резултат от тази тенденция е намаляване необходимостта от присъствието на физически служители в банковия обект; съответно и стремеж към редуциране на функционалната зона с работни места (бюра) за служителите. Този процес, за разлика от чуждестранните банкови обекти, в България настъпва по-бавно, тъй като онлайн банкирането все още не е сред най-предпочитаните (според Евростат само 9% от населението в България използва онлайн банкиране), като клиентите по-скоро посещават физически офиси, за да ползват финансови услуги (E-banking and e-commerce, 2022). Въпреки това, промените на интериорните пространства потвърждават драстичното намаляване на зоната на служителите. В съвременния банков обект се обособяват 2–3 работни места (с висока работна маса тип „бар плот“ с или без вграден touch-screen монитор в работния плот) за банкови консултанти (виж Фиг. 4), които да съдействат на клиентите при самостоятелната им работа в банковия обект.

Друга функционална зона, която претърпява драстично намаляване, е касовият възел (виж Фиг. 1–Фиг.4). За разлика от края на 1990-те години, когато той се явява водещата единица за предлаганите

банкови услуги – трансакциите на пари, то в съвременния банков обект при наличието на онлайн банкиране, касата е необходим елемент, но не носи значението, което преди е имала – техният брой е сведен до 1–2 бр. работни места.

От гледна точка на „back" офиса, или зоните, достъпни само служители, драстични промени не се наблюдават. Обслужващите помещения – санитарни възли, зона почивка и кухненски бокс, продължават да са неразделна част от плановата схема на банковия обект като при проектирането се обръща внимание условията за достъп да отговарят на Наредба №4 за достъпна среда за хора с увреждания (Наредба №4/01.07.2009 г.). Техническите помещения, сървъра и помещението за RACK кутията логично с навлизането на дигитализацията стават неизменна част от банковия обект, за сметка на площта архиви и трезори, която намалява. също залагат изцяло новия модел, изискващ максимално интегриране на технологията във физическия клон като същевременно се намалява броя на служителите в него. Концепцията за Е-средата и Е-услугата (изцяло онлайн обслужване) чрез налични таблети, вградени в работните плотове touch-screen монитори, обособеното място за видео-консултации са част от технологичните решения, намерили място в банковия обект на Банка ДСК (виж Таблица 2). Аналогично и следвайки тенденциите, новите банкови офиси на ОББ предлагат голяма част от тези решения. За разлика от Банка ДСК обаче, при офисите на ОББ не се забелязва намаляване броя на работните места за банковите служители.ДИСКУСИЯ

ВНЕДРЯВАНЕ НА ТЕХНОЛОГИИТЕ В БАНКОВИТЕ ОБЕКТИ.

От гледна точка на дигитализацията банковите обекти са пионери във внедряването на технологични решения и нови модели на опериране. От изцяло аналогови офиси през 1990-те години, в момента основният фокус на банковите институции е създаването на физически обекти, които да са технологично окомплектовани така, че да създадат условията клиентите изцяло сами да се обслужват финансово.

Банкоматите (ATM) за теглене и внасяне на суми пари са неизменна част от оборудването на "retail" офисите. След 2012 година, когато в България започва да се внедрява новият корпоративен дизайн „Branch of the Future" на „Уникредит Булбанк" АД, разработен от фирмата I-AM, се забелязва драстично покачване на изискванията към технологични решения за офисите на останалите банки. В офисите на Уникредит се налагат високотехнологичните (BNA) банкомати, за първи път се появява зоната за онлайн видео-консултации, touch-screen мониторите и екраните с информация за банката и услугите й.

В последствие, при разработката на „Офиса на бъдещето" за Банка ДСК през 2016-2017 архитектите от DA Architects

Това проучване установява пряка връзка между промените във функционалните схеми на банковите обекти и дигитализацията чрез внедряването на технологични решения за банковите услуги. При липсата на технологии в края на XX всеки банковият обект е натоварен с определена функция, което допринася за безкрайно голяма и сложна клонова мрежа с офиси – всеки със специфична дейност. За разлика от тях, след внедряването на технологичните решения интериорните пространства за банковите обекти се унифицират и функционалните им схеми придобиват сходен вид, тъй като клоновете вече изпълняват

повече от една функция. Банковите обекти – от офиси за извършване главно на парични операции, се превръщат в места за консултации с банкови експерти. Тази философия заляга и в интериорните решения на банковите клонове, които предлагат удобни кътове, насочени към комфорта на клиента.

При предстоящ по-обширен анализ на взаимовръзката между дигитализацията и трансформацията на интериорните решения на банковите обекти, следва да се обърне внимание и на обемно-пространственото изграждане на вътрешните пространства – цветове, материали, аромати, видове мебели – размери и повърхностна обработка, както и фасадното оформление на банковите обекти. Неразделна част от този анализ е и съпоставката между дигитализацията и все по-налагащата се тенденция за цялостен корпоративен дизайн на интериора, включващ както корпоративно лого, цветове, шрифтове, така и цели модели на поведение, взаимовръзки, обслужване и роли в банковия обект. Също така при следващи етапи на изследване е необходимо банковите обекти да се проучат и от гледна точка на корпоративната политика за обслужване на клиенти и как тя влияе върху плановите решения. Това би допринесло за завършване на цялостната картина относно психологическите модели на работа, които банковите институции целят да установят при опериране с клиенти.

ЗАКЛЮЧЕНИЕ

Функционалните схеми на банковите обекти в България претърпяват драстична промяна през последните 30 години. Основен фактор при тези промени са дигитализацията и внедряването на технологични решения. Те налагат нови модели на работа, а банките са тези, които най-бързо и най-рано адаптират физическите си офиси, за да отговорят на нуждите на клиентите си.

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PROCEEDINGS OF ELEVENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE "INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN" – INNO 2022, 3-5 OCTOBER, HOTEL RILA, BOROVETS, BULGARIA, PP. 41–48

COMPARATIVE INDICATORS OF LIGHTWEIGHT STRUCTURAL ELEMENTS OF WOODEN PREFABRICATED BUILDINGS

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ABSTRACT

The elements, involved in the construction of wooden prefabricated buildings according to their location and function are classified as facing and structural. For these purposes wood is used in massive lumber or as laminated material. Lightweight wooden beams with double-T-cross section, solid wood beams and stems made by medium density fiberboard and particleboard have been manufactured and tested. The webs and flanges are glued together using class D3 polyvinyl acetate adhesive and using a tongue and groove joint. A bending strength and elasticity module are determined in static bending of the created beams, as well as correlation dependencies between them. Compared the indicators, of the series of the examined beams are compared with the use of MDF and particleboard as material for the stems of the test samples. On the basis of the obtained results are presented forecast data on the strengths of bigger than the cross sections examined. Specific fields of application of the studied beams with stems from MDF and particleboard in the construction of wooden prefabricated buildings are proposed. The results obtained in the study, were analyzed and presented graphically.

Key words: double-T-cross section, wooden prefabricated buildings, elasticity module, MDF, particleboard, fields of application.

INTRODUCTION

Timber construction is relevant today, due to the fact that wood is a natural resource that, when used wisely, is inexhaustible. The constructions, facilities and products made of wood create favorable living conditions and a kind of coziness. The elements involved in the construction of wooden houses and buildings according to their location and function are classified as facing and structural. For these purposes, it is used both in massive and in blind form-Figure1. (Panayotov, P., Petkov,T.:2017).



Figure 1: Load-bearing structure made of lightweight beams with double T-profile

The combined solid wall beams and two belts used in the steel constructions [Chavov, T.: 1962] were used as a model of the wooden full-beam beams with I-shaped cross-section (I beams). In wooden structures, these parts are connected by nails or glue. The stem of lightweight wooden beams is different, depending on the support distance and the type of fastener.

Bending strength is one of the most important mechanical indicators of wood and wood materials (Lechev, S.: 1977; Enchev, E.: 1989; Kavalov, A: 1993). When bending wood, the normal stresses in a given cross section change according to complex dependencies. Figure 2 shows a diagram of the behavior of timber when an external load is applied during bending. If the wood does not form plastic cores when bent, it should be destroyed in the pressure zone. Experience shows the exact opposite – when bent, the wood is destroyed in the tensile zone, although its tensile strength is often greater than its compressive strength. This is because under bending loads, once the edge stresses in the pressure zone along the cross-section of the beam reach the ultimate resistances, from this point onwards the next layers begin to withstand additional loads, forming the so-called 'plastic core' of cross-sectional stresses. The type and shape of the plastic cores of the destructive stresses are different for the wood of different wood species (Tanev, V.: 2012).

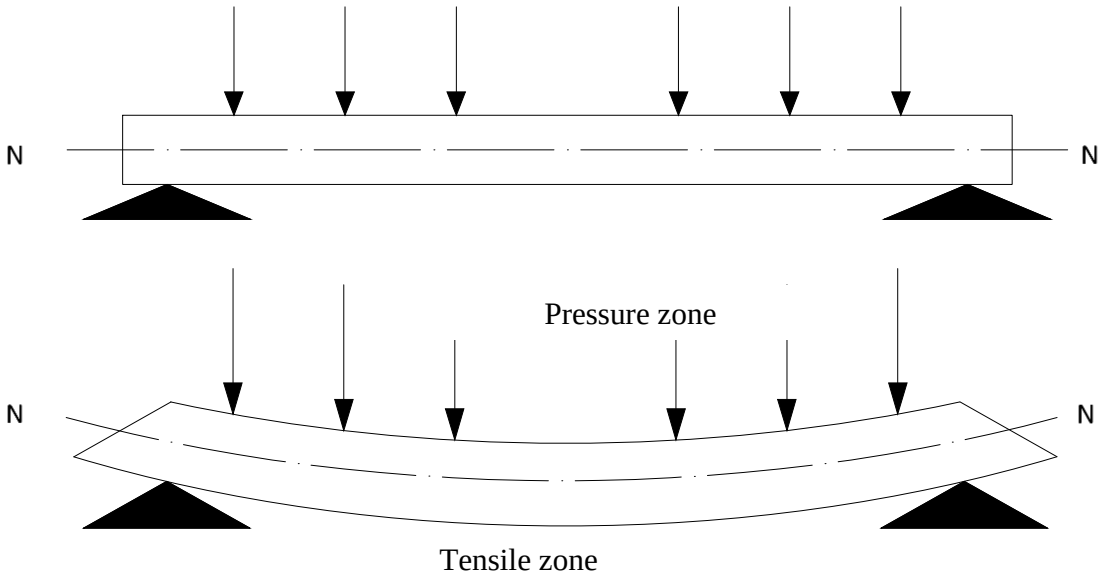


Figure 2: Bending of a wooden element – N-N- zero line

MATERIAL AND METHODS

6 series were made for two models of beams, 10 pieces for each series (60 pieces in total), small-sized beams with different cross-section and the same length – 1200 mm.

For the first model (D series), solid white pine wood with a moisture content of 12%, density 562 kg / m3 was used for the belts, and for the stems – wood particle boards produced by Kronospan (Bulgaria), with a thickness of 8 mm and a density of 700 kg/m^3. Three series of ten test specimens with cross-sectional dimensions presented in Figure 3 and a length of 1200 mm were made.

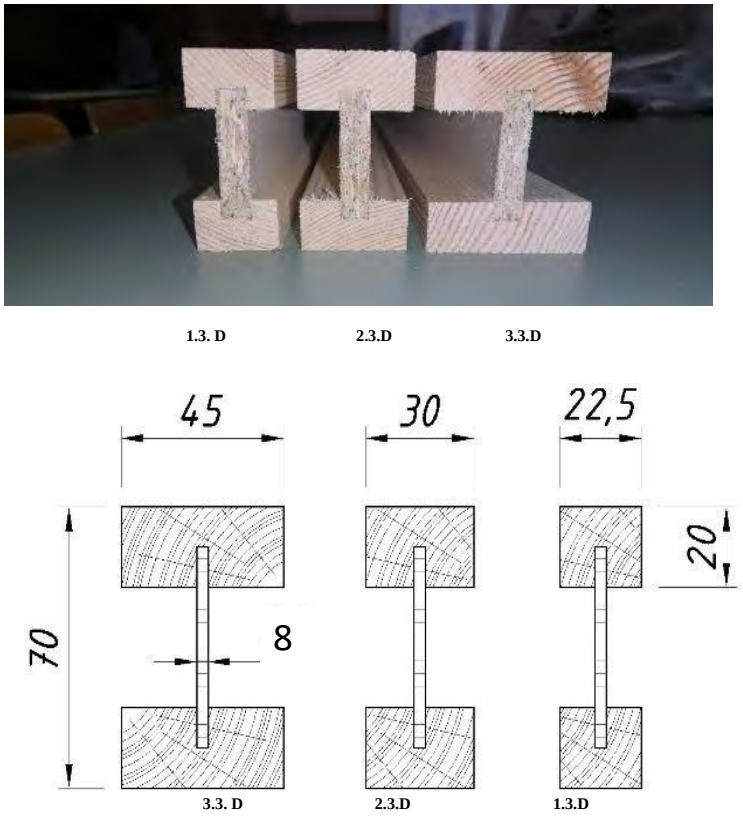


Figure 3: Cross-section and type of test specimens with double T-profile (D series)

For the second model (T series), for the belts, solid white pine wood with a moisture content of 12%, density 562 kg/m^3 was used, and for the stems – high density fiberboard boards (HDF – high density fiberboard) produced by Kronospan Bulgaria), with a thickness of 3.2 mm and a density of 900 kg/m^3. Three series of ten test specimens with cross-sectional dimensions presented in Figure 4 and a length of 1200 mm were made.

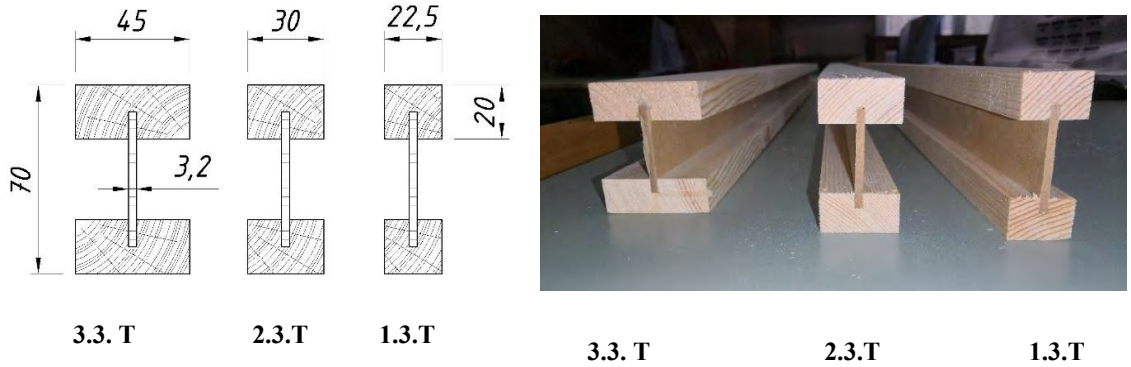


Figure 4: Cross-section and type of test specimens with double T-profile (T series)

The belts are attached to the stems by a nut and feather (Atanasov et al 2018, Koynov et al. 2022) and glued with PVA (polyvinyl acetate adhesive), water resistance class D3, manufactured by Jowat, Poland.

The test piece must have a minimum length of 18 ± 3 times the thickness of the section (h) and must also be subjected to symmetrical bending at two points, as shown in Figure 5.

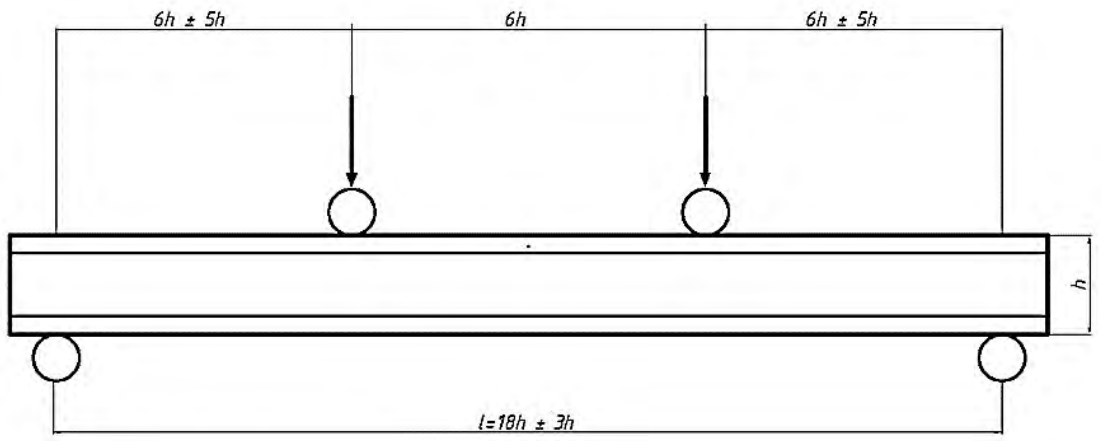


Figure 5: Scheme and dimensions of an experimental installation

The modulus of elasticity in static bending is calculated by formula (1) and the static bending strength by formula (2) – BDS EN 408 + A1: 2012:

$$\sigma = \frac{3.F_{max}.a}{b.h^2}, \text{N.mm}^{-2} \quad \textbf{(1)}$$

$$E = \frac{3.a.l^2 - 4.a^3}{2.b.h^3.\left(2.\frac{f_2 - f_1}{F_2 - F_1}\right)}, \text{N.mm}^{-2} \quad \textbf{(2)}$$

Where: E – modulus of elasticity in bending, N.mm^{-2}; σ – bending strength, N.mm^{-2}; Fmax – maximum load, N; a – distance between the loading plates in bending, mm; h – the thickness of the cross-sectional bending, mm; b – width of the cross section of the bending, mm; G – shear modulus, N.mm^{-2}; l – length of the workpiece to determine the modulus of elasticity, mm; F2-F1 – is an increase in the load in Newtons, respectively at 40 and 10% of Fmax with a correlation coefficient of 0.99 or better; w2-w1 – an increase of deformation mm, corresponding to F2 and F1.

RESULTS AND DISCUSSION

Table1: Correlation coefficient between bending strentgh and modulus of elasticity

CORRELATION	
Bending strentgh (σ)	**Modulus of elasticity (E), N.mm^{-2}**
D1	0,633
D2	0,696
D3	0,578
T1	0,627
T2	0,556
T3	0,692

The correlation between the bending strength and the modulus of flexural elasticity of the three series of investigated lightweight beams (for model D) are 0.633, 0.696 and 0.578, respectively, which is a significant correlation (0.5 <R <0.7). There is a destruction of the stems (ribs) before the destruction of the belts by the tensile below and the compressive stresses above – Figure 6. A linear weight of the beams was obtained, respectively 0.63 kg for 1.3D, 0.88 kg for 2.3D and 1,2 kg for 3.3D, which is very low for the realized high value of bending strength.



Figure 6: Test moments of beams with double T-bending profile (model D – chipboard rib)

The correlation between the bending strength and the flexural modulus of the three series (of model T) of the investigated lightweight beams are 0.627, 0.556 and 0.692, respectively, which is a significant correlation (0.5 <R <0.7). There is again destruction of the stems (ribs), before the destruction of the belts, respectively, by the tensile below and the compressive stresses above – Figure 7. A linear weight of the beams was obtained, respectively 0.59 kg / m for 1.3D, 0.84 kg/m for 2.3D and 1.03 kg / m for 3.3D, which is very low for the realized high value of bending strength. The load they take is again extremely high (up to about 4500 N, approximately 450 kg load capacity), taking into account the very small thickness of the beam stem – only 3.2 mm.



Figure 7: Test moments of beams with double T-bending profile (model T – HDF rib)

Figure 8 shows a load-deformation diagram until complete destruction of the three series of T-series beams is achieved.

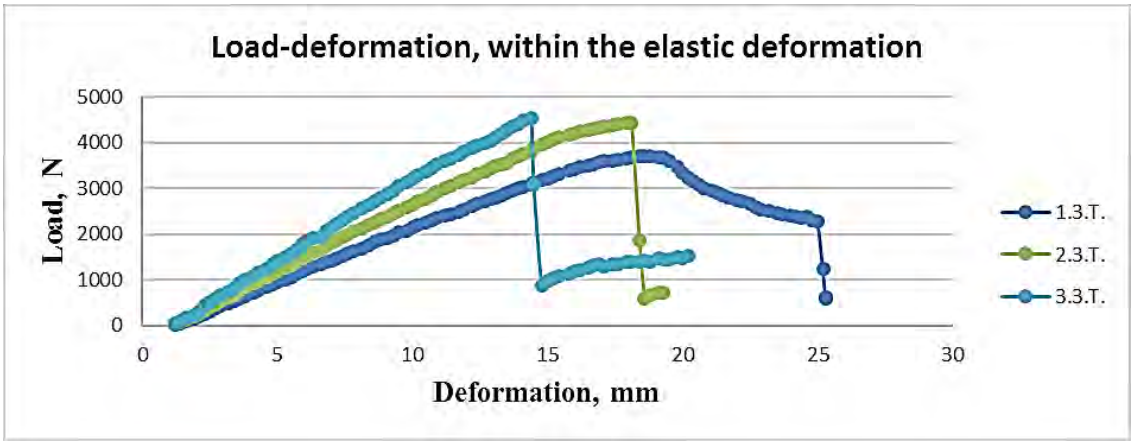


Figure 8: Load-deformation of three series of beams with double T profile (I beams)

Figure 8 shows that as the width of the belts increases (with the same thickness of the stems), the load capacity increases, while the size of the sag decreases. Maximum maximum load – 4541 N reaches the beams of series 3.3. T (45 mm belt width), then the beams 2.3. T – 4431 N (30 mm belt width) and finally series 1.3. T (15 mm belt width) – 3705 N. The average bending strength of the series 1.3. T is 24.72 N.mm^{-2} and the modulus of flexural elasticity is 6943 N.mm-2; the average bending strength of the series 2.3. T is 36.17 N.mm^{-2} and the modulus of elasticity in bending is 8980 N.mm^{-2}; series 3.3. T – the average bending strength is 40.33 N.mm^{-2}, and the modulus of elasticity in bending is 9556 N.mm^{-2}. The average maximum sag (deformation – f) of the beams of series 3.3. T is 14.99 mm; in the series 2.3. T is 18.5 mm, and in the series 1.3.T – 25.2 mm.

Figure 8 shows the load-deformation diagram until complete destruction of the three series of beams with double T-profile series D is achieved, 5mm to 45mm, strength increases by only 19.4%. This result shows a small influence on the width of the belt, to increase the bending strength. Significantly greater influence remains on the width of the rib and possibly its thickness, which should be established in additional studies. This is not the case with the sagging, which increases by 42.4% when the width of the belt increases, of course with heavier loads.

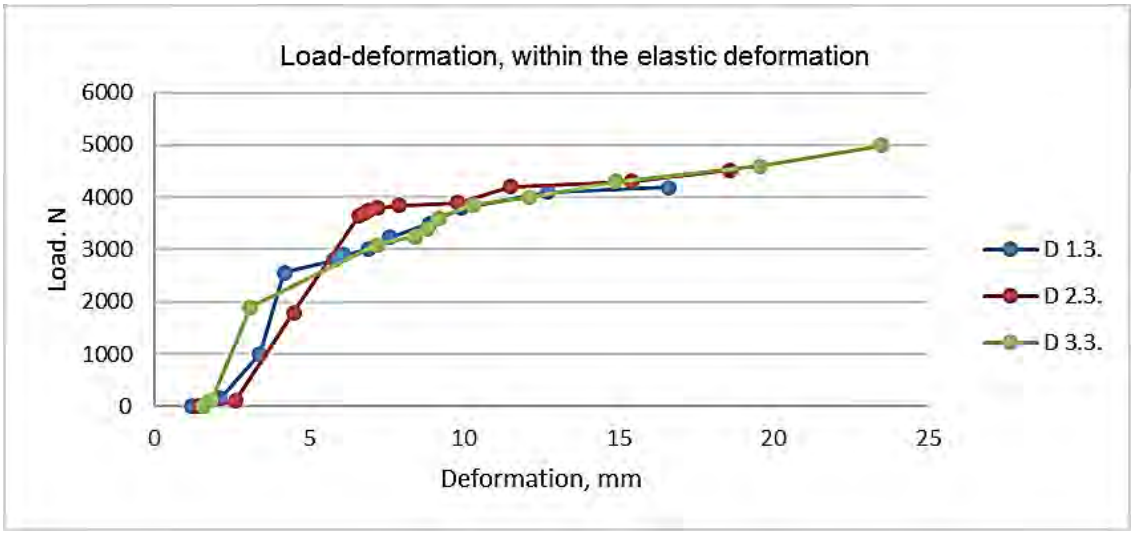


Figure 9: Load-deformation of three series of beams with double T profile (I beams)

Figure 9 shows that as the width of the belts increases (with the same thickness of the stems), the load capacity increases, while the size of the sag decreases. Maximum maximum load – 4996 N reaches the beams of series 3.3. D (45 mm belt width), then the beams 2.3. D – 4518 N (30 mm belt width) and finally series 1.3. D (22.5 mm belt width) – 4185 N. The average bending strength of the series 3.3. D is 34.35 N.mm-2 and the modulus of flexural elasticity is 9876 $N.mm^{-2}$; the average bending strength of the series 2.3. D is 28.24 $N.mm^{-2}$and the modulus of elasticity in bending is 8996 $N.mm^{-2}$; series 1.3. D – the average bending strength is 22.66 $N.mm^{-2}$, and the modulus of elasticity in bending is $N.mm^{-2}$. The average maximum sag (deformation – f) of the beams of series 3.3. D is 18.91 mm; in the series 2.3. D is 15.43 mm, and in the series 1.3.D – 13.28 mm.

CONCLUSION

The use of double T-beams (I beams) in wooden structures is widespread, thanks to its excellent performance and lower mass (such as support beams, ceiling reinforcing and load-bearing elements, roof trusses and others). Lightweight beams reduce the consumption of material and weight of the beam, but also the weight of the structure as a whole by up to 50%, while maintaining the good physical and mechanical properties of the beams. With a very small thickness of the stem, a significant load-bearing capacity of the beams has been achieved, which allows their mass application in wooden prefabricated buildings. From the results obtained and the conclusions drawn, it follows that it may be recommended to continue research in the following areas:

- use of another type of connection between the belts (lamellas), except for the groove and the feather, namely wedge-toothed connection;
- different sizes of teeth at wedge-shaped connection;
- use of different classes of dispersion adhesives;
- study of different heights of the used stem plates (rib);
- production of the lower and upper lamella (girder / belt) from solid wood, and the ribs (stems) from plywood, OSB and other wood-composite materials.

Provided that a serious load capacity (4000–5000 N) is achieved with a rib that is only 3.2 mm, it can certainly be argued that with increasing its thickness, it and the load-bearing capacity of the beams would increase to several tons, which can also be checked with specialized software. Bonded wooden structures, due to their low weight, high strength and durability in operation in various conditions, including in aggressive environments, as well as the ability to produce a variety of shapes and sizes, with each passing year are increasingly used in construction in Bulgaria, as well as around the world.

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METHODS FOR DIGITALISING MATERIAL SURFACES AND THEIR USAGE IN THE DIGITAL ENVIRONMENT

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ABSTRACT

The aim of this research is to outline the advantages and disadvantages of the two main methods for digitalising surfaces – textures: conventional and digital.

The conventional method consists of scanning the real surfaces with specialized cameras. Then the taken images are being edited to match the requirements for the photorealistic images.

The digital method uses various software products to generate the texture in order to achieve the desired result. In this case mathematical models and structures are being applied for maximal realistic effect.

Key words: digitalizing surfaces, interactivity, photography in architecture.

INTRODUCTION

Virtual reality usually consists of various objects, which are made of geometrical surfaces on which are applied various images. Those images are called textures and they contain various properties of the material, for example the normal of the material and how the light reacts with the surface. In modern computer-generated images the aim is for a better photorealistic effect. This can be achieved with the usage of high-resolution textures. To this moment there are two methods for generating the textures: The first one is trough taking a picture of a real-life objects (conventional method) and the second one is by generating them entirely in virtual environment (digital method).

1. METHODS OF GENERATING TEXTURES AND THEIR APPLICATION IN COMPUTER GENERATED IMAGES

What is texture and how to apply it in materials?

The texture is an image, which can be applied to an object in the digital environment. The materials in 3D software have different properties such as diffuse colour, reflection, refraction, bump, opacity etc. The main property of the material is colour, which can be assigned a colour value or a coloured texture. All other properties of the materials, such as reflection, refraction, opacity, bump etc., work on the principle of black-white maps – where the map is white, it indicates that the respective value is affecting the material at a 100% whereas black indicates 0% applied value. The grey gradient shows the percentage of the effect applied in the range between 0 and 100.

To create a material of a good quality, various textures need to be applied in order to manipulate the properties of the material. For example, figure 1 depicts computer generated image of a roof material generated with textures from Substance Source and Substance Designer software and Fig. 2 presents different maps which are as follows from top left to bottom right: diffuse map, reflection map, ambient occlusion map, reflection glossiness map, bump map and height map of the material in Fig. 1.



Figure 1: Images generated in 3D Studio Max (Fig. 1 has copyrights of Adobe Substance)

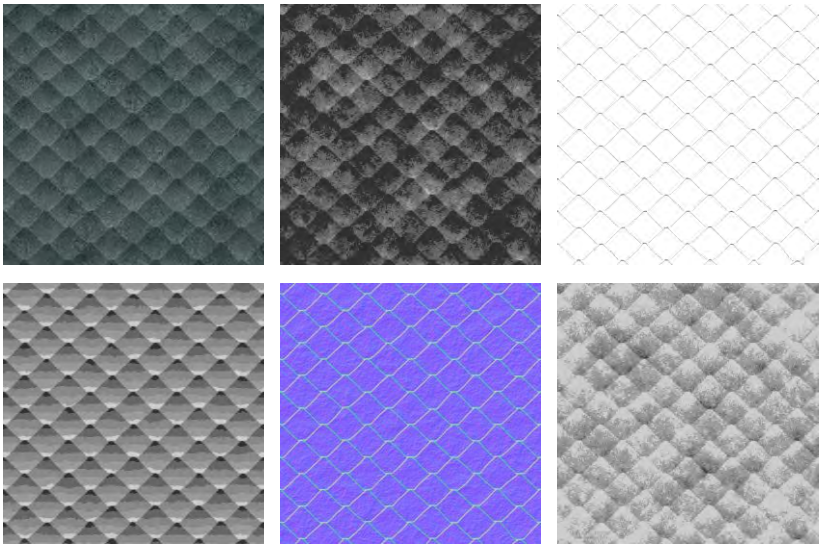


Figure 2: Images are generated with the Substance Source and Substance Designer software (Fig. 2 has copyrights of Adobe Substance)

2. CREATION OF TEXTURES BY CAPTURING EXISTING SURFACES (CONVENTIONAL METHOD)

2.1. Characteristics of the conventional method

The desired existing surface, which would be digitalized, needs to be available in person. The capturing of images requires equipment such as camera with high resolution capabilities. For the materials that would be used the following technical questions need to be addressed in advance, as for example: What characteristics should the final product have? What is the condition of the output materials? Have we gathered all information of the surface details for the object which would be digitalised?

The capturing process has the following steps:

- A high-resolution camera is placed directly above the texture and a photo is taken. The camera needs to be placed perpendicularly against the texture so that distortions can be avoided, and proper lighting is required when taking the photo. The light should not be too warm or too cold – it should be neutral white (6500K) so that the real colours of the texture are captured.
- Next the generated image should be edited using software (for example Adobe Photoshop) in order to avoid

the tiling of the texture. Tiling is a process involving the arrangement of texture on a digital surface where the differences between the neighbouring edges of each texture can be easily noticed. When the texture is placed several times one next to the other, the human eye easily recognizes that one and the same image is used, and the photorealism is lost.

An example using wood surface is depicted in Fig. 3A with the texture details being captured with a high-resolution camera. In Fig. 3B the same texture is depicted after software editing with Adobe Photoshop.

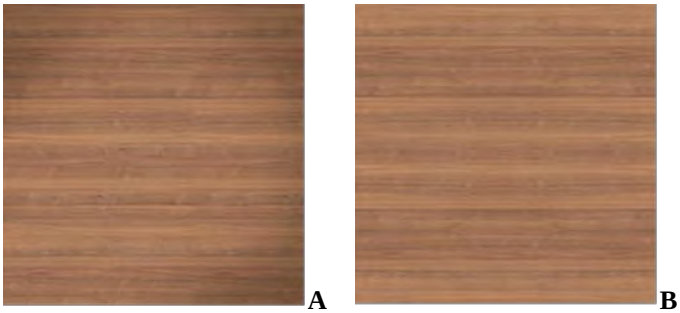


Figure 3: A – texture right after being captured with a digital camera (Source Arroway textures); B – texture from point A after software processing (processed by arch. Atanas Hristozov with Adobe Photoshop software)

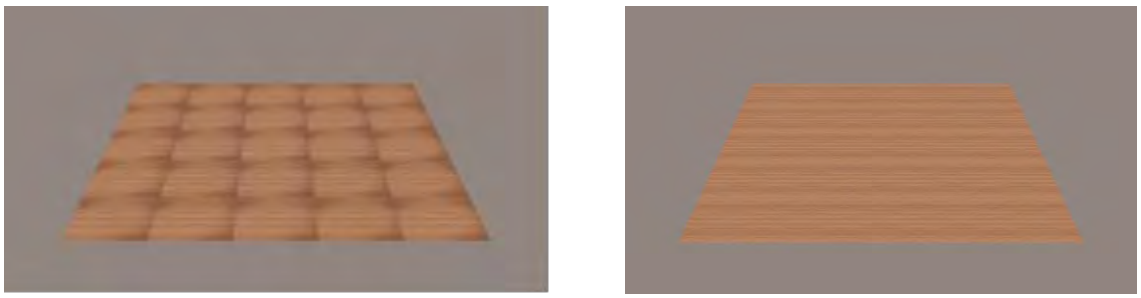


Figure 4: Images generated by arch. Atanas Hristozov with 3DS MAX. A – Material with raw texture; B – Material with modified texture, generated with software

2.2. Advantages of the conventional method

- The generated image can be shot, edited, and transferred fast to a digital environment.
- Greater details of the detail and its imperfection is captured with the conventional method.
- Basic software knowledge is sufficient when editing the texture digitally.

2.3. Disadvantages of the conventional method

- A real-life object is needed in order to capture it and transfer it to a digital environment.
- Using the conventional method requires more time to generate the additional texture maps such as reflection, bump, displacement, and others.

3. TEXTURES GENERATED IN A DIGITAL ENVIRONMENT (DIGITAL METHOD)

3.1. General process

In order to generate a texture using the digital method, specific software is needed. Textures can be generated when a computer

graphics artist comes up with it by drawing and/or painting them, for example pool tiles.

The digital method process for generating pool tiles starts by choosing a colour, then a grid – the fugue – is generated. After that the colour of each square is changed at random where on each square a little height is applied and an additional pattern on the top can be added for greater detail. At this stage the base colour (diffuse texture) and the rest of the maps, such as bump, reflection and other texture maps can be easily generated and exported.

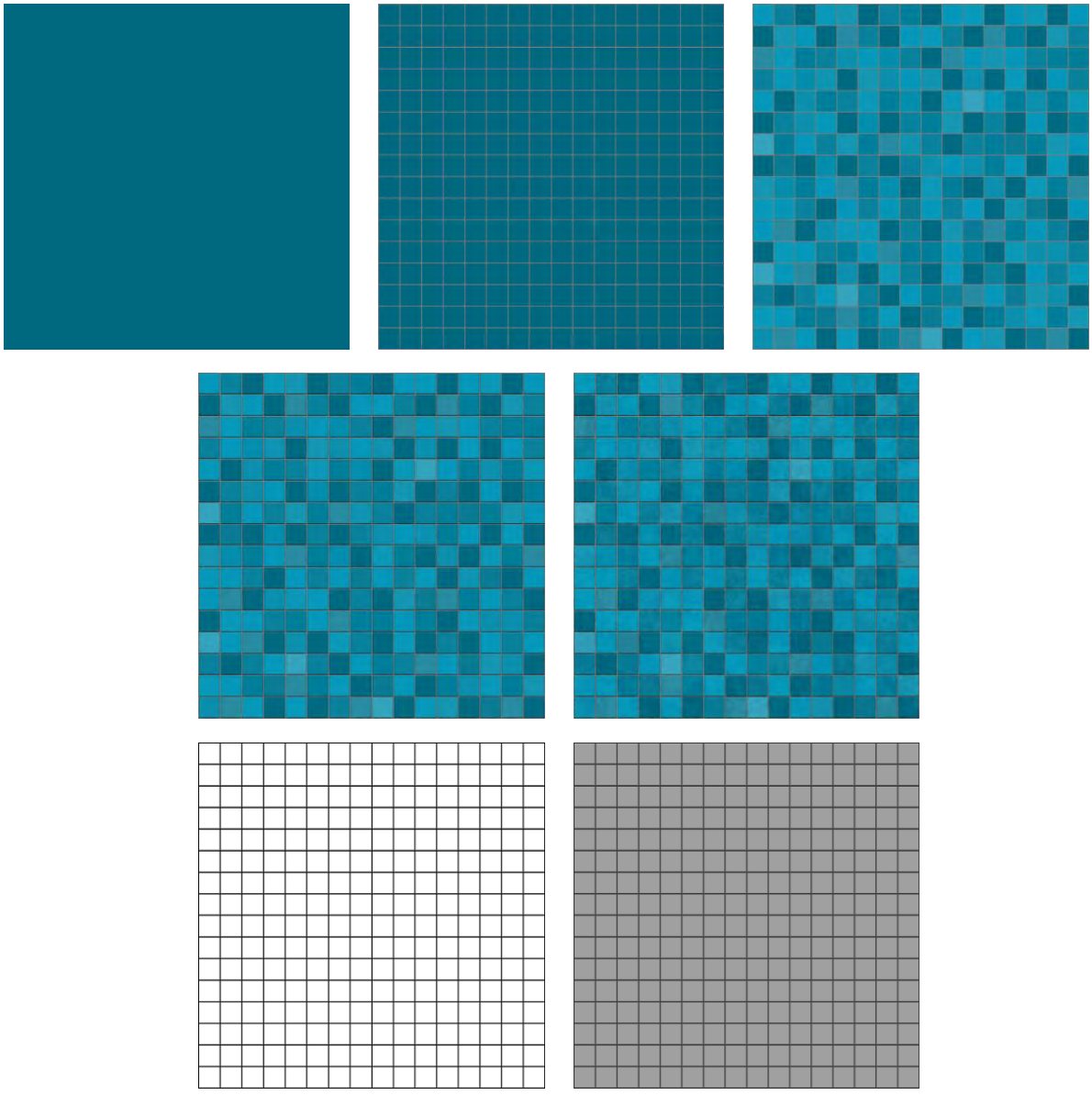


Figure 5: Depicts the process of the generation of a texture (Images created by arch Atanas Hristozov with Adobe Photoshop software)

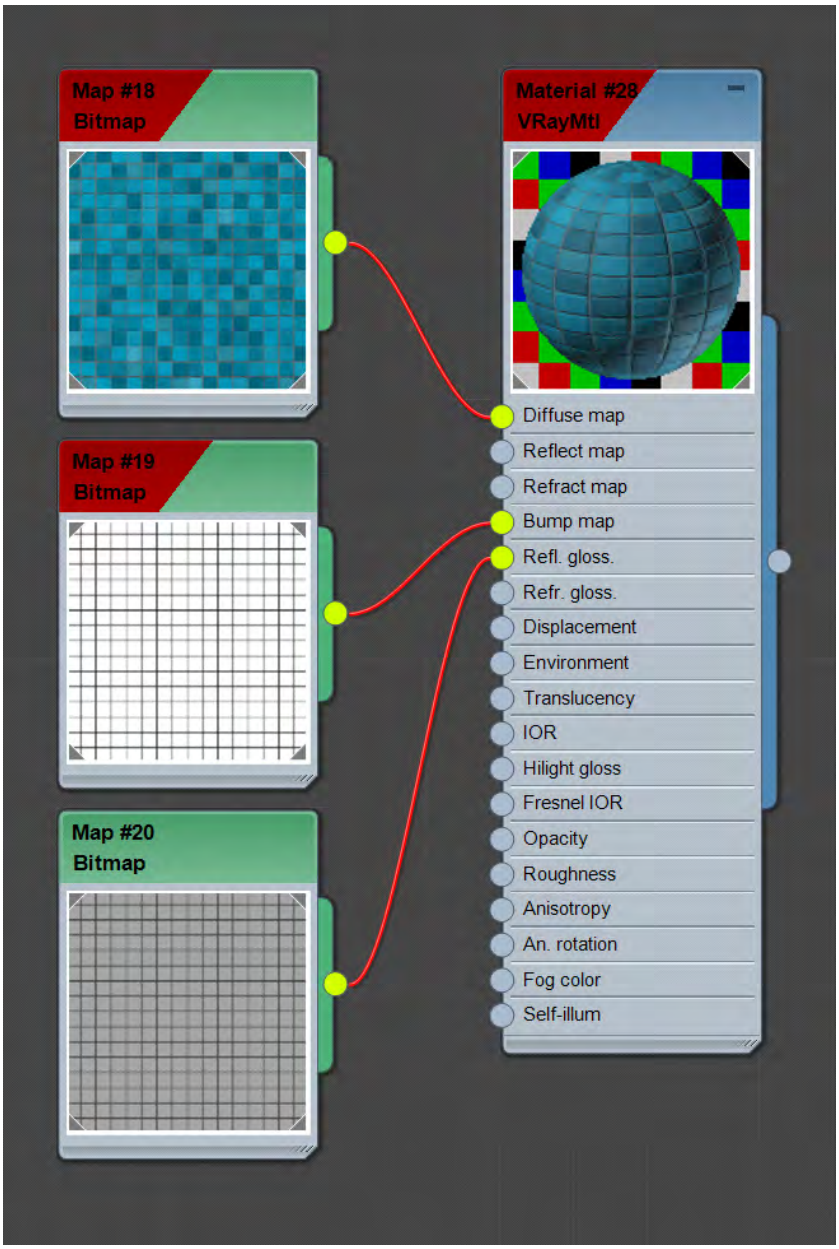


Figure 6: Depicts the generation of the material in 3DS MAX (Image made by arch Atanas Hristozov)

If the texture is too small for the surface of the object that needed to be covered a bigger texture with more squares can be generated at random. After that the rest of the needed maps can be generated as for the smaller texture as described above. By using this method, the tiling of the texture is avoided. If for example, the texture that would be generated is twice as big in size, the UVW mapping of the object need to be expanded proportionally. The new bigger texture of the material is updated and the issue with the tiling is avoided.

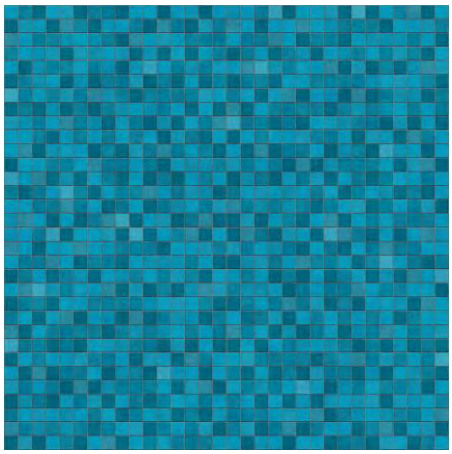


Figure 7: Depicts the expansion of the size of the texture (Image generated by arch Atanas Hristozov generated with Adobe Photoshop)

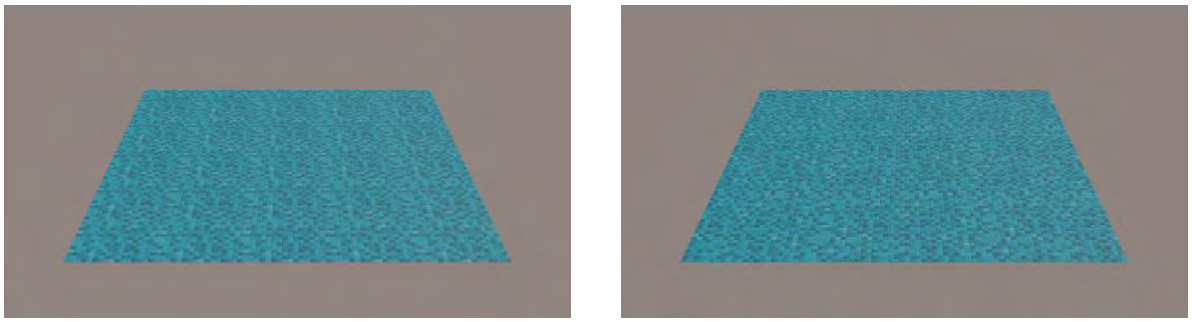


Figure 8: Depicts the difference between the usage of a texture with smaller mapping and a texture with bigger mapping on one and the same surface (Images generated by arch Atanas Hristozov with 3DS MAX software)

3.2. Generating endless materials with Substance designer

According to Roberto De Rose from the State of Art Academy it is physically impossible to generate endless textures, but in most cases, we don't even need it. For him the focus is mostly on avoiding repetitions (tiling), furthermore generating textures must be quick and easy and applicable to all kinds of textures. He lists the following problems CG artists face when generating textures:

1. Tiling – in Substance designer this issue can be solved easily by changing the random seed, in this way an infinite number of brothers of the original texture are generated. Fig. 9 presents the different brothers of the texture.
2. New textures are not tillable together – the reason for this is these new textures look different on the edges on every instance. In order to solve this problem, the outside of the texture is kept the same and only the inside is changed thus generating endless textures. Fig. 10 depicts the solution to the problem with the tiling.
3. Generation of a specific mask for the texture – in Substance Designer a specific mask can be easily generated as seen in Fig. 11. [1]

[1] Roberto De Rose, State of Art academy



Figure 9: Different brothers of the texture (Image is a property of State of Art Academy)

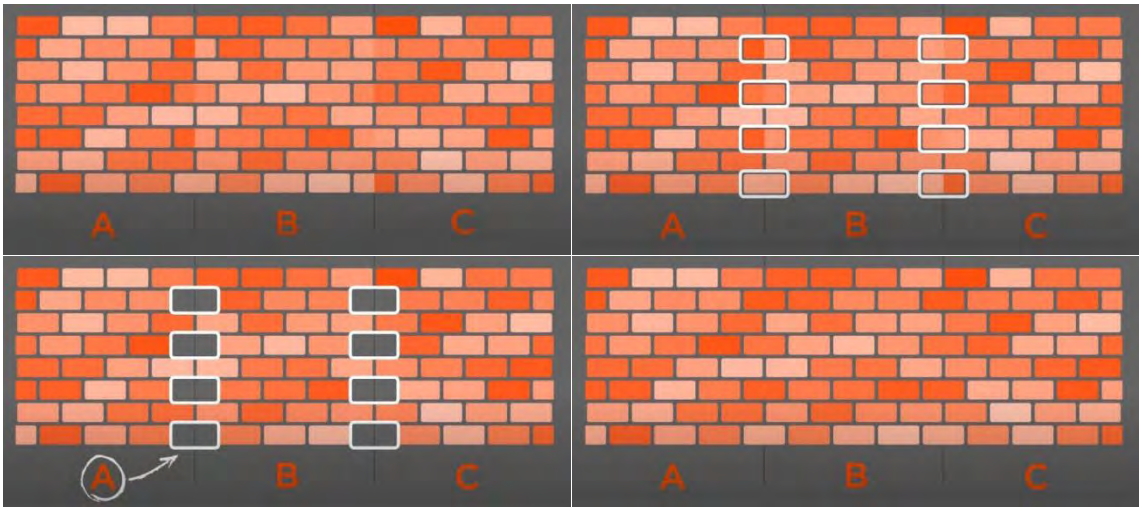


Figure 10: Problems and a solution to the problem with the tiling (Image is a property of State of Art Academy)

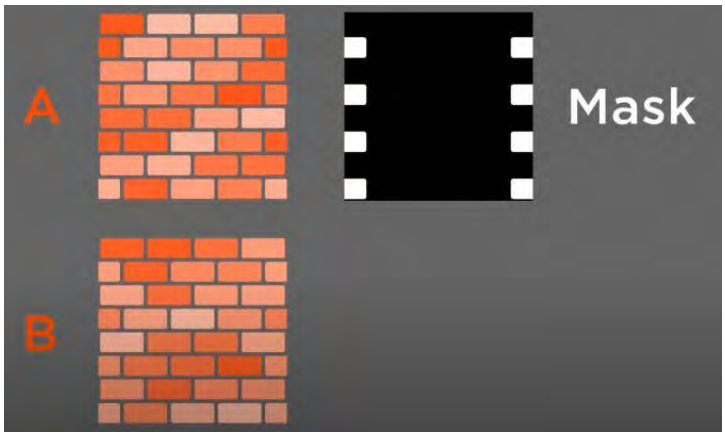


Figure 11: Generation of a specific mask of a texture (Property of the State of Art Academy)

An example of a generating a material in 3DS Max with texture maps created with Substance Designer is given below.

Firstly, the mask for the edges should be generated. Substance designer uses nodes to manipulate the textures. A node is an element, that changes or adds value to the parameters of the previous node or the input texture map. By using various gradient and blend nodes, the edges of the texture can be isolated and it can be converted to a mask. The process is illustrated in Fig. 12.

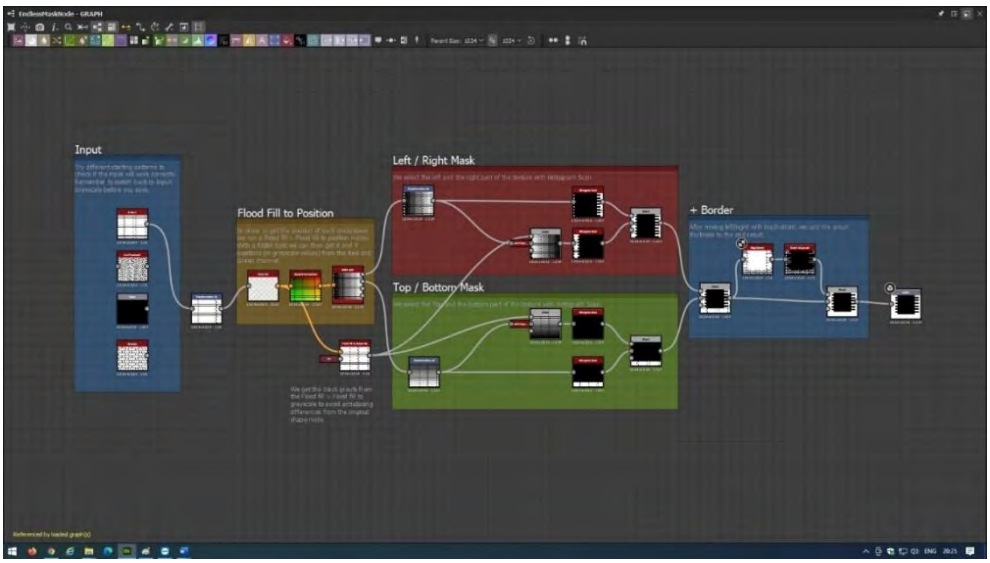


Figure 12: Generation of a specific mask for the edges of the texture (image is a property of State of Art Academy)

The second step is to create the texture maps for the material. Diffuse map, reflection map, reflection glossiness map, height map, bump map etc. need to be created. By choosing the desired pattern and again adding different nodes, the parameters of the input can be manipulated in order to reach the desired output. For example, the diffuse map can be generated by starting from brick pattern, then adding floodfill node and floodfill to random grayscale node in order to randomise the value of every single brick of the pattern. After that a Gradient map node can be applied on it and with it a different colour for each grayscale value can be assigned. In this way a white colour can assigned to the fugues of the texture and various red nuances for the bricks themselves. Everything generated so far is assigned to the diffuse output node and base colour of the texture is ready. In a similar way the reflection, height and bump output nodes are being generated. The process is illustrated on Fig. 13.

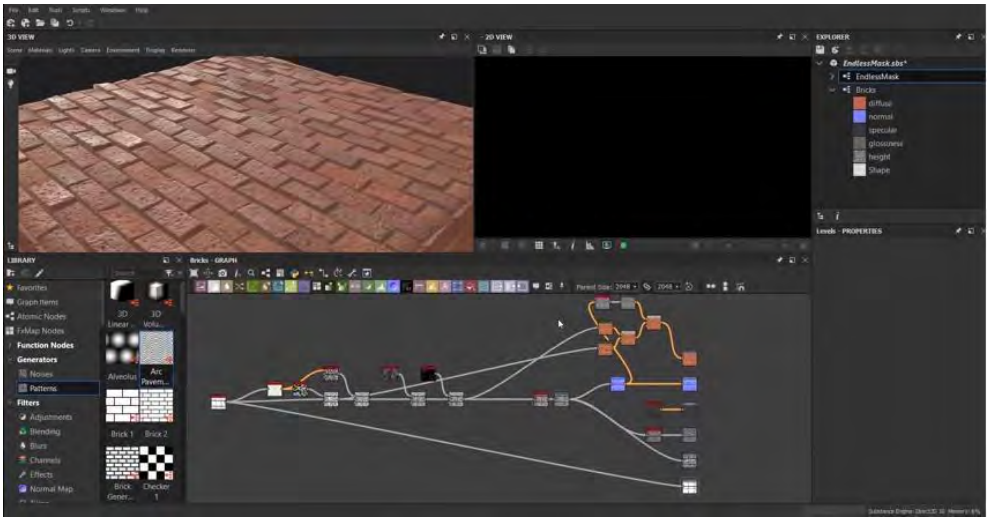


Figure 13: Generation of brick texture maps and their output: diffuse map, normal map, reflection map, reflection glossiness map, height map (image is a property of State of Art Academy)

The third stage is to blend a couple of instances of the textures. The file that was created in step two can be used and it needs to be copied two times as a starting input node. The parameters of the first instance of the material need to be locked so it cannot be modified further. After that the two instances of each output of the two textures (diffuse, normal, reflection, bump, height etc.) need to be blended by being mixed with the mask that was generated in step one. Then the result is applied in the output nodes (diffuse, normal, reflection, bump, height etc.). Also, the mask needs to be set as an output node. The process is illustrated on Fig. 14.

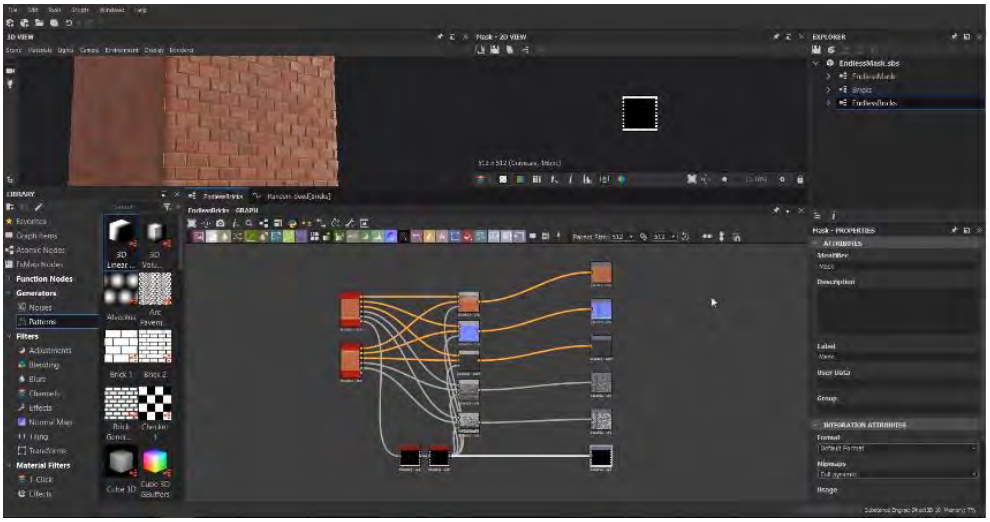


Figure 14: Generation of the variations of the brick texture maps and their output: diffuse map, normal map, reflection map, reflection glossiness map, height map (image is a property of State of Art Academy)

The fourth step is to import the file from step three to Substance player. In this software the number of the variations of the texture maps can be chosen to be exported. Then it can be adjusted to the desired resolution, the format, the specific texture maps (diffuse, glossiness, height etc.) and the folder location for exporting the textures in. Then the program generates the textures and saves them in the output location.

The fifth step is the creation of the material in 3DS Max which uses the textures, generated by Substance designer and Substance Player. This is done by applying a Bercontile map in the diffuse parameter of the material. Its tile width and height parameters need to be set to 1, edge width and height to 0. The scatter parameter needs to be changed to custom and the custom bond pattern parameter to 0,1,1. Then a Multitexture map needs to be applied in the Bercontile. The randomise by parameter in the Multitexture map needs to be set to Bercontile method and all the textures generated with Substance player are being imported in the manage texture property of the Multitexture map. This is how the tilling of the texture is avoided and the material is generated.

3.3. Advantages of the digital method

- A real-life object is not required in order to generate texture.
- Any ideas about how a texture should be created can be applied.
- Using this method, additional texture maps can be generated much faster compared to the conventional method – for example reflection map, bump map, displacement map etc.

3.4. Disadvantages of the digital method

- The generation of the texture is much more time consuming.
- Additional skills with various software products are required.

CONCLUSION

Both methods could lead to the same end result. It is a question of how much time the generation of a texture takes and the complexity of the geometry it is been applied to. When choosing a method for texture generation, firstly the type of object and the size of the surface the texture will be applied to need to be considered. When the size is too large, it is better to use computer generated textures as this way enough variety in the structure of the texture can be added, and the tiling of the texture will not be spotted by human eye. Moreover, when textures are generated digitally, it is easier to generate the needed texture maps.

When the object's size is smaller, it would be better to use textures generated by taking a photo. With this method textures can be generated faster and a greater detail in the imperfections can be achieved.

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EVALUATION OF THE QUALITY OF SURFACES PROCESSED WITH HAND-GUIDED CNC MILLING MACHINE

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ABSTRACT

The paper presents results from experimental study, investigating the surface quality, after processing with hand-guided CNC milling machine, model Shaper Origin. For the aim of the experiment, an end milling machine with cutting diameters (D) 3 and 5 mm was used. Surfaces from plywood and wood from beach (Fagus Sylvatica L.) were processed. The processing was performed at different rotational speed of the spindle (n) and milling depth (h) of the CNC machine. The roughness of the surface was measured with portable surface roughness tester Surftest SJ-210 (Mitutoyo, Japan) and it is characterized by the roughness parameter Rz, The results show that the values of Rz vary from 32 to 69 μm. The surface roughness deteriorates with the increase of the milling depth (h), while with the increase in the rotational speed of the cutting tool (n) its quality improves. Based on the performed experiments, graphical dependences, presenting the influence of the investigated factors on the quality of the processed surfaces have been derived as well as recommendations with practical implementation have been made.

Key words: surface roughness, wood, end milling machine, CNC router, spindle speed.

ОЦЕНКА НА КАЧЕСТВОТО НА ПОВЪРХНИНИТЕ ФРЕЗОВАНИ С CNC ОБЕРФРЕЗА С РЪЧНО ВОДЕНЕ

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РЕЗЮМЕ

В работата са представени експериментални изследвания върху качеството на фрезовани повърхнини със CNC фреза, модел Shaper Origin. За целите на изследванията са използвани опашкови фрезери с диаметри на рязане (*D*) 3 и 5 mm. Обработвани са повърхнини от шперплат и дървесина на обикновен бук (*Fagus Sylvatica* L.). Детайлите са обработвани при различни параметри на CNC обработката, като честота на въртене на вретеното (*n*) и дълбочина на фрезоване (*h*). Грапавостта на повърхнините е измерена с помощта на профиломер за грапавост, модел Surftest SJ-210 (Mitutoyo – Япония). За оценка на грапавостта е използван параметър за грапавост R_z, чиито стойности се изменят от 32 да 69 μm. Резултатите показват, че с увеличаване дълбочината на фрезоване (*h*) се увеличава и грапавостта на повърхнините, а с увеличаване честотата на въртене на инструмента (*n*) – подобряване качеството на фрезованите повърхнини. На база на проведените експерименти са изведени графични зависимости на изследваните фактори и са формулирани препоръки за процеса на фрезоване с практическа насоченост.

Ключови думи: грапавост на повърхнинните, дървесина, опашкови фрезери, CNC рутер, скорост на вретеното.

ВЪВЕДЕНИЕ

CNC технологиите отдавна са намерили своето широко приложение в мебелната индустрия и производството на изделия от дървесина. Благодарение на глямото им разнообразие по отношение на техните технологични и функционални възможности, те намират приложение при множество технологични операции (Кавалов, 2014; Гочев, 2018).

В научната литература съществуват редица научни и приложни изследвания на работата и поведението на CNC дърво-обработващите машини (Karagos et al., 2011, Pinkowski et al., 2013; Kminiak & Šustek, 2016; Palubicki & Rogozinski, 2016; Kminiak & Banski, 2017; Kminiak et al., 2017; Nemec et al., 2017). Управлението на машините чрез CNC технологии се е развило до такава степен, че те вече успешно се прилагат и при оберфрези с ръчно водене от оператор. Като пример за такъв тип машина може да бъде посочена оберфреза модел Shaper Origin. При работа с тази машина няма специфични изисквания към работната маса, върху която ще се поставят обработваните детайли. Едновременно с това, обаче, въпреки ръчното водене на машината от оператор остават високите изисквания по отношение на точността на обработка и качеството на повърхнините. Известно е, че върху грапавостта на обработените повърхнини влияние оказват редица фактори, сред които скорост на подаване, скорост на рязане, дебелина на снемания слой и характеристиките на режещия инструмент (Тричков 1996; Тричков 2006; Keturakis & Juodeikiene 2007; Gochev 2014a; Gochev2014b; Kminiak et al. 2016; Kminiak et al. 2017; Vitchev et al. 2018a; Vitchev & Gochev 2018b; Vitchev & Gochev 2018c; Vitchev 2019).

Настоящата работа има за цел експериментално да се изследва качеството на повърхнините на детайли от шперплат от дървесина на бреза (*Betula pendula* L.) и от дървесина на обикновен бук (*Fagus Sylvatica* L.), обработени с CNC оберфреза модел Shaper Origin при изменение на честотата на въртене на режещия инструмент (n) и дълбочината на фрезоване (h). Използвани са челни фрезери с диаметър на рязане 3 и 5 mm.

МЕТОДИКА НА ИЗСЛЕДВАНЕТО

За провеждане на експерименталните изследвания е използвана CNC оберфреза с ръчно водене, модел Shaper Origin (фиг. 1). Шпинделът на машината може да работи с шест различни честоти на въртене (n), како следва: 10000 min^{-1}; 13200 min^{-1}; 16400 min^{-1}; 19600 min^{-1}; 22800 min^{-1}; 26000 min^{-1}.



Фигура 1: CNC оберфреза, модел Shaper Origin – общ вид

Машината разполага с три софтуерно управляеми оси – *X, Y* и *Z*. Движението на шпиндела по ос *Z* определя дълбочината на обработване, която се задава софтуерно при създаване на програмата за управление. В процеса на рязане движението по ос *Z* не може да се променя. В процеса на обработване, на дисплея на машината се визуализира геометрията на рязане, оста на въртене на режещия инструмент и зоната на самокоригиране на шпиндела по оси *X* и *Y* (фиг. 2). В случай че операторът излезе от геометрията на рязане, повече от зоната на саморегулиране, която е с радиус 10 mm плюс радиуса на режещия инструмент, шпинделът на машината се прибира автоматично.



Фигура 2: Екранна снимка в процес на рязане на (CNC Shaper Origin)

Машината се ориентира в пространството благодарение на предварително залепени върху обработвания детайл кодирани хартиени ленти (Shaper Tape), които трябва да се сканират от сканиращата камера на машината преди процеса на рязане.

За процеса на фрезоване са използвани челни (опашкови) фрезери с характеристики представени в таблица 1.

Таблица 1: Характеристика на режещите инструменти

Параметри	Инструмент 1	Инструмент 2
Външен диаметър *D*	5 mm	3 mm
Диаметър на опашка *d*	8 mm	8 mm
Обща дължина *L*	50 mm	45 mm
Работна дължина *l*	12 mm	10 mm
Брой режещи ръбове *z*	2	2
Максимална честота на въртене *n*	24 000 min^{-1}	27 000 min^{-1}

В хода на изследванията са обработвани детайли от дървесина на обикновен бук (*Fagus Sylvatica* L.), с плътност ρ = 690 $kg.m^{-3}$ и влажност *W* = 12% и шперплатни плочи с дебелина 18 mm от дървесина на бреза (*Betula pendula* L.). Характеристиките на използвания материал са определени съответно по БДС ISO 3131 и БДС ISO 3130.

Експерименталното изследване е проведено на два етапа. По време на първия се проследи влиянието на дълбочината на фрезоване (*h*) върху грапавостта

на обработените повърхнини. Фрезовани са „джобове“ с дълбочина (*h*) 1 mm, 2 mm и 3 mm при честота на въртене на шпиндела *n* = 19600 min^{-1}. Вторият етап на експеримента проследява влиянието на честотата на въртене на инструмента върху грапавостта на фрезованата повърхнина. Фрезовани са „джобове“ с дълбочина (*h*) 2 mm при честота на въртене на инструмента (*n*) 16400 min^{-1}; 19600 min^{-1}; 22800 min^{-1}. При двата етапа на експеримента са използвани режещи инструменти 1 и 2 (табл. 1).

За определяне качеството на обработените повърхнини, в зависимост от променливите фактори, е използван параметърът за грапавост R_z, µm, който се определя по отделно за пет базови дължини в направление по дължина на дървесните влакна на всеки детайл. За всяка базова дължина параметърът за грапавост R_z се определя по формулата

$$\boldsymbol{R_z = \frac{\sum_{i=1}^{5}\left|y_{p_i}\right|+\sum_{i=1}^{5}\left|y_{V_i}\right|}{5}, \mu m} \qquad \textbf{(1)}$$

където: y_{pi} е височината на *i*-тата най-голяма издатина на профила, µm; y_{vi} – дълбочината на *i*-тата най-голяма падина на профила, µm.

Грапавостта на повърхнината на всеки детайл е определяна на база на средно аритметичната стойност $\overline{R_z}$ от петте измервания. Методиката на измерванията подробно е разгледана от Гочев (2005) и е съобразена с изискванията, регламентирани в БДС EN ISO 4287.

За определяне на грапавостта на повърхнините на обработените детайли в зависимост от променливите фактори и режещи инструменти е използван електронен профиломер, модел „Surftest SJ-210“ (Mitutoyo, Япония) (фиг. 3).



Фигура 3: Профиломер модел Surftest SJ-210 – общ вид

РЕЗУЛТАТИ И ДИСКУСИЯ

На базата на представената методика са проведени експериментални изследвания за оценяване качеството на фрезованите повърхнини на детайли от дървесина на бук (фиг. 4) и повърхнини на шперплат (фиг. 5).



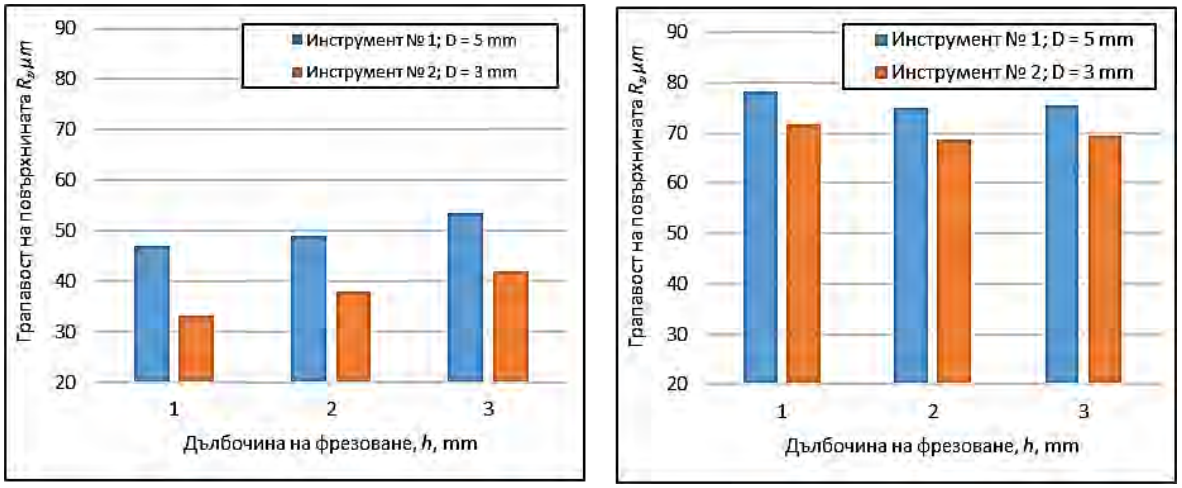
Фигура 4: Експериментален образец на фрезована повърхност на детайл от дървесина на бук (*Fagus Sylvatica* L.) при различни дълбочина на фрезоване (*h*), честота на въртене на режещия инструмент (*n*) и диаметър на режещия инструмент (*D*)



Фигура 5: Експериментален образец на фрезована повърхност на шперплат при различни дълбочина на фрезоване (h), честота на въртене на режещия инструмент (n) и диаметър на режещия инструмент (D)

Оценката на грапавостта на обработените повърхнини е на базата на изменението на параметъра за грапавост R_z, в зависимост от дълбочината на фрезоване (h) и честотата на въртене на режещия инструмент (n).

На фиг. 6 графично е представено влиянието на дълбочината на фрезоване (h) върху грапавостта на повърхнините от дървесина на бук (фиг. 6-а) и шперплат от дървесина на бреза (фиг. 6-б) при използване на два фрезови инструмента: Инструмент № 1 с диаметър D = 5 mm; Инструмент № 2 с диаметър D = 3 mm.

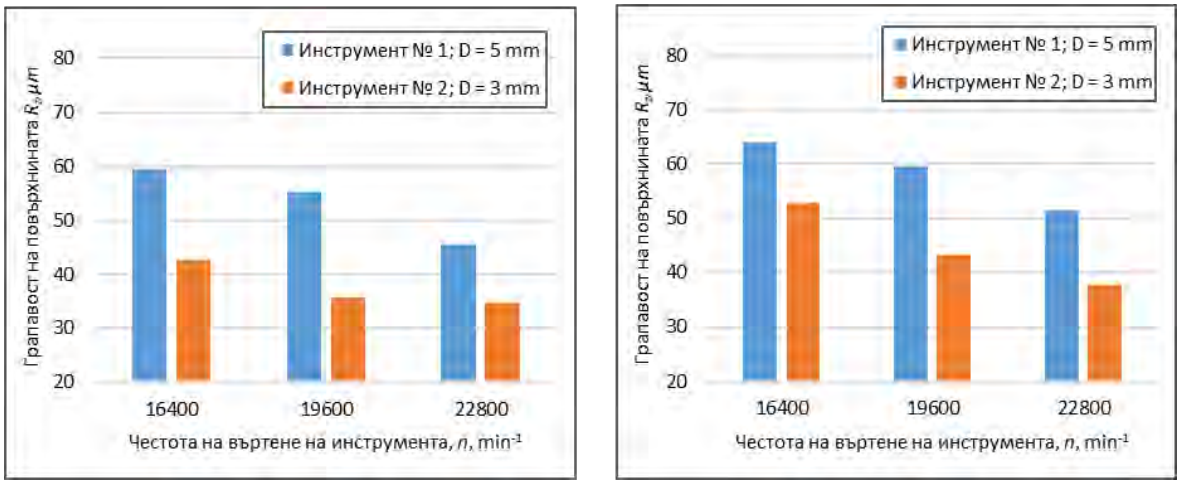


Фигура 6: Изменение на параметъра за грапавост R_z в зависимост от дълбочината на фрезоване (h) и диаметъра на фрезовия инструмент (D): *а*) фрезовани повърхнини от дървесина на бук; *б*) фрезовани повърхнини на шперплат

При фрезоването на дървесина от бук се забелязва изменение на грапавостта, макар и в не големи граници (фиг. 5-а). С увеличаване на дълбочината на фрезоване нараства и стойността на параметъра за грапавост R_z. По-значително изменение на грапавостта се констатира в зависимост от диаметъра на режещия инструмент. Средната грапавост при използване на Инструмент № 1 (D = 5 mm) е $\overline{R_z} = 49\ \mu m$, докато при използване на режещ Инструмент № 2 (D = 3 mm) средната грапавост е $\overline{R_z} = 38\ \mu m$. Тази разлика се равнява на около 22% по-добро качество на повърхнината при използване на фрезовия инструмент с по-малък диаметър. При обработване на повърхности на шперплат от бреза, при същия режими на фрезоване, се констатира значително по-висока грапавост на повърхнините в сравнение с тези от дървесина на бук (фиг. 5-б). Едновременно с това се забелязва и по-ниска стойност на параметъра за грапавост R_z при използване на режещ Инструмент № 2 (D = 3 mm), в сравнение с Инструмент № 1 (D = 5 mm). Разликата в грапавостта на обработените повърхнини на детайли от букова дървесина и детайли от брезов шперплат, се дължи на разликата в плътността на двата дървесни вида, както и на разликата в структурата на двата материала. Детайлите от шперплат са изградени от няколко на брой взаимно перпендикулярни помежду си дървесни слоя, между всеки от които е нанесен лепилен слой.

Изменението на грапавостта на обработените повърхнини, в зависимост от честота на въртене на режещия инструмент (n) е представена графично на фиг. 7.

От графиките ясно се вижда, че увеличаването на честотата на въртене (*n*) води до понижаване на стойността на параметъра за грапавост R_z, което е очаквано, тъй като по-високата честота на въртене на инструмента осигурява по-висока скорост на рязане.



а) **б)**

Фигура 7: Изменение на параметъра за грапавост R_z в зависимост от честотата на въртене на режещия инструмент (*n*) и диаметъра на фрезовия инструмент (*D*):
***а*) фрезовани повърхнини от дървесина на бук; *б*) фрезовани повърхнини на шперплат**

Резултатите на графиките на фиг. 7 корелират с резултатите от графиките на фиг. 6. Потвърждава се, че по-добро качество на фрезованите повърхнини се постига с използване на Инструмент № 2 с диаметър на рязане $D = 3$ mm в сравнение с Инструмент № 1 ($D = 5$ mm). Увеличаването на честота на въртене на инструмента (*n*) от 16400 min^{-1} до 22800 min^{-1} води до намаляване на параметъра на грапавост R_z от 59,55 μm на 45,46 μm при използване на режещ Инструмент № 1 ($D = 5$ mm), а при Инструмент № 2 ($D = 3$ mm) от 42,72 μm на 34,70 μm.

Трябва да се отчете и фактът, че въпреки ръчното водене на машината от оператор, без да се ползват допълнителни водещи линеали и шаблони, геометрията на обработените повърхнини отговаря напълно на предварително зададените в програмата за управление на CNC оберфреза модел Shaper Origin.

На следващ етап се предвижда да се проведе експериментално изследване, с цел проучване на комплексното влияние на изследваните фактори и степента на тяхната значимост върху изменението на грапавостта на фрезованите повърхнини със CNC оберфреза модел Shaper Origin чрез провеждане на планиран двуфакторен експеримент.

ИЗВОДИ И ПРЕПОРЪКИ

В резултат от проведеното начално експериментално изследване, върху оценяване качеството на обработените повърхнини със CNC фреза модел Shaper Origin, могат да бъдат обобщени следните поважни изводи и направени следните препоръки:

Благодарение на успешно приложената CNC технология при оберфреза, модел Shaper Origin, дори и при ръчно водене на машината от оператор, геометрията на обработените повърхнини съответства напълно на предварително зададените.

От използваните режещи инструменти се установи, че по-добра грапавост на по-

върхнините се достига с използване на челен фрезер, с диаметър на рязане (*D*) *D* = 3 mm (Инструмент № 2), в сравнените с челен фрезер с *D* = 5 mm (Инструмент № 1).

Констатира се, че с увеличаване дълбочината на фрезоване (*h*) се увеличава грапавостта на обработените повърхнини, а увеличаването на честотата на въртене (*n*) на инструмента води до намаляване на грапавостта.

Като оптимални стойности на променливите фактори, с цел получаване на повърхнини с ниска грапавост могат да бъдат препоръчани: диаметър на режещия инструмент *D* = 3 mm; честота на въртене на инструмента *n* = 22800 min^{-1}; дълбочина на фрезоване *h* = 2 mm.

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SELECTION OF MODES FOR CO2 LASER HEAT TREATMENT WHEN ENGRAVING COMPLEX GRAPHIC IMAGES ON PLYWOOD

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ABSTRACT

The article presents the results of the study of the modes of laser engraving of complex graphic images on plywood samples. The influence of varying the laser power output and scanning speed of a CO_2 laser beam has been studied as well as the focal length of the optical system and the position of the focus on color shades in the design of complex graphic images.

Key words: CO_2 laser beam, scanning speed, power output, focal length, optical system, plywood, graphic images.

INTRODUCTION

The laser beam, with its specific properties, is widely used in various fields of industry, including the woodworking and furniture industries. One of the main factors determining the applicability of the CO_2 laser (wavelength $\lambda = 10{,}6$ μm) for the treatment of wood and wood-based materials (WBM) is the absorption capacity of the material. For most tree species and WBM, the average absorption in the IR spectrum is of the order of 88% (Gochev 1996).

The main role in creating one or another heating zone, determining the nature of the processing, have the energy parameters of the laser beam: power; spatial distribution of the power density of emission; focusing conditions, physical properties of the material, etc.

The laser beam, in addition to being a cutting tool, can also be used as a means of surface treatment – engraving, marking, and construction of complex decorative images on wood and WBM. The surface treatment effect is obtained when a line is applied to the material with an unfocused or focused laser beam, characterized by a certain width, depth, and color.

Laser machines with low power (40 W-80 W) and reasonability prices are especially suitable for engraving wood products and WBM with a high level of uniqueness and aesthetic appearance. The literature provides various information for engraving or decorating with the help of CO_2 laser beam, as well as with semiconductor lasers and color changes of beech, oak, ash, linden, spruce, and other tree species. (Petutschnigg at al. 2013; Gurau et al. 2017; Vidholdová et al. 2017; Sikora at al. 2018; Jurek et al. 2021, etc.).

The aim of the present work is to study the influence of the parameters of CO2 laser beam on the changes in the colour of birch plywood samples and its use in the engraving of complex graphic images, on the basis of which to formulate the relevant conclusions and recommendations.

METHODOLOGY

The experimental studies were performed using a laser machine for engraving and cutting of FormaTec, model K40 (China) (Fig. 1) with a power of 40 W.

The colour changes of the surface layer of the material were studied by varying the power of the laser beam (P) from 8 to 0,4 W;

scan speed V_f = 270 mm / s; lens focal length from ZnSe, F = 50,8 mm. Focus position: on the surface of the material – ΔF = 0 mm.

The power density of the laser beam is determined by a formula

$$q = \frac{P}{Q} \quad (1)$$

Where q is the power density of the laser beam, W/mm^2;

$Q = \frac{\pi.d^2}{4}$ – the cross-sectional area of the laser beam, mm^2;

d – the diameter of the beam (d = 5), mm.



А Б

Figure 1: A – laser machine for engraving and cutting K 40; B – focusing lens made from ZnSe

Samples of birch plywood (Petula pendula Roth.) With a thickness of 3.0 mm and dimensions of 200 x 200 x 3 mm – ρ = 400 kg/m^3 were used; W = 6%.

A portable colour difference colorimeter, model SC-30 (China), with a measuring aperture of Ø8 mm, was used to measure the difference in the colours of a standard sample (without laser irradiation) and of a test sample (after irradiation to laser beam), fig. 2.

The device allows measurements in two color spaces $L^*a^*b^*$ and $L^*c^*h^*$, in two measurement modes – single measurements and averaged measurements. Automatically shows the colour difference between the sample and the standard sample: ΔE^*; ΔL^*; Δa^* and Δb^* or $\Delta(L^*C^*H^*)$.

The difference in colour shades of the plywood samples is measured in a three-dimensional color model, with CIELAB ($L^*a^*b^*$) as the reference standard. CIE (in French – *Commission Internationale de l'Eclairade; in English – International Commission on Illumination*) – International Commission on Illumination.

The colour space $L^*a^*b^*$ uses three axes to represent the almost uniform distribution of the perceived colour difference. The vertical axis L represents lightness / darkness, where at L = 100 we have white, and at L = 0 we have black and shows differences between dark colours and lighter pastels. The horizontal and mutually perpendicular axes, „a“ and „b“, represent the main colour coordinates, with red predominating at positive „a“ and green at negative „a“; and yellow for positive „b“ and blue for negative b“. This colour model represents the colours with exact coordinates in the colour space and characterizes the total colour difference by ΔE.

RESULTS AND DISCUSSION

It is known that wood is composed of cellulose, lignin, hemicellulose and extractive substances that are thermally unstable. The content of cellulose in the wood reaches 50%, lignin in coniferous tree species reaches 30%, in deciduous trees up to 20%, and the content of hemicellulose in coniferous wood reaches 20%, and in deciduous trees up to 30%.



Figure 2: Colorimeter SC-30 to measure the colour difference

Heat transfer in the horizontal direction is carried out by thermal radiation (TR) from the laser beam.

At a temperature higher than 120°C structural changes in the cellulose begin – destruction, which is accompanied by the formation and release of volatile substances. Above 200°C the rate of pyrolysis increases, first decomposing hemicellulose (200–260°C), followed by cellulose (240–300°C) and finally lignin (280–500°C) (Poletto and al. 2013).

The variations of the laser effect create a scale of changes in the colour of the surface of birch plywood, defined in the CIE *L*a*b** system, ranging from obviously unaffected to completely dark areas due to the effect of carbonization.

The experimental studies were performed at a laser beam power P = 8 W; scan speed V_f = 270 mm / s; focal length of ZnSe lens, F = 50.8 mm and focus position: on the surface of the material – ΔF = 0 mm.

This power, from 8 W, corresponds to 100%, and in the engraving test the power of the laser beam is programmatically adjusted from 100% to 5%, in steps of 5%. The results of the changes in the colour of the investigated birch plywood material are shown in fig. 3.

On the surface of the sample is engraved a system of isolated areas with different colours from dark brown to light, approaching the natural color of birch plywood. Each zone is irradiated with a different laser beam power density – from q = 0.41 W/mm^2 (P = 8 W – 100%) to q = 0,02 W/mm^2 (P = 0.4 W – 5%).

Specialized „Inkscape“ software was used to conduct this study (https://wiki bgbg.top/wiki/Inkscape, https://paradacreativa.es/bg/que-es-inkscape-y-como-funciona/).

Inkscape is a vector graphics editor with features similar to Adobe Illustrator, Freehand and CorelDraw, using the standard SVG file format and is convenient for creating both artistic and technical illustrations, even for use as a CAD system with general purpose, fully compliant with XML, SVG, and CSS standards.

The change in colour of the test material – samples of birch plywood, when exposed to CO_2 laser beam, was examined with a calorimeter SC-30, which automatically shows the difference in colour between the measured sample and the standard sample, and also shows the degree of changes in the colours.

To ensure the most accurate results, the colour was measured in averaging mode (allowing measurements on uneven surfaces) at three specific locations of the test material, before and after exposure to the laser beam (Fig. 4). To estimate the difference between two colours, the total colour difference ΔE * (expressing the distance between two points in the system *L*a*b**) was used. Δ*E** is evaluated according to (BDS EN ISO 11664-6: 2016) and calculated by formula

$$\Delta \boldsymbol{E}^* = \sqrt{(\Delta \boldsymbol{E}^*)^2 + (\Delta \boldsymbol{a}^*)^2 + (\Delta \boldsymbol{b}^*)^2} \quad \textbf{(2)}$$

Where ΔL^*, Δa^* and Δb^* are differences in the individual axes (difference between the values measured after the laser action and the reference sample). The results of the measurements are shown in Table 1.

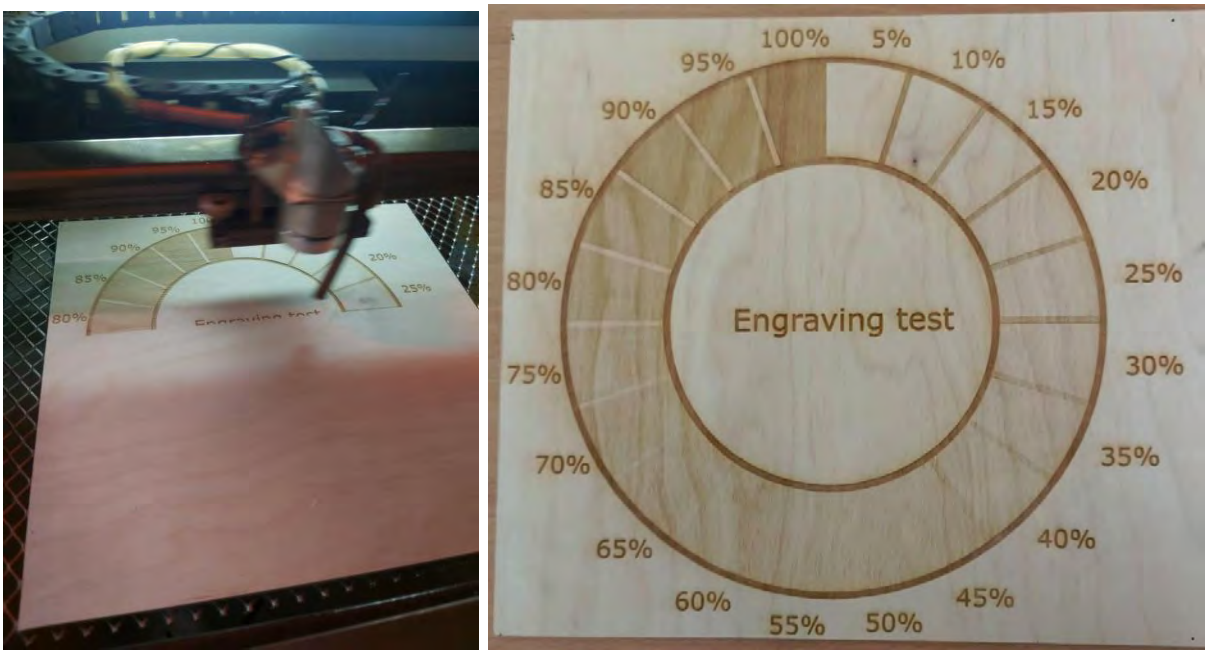


Figure 3: Results of an engraving test in the study of changes in the colour of birch plywood

Colour analyses of CIE $L^*a^*b^*$ show a gradual darkening of the laser-treated samples with increasing laser beam power, i. the radiation dose, which corresponds to a decrease in the values of L^* (Fig. 3, Table 1). The measured value of the L^* (illuminance) axis of the standard (reference) sample is 84.2%, the difference to absolute white (100%) being 15.8%.

When the colour changes, as a result of the laser impact, the value of the axis L^* (illuminance) shows the most significant change in the power of the laser beam P = 8 W (q = 0.41 W / mm^2) and has a value of 69.3%, which corresponds to dark brown (Fig. 4, Table 1). In addition, a visible change in the colour of the sample, to light brown, is obtained at an axis value L^* 78.8%, which corresponds to P = 5.2 W (65%) and q = 0.26 W/mm^2 (Fig. 3). At powers less than 5.2 W (65%) the values of the L^* axis are very close or coincide with that of the standard (reference) sample of 84.2%, i.e. changes in nuances in the construction of complex graphic images, type of photography will not be noticeable.

As a result of the laser modification there is a transition from red to green shades (a^* changed from 11.0 to 6.0). Similarly, there is a transition from yellow to blue (b^* changed from 26.2 to 17.1). As the dose of laser radiation increased, the total colour difference ΔE^* continued to increase for modified samples from 2.2 to 19.3. This parameter shows an almost continuous increase, and its values are mainly influenced by the changes of L^*.

In Fig. 5 shows the effect of the laser action on the values of a^*, in fig. 6– on b^*, and on 8 – on ΔE^*.

The total colour difference ΔE^* varies significantly with increasing laser beam power.

At the focus point, the laser beam has the highest density and falling like TI, perpendicular to the processed material – plywood made of ordinary birch, concentrates the

greatest accumulation of heat and, accordingly, the fastest increase in temperature. It is in the area of this point that the processes related to the heating of the material and the structural changes that occur in it, related to the change in the colour of the surface layers and the processes of pyrolysis, take place first.

Table 1: Measurement results in colour changes of birch plywood when laser engraved

№	Power,%, (W)	*L**		*a**		*b**		Δ*E**
		standard	standard	standard	standard	standard	standard	
0.	0 (0) no laser	84,2	-	5,2	-	14,5	-	0,0
1.	100 (8)	84,2	69,3	6,0	11,0	14,9	26,2	19,3
2.	95 (7,6)	84,2	71,0	6,0	10,3	14,9	26,2	17,9
3.	90 (7,2)	84,2	76,0	6,0	8,7	14,9	24,2	12,6
4.	85 (6,8)	84,2	78,2	6,0	7,1	14,9	22,4	9,6
5.	80 (6,4)	84,2	76,1	6,0	7,9	14,9	23,0	11,6
6.	75 (6,0)	84,2	77,0	6,0	7,9	14,9	21,3	9,8
7.	70 (5,6)	84,2	77,9	6,0	8,2	14,9	20,3	8,5
8.	65 (5,2)	84,2	78,8	6,0	7,8	14,9	20,1	7,7
9.	60 (4,8)	84,2	79,2	6,0	7,8	14,9	20,7	7,8
10.	55 (4,4)	84,2	78,9	6,0	8,0	14,9	20,0	7,6
11.	50 (4,0)	84,2	81,2	6,0	7,2	14,9	18,9	5,1
12.	45 (3,6)	84,2	78,6	6,0	7,9	14,9	19,6	6,8
13.	40 (3,2)	84,2	79,2	6,0	7,9	14,9	18,9	6,6
14.	35 (2,8)	84,2	80,5	6,0	7,3	14,9	17,6	4,7
15.	30 (2,4)	84,2	81,1	6,0	7,2	14,9	17,9	4,4
16.	25 (2,0)	84,2	82,5	6,0	6,6	14,9	18,0	3,5
17.	20 (1,6)	84,2	82,6	6,0	6,3	14,9	16,5	2,2
18.	15 (1,2)	84,2	84,5	6,0	6,0	14,9	17,1	2,2
19.	10 (0,8)	84,2	84,5	6,0	6,0	14,9	17,1	2,2
20.	5 (0,4)	84,2	84,5	6,0	6,0	14,9	17,1	2,2

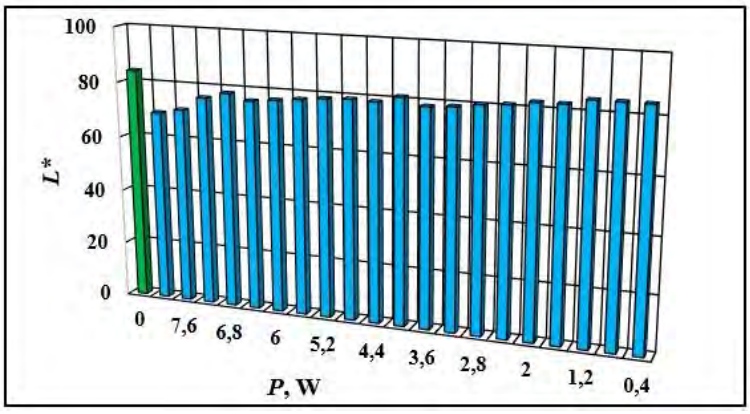


Figure 4: Graphical representation of the dependence of the values of the axis *L on the power of the laser beam *P*, W**

The depth of engraving (δ, mm) left by the laser beam is influenced by a number of factors, such as: laser beam power, scanning speed, focal length of the lens, position of focus on the surface of the material, physic-mechanical parameters of research material (in this case ordinary birch plywood), etc.

In Fig. 8 presents the results of the engraving depth at a laser beam speed V_f = 270 mm/s and different beam powers from 8 W (q = 0.41 W/mm^2) to 5,2 W (q = 0.26 W/mm^2).

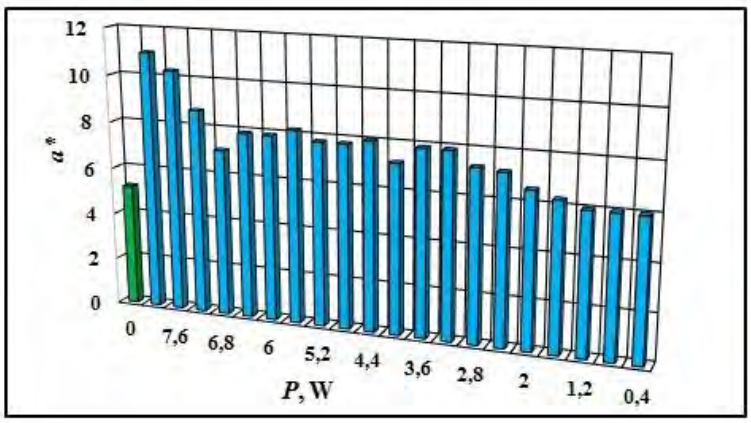


Figure 5: Graphical representation of the dependence of the values of *a on the power of the laser beam *P*, W**

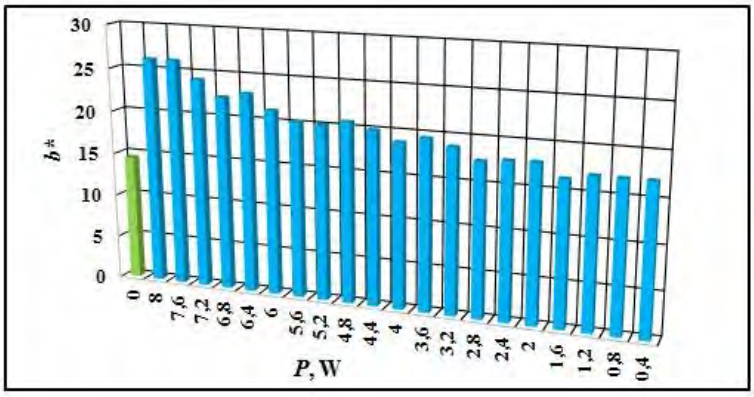


Figure 6: Graphical representation of the dependence of the values of *b on the power of the laser beam *P*, W**

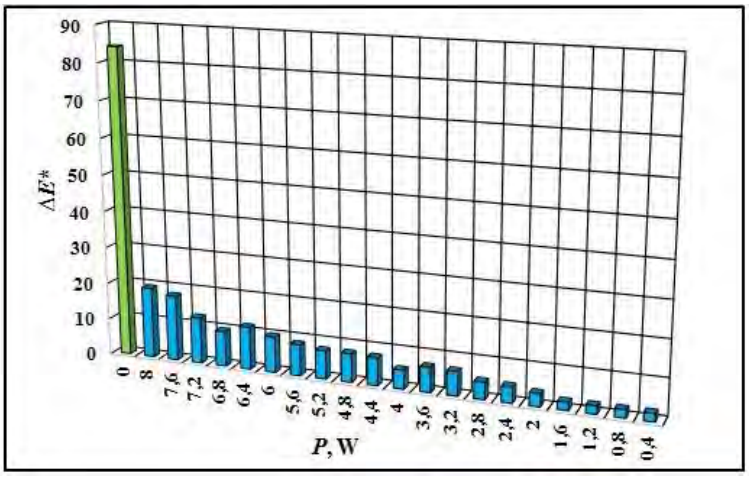


Figure 7: Graphical representation of the dependence of the values of Δ*E on the power of the laser beam *P*, W**

It is obvious that as the power of the laser beam increases, the depth of the trace increases, varying from 0.1 to 0.5 mm.

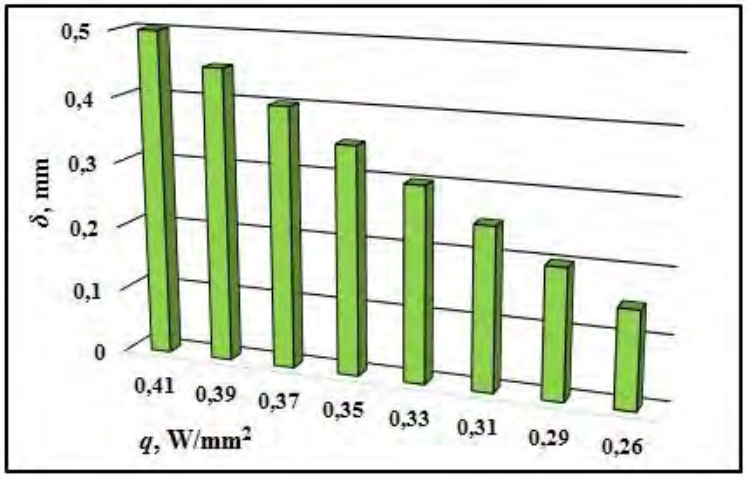


Figure 8: Dependence between laser beam power density and trace depth at a scanning speed of 270 mm/s

The results of the conducted research allow to offer modes for surface treatment with laser beam in the construction of complex graphic images on plywood products, in this case of ordinary birch. What should be the specific values of the above, two main factors laser beam power and scanning speed depend on the goal to be achieved in the decorative painting and the aesthetic effect of the image being built?

In Fig. 9 shows two variants of a complex graphic image, a type of photography at a scanning speed of the laser beam 270 mm/s and a beam power of 7.2 W (q = 0.37 W/mm^2) and 5,6 W (q = 0.29 W/mm^2).



А **Б**

Figure 9: Variants in building a complex graphic image, type of photography: А – V_f = 270 mm/s and P = 7,2 W (q = 0,37 W/mm^2); В – V_f = 270 mm/s and P = 5,6 W (q = 0,29 W/mm^2)

Larger values of laser beam power (power density or irradiation intensity) cause a greater degree of carbonation and colour saturation, while smaller ones form a lighter shade in the graphic design of complex photographic images.

CONCLUSION

As a result of the conducted researches and the made analyzes the following more important conclusions and recommendations can be made:

1. Colour analyses of CIE $L^*a^*b^*$ show a gradual darkening of the laser-treated samples with increasing laser beam power. The value of the L^* axis (illuminance) shows the most significant change in the power of the laser beam P = 8 W (q = 0.41 W/mm^2) and

has a value of 69.3%, which corresponds to dark brown.

2. A visible change in the color of the sample, to light brown, is obtained at an axis value L^* 78.8%, which corresponds to P = 5.2 W (65%) and q = 0.26 W/mm^2. At laser beam powers less than 5.2 W (65%) the values of the L^* axis are very close or coincide with that of the standard (reference) sample of 84.2%, ie. changes in nuances in the construction of complex graphic images, type of photography will not be noticeable.

3. When the power density of the laser beam is less than 4.8 W (q = 0.24 W/mm^2) and the exposure time (t) is 0.5 s, no visible changes on the surface of the birch plywood are observed.

4. The operating modes for engraving complex photographic images must be selected depending on the desired effect and contrast that we want to achieve.

5. It is recommended to use a scanning speed of the laser beam 270 mm/s and a beam power of 7.2 W or 5.6 W for a graphic image, photo type on samples of ordinary birch plywood. Larger values of laser beam power (power density or irradiation intensity) cause a greater degree of carbonation and colour saturation, while smaller ones form a lighter shade in the graphic design of complex photographic images.

6. It is necessary to conduct additional research at variable feed rates (scanning) of the laser beam, as well as using lenses with different focal lengths.

7. The colour change created by the impact of the laser beam on the wood also depends on the impact of the environment (air and O_2 content), ie. The type of wood, its temperature (and ambient temperature), its humidity (and ambient humidity), hardness and the current chemical composition of the engraved layers (age of the wood and its surface treatment) are also important for colour change.

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INFLUENCE OF COMPONENTS (UV + VIS) OF SOLAR RADIATION ON THE COLOR CHANGE OF UNSTEAMED AND STEAMED BEECH WOOD

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ABSTRACT

The paper presents the differences of color changes of unsteamed and steamed beech wood with saturated water steam with temperature t = 135 °C for τ = 7.5 h caused by long-term exposure of sunlight to the surface of wood in interiors for 36 months. Light white-gray color with a yellow tinge of native beech wood with values on the coordinates of the color space CIE $L^*a^*b^*$ (L^* = 76.6, a^* = 7.8, b^* = 19.8) darkened due to sunlight and the wood turned pale-brown color with a touch of yellow (L^* = 71.3, a^* = 12.2, b^* = 26.8). The degree of darkening and browning is quantified by the value of the total color difference ΔE^* = 13.0. The deep brown-red color of steamed beech (L^* = 55.3, a^* = 14.5, b^* = 23.5) brightened during exposure due to sunlight and the wood surface took on a pale brown hue (L^* = 77.6, a^* = 14.1, b^* = 27.8). The degree of lightening of the color of steamed beech wood in the color space CIE $L^*a^*b^*$ is quantified by the value of the total color difference ΔE^* = 7.1. A comparison of the color changes of native and steamed beech wood through the total color difference ΔE^* due to daylight shows that the surface of steamed beech wood shows 52.2% smaller changes than unsteamed beech wood. The lower value of the total color difference of steamed beech wood indicates the fact that changes in beech wood chromophores caused by steaming steam have a positive effect on color aging due to natural aging and partial resistance of steamed beech to the initiation of photochemical reactions caused wavelengths UV+VIS sunlight.

Key words: beech wood, color space CIE $L^*a^*b^*$, UV + VIS radiation, color change.

INTRODUCTION

The color of wood is a basic physical-optical property, which belongs to the group of macroscopic features on the basis of which the wood of individual woody plants differs visually. The color of the wood is formed by chromophores, i.e., functional groups of the type: >C=O, -CH=CH-CH=CH-, -CH=CH-, aromatic nuclei found in the chemical components of wood (lignin and extractive substances such as dyes, tannins, resins and others), which they absorb some components of the electromagnetic radiation of daylight and thus create the color of the wood surface perceived by human vision.

Wood exposed to long-term exposure to sunlight changes color on its surface. The surface of the wood darkens and mostly yellows and browns. This fact is also referred to in the professional literature as natural aging Hon (2001), Reinprecht (2008), Baar – Gryc (2011).

Solar radiation is electromagnetic radiation with wavelengths in the range from 100 to 3000 nm Hrvoľ – Tomlain (1997), which consists of ultraviolet radiation, visible radiation (light) and infrared radiation. Ultraviolet radiation (UV) with wavelengths of 100 – 380 nm makes up about 2% of the daylight spectrum. According to the effect of UV radiation on biological materials and their effects on these materials, UV radiation is divided into: UV-A radiation with a wavelength of 320 – 380 nm, UV-B radiation with a wavelength of 280 – 320 nm and UV-C radiation with a wavelength below 280 nm. The spectrum of UV radiation falls on the Earth's surface from solar radiation, which is made

up of 90–99% UV-A radiation and 1–10% UV-B radiation. The most dangerous UV-C radiation is completely absorbed by the atmosphere. The visible light spectrum, referred to as VIS with wavelengths from 380 to 780 nm, represents approximately 49% of the daylight spectrum. The rest consists of infrared IR radiation with wavelengths of 780 – 3000 nm. The wavelengths of visible and infrared radiation are absorbed or reflected by the wood surface. The reflected wavelengths of the visible spectrum allow a person to perceive its color when looking at a given object. The absorbed wavelengths of infrared solar radiation change to heat on the surface.

Components UV + VIS of solar radiation (daylight) initiate wood photodegradation processes when impacting on wood surface (photolytic and photooxidation reactions with lignin, polysaccharides and wood accessory substances), carbohydrates absorb 5 – 20% and 2% of the accessory substance Kuo – Hu (1991), Gandelová et al. (2009). These reactions cleave both lignin macromolecules with the simultaneous formation of phenolic hydroperoxides, free radicals, carbonyl and carboxyl groups, as well as polysaccharides into polysaccharides with a lower degree of polymerization to form carbonyl, carboxyl groups and gaseous products (CO, CO_2, H_2) Hon (2001), Baar – Gryc (2011), Persze – Tolvaj (2012), Denes – Lang (2013), Geffertová et al. (2018).

The aim of work is to compare the effect of solar radiation on the surface of thermally treated beech wood with saturated steam (steaming) and unsteamed beech wood. Through changes in the coordinates L^*, a^*, b^* in the color space CIE $L^*a^*b^*$ and the total color difference ΔE^*, changes are evaluated color of native and steamed beech wood caused by UV+VIS components of sunlight (daylight) are evaluated.

MATERIALS AND METHODS

Blanks with dimensions 32 × 60 × 600 mm made of beech wood had a moisture content $w_p = 56.4 \pm 4.2\%$ and were divided into 2 groups. The first group blanks were not thermally steamed prior to drying. The blanks of the second group were steamed with saturated water steam at a temperature of $t = 135 \pm 2.5$°C for 9 hours in order to modify the color of beech wood to a brown-red color. Steaming was performed in an APDZ 240 pressure autoclave (Himmasch AD, Haskovo, Bulgaria) installed at Sundermann Ltd. (Banská Štiavnica, Slovakia).

Unsteamed and steamed beech blanks were dried by a low-temperature drying mode preserving the original wood color to a moisture content $w_k = 12 \pm 0.5\%$ in a convection hot air dryerKWC [9].

Samples of the following dimensions were produced from native and steamed beech wood blanks: 20 × 50 × 400 mm. The planed surface of unsteamed and steamed beech wood samples was exposed to daylight for a long time at an angle of 45° in the northern temperate zone – Slovakia (Central Europe) – locality for 36 months. The temperature and relative humidity of the indoor air during the exposure was $t = 20 \pm 2.5$°C, $\varphi = 50 \pm 10\%$.

The surface color of beech samples before and during the exposure was evaluated in the color space CIE $L^*a^*b^*$ at monthly intervals using a colorimeter Color reader CR-10 (Konica Minolta, Japan) was measured. A D65 light source was used and the diameter of the optical scanning aperture was 8 mm.

The total color difference ΔE^* of the beech wood surface change during the 36-month exposure to sunlight was determined according to the following ISO 11 664-4 equation:

$$\Delta E^* = \sqrt{(L^*_{36} - L^*_0)^2 + (a^*_{36} - a^*_0)^2 + (b^*_{36} - b^*_0)^2} \quad (1)$$

Where: L^*_0, a^*_0, b^*_0 the coordinates of the color space CIE $L^*a^*b^*$ on the surface of the dried, milled beech wood before exposure, L^*_{36}, a^*_{36}, b^*_{36} the coordinates of the color space CIE $L^*a^*b^*$ on the surface of the dried, milled beech wood after exposure.

RESULTS AND DISCUSSION

Beech wood, according to Makovíny (2010), Klement et al. (2010), has a light white-brown-yellow color. In the steaming process with a steam-air mixture at atmospheric pressure, or thermal treatment of beech wood with saturated water steam, as reported by the works: Trebula (1986), Deliiski (1991), Tolvaj et al. (2009), Dzurenda (2014), depending on the temperature and length of the thermal treatment process, the wood darkens and acquires shades from pale pink-yellow color shade to brown-red color.

The color of unsteamed and steamed beech wood at a moisture content of w = 12% on the planed surface before and after 36 months of dazzling is shown in Fig. 1.



Figure 1: View of beech wood: (left) unsteamed before and after exposure, (right) thermally treated before and after exposure

In Table 1 shows the coordinates of the color space CIE $L^*a^*b^*$ of unsteamed and steamed beech wood at a moisture content of w = 12% on the planed surface before and after 36 months of dazzling.

Table 1: Coordinate values of color space CIE $L^*a^*b^*$ of unsteamed and steamed beech wood

Beech wood	Unsteamed beech wood			Steamed beech wood		
	Coordinates of color space CIE $L^*a^*b^*$					
	L^*	a^*	b^*	L^*	a^*	b^*
Before exposure	76.6 ± 1.7	7.8 ± 1.5	19.8 ± 1.7	55.3 ± 1.6	14.5 ± 1.0	23.5 ± 0.8
After exposure	71.3 ± 0.9	12.2 ± 0.6	26.8 ± 0.9	57.6 ± 0.9	14.1 ± 0.8	27.5 ± 0.6

From the comparison of wood colors in Fig. 1 and the presented values on the coordinates L^*, a^*, b^* of unsteamed and steamed beech wood in Table 1 shows that while the surface of the unsteamed beech wood darkened and browned, the brown-red color on the steamed wood lightened.

The courses of the measured values of beech wood color on the coordinates: L*, a*,

b* of the color space CIE *L*a*b** in individual months, during 36 months of dazzling by the sunlight of daylight are shown in Fig. 2 and Fig. 3.

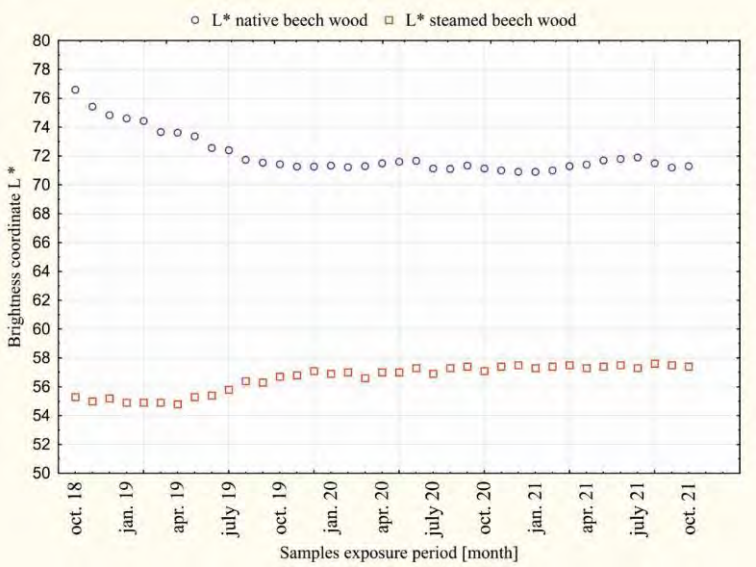


Figure 2: Values on the *L coordinate of dazzled native and steamed beech wood over a period of 36 months (October 2019 to October 2021).**

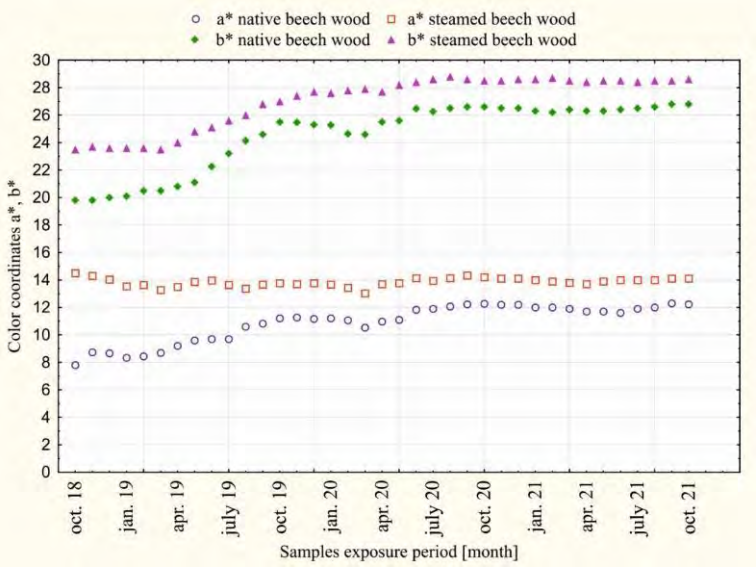


Figure 3: Values on chromatic coordinates of red color *a and yellow color *b** of dazzling native and steamed beech wood over a period 36 months (October 2019 to October 2021).**

The course of the measured values on the light coordinate *L** and the chromatic coordinates of the color *a** and the yellow color *b** in Fig. 3 and Fig. 4 during 36 months of dazzling is not fluent. The fluctuations are attributed to the influence of the intensity of solar radiation during the individual seasons, causing photochemical reactions of UV radiation with wood.

The highest intensity of solar radiation in Slovakia is in the summer months of June and July, when it reaches a value of 5.9 to 6.0 kWh/m^2 per day. During the autumn, the intensity of sunlight decreases and is lowest during the winter. In December, the intensity of solar radiation is the weakest with an approximate value of 1.7 kWh/m^2 per day Hrvoľ – Tomlain (1997).

In Fig. 4 show the magnitudes of changes in the average values of ΔL^*, Δa^* and Δb^* in individual seasons during the exposure.

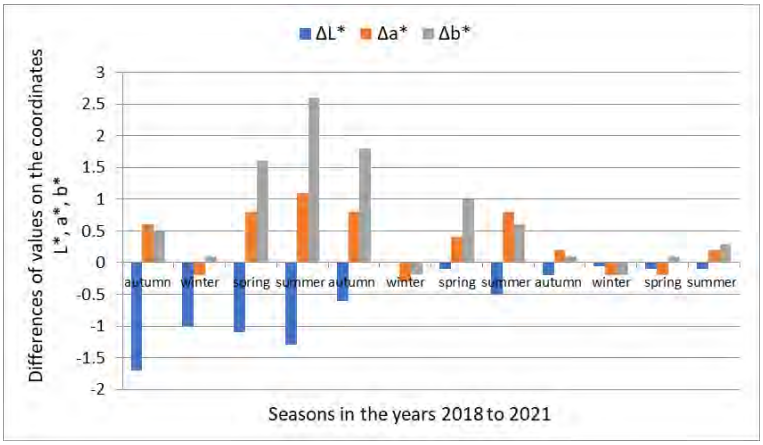


Figure 4: The magnitudes of changes in the ΔL^*, Δa^*, Δb^* values in the color space CIE $L^*a^*b^*$ native beech wood during the 36-month exposure to sunlight, depending on the season

The darkening and browning of unsteamed beech wood numerically documents the shift on the brightness coordinate L^* from the value $L_0^* = 76.6$ to $L_{36}^* = 71.3$ i.e. by the value $\Delta L^* = -5.3$ and changes in chromatic coordinates: red color a* from $a_0^* = 7.8$ to $a_{36}^* = 12.2$ i.e. by the value $\Delta a^* = +4.4$ and the yellow color b^* from the value $b_0^* = 19.8$ to $b_{36}^* = 26.8$ i.e. by the value $\Delta b^* = +10.0$. The largest darkening of unsteamed beech wood occurred during the first year of dazzling, when changes in the brightness coordinate ΔL^* reached 76.9% of the total change in brightness of beech wood caused by daylight, in the second year it is 16.8 and in the third year 6.3%. The browning of unsteamed beech wood is described by changes in the chromatic coordinates: red a^* and yellow b^*. The change in the red coordinate in the first year of exposure was 57.5% of the total change Δa^*, in the second year of dazzling 42.5% and in the third year oscillated around $a^* = 12$. In the yellow coordinate the change Δb^* in the first year of dazzling was 57.7% of the total value of the change in Δb^* beech wood, 38.7% in the second year and 3.6% in the third year. The changes in the red a^* and yellow b^* coordinates of the color space CIE $L^*a^*b^*$ in the third year, as the measurements show, are small and, in addition, the different seasons are contradictory, while in winter and spring they show a decrease in values, so in summer in times of more intense sunlight, their growth. The darkening of wood due to solar radiation is in line with the views of experts dealing with changes in the properties of wood due to long-term exposure to sunlight, who state that the wood surface darkens and mostly yellows and browns Reinprecht (2008), Baar – Gryc (2011), Kúdela – Kubovský (2016), Dudiak 2022, Dudiak et al. 2022.

In Fig. 5 show the magnitudes of changes in the average values of ΔL^*, Δa^* and Δb^* in individual seasons during the exposure.

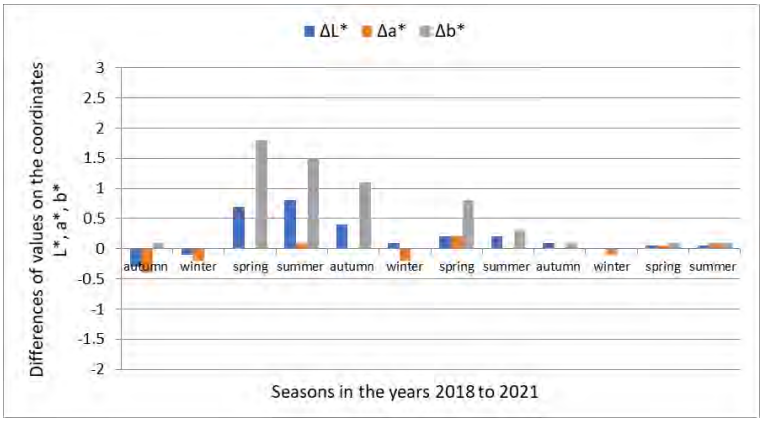


Figure 5: The magnitudes of changes in the values of ΔL^*, Δa^*, Δb^* in the color space CIE $L^*a^*b^*$ of steamed beech wood during the 36-month exposure to sunlight, depending on the season

Steamed beech wood under the influence of sunlight for 36 months compared to unsteamed wood showed the opposite character of the color change, the surface of the wood faded. Visually, this is documented in Fig. 2, as well as the shift on the brightness coordinate L^* from the value $L_0^* = 55.3$ to $L_{36}^* = 57.2$ i.e. by the value $\Delta L^* = + 1.9$, on the red coordinate a^* offset from $a_0^* = 14.5$ to $a_{36}^* = 14.1$ i.e. by the value $\Delta a^* = – 0.4$ and on the chromatic coordinate of yellow color b^* from the value $b_0^* = 19.8$ to $b_{36}^* = 25.5$. i.e. by the value $\Delta b^* = + 5.7$. On the basis of comparison of individual changes ΔL^*, Δa^*, Δb^* on the coordinates of the color space CIE $L^*a^*b^*$ of steamed beech wood caused by the action of sunlight with changes ΔL^*, Δa^*, Δb^* on the coordinates of the unmatched of beech wood caused by daylight, it can be stated that the values expressing the magnitude of changes in steamed beech wood are smaller. The magnitude of changes in the brightness coordinates L^* and yellow b^*, similar to unsteamed beech wood, are largest in the first year of exposure. The red coordinate changes of a^* oscillated around the value of $a^* = 14.0$. In winter, at low sunlight intensity, the values on the red coordinate a^* decrease and from spring to autumn they increased at higher sunlight intensity. The rate of decline, or the increase in red coordinate values decreases over the years.

The contribution of the influence of beech wood steaming on the color fastness and resistance to the effects of sunlight declares decrease in the value of the total color difference ΔE^* in Fig. 6.

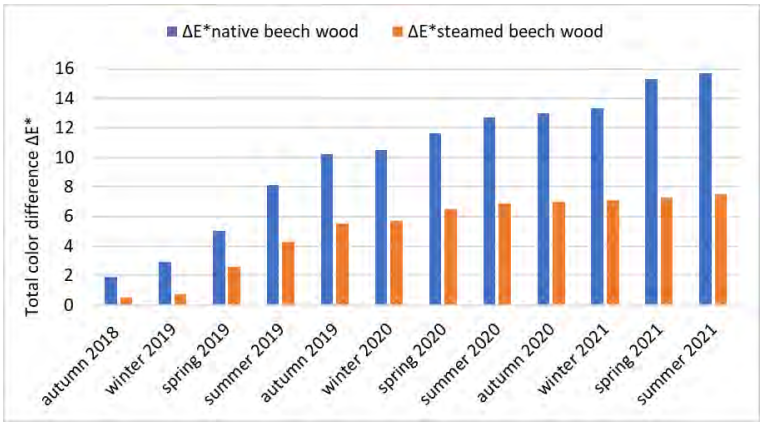


Figure 6: Values of the total color difference ΔE^* of native and steamed beech wood during 36 months of dazzling (October 2019 to October 2021).

While the change in the color of unsteamed beech wood caused by solar radiation expressed by the value of the total color difference over 3 years is $\Delta E^* = 15.7$, then the change in the total color difference of steamed beech wood in the same period is $\Delta E^* = 7.5$ which is the decrease in color changes about 52.2%. This fact points to the fact that beech wood steaming has a positive effect on changes in the chromophore system of steamed beech wood and the partial resistance of steamed beech wood to the initiation of photochemical reactions induced by daylight wavelengths.

From the course of changes in the values of the total color difference presented in Fig. 6 and from the aspect of dazzling time, it can be stated that after the most intensive color change of the surface of unsteamed and steamed beech wood cca 70% in 1 year of dazzling, the rate of color changes of wood decreases in 2 years of dazzling at 23% and 3 years is minimal. The data in Table 2.

Table 2: Changes in the total color difference ΔE^* of steamed and unsteamed beech wood in individual years.

Period dazzling	Total color difference ΔE* samples	
	unsteamed beech wood	steamed beech wood
1 year	10.2	5.5
2 year	3.3	1.5
3 year	1.0	0.5

CONCLUSION

The paper presents the results of the color change of the surface of unsteamed and steamed beech wood with saturated water steam in a pressure autoclave, which was been exposed to daylight interior for 36 months. The results of analyzes of the effect of solar radiation on unsteamed and steamed beech wood showed:

1. The color surface of unsteamed beech wood changed under the influence of daylight during the exposure, the wood darkened and browned into a brown-yellow color shade. The opposite tendency, i.e., lightening, occurred during exposure on steamed beech wood samples.
2. The measured changes in the values at the coordinates of the color space CIE $L^*a^*b^*$ caused by solar radiation in unsteamed beech wood are: $\Delta L^* = -5.3$; $\Delta a^* = +4.4$; $\Delta b^* = +10.0$ changes were recorded also for steamed beech wood: $\Delta L^* = +1.9$; $\Delta a^* = -0.4$; $\Delta b^* = 5.7$.
3. The evaluation of the color change of beech wood in the form of the total color difference ΔE^* shows that the surface of steamed beech wood shows approximately 52.2% less color change than the total color difference of unsteamed beech wood.
4. The decrease in the values of ΔL^*, Δa^*, Δb^* and the total color difference ΔE^* of steamed beech wood indicate a positive effect of steaming of wood on the partial resistance of steamed beech wood to the initiation of photochemical reactions induced by wavelengths daylight.

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COMPARATIVE ANALYSIS OF PHYSICAL AND MECHANICAL PROPERTIES OF SOME THIN AND ULTRA-THIN WOOD-BASED AND NON-WOOD-BASED FURNITURE PANELS

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ABSTRACT

Thin structural furniture materials are becoming increasingly popular due to design trends and the need to reduce the natural resources used. However, their use requires the necessary information on their physical and mechanical properties. The present study includes two ultra-thin and seven thin wood-based materials and two non-wood materials. Their density, actual thickness, modulus of elasticity and bending strength were determined. All studied materials meet the requirements of European standards for modulus of elasticity in bending and bending strength. The highest modulus of elasticity in bending and bending strength were determined for 9 mm and 12 thick birch plywood, 9 mm thick laminated with HPL birch plywood, 10 mm thick compact HPL and 6 mm thick mineral thermoplastic solid surface composites. The lowest characteristics show MDF with a thickness of 10 and 12 mm, coloured MDF with a thickness of 10 mm and 12 mm thick laminated particleboard. Radar-type graph was created to evaluate the severity of the investigated thin and ultrathin structural materials concerning the modulus of elasticity, bending strength, thickness and density.

Key words: wood-based materials, non-wood materials, thin and ultra-thin materials, modulus of elasticity, bending strength, composite materials.

INTRODUCTION

The choice of material is one of the essential phases of furniture design. The material's aesthetic, physical, mechanical and technological properties, availability and deliverability, environmental friendliness, recyclability and reusability, cost, etc. are all important.

The most commonly used thin materials in furniture construction are wood-based composites (particleboard, medium-density fiberboard, laminated wood, etc.), but non-wood materials such as metal, glass, plastic, compact HPL (decorative laminate), mineral thermoplastic composites (solid surfaces) and various combinations thereof are also used (Jivkov & Elenska-Valchanova, 2019). It is known from practice that the use of thin wood-based panels as a structural material for furniture, especially if subjected to higher service loads, can be critical to their behaviour in service, so they must be carefully selected and used.

Structural wood-based furniture materials can be categorised into five groups according to their structural-technological properties: ultra-thin – less than 10 mm; thin – 10÷15 mm; standard – 16÷19 mm; thick – 20÷40 mm and ultra-thick – more than 40 mm (Jivkov & Elenska-Valchanova, 2019). The design and manufacture of furniture with thin and especially ultra-thin structural elements are challenging because of joint issues and their strength characteristics. They do not have sufficient stiffness to take the service loads, which can cause unacceptable deformations and even failure.

There is little data in the specialised literature on the physical and mechanical properties of furniture panels less than 16 mm

thick. The physical and mechanical properties of thin and especially ultrathin structural elements for furniture are considerably less studied. Jivkov & Elenska-Valchanova (2019) studied four types of wood-based panels: 12.12 mm thick MDF, 11.20 mm thick beech veneered MDF, 11.75 mm thick HPL faced MDF, and a three-layer furniture board composed of a middle layer of poplar plywood (4 mm) with beech veneer on the face and outer layers of MDF (4 mm) with a total thickness of 12.79 mm. The results show that HPL lamination significantly increases bending strength and modulus of elasticity. Therefore, these materials can be used as a thin structural materials for various applications in furniture construction. A similar conclusion was reached by Segovia et al. (2015), who investigated the effect of laminating thin HDF, MDF, OSB and aspen veneer plywood with 0.6 mm thick sheets of aluminium alloy (3003). The results show that panels laminated with aluminium sheets have higher dimensional stability and bending properties, and the modulus of elasticity and modulus of rupture increases significantly with face-lamination.

Bulgarian scientists have experimentally produced ultrathin eco-friendly medium-density fibreboards with a thickness of 6 mm obtained with an adhesive composition based on calcium lignosulfonate (Antov et al., 2019; Savov et al., 2019; Savov & Antov, 2020). The authors found no significant change in bending strength values at 30% concentration and elevated pressing temperature.

A study to determine the effect of moisture content on three ultra-thin (HDF, 3-ply plywood, and MDF) and three thin structural materials (rPB, MFP, and OSB) found that 4 mm thick plywood had the highest MOR and MOE (Sala et al., 2020). In another study on the effect of thermal impact on 3.8 mm thick plywood and 2.6 mm and 12 mm thick MDF, it was found that plywood and 2.6 mm thick MDF exhibited typical elastic-plastic behaviour. In comparison, 12 mm thick MDF did not exhibit any plastic behaviour, and the bending strength and modulus of elasticity decreased with increasing temperature (Zhou et al., 2012).

Two types of plywood with a thickness of 14 mm were the subject of a study by Fekiac et al. (2022). One plywood is standard with a density of 708 kg/m^{3,} and the other is lightweight with a density of 587 kg/m^3. Their bending strength according to EN 310 is 82.5 and 36.7 MPa, respectively, and their modulus of elasticity is 7916 and 10692 MPa. It is noteworthy that standard plywood has a high bending strength but a lower modulus of elasticity than lightweight plywood.

The physical and mechanical properties of plywood of ailanthus veneer (*Ailanthus altissima* Mill.) were investigated by Barboutis and Kamperidou (2011). Two thicknesses of plywood were studied, 3.13 mm with a veneer layer thickness of 1 mm and 4.58 mm with a veneer layer thickness of 1.5 mm. The thinner plywood showed higher bending strength (91.22 N/mm^2) than the thicker plywood (88.19 N/mm^2). On the other hand, the thicker plywood has a higher modulus of elasticity (9870.3 N/mm^2) compared to the thinner plywood (8716.66 N/mm^2).

A study to establish the physical and mechanical properties of 3 mm thick ultrathin plywood was carried out by Vasileiou et al. (2011). They aimed to investigate the mechanical and hygroscopic properties of thin three-layer plywood made with Ailanthus wood (*Ailanthus altissima* Mill.) veneer to compare with the corresponding properties of thin three-layer poplar plywood. According to the results, the

ailanthus plywood showed higher strength characteristics than the poplar plywood. The bending strength was 49.9% higher for the plywood made of ailanthus (91.22 N/mm^2) than that of poplar (60.85 N/mm^2). In addition, the modulus of elasticity was 39.4% higher for the ailanthus plywood (8716.66 N/mm^2) than the poplar plywood (6251.88 N/mm^2).

Reinforcement of thin structural elements is another option for increasing the strength characteristics of thin materials. For example, the improvement of static load-deformation characteristics by reinforcement with plywood strips are between 20 and 30% for MDF and between 12 and 20% for particleboard (Jivkov et al., 2010, Jivkov and Marinova, 2016). Furthermore, reinforcing MDF with metal and woven synthetic net significantly increased their bending performance (MOE and MOR) by 112% and 79%, respectively (Mohebby et al., 2010, 2011). Integrating aluminium profiles for LED lighting strips in thin wood-based panels can also increase deformation resistance. For example, in research by Elenska-Vulchanova (2021), it was found that two aluminium LED strip profiles integrated into a groove in a 12 mm thick MDF shelf reduced creep by 31% after 180 days under static loading with a uniformly distributed load of 50 kg/m^2.

Sala et al. (2020) investigated the effect of water content in some furniture panels, six of which are less than 16 mm thick, on their strength characteristics. Three are ultra-thin: 1.9 mm thick HDF, three-ply beech veneer plywood (4 mm) and MDF (5 mm). The thin panels are uncoated particleboard (10 mm), general-purpose particleboard (12 mm) and OSB (14 mm). At 65% humidity, plywood has the highest bending strength, followed by HDF. Conversely, the lowest strength shows uncoated particleboard 10 mm thick. The situation is similar for the modulus of elasticity, but there, except for plywood, the other materials have relatively similar results.

Pinchevska et al. (2021) investigated the possibility of using 10 mm thick MDF in three variants – uncoated, painted and veneered – for kitchen worktops. A mathematical model has been developed to establish the durability, which allows determining the time to failure of MDF of different thicknesses and with different surface treatments under the influence of thermal and power loads on panels with a moisture content ranging from 6% to 20%. The method involves calculating the thermal activation parameters of MDF based on the experimentally determined bending strength and failure time at temperatures ranging from 20 °C to 80 °C. The results of the calculations correspond to the weighted average service life of furniture intended for use in kitchen furniture. The proposed method for calculating the durability of the worktop proves the feasibility of using thin MDF for kitchen worktops, which is in line with current trends.

One of the most used non-wood materials as a structural material in furniture is thermoplastic composite with mineral composition (solid surface). It generally consists of 1/3 polymer (PMMA) and 2/3 mineral – aluminium hydroxide ($Al(OH)_3$), often described as aluminium trihydrate – ATH (Jivkov & Elenska-Valchanova, 2019). However, there is very little data in the literature on the mechanical properties of this composite. Jivkov and Elenska-Valchanova (2019) investigated composites' physical and mechanical properties with thicknesses of 6 and 12 mm and the possibility of their veneering with PVA adhesive. They found that a 6 mm thick composite veneering improved the bending strength by about

7.5%. However, veneering did not increase the modulus of elasticity. There was no significant difference in strength and modulus of elasticity between the 6 mm and 12 mm thick composites.

Wronka & Kowaluk (2020) investigated the mechanical properties of two types of solid surface materials with the trade names Corian® and Staron®. They established the modulus of elasticity and bending strength at material temperatures ranging from 20 to 160 °C. The highest values for modulus of elasticity and bending strength were obtained for Corian® at room temperature, 9374 N/mm^2 and 91.4 N/mm^2, respectively. The authors also found that the modulus of elasticity and bending strength of both materials decreased significantly with increasing temperature

MATERIALS AND METHODS

MATERIALS

For the purpose of this work, the three primary wood-based materials used for structural elements of furniture – plywood (9 and 12 mm), MDF (8, 10 and 12 mm) and particleboard (12 mm) were selected. Plywood and MDF are with and without HPL lamination. In addition, two types of non-wood materials have been selected: compact HPL 10 mm thick and acrylic-based thermoplastic solid surface composite 6 mm thick. The reason for this choice is that both materials are the only ones that can be processed with the woodworking machines used in the furniture industry. This puts them technologically in the same group as wood materials.

The ultrathin wood-based materials include 8 mm MDF laminated with 0.8 mm HPL (MDF_8_HPL) and 9 mm plywood with birch face veneer (Ply_9). Thin wood-based materials are: 9 mm plywood with birch face veneer laminated with 0.8 mm HPL (Ply_9_HPL), 10 mm MDF (MDF_10), 10 mm MDF faced with HPL 0.8 mm (MDF_10_HPL), 10 mm MDF coloured (black) (MDF_10_Black), 12 mm MDF (MDF_12), 12 mm birch plywood veneer (Ply_12) and 12 mm laminated particleboard (LPB_12). Non-wood materials are include 10 mm compact HPL (HPL_10) produced by Abet Laminati Italy and 6 mm mineral thermoplastic solid surface composites (Comp_6_Min) with a trading name Kerrock®, produced by Kolpa Slovenia.

METHODS

In order to establish the physical and mechanical characteristics of all the types of panels used in this study, test specimens were made with dimensions complying with the requirements of BDS EN 310 "Wood-based panels. Determination of modulus of elasticity in bending and of bending strength". As a result, the following physical and mechanical characteristics were determined: density, material thickness, modulus of elasticity and bending strength. These characteristics are essential for determining the properties of the materials studied.

The density was established by the weight method measuring the mass of a test specimen with dimensions 50 x 50 mm and thickness corresponding to the thickness of the tested material, according to BDS EN 323:2001 "Wood-based panels – Determination of density". An electronic balance accurate to 0.01 g was used.

The thickness of the panels was measured with an electronic calliper with an accuracy of 0.01 mm.

The modulus of elasticity in bending and the bending strength have been tested according to the requirements of BDS EN 310 "Wood-based panels. Determination of modulus of elasticity in bending and of bending strength". The loading scheme and the test specimens parameters are shown in Figure 1.

The modulus of elasticity in bending E_m [N.mm^{-2}] for each test specimen was calculated according to the formula:

$$E_m = \frac{l_1^3 (F_2 - F_1)}{4bt^3 (a_2 - a_1)} \quad \textbf{(1)}$$

where: l_1 is the distance between the centres of the supports, mm; b – width of the test specimens, mm; t – thickness of the test specimens, mm; F_2-F_1 – the difference between the test specimens' upper and lower load limits on the straight-line portion of the load-deflection diagram. F_1 should be approximately equal to 10% and F_2 approximately equal to 40% of the failure load, N; a_2-a_1 – the difference in deflection arrow measurements at the midpoint of the test specimen length corresponding to F_2-F_1, mm.

Bending strength f_m [N.mm^{-2}] for each test specimen was calculated according to the formula:

$$f_m = \frac{3F_{max} l_1}{2bt^2} \quad \textbf{(2)}$$

Where: F_{max} is ultimate load, N; l_1, b and t, are the same as the modulus of elasticity, mm.

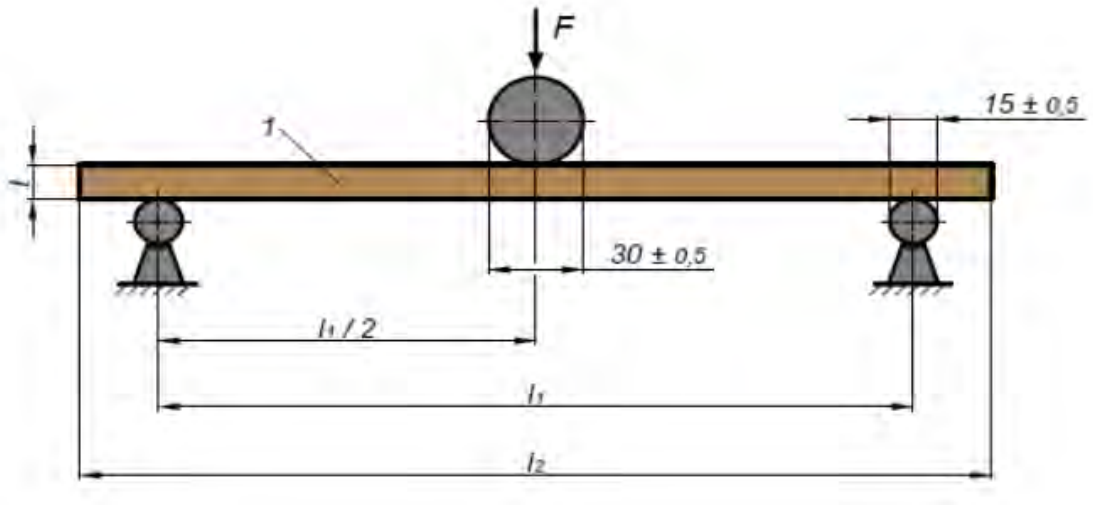


Figure 1: Method for determining the modulus of elasticity and bending strength: 1 – test specimens; F – loading force; t – thickness of test specimens; l_1 =20t and l_2 = l_1 +50.

The specimens were tested on a Zwick/RoellZ010 universal testing machine (ZwickRoell GmbH & Co. KG, Ulm, Germany) at the University of Chemical Technology and Metallurgy (CCTM) in the Department of Pulp, Paper and Printing.

STATISTICAL DATA PROCESSING

The obtained experimental data were processed by the method of variational statistics and the following variational statistical indices were determined: mean ($\overline{x}$); minimum value (MIN); maximum value (MAX); median (Med); standard deviation (s); standard error (SE); coefficient of variation (CV,%). XLSTAT Statistical and Data Analysis Solution software (New York, USA. https://www.xlstat.com, Addinsoft, 2022) was used for statistical processing and visualisation. Grubbs' test was used to detect the presence of extreme outliers in data that are assumed to be outside a normally distributed population (Grubbs, 1950 and 1969).

A boxplot presents all statistical results. Here, 0.25 x, 0.50 x, and 0.75 x quantiles are calculated, which are called the distribution's first, second and third quantiles, respectively,

and are denoted by Q1, Q2, and Q3. In it, 50% of the results of the conducted experimental study are encompassed by a rectangle in which the geometric centre of the results (the median) is indicated by a line and the arithmetic mean by "+". The lines above and below the rectangle show the scatter of the results and define the 25% of the largest and smallest values obtained outside the middle rectangle.

The results obtained for the physical and mechanical properties of the materials were subjected to pairwise comparative ANOVA analysis of the individual homogeneity groups, performed using Tukey's HSD test for a significant difference of α=0.05 at a 95% confidence level. Homogeneity groups are indicated by Latin capital letters (e.g., A, B, C, D, etc.). Results of different series falling into the same group have no statistically significant difference. In all tables presenting homogeneity groups, results are presented in descending order.

RESULTS AND DISCUSSION

In the present work, 11 types of materials were investigated, which were of nominal sizes from 9 to 12 mm. The density, actual thickness, modulus of elasticity and bending strength were determined. A comparative analysis of the parameters' results was also carried out.

DENSITY

Density is an essential characteristic of structural materials. It is an indicator of their strength and performance properties. The density of the tested materials was established according to BS EN 323:2001. The results are given in Table 1. The density results of the selected materials are within the expected range and confirm the results of other studies (Jivkov, & Elenska-Valchanova, 2019; Buyuksari, 2012; Wronka & Kowaluk, 2020; Sala et al., 2020; Zhou et al., 2012). With the lowest density of all materials are the two plywoods with a face layer of birch wood veneer with a thickness of 9 and 12 mm (704 и 667 kg/m^3) and 12 mm thick laminated particleboard (709 kg/m^3). Next is the group of medium density fibreboard (MDF) panels: coloured (black) 10 mm thick MDF – 756 kg/m^3, 12 mm thick MDF – 777 kg/m^3 and 10 mm thick MDF – 789 kg/m^3. Logically, the following three wood-based materials are laminated with a decorative HPL 0.8 mm thick. These are 9 mm thick plywood (821 kg/m^3), 10 mm thick MDF (886 kg/m^3) and 8 mm thick MDF (934 kg/m^3). The compact HPL (1490 kg/m^3) and the thermoplastic solid surface composites (1712 kg/m^3) have significantly higher densities. The ratio between the highest and lowest density materials is about 2.5 times.

Table 1: Statistical data on the density of wood and non-wood materials

Type of material	Number of test specimens	$\bar{x}$, kg/m^3	MIN, kg/m^3	MAX kg/m^3	Med, kg/m^3	s, kg/m^3	SE, kg/m^3	CV, %
MDF_8_HPL	14	**934.05**	928.45	937.72	934.82	2.96	0.82	0.29
MDF_10	15	**788.74**	775.78	799.86	789.42	6.29	1.68	0.73
MDF_10_Black	15	**756.12**	731.44	772.10	760.21	11.91	3.18	1.49
HPL_10	15	**1490.37**	1478.66	1505.48	1488.53	8.62	2.30	0.60
MDF_10_HPL	15	**885.77**	878.06	892.11	885.80	3.12	0.83	0.36
MDF_12	15	**777.24**	767.74	782.18	779.66	4.94	1.32	0.65
LPB_12	15	**708.96**	680.49	737.64	714.61	18.69	5.00	2.49
Ply_9	14	**703.94**	693.68	718.33	701.86	7.30	2.03	1.04
Ply_9_HPL	15	**821.26**	812.00	827.96	821.10	5.96	1.59	0.69
Ply_12	15	**666.71**	648.05	675.31	670.27	8.04	2.15	1.14
Comp_6_Min	10	**1712.45**	1703.67	1719.68	1712.48	5.42	1.81	0.32

Table 2 provides a comparative analysis of the mass percentage of the lightest material, 12 mm plywood, compared to the other materials. For this purpose, the 12 mm plywood is taken as the base. The percentage of furniture weight would increase if any of the other materials tested were used with the corresponding thickness is given.

The analysis shows that for 12 mm thick particleboard and 9 mm thick plywood, the increase in mass would be minimal, 6.33 and 5.58%, respectively, for 10 and 12 mm thick MDF, it is between 18.30 and 16.57% and for 10 mm thick coloured (black) MDF it is 13.41%. However, with HPL laminating, the increase is 23.18% for 9 mm plywood, 32.85% for 10 mm MDF and 40.09% for 8 mm MDF. For non-wood materials, the increase is 123.54% for compact HPL and 156.85% for thermoplastic solid surface composites. This clearly shows that an increase in the furniture's weight is expected when using such materials. From the data obtained, it can be concluded that lamination with HPL increases the density of structural materials, which is 12.29% for 10 mm thick MDF and 16.66% for 9 mm thick plywood.

Table 2: Comparative analysis of the mass ratio of the wood and non-wood materials against 12 mm thick plywood

Type of material	$\bar{x}$, kg/m^3	Mass increase,%
MDF_8_HPL	**934.05**	40.09
MDF_10	**788.74**	18.30
MDF_10_Black	**756.12**	13.41
HPL_10	**1490.37**	123.54
MDF_10_HPL	**885.77**	32.85
MDF_12	**777.24**	16.57
LPB_12	**708.96**	6.33
Ply_9	**703.94**	5.58
Ply_9_HPL	**821.26**	23.18
Ply_12	**666.71**	**-**
Comp_6_Min	**1712.45**	156.85

THICKNESS

The results of the thickness measurements of the tested materials are given in Table 3.

From the data obtained, it is noticeable that all the materials have a thickness above the nominal one, with the most significant deviation being the compact HPL, which has a thickness 4.5% greater than the nominal one. The maximum value is 0.5 mm larger than the nominal size. In the case of plywood, the one with a thickness of 12 mm has a more significant deviation (0.32 mm) compared to the 9 mm thick plywood (0.13 mm). The thermoplastic solid surface composite, with only 0.01 mm deviation, most accurately matches the nominal thickness. The coloured medium density fibreboard (MDF_10_Black) has a tolerance of 0.25 mm, which exceeds the standard's requirements, where the tolerance is ±0.2 mm. The laminated with HPL panels are also close to the nominal size in thickness. More significant variances in panel thickness would be a problem for some design solutions where the structural elements enter the joints with thickness.

Table 3: Statistical data on the thickness

Type of material	Number of test specimens	$\bar{x}$, mm	MIN, mm	MAX mm	Med, mm	s, mm	SE, mm	CV, %
MDF_8_HPL	14	**9.63**	9.61	9.66	9.62	0.019	0.005	0.19
MDF_10	14	**10.11**	10.08	10.13	10.11	0.014	0.004	0.14
MDF_10_Black	15	**10.25**	10.18	10.30	10.27	0.038	0.010	0.37
HPL_10	15	**10.45**	10.31	10.53	10.45	0.050	0.013	0.48
MDF_10_HPL	15	**11.75**	11.72	11.79	11.74	0.020	0.005	0.17
MDF_12	15	**12.14**	12.09	12.19	12.14	0.030	0.008	0.25
LPB_12	15	**12.14**	12.10	12.17	12.14	0.022	0.006	0.18
Ply_9	14	**9.13**	9.09	9.17	9.13	0.030	0.008	0.32
Ply_9_HPL	15	**10.73**	10.68	10.79	10.71	0.040	0.011	0.38
Ply_12	15	**12.32**	12.27	12.38	12.32	0.025	0.007	0.20
Comp_6_Min	10	**5.99**	5.93	6.04	5.99	0.033	0.007	0.55

MODULUS OF ELASTICITY IN BENDING

The modulus of elasticity data of the studied materials is given in Table 4 and graphically in Figure 2. It is clear from the data that the modulus of elasticity varies over a wide range. For example, the three types of non-laminated MDF with the lowest values are coloured MDF 10 mm thick (3105 $N.mm^{-2}$), MDF 12 mm thick (3399 $N.mm^{-2}$) and MDF 10 mm thick (3533 $N.mm^{-2}$). All three values are above the minimum requirements according to the European standard BDS EN 12369-1:2004 for the modulus of elasticity for medium-density fiberboard with a thickness between 9 and 12 mm and intended for use in dry environments, where a minimum value of 2200 $N.mm^{-2}$ is specified. Similar results for the modulus of elasticity of 12 mm thick MDF were obtained by Sala et al. (2020). Laminated particleboards also show very good deformation properties. Their modulus of elasticity is 3815 $N.mm^{-2}$. This value exceeds by about 10% the results obtained by Jivkov et al. (2010) and by 50% the results obtained by Sala et al. (2020). For 10 mm thick MDF, the modulus of elasticity is 3533 $N.mm^{-2}$, a value close to that obtained by Jivkov and Elenska-Valchanova (2019) for 10 mm thick MDF (3844 $N.mm^{-2}$). Laminating MDF with a 0.8 mm thick decorative HPL significantly increases the modulus of elasticity. The increase due to lamination is 63%. There is a significant difference between the results obtained for the modulus of elasticity for MDF laminated with HPL by Jivkov and Elenska-Valchanova (2019) and those in the present study – 8485 versus 5773 $N.mm^{-2}$. The difference is probably due, on the one hand, to the better physical and mechanical properties of MDF and, on the other hand, to the use of HPL with different thicknesses – 0.9 vs 0.8 mm.

The 9 mm thick plywood had the highest modulus of elasticity when the test specimen was loaded perpendicular to the grain direction of the face veneer (10035 $N.mm^{-2}$). This is the highest value obtained for all materials. When loaded parallel to the grain direction of the face veneer, the modulus of elasticity drops by about 35% and is 6687 $N.mm^{-2}$. Plywood 9 mm thick, which is laminated with HPL, has a modulus of elasticity of 9039 $N.mm^{-2}$. The direction of the wood

grains of the face veneer is parallel. The increase in modulus of elasticity due to lamination is 30%. Plywood 12 mm thick is similar to HPL laminated plywood 9 mm thick.

Table 4: Modulus of elasticity statistics

Type of material	Number of test specimens	$\bar{x}$, N.mm^{-2}	MIN, N.mm^{-2}	MAX N.mm^{-2}	Med, N.mm^{-2}	s, N.mm^{-2}	SE, N.mm^{-2}	CV, %
MDF_8_HPL	13	**8333**	8236	8469	8329	65.68	18.96	0.79
MDF_10	14	**3533**	3421	3628	3534	63.73	17.68	1.80
MDF_10_Black	15	**3105**	2883	3263	3181	131.97	35.27	4.25
HPL_10	15	**8886**	8636	9182	8908	151.46	40.48	1.70
MDF_10_HPL	15	**5773**	5673	5988	5724	108.69	29.05	1.88
MDF_12	15	**3399**	3248	3581	3377	110.10	29.43	3.24
LPB_12	15	**3815**	3302	4326	3876	283.63	75.80	7.43
Ply_9 II	15	**6687**	6112	7388	6668	365.03	97.57	5.50
Ply_9 ⊥	16	**10035**	9000	10956	10073	510.83	131.90	5.10
Ply_9_HPL	15	**9039**	8861	9313	9069	139.56	37.30	4.50
Ply_12 ⊥	15	**9105**	8418	9652	9181	377.19	100.81	6.50
Comp_6_Min	10	**9888**	9589	10075	9964	158.31	52.77	1.60

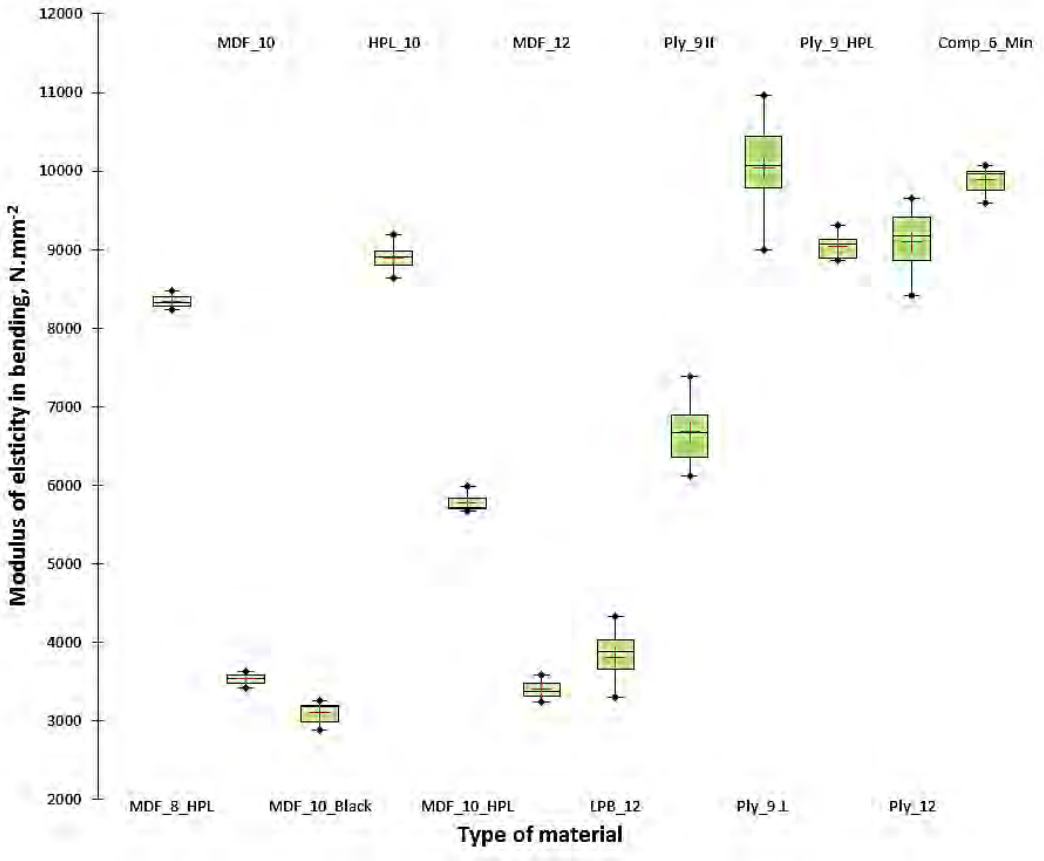


Figure 2: Modulus of elasticity in bending

According to BDS EN 636, plywood with a thickness of 9 and 12 mm loaded in the direction perpendicular to the direction of the grain of the outer layers falls into group E 100 and plywood with a thickness of 9 mm loaded in the direction parallel to the direction of the grain of the outer layers falls into group E 70.

Both non-wood composites have a very high modulus of elasticity. The thermoplastic solid surface composite values (9888 $N.mm^{-2}$) are about 11% higher than those of the compact HPL (8886 $N.mm^{-2}$). The result obtained for the modulus of elasticity of the thermoplastic solid surface composite in the present study is about 5.5% higher than that obtained for Corian – 9374 $N.mm^{-2}$ in a study by Wromka & Kowaluk (2020). In the same study, Staron was found to have a significantly lower modulus of elasticity – below 7000 $N.mm^{-2}$.

BENDING STRENGTH

The bending strength data are given in Table 5 and Figure 3. The situation is almost identical to that of the modulus of elasticity. The difference is only at the lowest and highest values, shown by laminated particleboard (26.09 $N.mm^{-2}$) and compact HPL (104.90 $N.mm^{-2}$), which is about four times higher in strength. The result for laminated particleboards was 72% higher than that obtained by Sala et al. (2020). The three types of MDF were grouped with similar values, with the coloured MDF having the lowest value (30.97 $N.mm^{-2}$) and those with 10 and 12 mm thickness having exactly the same bending strength (34.97 $N.mm^{-2}$). These values are higher than the minimum performance requirements according to the European standard BDS EN 12369-1:2004 for medium density fiberboard with a thickness between 9 and 12 mm and intended for use in dry environments, where the requirements are for a minimum strength of 20 $N.mm^{-2}$. The 12 mm thick MDF results are confirmed by the study of Jivkov and Elenska-Valchanova (2019), with a difference of only 3%. On the other hand, laminated 10 mm thick MDF with HPL increases the bending strength by 46%. For both the modulus of elasticity and bending strength, the results of this study were significantly lower for 10 mm thick MDF coated with decorative laminate compared to the results of Jivkov and Elenska-Valchanova (2019). For 8 mm thick MDF faced with 8 mm thick decorative laminate, the value obtained was 74.39 $N.mm^{-2}$, slightly lower than that obtained for 10 mm thick MDF by Jivkov and Elenska-Valchanova (2019). For both the modulus of elasticity and bending strength, the 8 mm thick laminated MDF has much better strength and deformation properties than the 10 mm thick MDF. This is due to the more significant influence of the thickness of the decorative laminate and probably to the better quality of the 8 mm thick fibreboards.

The highest bending strength shows 9 mm thick plywood, loaded in the direction perpendicular to the wood grain of the veneer face layer (103.85 $N.mm^{-2}$). In contrast, the strength decreased by about 25% (78.09 $N.mm^{-2}$) in the direction parallel to the veneer face layer. The 9 mm thick plywood with the parallel grain direction of the face veneer, which is laminated with HPL, shows a bending strength of 98.05 $N.mm^{-2}$. The increase in bending strength due to lamination is 25%. The 12 mm thick plywood shows strength characteristics about 12% lower than the 9 mm thick laminated plywood. This can be explained by its lower density, which is evidence of the veneer's layers' lower physical and mechanical characteristics. The highest bending strength of all the tested materials was 10 mm thick compact HPL (104.90 $N.mm^{-2}$).

Table 5: Bending strength statistics

Type of material	Number of test specimens	$\bar{x}$, N.mm^{-2}	MIN, N.mm^{-2}	MAX, N.mm^{-2}	Med, N.mm^{-2}	s, N.mm^{-2}	SE, N.mm^{-2}	CV, %
MDF_8_HPL	14	**74.39**	67.61	80.62	73.39	3.50	0.97	4.70
MDF_10	14	**34.97**	32.06	38.45	34.48	1.89	0.52	5.41
MDF_10_Black	15	**30.97**	27.18	34.93	30.78	2.37	0.63	7.67
HPL_10	14	**104.90**	101.48	109.26	104.56	2.18	0.61	2.08
MDF_10_HPL	14	**51.19**	46.39	53.70	51.54	1.91	0.53	3.73
MDF_12	15	**34.97**	31.78	38.28	35.03	1.86	0.50	5.31
LPB_12	14	**26.09**	23.32	29.03	26.30	1.79	0.50	6.85
Ply_9 II	15	**78.09**	75.36	81.57	77.86	2.23	0.84	2.85
Ply_9 ⊥	16	**103.85**	97.50	109.91	102.94	4.47	2.00	4.31
Ply_9_HPL	14	**98.05**	91.66	106.94	98.87	4.37	1.21	4.45
Ply_12 ⊥	14	**86.59**	76.96	93.20	88.93	5.62	1.56	6.49
Comp_6_Min	10	**71.21**	66.33	75.45	71.06	2.78	0.93	3.93

In contrast to the modulus of elasticity, where thermoplastic solid surface composites show very high values, in bending strength, they have an average strength (71.21 N.mm^{-2}). It should be noted that in the study by Wronka & Kowaluk (2020), the bending strength of Corian was 91.4 N.mm^{-2} and that of Staron was 67.1 N.mm^{-2}, indicating that the results obtained in the present study are a range between two other similar materials.

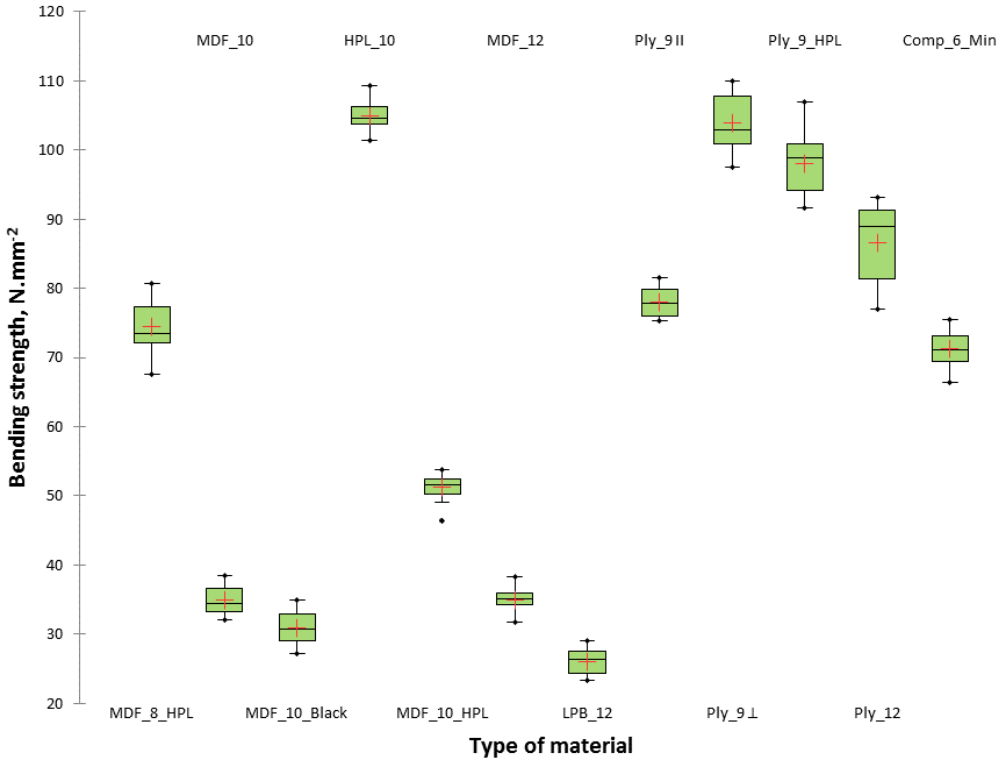


Figure 3: Bending strength

COMPARATIVE ANALYSIS OF THE STRENGTH AND DEFORMATION CHARACTERISTICS OF THIN AND ULTRATHIN STRUCTURAL MATERIALS

Figure 4 shows a radar-type graph from which conclusions can be quickly drawn about the ratio of the various properties of the materials under study to their characteristics, such as density, thickness, bending strength and modulus of elasticity. A dimensionless coefficient is used to compare the different material characteristics, which is obtained by dividing the corresponding value by the smallest in the given index. Thus, the larger the coefficient, the greater the influence of that index. For example, the most significant coefficient was obtained for the bending strength of 10 mm thick compact HPL – 4.02.

From the graph shown in Figure 4, it can be seen that compact HPL (HPL_10) has high bending strength and modulus of elasticity but also high density. The 9 mm thick plywood (Ply_9_⊥), when loaded perpendicular to the grain direction of the face veneer, has high strength and deformation characteristics but low density and thickness. At the other pole are particleboard, MDF with a thickness of 10 and 12 mm. Laminated MDF with a thickness of 8 mm can be classified as a structural material with good strength and deformation properties while having a small thickness and low density. Thermoplastic solid surface composites (Comp_6_Min) also show excellent strength properties at a small thickness (6 mm), but their density is the highest.

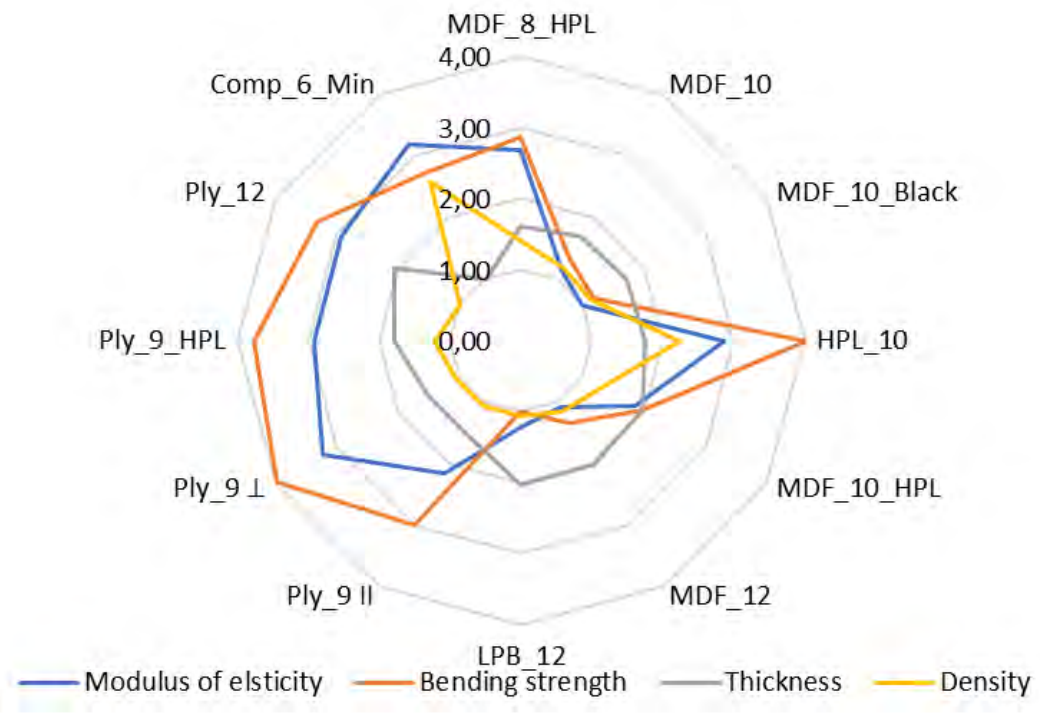


Figure 4: Radar-type graph for the evaluation of the severity of the investigated thin and ultrathin structural materials concerning the modulus of elasticity, bending strength, thickness and density

The results obtained for the bending strength and modulus of elasticity in bending were subjected to pairwise ANOVA comparative analysis of the groups of homogeneity using Tukey's honestly significant difference (HSD) test for a significant difference of α=0.05 at 95% confidence level. The results are presented in Tables 6 and 7.

In the modulus of elasticity, there are eight groups of homogeneity, one of which includes three types of material – 12 mm thick plywood, 9 mm thick plywood laminated with HPL and 10 mm thick compact HPL. Four groups are with two materials and three groups with one material. The materials between which there was no statistically significant difference were the two types of MDF with thicknesses of 10 and 12 mm. Therefore, the materials studied can be divided into three groups from the results obtained and the statistical analysis performed. The first group includes materials with high deformation characteristics, from 10035 to 8333 N. mm^{-2}. It comprises 9 mm thick plywood with a face layer of birch wood veneer with the perpendicular direction of the wood grains to the outer layers under load (Ply_9 ⊥); 6 mm thick thermoplastic solid surface composites (Comp_6_Min); 12 mm birch veneer faced plywood (Ply_12); 9 mm HPL faced plywood (Ply_9_HPL); 10 mm compact HPL (HPL_10) and 8 mm HPL faced MDF (MDF_8_HPL). The second group includes two materials with a modulus of elasticity of 6687 and 5773 N/mm^{-2}, respectively. These are the 9 mm thick plywood with parallel grain direction to the outer layers under load (Ply_9 II) and the 10 mm thick MDF laminated with HPL. The materials with relatively lowest deformation properties are 12 mm thick laminated particleboard (LPB_12), MDF 10 and 12 mm thick, and coloured (black) MDF 10 mm thick.

Table 6: Homogeneity groups for the modulus of elasticity in bending

Type of materials	$\bar{x}$, N.mm^{-2}	Homogeneity groups							
Ply_9 ⊥	10035	A							
Comp_6_Min	9888	A							
Ply_12	9105		B						
Ply_9_HPL	9039		B						
HPL_10	8886		B						
MDF_8_HPL	8333			C					
Ply_9 II	6687				D				
MDF_10_HPL	5773					E			
LPB_12	3815						F		
MDF_10	3533						F	G	
MDF_12	3399							G	H
MDF_10_Black	3105								H

For bending strength, nine homogeneity groups were identified (Table 7). For four pairs of materials, there was no statistically significant difference. These are – the 10 mm compact HPL (HPL_10) and the 9 mm plywood loaded perpendicular to the direction of the wood grain of the face veneer layer (Ply_9 ⊥); 9 mm plywood loaded parallel to the grain direction of the face veneer (Ply_9 II) and 8 mm MDF laminated with HPL (MDF_8_HPL); 8 mm MDF laminated with HPL and mineral thermoplastic solid surface composite and 10 and 12 mm natural MDF. Three main groups can be formed with little difference in modulus of elasticity and in bending strength. The difference here is that only three materials can be included in the group with the highest strength – the 10 mm

compact HPL (HPL_10) together with the 9 mm plywood loaded perpendicular to the direction of the grain of the veneer face (Ply_9 ⊥) and the 9 mm plywood laminated with HPL (Ply_9_HPL). The group with the lowest strength is the same as the modulus of elasticity.

Table 7: Homogeneity groups for the bending strength

Type of materials	$\bar{x}$, N.mm^{-2}	Homogeneity groups
HPL_10	104.90	A
Ply_9 ⊥	103.85	A
Ply_9_HPL	98.05	B
Ply_12	86.59	C
Ply_9 II	78.09	D
MDF_8_HPL	74.39	D E
Comp_6_Min	70.82	E
MDF_10_HPL	51.19	F
MDF_12	34.97	G
MDF_10	34.97	G
MDF_10_Black	30.97	H
LPB_12	26.09	I

CONCLUSIONS

The following conclusions can be drawn from the study carried out to establish some of the physical and mechanical characteristics of the tested materials:

- All the investigated panels, which are industrially produced, have strength and deformation characteristics above the minimum requirements of European standards.
- Considering the bending strength and modulus of elasticity for all the materials studied, the 9 mm thick plywood loaded perpendicular to the grain direction of the veneer face layer had the best strength and deformation characteristics. Other panels with good characteristics are 12 mm thick plywood, 9 mm thick decorative laminated plywood, 10 mm thick compact HPL and 6 mm thick mineral thermoplastic solid surface composites.
- The lowest bending strength and modulus of elasticity show MDF with a thickness of 10 and 12 mm, coloured MDF with a thickness of 10 mm and 12 mm thick laminated particleboard.
- The lamination of 10 mm thick MDF with decorative HP increases bending strength by 46%.
- The lamination of 9 mm thick birch plywood with decorative HP increases bending strength by 25%.
- The lamination with decorative HPL increases the density of structural materials for 10 mm thick MDF by 12.29% and for 9 mm thick birch plywood by 16.66%.
- All the investigated materials are suitable for use as thin and ultra-thin structural elements for furniture.

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BEECH WOOD MODIFIED BY RADIO-FREQUENCY DISCHARGE PLASMA

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ABSTRACT

The radio-frequency discharge plasma (RFDP) has been used to improve the wetting and adhesive properties of beech (*Fagus Sylvatica* L.) wood. The pre-treatment of wood surface using discharge plasma is attractive for various wood applications, mainly because of its high efficiency and low production cost. Moreover, a significant increase of the polar component of wood surface energy after modification by RFDP has been identified, while the polar component of the surface energy is associated with the presence of acid-base forces (electron donor–acceptor bonds). The surface energy of beech wood pre-treated by RFDP during 120 s in air significantly decreased. The shear strength of adhesive joint beech wood-polyurethane adhesive increased non-linearly from 5.2 MPa (native beech wood) up to 7.8 MPa. FTIR-ATR results confirm the increase of the beech wood polarity during RFDP treatment due to growth in –OH polar groups amount. The enhancement of the wood wettability is a necessary condition to promote a better adhesion with a water-based adhesives and coatings, which is currently being studied.

Key words: adhesion, beech wood, plasma treatment, surface chemistry, hydrophilicity.

INTRODUCTION

The radio-frequency discharge plasma (RFDP) used for a treatment of the wood surface lead to an increase of the adhesion of wood to various substrates by adhesives (Wolkenhauer *et al.* 2009, Acda *et al.* 2012). There are two reasons why discharge plasma can be applied and leads to the surface treatment. Firstly, discharge plasma in air significantly increases hydrophilicity of the wood because of formation various polar groups (e.g. hydroxyl, carbonyl, carboxyl groups, etc.), and the wood macromolecules are also cross-links (up to a few microns), what leads to the increase in scratch resistance, and to the improvement in barrier properties of the wood material (Rehn *et al.* 2003, Moghadamzadeh *et al.* 2011). Second reason for the plasma use is an increase of adhesion in adhesive joint between polymeric adhesive and wood substrate due to growth of wood wettability, that is important for industrial applications. The RFDP working at reduced press 100 Pa in air as processing gas is considered as a "green" and ecological friendly method (Odrášková *et al.* 2008, Müller *et al.* 2009). For a common industrial wood application various woods have to possess a large set of various surface characteristics, including polarity (hydrophobicity or hydrophilicity), dyeability, scratch resistance, tailored adhesive properties, antibacterial resistance etc.

This contribution is focused on a study of the surface, and adhesive properties as well as on analysis of chemical changes of plasma modified beech wood, namely polar groups, of the beech wood modified by the RFDP.

EXPERIMENTAL METHODS

MATERIALS

Beech wood (*Fagus Sylvatica* L.) plates with dimensions 50 × 15 × 5 mm (Technical University in Zvolen, Slovakia) with 8% of humidity, water-based polyurethane adhesive Dispercoll U 53 (Bayer, Germany), twice distilled water was used as a testing liquid, and dichloro methane (Fluka, Germany) for degreasing of the surface.

PLASMA MODIFICATION METHOD

The surface of beech wood sample was modified by RFDP in air (Slovak Academy of Sciences). The modification of wood by the capacitive coupled RFDP was performed in a laboratory plasma system working at reduced pressure 100 Pa consists of two 240 mm brass parallel circular electrodes with symmetrical arrangement, and 10 mm thick, between which RFDP was created. The electrodes of RFDP system are placed in a locked-up stainless steel vacuum cylinder. The voltage of RFDP reactor is 2 kV, frequency 13.56 MHz, max. current intensity is 0.6 mA, and the max. power of the plasma source is 1200 W. The wood samples were modified by RFDP at the power 300 W.

MEASUREMENTS METHODS

The hydrophilicity of beech wood was measured by contact angles determination using twice distilled water, the drop volume was 20 μm. Contact angle of the beech wood was determined by professional Surface Energy Evaluation (SEE) contact angle meter equipped with a web camera (Advex, Czech Republic), and necessary PC software.

The shear strength of plasma-treated beech wood to polyurethane adhesive was tested with overlapped adhesive joints in universal testing machine Instron 4301 (Instron, England) equipped with 5 kN force chamber.

Fourier Transform Infrared Spectroscopy Attenuated Total Reflectance (FTIR-ATR) measurements were performed with an FTIR Nicolet TM spectrometer (Thermo Scientific, USA) using a single bounce ATR accessory equipped with a Ge crystal. For each measurement, the spectral resolution was 2 $cm^{-1}$and 64 scans were performed.

RESULTS AND DISCUSSION

The contact angle of water drop on the beech wood surface was measured 3 s after drop deposition due to thermo-dynamical equilibrium achievement. The contact angle of water on beech wood surface modified by RFDP in air vs. activation time is shown in Fig. 1.

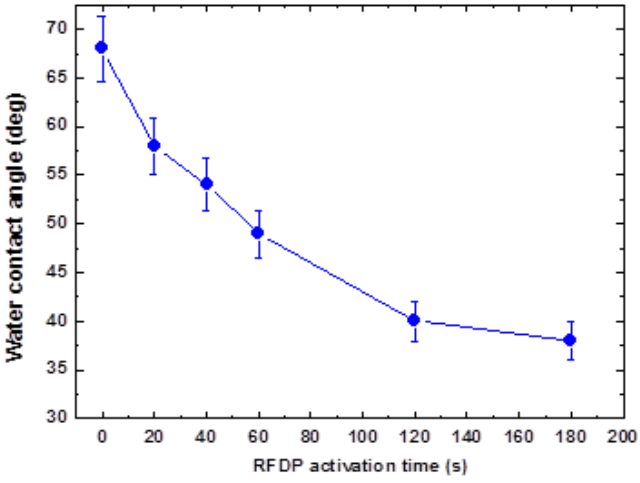


Figure 1: Water contact angle on beech wood surface modified by RFDP in air vs. activation time

The contact angles of water decreased with time of the activation by RFDP in air (Fig. 1), and showed a steep decrease from 66° (native beech wood) to 40° after 120 s activation of beech wood by RFDP. The decrease of the contact angle of polar testing liquid (water) can be explained by an increase of the hydrophilicity of beech wood surface during pre-treatment by RFDP. The hydrophilicity of the wood surface depends on the formation of polar oxygenic functional groups during plasma modification of wood in air. After saturation of the wood surface with polar groups the hydrophilicity was stabilized.

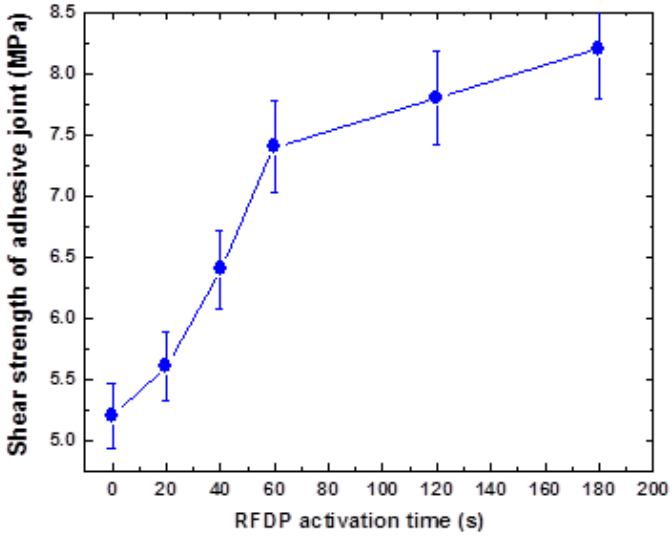


Figure 2: Shear strength of the adhesive joint beech wood-polyurethane after treatment of wood by RFDP in air vs. activation time

The shear strength of adhesive joint beech wood modified by RFDP in air – polyurethane adhesive vs. activation time is shown in Figure 2. The shear strength of adhesive joint beech wood-polyurethane increases non-linearly from 5.2 MPa (native beech wood) to 7.8 MPa (120 s activation by RFDP). The increase of the strength of adhesive joint beech wood-polyurethane-beech wood is depending on surface energy of the wood as well as on the topography/roughness of the wood surface.

Table 1 contains the results of normalized FTIR of beech wood modified by RFDP in air for different treatment time. The calculations with modified FTIR spectra were multiplied by a specific factor in order to have better readability common range of FTIR spectra. After this modification one can more clearly see the subtle changes in FTIR spectra the subtle changes in the shape of lines of C=O and C–O–C bonds, which confirm the changes that occurred on the wood surface. To quantify these changes following procedure have been realized: the integrated intensity ratios of polar –OH groups with a maximum at 3400 cm^{-1} and of non-polar CH_2 groups with a maximum at 2985 cm^{-1} $(–CH_2)sym$ were estimated. Table 1 shows the ratios of the integrated intensities with $P(OH)/P(–CH_2)$, where the vibration of $–CH_2–$ was chosen as an internal standard with that assumption, that the plasma treatment does not affect this area. An increase of the ratio $P(OH)/P(–CH_2)$ during plasma treatment of the beech wood was observed. The ratio $P(OH)/P(–CH_2)$ correlates with time of plasma treatment. The significant increase of the integrated intensities ratio was observed

from value 10.5 (native wood) up to value 28.3 (RFDP-treated wood, 120 s).

Table 1: Ratio of integrated intensities P(OH)/P(CH_2) of beech wood modified by RFDP in air calculated from FTIR-ATR spectra

Beech wood	P(2895, CH_2 stretch)	P(3400, OH stretch)	P(OH)/P(CH_2)
Native	0.496	5.203	10.490
RFDP, 40 s	0.286	5.811	20.318
RFDP, 80 s	0.264	6.512	24.667
RFDP, 120 s	0.244	6.913	28.332

CONCLUSIONS

The surface energy of beech wood treated by RFDP in air during 120 s decreased from 66 to 40°. The shear strength of adhesive joint beech wood-polyurethane increases non-linearly from 5.2 MPa (native beech wood) to 7.8 MPa (120 s activation by plasma). FTIR-ATR results confirm the increase of the beech wood polarity during RFDP treatment due to growth in –OH groups amount.

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SURFACE ROUGHNESS PARAMETERS FOR EVALUATION OF SANDING AND SANDPAPER GRIT SIZE IN PLYWOOD SURFACE PREPARATION FOR FILM FORMATION

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ABSTRACT

The subject of the present study is the selection of roughness parameters, suitable for estimating beech plywood surface changes during sanding which precedes film formation. The values of the studied parameters are presented, as well as the material ratio curves in the same evaluation length before and after sanding. The results of the research can be used to create more rational methods for evaluating the results of mechanical wood surface treatment.

Key words: sanding, roughness, material ratio curve, beech plywood.

ПАРАМЕТРИ НА ГРАПАВОСТ, ПОДХОДЯЩИ ЗА ОЦЕНКА НА ШЛИФОВАНЕТО И ЗЪРНИСТОСТТА НА ШКУРКАТА, ПРИ ПОДГОТОВКА НА ШПЕРПЛАТНИ ПОВЪРХНОСТИ ЗА ФИЛМООБРАЗУВАНЕ

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РЕЗЮМЕ

Предмет на настоящото изследване е избор на параметри на грапавост, подходящи за оценка на изменението на микрорелефа на букова шперплатна повърхност при шлифоване, предхождащо формирането на покритие. Представени са стойностите на изследваните параметри и кривите на Abbott – Firestone в една и съща дължина за оценяване, преди и след шлифоване. Резултатите от изследванията могат да послужат за създаване на по-рационални методики за оценка на резултатите при механично обработване на дървесни повърхности.

Ключови думи: шлифоване, грапавост, крива на Abbott – Firestone, буков шперплат.

УВОД

С навлизането на тънките плочести дървесни материали в интериора нараства необходимостта от придобиване на знания относно повърхностната им обработка. Финален процес, при подготовка на дървесните повърхности за изграждане на защитно-декоративни покрития, е шлифоването. Същността на шлифоването се изразява в неорганизирано рязане с помощта на многобройни, случайно ориентирани резци на абразивни зърна (Гочев 2018). Средният размер на абразивните зърна определя зърнистостта на шкурката (ISO 6344-2:2021, ISO 6344-3:2021). При отделянето на стружки върху обработваната повърхност се формират редуващи се клинообразни форми, които съвместно с прерязаните анатомични елементи създават нейния микрорелеф (Csanády and Magoss 2013, Кавалов и Ангелски 2015). Комплексен показател, който може да

служи за технологична оценка на дървесните повърхности е тяхната грапавост. Няма идеален показател за определяне грапавостта на повърхнините, затова тя се описва чрез група параметри, подбирани в зависимост от целта и обекта на изследването (Magoss et al. 2019, Salcă et al. 2019).

Според изследвания на Атанасова (2022), при шлифоване на букова шперплатна повърхност преди филмообразуване, средноаритметичното отклонение *Ra* и максималната височина на елементите на профила *Rz* са подходящи параметри за обща оценка на изменението на микрорелефа, но те не дават детайлна оценка за характера на това изменение. Също така изменението на параметъра *Ra* не се влияе от зърнистостта на използваната шкурка. От представените графично онагледени профили на повърхнините преди и след шлифоване (Фиг. 1) е направен извод, че в тази фаза от обработването се въздейства върху най-външния слой на дървесната основа и най- адекватен параметър, от наблюдаваните, е максималната височина на връх на профила *Rp*.



Фигура 1: Изменение на профила на шперплатна повърхнина в резултат от шлифоване с шкурка *P150* (Атанасова 2022)

Параметърът *Rp* се дефинира посредством средната линия. Той е свързан с максималната височина на елементите на профила *Rz* и максималната дълбочина на падина на профила *Rv* чрез уравнение (1):

$$\boldsymbol{R_z = R_p + R_v} \qquad \textbf{(1)}$$

При прилагане на филтър на Гаус средната линия се изчислява при филтриране на сигнала, т.е. стойността на *Rp* се определя спрямо нефиксирана база и по тази причина оценяването само чрез *Rp* не е коректно. В тази връзка целта на настоящото изследване е да се изберат рационални параметри на грапавост, подходящи за оценка на изменението на микрорелефа на шперплатна повърхност, в резултат от шлифоване, предхождащо формирането на филмово покритие.

МАТЕРИАЛИ И МЕТОД НА РАБОТА

Изследванията са проведени върху буков шперплат. Лицевият слой на шперплата е изработен от рязан фурнир с ясно изразена декоративна текстура. По данни на производителя (S.C. Cildro Plywood, Румъния) шперплатните повърхности са шлифовани последователно с шкурка P80 и P120 и отговарят на качество II/III по БДС EN 635-2:2004. Шперплатният лист е кондициониран 6 месеца при температура 23 ± 2°C и относителна влажност на въздуха 55 ± 5%. Пробните тела са с размери 120 x 410 mm. Разкроени са от една и съща плоча.

За определяне броя измервания, необходим за постигане на показател на точност $p < 5\%$ и придобиване на обща представа за изменението на изследваните параметри са направени предварителни измервания на дървесната повърхност преди и след шлифоване.

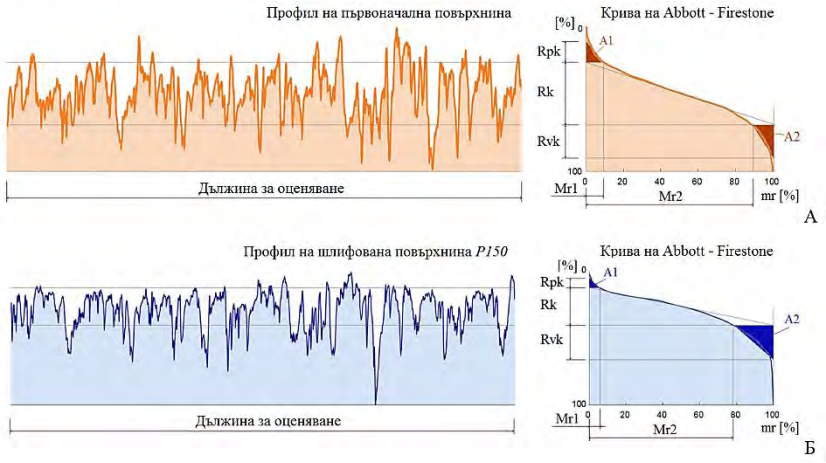
За определяне характера на изменението на дървесните повърхности върху три серии пробни тела, шлифовани съответно с шкурка *P100, P150* или *P240*, са проведени по 12 броя измервания, в едни и същи дължини за оценяване. Тази методика позволява игнориране в голяма степен на влиянието на микрорелефа на първоначалната повърхнина, както и анализиране на разсейването на стойностите на изследваните параметри.

Параметрите на грапавост са измервани с профиломер модел SJ-210 на фирмата Mitutoyo, Япония със сензор с обратен ход и диамантен V-образен връх на сондата с радиус R = 5 μm, съгласно БДС EN ISO 3274:2002, при следните настройки:

- профил – R, филтър на профила – Гаус;
- брой базови дължини n = 5;
- дължина за оценяване ln =12.5 mm;
- горна граница на филтъра λc = 2.5 mm;
- долна граница на филтъра λs = 8 μm;
- скорост на измерване 0.25 $mm.s^{-1}$.

Избраните параметри за анализ и оценка, както и използваните термини, са дефинирани по БДС EN ISO 4287:2006 и БДС EN ISO 13565-2:2002. Измерванията са проведени напречно на дървесните влакна.

Паралелно с традиционно измерваните параметри са определени и параметрите от кривата на относителната опорна дължина на профила (material ratio curve of the profile), наричана още крива на Abbott – Firestone. При измерване, графиката ѝ може да бъде обозначена с абревиатурата BAC (https://mitutoyo.eu/en_us). Координатите на точките от кривата се изчисляват от профила на повърхнината в измерваната дължина за оценяване (Фиг.2). Получената крива онагледява съотношението между наличието и липсата на материал в изследвания профил. Зависимостта се построява в двумерна правоъгълна координатна система. По двете оси измерванията, свързани с построяването, са в% . По ординатата ограничаваща е стойността на пълната височина на профила *Rt*. Съществува система, при която лимитираща е *Rz*. Тази стойност (*Rt* или *Rz*) се приема за 100% . Съществуват различни системи, в зависимост дали изходната позиция за измерване е най-високата или най-ниската точка на ограничаващия елемент. За настоящите измервания изходната позиция за измерване е най-високата точка на пълната височина на профила *Rt* в дължината за оценяване. По абсцисата ограничаваща е стойността на дължината за оценяване. При построяване на прави, успоредни на средната линия, със стъпка 1%, всяка права се разделя от профила на повърхнината на отсечки, чиито дължини отразяват наличието или липсата на материал в профила. Сумата от всички отсечки, лежащи на една права и отбелязващи наличието на материал, изразена в% , определя втората координата на търсената точка. Нарича се относителна опорна дължина на профила или mr стойност и се нанася по абсцисната ос. За 100% се приема състоянието, при което правата не пресича профила и се намира изцяло в материала, т.е. това е правата, преминаваща през най-ниската точка на ограничаващия във височина елемент.



Фигура 2: Графично представяне на параметрите по кривата на Abbott – Firestone: А – за първоначалната повърхнина от Фиг.1; Б – за шлифованата повърхнина от Фиг.1.

От вече построената крива се определят т.н. параметри на Abbott (БДС EN ISO 13565-2:2002):

- дълбочина на ядрото (core roughness depth) Rk [µm];
- редуцирана височина на върховете (reduced peak height) Rpk [µm];
- редуцирана дълбочина на падините (reduced valley depths) Rvk [µm];
- долна граница на ядрото (долна гранична mr стойност) Mr1 [%];
- горна граница на ядрото (горна гранична mr стойност) Mr2 [%];
- площ на върховете (peak area) A1;
- площ на падините (valley area) A2.

На Фиг. 2 параметрите на Abbott са обозначени върху кривите, отговарящи на представените на Фиг. 1 профили.

Използваният профиломер дава цифрови стойности на параметрите на Abbott, а BAC кривата е представена графично.

Значимостта на фактора „зърнистост“ на шкурката при шлифоване, когато $p < 5\%$, е проверявана чрез статистическата функцията за дисперсионен анализ към Microsoft Excel – ANOVA.

РЕЗУЛТАТИ И ДИСКУСИЯ

Предварителното изследване показа, че при 32 броя измервания всички наблюдавани параметри имат показател на точност $p < 5\%$ и вариационен коефициент $V < 30\%$, с изключение на площта на върховете *A1*. По тази причина *A1* е изключен от групата изследвани параметри. Изключени са също и параметрите *Rp* и *Rv*, поради връзката между тях (уравнение 1).

Средни стойности на резултатите, получени от предварителното общо измерване са представени в Таблица 1. Те дават основание да бъдат направени следните изводи:

1. Параметрите *RSm* и *Rvk* не са подходящи за оценка на шлифоването поради малкото им изменение.

2. При шлифоване стойностите на всички избрани параметри намаляват, с изключение на площта на падините *A2*. По тази причина не е коректно *A2* да бъде тълкуван самостоятелно. Удачен е анализа му като спомагателен параметър.

3. Параметрите *Rk*, *Rpk*, *Mr1* и *Rpk+Rk* са най-подходящи за оценка на шлифоването поради голямото им изменение ($\Delta R > 35\%$, $1.5\% < p < 4.9\%$, $9\% < V < 28\%$).

4. Параметрите *Ra*, *Rz*, *Rt*, *Rk+Rvk* и *Rpk+Rk+Rvk* са подходящи за оценка на шлифоването поради малкото им разсейване (1.4% < *p* < 2,9%, 8% < *V* < 17%). Тези параметри са взаимно заменими (22% > *ΔR* > 27%).

5. Параметърът *Mr2* поражда интерес поради малкото му разсейване (*p* < 0.77%, *V* < 4.5%). Неговото изменение ще бъде отчитано и при следващите експерименти.

Таблица 1: Средни стойности на изследваните параметри на грапавост за дървесната повърхнина преди и след шлифоване

	$\overline{Ra}$ [µm]	$\overline{Rz}$ [µm]	$\overline{Rp}$ [µm]	$\overline{Rv}$ [µm]	$\overline{RSm}$ [µm]	$\overline{Rt}$ [µm]	$\overline{Rk}$ [µm]	$\overline{Rpk}$ [µm]	$\overline{Rvk}$ [µm]	$\overline{Mr1}$ [%]	$\overline{Mr2}$ [%]	$\overline{A1}$	$\overline{A2}$	$\overline{Rk+Rvk}$ [µm]	$\overline{Rpk+Rk+Rvk}$ [µm]	$\overline{Rk+Rpk}$ [µm]
Преди	15,70	100,42	42,90	57,53	396,24	131,22	49,11	15,93	26,11	7,82	87,30	63,78	168,33	75,22	91,11	63,76
След	12,06	77,90	25,40	52,34	391,43	99,45	31,04	7,74	27,21	5,10	80,10	20,41	273,10	58,25	66,70	38,92
ΔR [%]	-23	-22	-41	-9	-1	-24	-37	-51	4	-35	-8	-68	62	-23	-27	-39

В Таблица 2, Таблица 3 и Таблица 4 са представени средните стойности на изследваните параметри за трите серии пробни тела, шлифовани с шкурки *P100*, *P150* и *P240*, стойностите на вариационния коефициент *V* [%] и показателя на точност *p* [%] за всяка група измервания, както и изменението *ΔR* [%] на стойностите на параметрите преди и след шлифоване.

Сравнителна графика на измененията на стойностите на изследваните параметри е представена на Фиг. 3.

Данните, представени в Табл. 2, Табл. 3 и Табл. 4, графичната визуализация на тяхното изменение от Фиг. 3 и резултатите от дисперсионния анализ дават основание да се направят следните изводи:

1. Поради малкото си изменение параметрите *Ra*, *Rz* и *Rt* не са подходящи за оценка на влиянието на зърнистостта на шкурката при шлифоване, преди нанасяне на покритие.

2. Поради най-голямото си изменение, най-подходящ показател за оценка на влиянието на зърнистостта на шкурката е площта на падините *A2,* следван от групата параметри *Rpk*, *Rk+Rpk* и *Rk*. С намаляване на зърнистостта на шкурката стойностите на *A2* нарастват, като разсейването им намалява, което показва, че повърхността става по-равномерна. Това твърдение е в съответствие с резултатите, докладвани от Herna´ndez and Cool (2008). Показателят на точност остава по-голям от 5%, което затруднява изследователската работа. Както беше посочено по-горе, удачно е използването на *A2* като допълнителен параметър.

3. Параметърът *Rpk* характеризира предходните фази на обработване в „най-външната“ част от профила на повърхнината, където структурата на основата не оказва влияние. *Rk* е показател, който характеризира областта на комбинирано влияние на дървесната структура и предходното обработване. Разделител между *Rk* и *Rpk* е долната гранична mr стойност

Mr1. Впечатление прави факта, че показателят на точност за *Rk* е под границата от 5%, за разлика от показателя на точност за *Rpk*. Голямото разсейването на *Rpk* е съвсем логично, защото като параметър на обработването основно влияние върху него оказват режимните параметри и характеристиките на инструмента, които не са обект на настоящото изследване. Зърнистостта се явява само един от тази група взаимосвързани параметри, като нейното влияние не е определящо. Позовавайки се на сходния характер на изменение на двата параметъра (Фиг. 3), и поради помалкото му разсейване, *Rk* може да бъде използван за оценка на влиянието на зърнистостта, когато изследването не отчита влиянието на дървесната структура. В реални условия влиянието на дървесната структура е съществено и не може да бъде пренебрегвано, поради което най-адекватна оценка за влиянието на зърнистостта на шкурката върху параметрите на дървесната повърхност предоставя съставния показател *Rk+Rpk*.

Таблица 2: Средни стойности на изследваните параметри на грапавост за първоначалната повърхнина и след шлифоване с шкурка *P100*

Параметри на грапавост	**Стойност за първоначалната повърхнина**	**Стойност при шлифоване с *P100***	***ΔR* [%]**	***V* [%]**	***P* [%]**	***W*$_{100}$ [%]**	***p*$_{100}$ [%]**
$\overline{Ra}$ [μm]	15,35	11,99	-22	8,12	2,34	9,05	2,61
$\overline{Rz}$ [μm]	99,28	78,78	-21	9,04	2,61	7,85	2,26
$\overline{Rt}$ [μm]	133,14	102,25	-23	16,51	4,77	15,44	4,46
$\overline{Rk}$ [μm]	47,89	33,22	-31	7,50	2,17	8,79	2,54
$\overline{Rpk}$ [μm]	14,81	8,54	-42	16,04	4,63	22,30	6,44
$\overline{Rvk}$ [μm]	25,47	25,59	0	15,88	4,58	13,86	4,00
$\overline{Mr1}$ [%]	7,45	5,65	-24	22,07	6,37	29,52	8,52
$\overline{Mr2}$ [%]	86,80	82,42	-5	3,13	0,90	3,16	0,91
$\overline{A2}$	170,64	227,49	33	34,24	9,88	27,56	7,96
$\overline{Rk + Rvk}$ [μm]	73,36	58,81	-20	8,04	2,32	6,95	2,01
$\overline{Rpk + Rk + Rvk}$ [μm]	88,17	67,35	-24	7,21	2,08	6,43	1,86
$\overline{Rk + Rpk}$ [μm]	62,70	41,76	-33	7,36	2,12	7,33	2,12

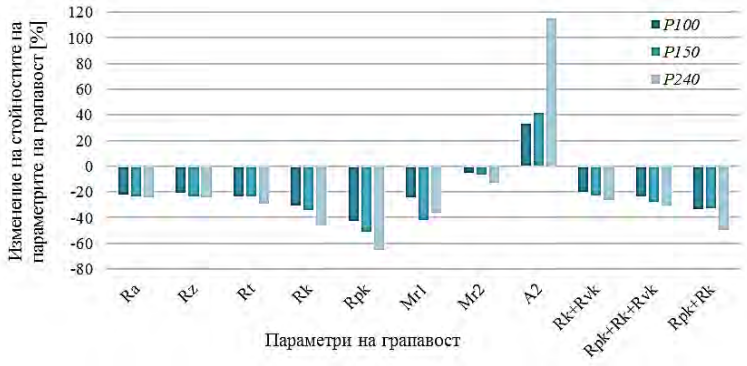
Таблица 3: Средни стойности на изследваните параметри на грапавост за първоначалната повърхнина и след шлифоване с шкурка *P150*

Параметри на грапавост	**Стойност за първоначалната повърхнина**	**Стойност при шлифоване с *P150***	***ΔR* [%]**	***V* [%]**	***p* [%]**	***V*** $_{P150}$ **[%]**	***p*** $_{P150}$ **[%]**
$\overline{Ra}$ [μm]	15,78	12,04	-24	7,89	2,28	10,09	2,91
$\overline{Rz}$ [μm]	103,44	79,36	-23	7,39	2,13	9,20	2,65
$\overline{Rt}$ [μm]	132,78	101,99	-23	11,45	3,31	12,84	3,71
$\overline{Rk}$ [μm]	48,56	32,21	-34	9,68	2,79	14,90	4,30
$\overline{Rpk}$ [μm]	17,17	8,47	-51	23,92	6,90	33,12	9,56
$\overline{Rvk}$ [μm]	27,54	26,75	-3	15,06	4,35	14,46	4,17
$\overline{Mr1}$ [%]	8,38	4,89	-42	22,77	6,57	22,37	6,46
$\overline{Mr2}$ [%]	87,29	81,40	-7	2,74	0,79	2,92	0,84
$\overline{A2}$	176,15	248,92	41	27,22	7,86	19,39	5,60
$\overline{Rk + Rvk}$ [μm]	76,10	58,96	-23	9,29	2,68	11,17	3,23
$\overline{Rpk + Rk + Rvk}$ [μm]	93,26	67,43	-28	9,28	2,68	12,04	3,48
$\overline{Rk + Rpk}$ [μm]	61,32	41,49	-32	19,81	5,72	16,72	4,83

Таблица 4: Средни стойности на изследваните параметри на грапавост за първоначалната повърхнина и след шлифоване с шкурка P240

Параметри на грапавост	Стойност за първоначалната повърхнина	Стойност при шлифоване с *P240*	*ΔR* [%]	*V* [%]	*p* [%]	V_{P240} [%]	p_{P240} [%]
$\overline{Ra}$ [µm]	16,10	12,16	-24	8,70	2,51	15,32	4,42
$\overline{Rz}$ [µm]	100,08	75,99	-24	10,87	3,14	15,35	4,43
$\overline{Rt}$ [µm]	134,25	94,92	-29	22,34	6,45	20,27	5,85
$\overline{Rk}$ [µm]	51,53	27,90	-46	8,73	2,52	15,53	4,48
$\overline{Rpk}$ [µm]	17,56	6,17	-65	43,34	12,51	52,53	15,17
$\overline{Rvk}$ [µm]	25,55	28,92	13	18,30	5,28	17,06	4,92
$\overline{Mr1}$ [%]	7,39	4,71	-36	17,84	5,15	47,98	13,85
$\overline{Mr2}$ [%]	87,98	76,59	-13	2,75	0,80	3,55	1,02
$\overline{A2}$	156,82	337,31	115	34,36	9,92	17,95	5,18
$\overline{Rk + Rvk}$ [µm]	77,08	56,82	-26	8,96	2,59	15,53	4,48
$\overline{Rpk + Rk + Rvk}$ [µm]	94,52	65,40	-31	13,12	3,79	18,22	5,26
$\overline{Rk + Rpk}$ [µm]	67,26	34,07	-49	17,73	5,12	21,56	6,22

* *разсейването на параметрите на шлифованата повърхнина в голяма степен се определя от разсейването на параметрите на първоначалната повърхнина*



Фигура 3: Изменение на стойностите на изследваните параметри на грапавост при шлифоване с шкурки с различна зърнистост

Съставният показател *Rk+Rpk* обхваща област от профила на дървесната повърхност, където влияние оказва предходното обработване. Характерът на изменението му показва, че с намаляване на зърнистостта на шкурката при шлифоване нараства влиянието на структурата на дървесината върху нейния микрорелеф, за сметка на обработването.

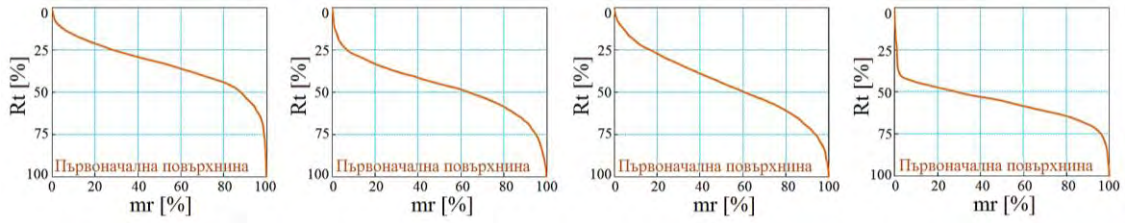
4. Долната гранична mr стойност *Mr1* ограничава влиянието на дървесната структура. От нейната големина зависи характерът на изменение на съставния показател *Rk+Rpk.* За шлифовани повърхнини, подобно на *Rpk*, стойностите на *Mr1* се характеризират с голямо разсейване, поради пряката зависимост от режимните параметри на шлифоването. Характерът на изменението на *Mr1* е повлияно в достатъчно голяма степен от структурата на дървесината и теоретично параметърът може да бъде използван за оценка на измененията на дървесната повърхност, в зависимост от зърнистостта на шкурката, с която е шлифовано.

5. Горната гранична mr стойност *Mr2* указва границата на влияние на предходното обработване (границата между *Rvk* и *Rk+Rpk*). В такъв аспект тя е повлияна силно от структурата на дървесината. Дисперсионният анализ потвърждава зна-

чимостта на фактора зърнистост при изменение стойностите на параметъра *Mr2* за букова шперплатна повърхност. Характерът на изменение на *Mr2* наподобява характера на изменението на *Rk* и *Rpk+Rk+Rvk* без да е идентичен с някой от тях. Интересното в параметъра е, че неговите стойности имат много малко разсейване, което позволява бърза и относително точна оценка на ефекта от шлифоване на дървесна повърхност.

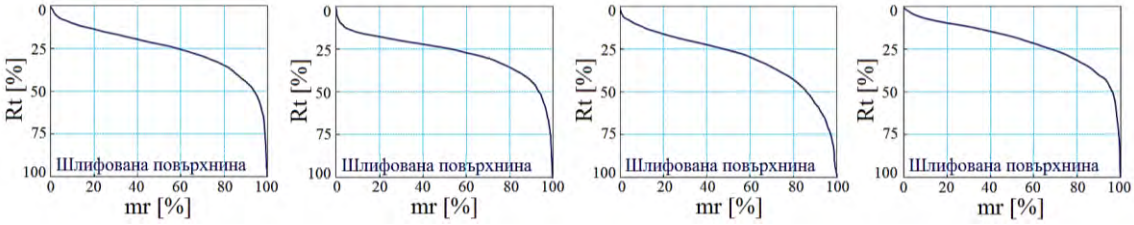
6. Изменението на параметрите *Rvk+Rk+Rpk* и *Rvk+Rk* е еднотипно, което ги прави равностойни при обща оценка на шлифоването.

На Фигура 4 и Фигура 5 са представените характерни криви на Abbott-Firestone за първоначалната и за шлифованата повърхнина, в едни и същи дължини за оценяване.



Фигура 4: Криви на Abbott – Firestone за първоначалната повърхнина

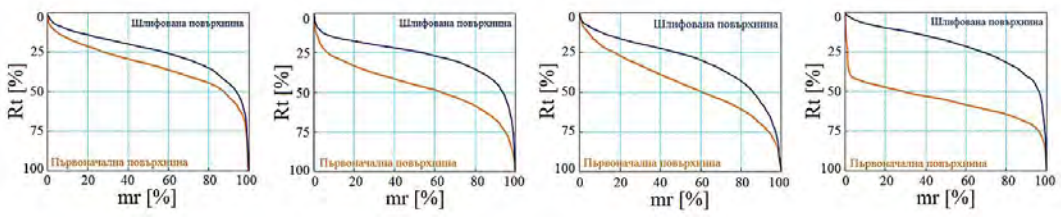
Различието в кривите от Фиг. 4 отразява неблагоприятните условия на съхранение и транспорт на шперплатния лист, които са повлияли върху показателите на неговите повърхности в зоната на контакт с околната среда. В такъв аспект Rpk се явява характеристика на предходните фаза на обработване, както и на условията на околната среда, което е допълнителна причина за голямото разсейване на стойностите му.



Фигура 5: Криви на Abbott – Firestone за шлифована повърхнина

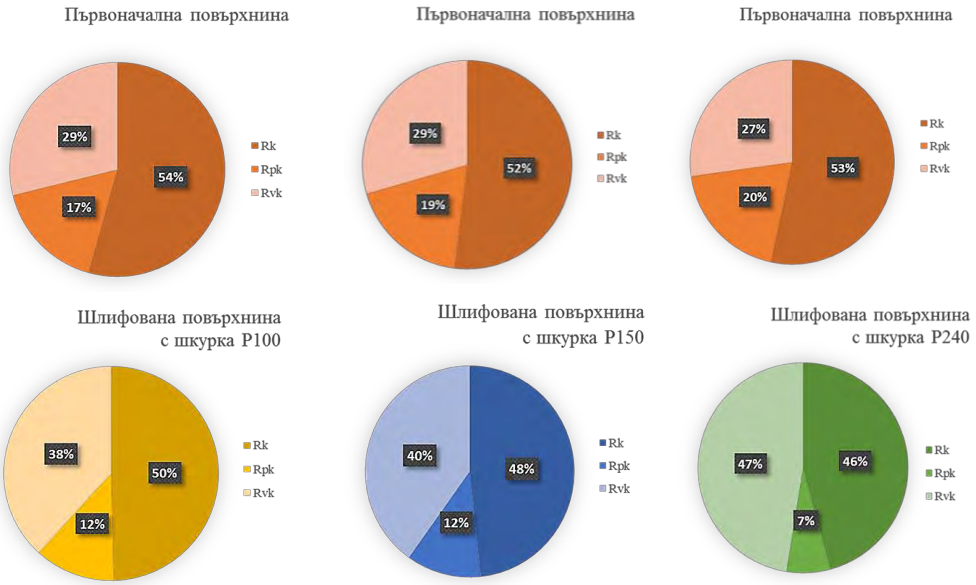
Еднаквият характер на кривите от Фиг. 5 дава основание да се направи извод, че шлифоването придава на обработваните повърхнини еднотипни характеристики.

Сравнителни графики на кривите от Фиг. 4 и Фиг. 5 са представени на Фиг. 6.



Фигура 6: Сравнителна графика на измененията на кривите на Abbott – Firestone в резултат от шлифоване

Диаграми на процентното изменение на параметрите *Rvk*, *Rk* и *Rpk* в съставния параметър *Rvk+Rk+Rpk,* в резултат на шлифоване с шкурка *P100*, *P150* или *P240*, са представени на Фигура 7.



Фигура 7: Изменение на параметрите *Rvk, Rk* и *Rpk* в общия параметър *Rvk+Rk+Rpk* в резултат на шлифоване с шкурки *P100, P150* и *P240*

Анализът на диаграмите на шлифованите повърхнини показва, че с намаляване зърнистостта на шкурката относителният дял на параметъра *Rpk* в комплексния показател *Rvk+Rk+Rpk* намалява, за сметка на *Rvk*, като *Rk* остава относително постоянен, т.е. грапавостта на повърхнината зависи в по-малка степен от неравностите, причинени от механичната обработка в сравнение с неравностите, определени от структурата на дървесината. Така направеното заключение съответства на по-горе изложените разсъждения, както и на резултатите, докладвани от Gurau et al. (2019), относно поведението на букова повърхност при шлифоване. В такъв аспект *Rpk* се явява характеристика на шлифоването, а *Rvk* – на структурата на дървесната основа.

ЗАКЛЮЧЕНИЕ

Представените в таблична и графична форма резултати от проведените изследвания, с избраните материали и при посочените условия, дават основание да бъдат направени следните изводи:

1. Групата от най-рационални параметри на грапавост, подходящи за оценка на изменението на микрорелефа на букова шперплатна повърхност, в резултат от шлифоване, предхождащо формирането на филмово покритие, включва: *Rk*, *Rpk+Rk*, *Rpk+Rk+Rvk, Ra* и *Rz* (или *Rt*, в зависимост от това, кой параметър е заложен за построяване на кривите на Abbott – Firestone).

2. Най-рационалният параметър на грапавост, подходящ за оценка на влиянието на зърнистостта на шкурката върху изменението на микрорелефа на букова шперплатна повърхност при шлифоване е съставния параметър *Rpk+Rk*. Използването на площта на падините *A2* и долната гранична mr стойност *Mr1* като допълнителни параметри изисква провеждане на по-голям брой измервания, поради по-голямото разсейване на стойностите им.

3. Основен параметър за оценка на ефекта от шлифоването и зърнистостта на шкурката с цел рационализиране на режимните параметри при обработване е *Rpk*. Поради голямото разсейване на неговите стойности е допустимо да бъде заменен от *Rk*. Във втория случай е некоректно сравняване на повърхности на различни дървесни видове.

4. Шлифоването се онагледява графично от крива на Abbott – Firestone с характерна форма. В такъв аспект, в резултат от шлифоване обработваните повърхнини придобиват сходни геометрични характеристики.

5. С намаляване на зърнистостта на шкурката определящо влияние върху микрорелефа на изследваната повърхност придобива структурата на дървесината.

Резултатите от изследванията могат да послужат в практиката, за създаване на по-рационални методики за технологично и качествено оценяване на шлифовани дървесни повърхнини.

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THE INFLUENCE OF THERMAL MODIFICATION OF OAK, SPRUCE AND MERANTI BLANKS ON SURFACE ROUGHNESS DURING SANDING

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ABSTRACT

Products made of thermally treated wood have different requirements for the quality of the created surface, depending on their application area. While we can make do with a milled surface for tiling and flooring, we have more sophisticated products such as garden furniture, etc. that require final surface sanding. The article focuses on the effect of thermal modification on the quality of the ground surface. It compares the surface quality of the ground surface of native woods oak, spruce and meranti with their thermally treated variants at temperatures of 160°C, 180°C, 200°C and 220°C. Quality is examined on a surface sanded with a belt sander with 80-grit sandpaper.

It points to the fact that the process of a thermal modification slightly impairs the quality of the ground surface. However, when evaluating a surface on a larger scale, the quality of the created surface is influenced mainly by the "natural roughness of the wood" by the opening of anatomical elements of the wood, which are the primary source of increased roughness.

Key words: thermally treated wood, sanded surface, surface roughness, natural wood roughness.

INTRODUCTION

Thermowood is wood treated by heat, steam, and water, without harmful chemicals, with new physical and mechanical properties. This method of wood treatment has been known for several millennia. Thermal modification (heat treatment) is one of the environmentally friendly methods used to improve and develop the properties of wood materials (Očkajová *et al.* 2020, Kminiak *et al.* 2020a). This method, it is aimed to improve the properties of wood material without the use of chemicals. The method has shown that by exposing the wood material to temperatures between 170°C and 220°C in an oxygen-free environment, it is possible to modify wood components that are sensitive to moisture absorption and biodegradation (Dagbro *et al.* 2010, Demirel and Temiz 2015, Dagbro 2016, Korčok *et al.* 2019, Kminiak and Banski 2019).

Wood with these properties is like tropical wood, which in many cases can be replaced by temperate woods, which are less economically significant (Thermowood, 2016). Thermowood has two forms of treatment, the Thermo-S class is an increase in wood stability and the Thermo-D class is an increase in wood durability (ThermoWood Handbook 2003). The advantages of Thermowood particularly include the reduction of moisture absorption, dimensional stability, biological resistance, the attractive appearance of heat-treated wood, the application of material without surface treatment, the high durability of heat-treated wood, the displacement of resin from the material, as it causes a problem with cutting tools as well as with the

use of natural wood without surface treatment, the reduction of thermal conductivity, the increase of wood surface hardness (for weathered areas), the increase of resistance against cracks. Heat-treated wood has lower dynamic strength, mainly bendability and toughness, in terms of mechanical properties, which results in a more brittle wood, not excluding its versatile use in the exterior and interior of a very humid environment (Tepelně upravené dřevo Thermo Wood 2013, Kminiak *et al.* 2020b).

Thermowood is the subject of much research. The researchers examined the changes in the physical-mechanical properties (Gunduz *et al.* 2009), the chemical properties (Reinprecht and Vidholdová 2008, Kačíková and Kačík 2011, ThermoWood Handbook 2003, Čabalová *et al.* 2016), the quality of the surface obtained (Budakci *et al.* 2013, Kvietková *et al.* 2015, Vančo *et al.* 2017, Kaplan *et al.* 2018) the color of the wood, the woodworking (Sandak *et al.* 2017, Reinprecht and Vidholdová 2008, Král and Hrázský 2005), the workability in the context of energy consumption (Kubš *et al.* 2016), the stability against the impact of weather (Panayot and Jivko 2008, Yildiz *et al.* 2011), the granulometry of the chips (Barcík and Gašparík 2014), or sawdust (Dzurenda *et al.* 2010).

In terms of processing, heat-treated wood has no limitations compared to natural wood. A problem can be the formation of a fine fraction or dust when processing and sanding thermally treated wood, which is caused by an increase in fragility and a decrease in some mechanical properties (Reinprecht and Vidholdová 2008, Kráľ and Hrázský 2005). Most of the mechanical properties of thermally modified wood are reduced because the weight and density of the thermally modified wood are reduced, as well as due to microcracks.

In the production of wood products, it is necessary to monitor their quality. For the product to meet certain quality requirements, production processes must be optimized, such as feed rate, machining direction, revolutions, etc.

Roughness is a measure of fine irregularities on the surface of the wood. The width, height, and shape of irregularities on the surface determine the quality of the product's surface. The roughness of the wood surface plays an important role, as any surface irregularities can manifest as thin layers that reduce the final quality of the wood (Hiziroglu and Kosonkorn 2006). Subtle irregularities on the surface of the wood will be reflected by the overlap and this affects the quality of the product and its final treatment. (Nemec *et al.* 2017, Hiziroglu 1996).

The aim of this paper is to define the effect of thermal modification on the quality of the created surface during sanding, depending on the type of wood (spruce, oak, meranti) and heat treatment conditions (temperatures 160°C, 180°C, 200°C and 220°C), by sanding at vertical belt sander.

EXPERIMENTAL METHODS

Experimental samples:

Sessile oak *(Quercus petraea)* and Norway spruce *(Picea abies)* was gathered in Vlčí jarok (Budča, Slovakia), at 440 m above sea level. Radial boards were sawed from the logs and processed in test samples measuring 20 mm × 100 mm with a length of approximately 700 mm. The samples were then dried to residual moisture of 8 %. The entire process was performed in the Research and Development Workshops of the Technical University in Zvolen (Zvolen, Slovakia).

Meranti *(Shorea spp.)* wood was obtained from Indonesia. The region of origin is not specified by the importer (Wood Store, Prague, Czech Republic).

Heat treatment and sample processing methods:

The processed samples, measuring 20 mm × 100 mm × 700 mm, were thermally modified in the Arboretum FLD (Czech University of Life Sciences, Prague, Czech Republic) in the town Kostelec nad Černými lesy. The S400/03 (LAC Ltd., Rajhrad, Czech Republic) chamber, shown in Fig. 1, was used for thermal modification and was designed to heat the wood with ThermoWood technology at a maximal temperature of 300°C and a volume of 380 L. Five samples were prepared for each treatment. The thermal modification methodology of samples is published in the paper of Kučerka and Očkajová 2018, Očkajová *et al.* 2018.



Figure 1: Chamber S400/03

The heat treatment procedure for the individual temperatures was as follows: the application of temperature sensors and a humidity sensor for the sensors, the storage of samples in the chamber, the closure and locking of the chamber door, the setting of the heat treatment parameters with a computer program – target temperature, steepness [°C /hr.] for heating and cooling, heat treatment of samples, sample collection from the chamber.

The thermal modification was conducted at 160, 180, 200 and 220°C in six phases: 1st phase – an increase of temperature to 40°C, 2nd phase – increase of temperature to 130°C, drying, 3rd phase – heat treatment – heating to working temperature, 4th phase – heat treatment – working temperature of 3 hours, 5th phase – cooling to 130°C and humidity treatment, 6th phase – cooling to 60°C with humidity treatment at the level of 4–7%. The process is complete when the temperature reaches 60°C.

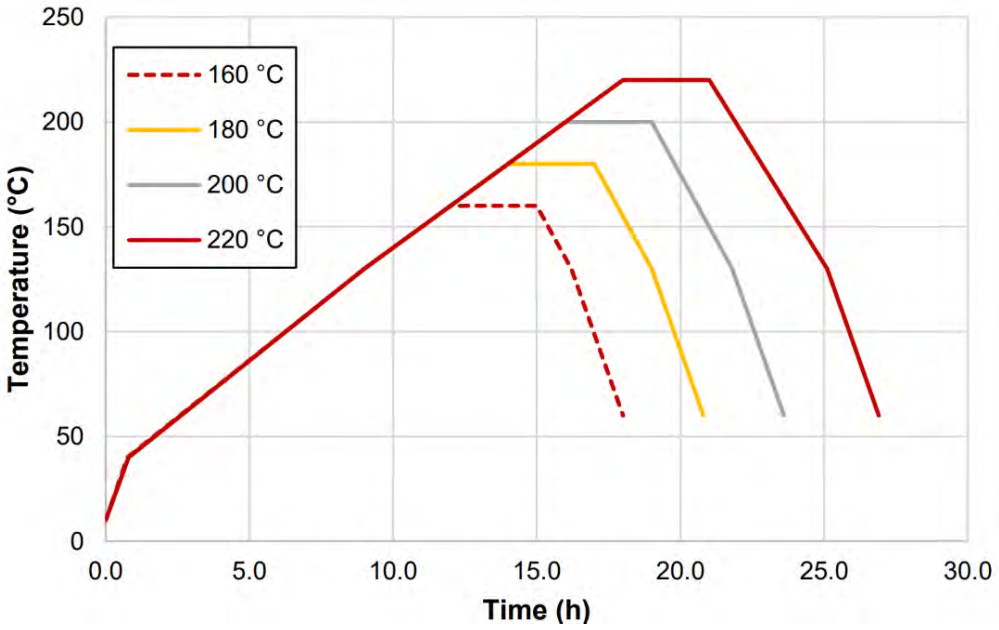


Figure 2: Durations and temperatures of heat-treatment of wood (Koleda *et al.* 2018)

Machinery:

A JET JSG-96 (JPW Tool AG, Fällanden, Switzerland), a narrow belt sander (NBS) with a cutting speed of 10 m.s-1, and a HIOLIT XO P 80 (KWH Group Ltd., Vaasa, Finland) grain sanding belt that kept individual pressure on the wood samples, were used in the laboratory experiments. A sharp sanding belt was used for each thermal treatment.



Figure 3: Narrow belt sander JET JSG-96 (JPW Tool AG, Fällanden, Switzerland)

Measurement of surface roughness:

The three-dimensional morphology of the samples was measured using the 3D – optical microscope Infinite Focus (Alicona Imaging GmbH, Graz, Austria) at five-fold magnification, with a vertical resolution of 1 µm and a measurement area of 10 × 10 mm^2. The surface morphology was then examined using the software IFM 2.0-1 from Alicona Imaging GmbH (Graz, Austria). As texture indicator, the amplitude parameters S_z (Maximum height of selected area).



Figure 4: 3D – optical microscope Infinite Focus Alicona



Figure 5: Colour range of thermally treated woods

Table 1: Effect of thermal modification on density (Koleda *et al.* 2020a)

Modification	Spruce (Koleda *et al.* 2018)	Oak (Koleda *et al.* 2020b)	Meranti (Rajko *et al.* 2021)
natural	442.23	775.85	639
160	430.99	719.73	617
180	409.15	687.39	580
200	371.72	617.84	559
220	362.88	608.96	549

RESULTS AND DISCUSSION

The obtained data were subjected to statistical analysis in the Statistica program. A two-factor variance analysis was used for the basic evaluation of the influence of the studied factors on wood species and the degree of thermal modification (Table 2). This showed that both investigated parameters are highly statistically significant ($p > 0.005$). The analysis further showed that the wood factor is twice as important as the thermal modification factor.

Table 2: Two-factor analysis of the influence of the studied parameters

	SČ	Degrees of freedom	PČ	F	p
Absolute element	5074641	1	5074641	1531.264	0.000000
Wood species	181108	2	90554	27.325	0.000000
Degree of thermal modification	150858	4	37715	11.380	0.000001
Wood species*degree of thermal modification	18691	8	2336	0.705	0.685875
Error	198841	60	3314		

The mutual comparison shows that the quality of the created surface decreases, while the S_z parameter increases in the order of oak, spruce, and meranti. While the average difference (independent of the degree of thermal modification) between S_z oak and S_z spruce is 15.7 % (reference oak), the average difference between S_z oak and S_z meranti is up to 44.4 % (reference oak), and the difference between S_z spruce and S_z meranti 27 % (spruce reference).



a) **b)** **c)**

Figure 6: View of the 3D surface profile a) natural oak, b) natural spruce, c) natural meranti

As the view from the 3D representation of the surface profile suggests (Fig. 6), the significant characteristics of the surface are not caused by traces of the grinding tool, but by the anatomical structure of the examined material and its natural roughness. In the case

of oak and meranti trees, it is the occurrence of stem rays. In the case of spruce wood, the cause can be considered significant differences between spring and summer wood and the very mechanism of surface formation, where the different release of wood fibers occurs.

Table 3: The effect of thermal modification on the quality of the created surface during sanding

Wood species	Degree of thermal modification	Maximum height of the selected area Average	Maximum height of the selected area Standard deviation	Maximum height of the selected area -95.00 %	Maximum height of the selected area +95.00 %
Oak	0	267,1818	25,74498	215,6842	318,6794
Oak	160	171,3786	25,74498	119,8810	222,8762
Oak	180	179,3928	25,74498	127,8952	230,8904
Oak	200	179,2464	25,74498	127,7488	230,7440
Oak	220	235,8286	25,74498	184,3310	287,3262
Spruce	0	280,2620	25,74498	228,7644	331,7596
Spruce	160	214,2666	25,74498	162,7690	265,7642
Spruce	180	201,0294	25,74498	149,5318	252,5270
Spruce	200	234,4372	25,74498	182,9396	285,9348
Spruce	220	312,3932	25,74498	260,8956	363,8908
Meranti	0	392,4602	25,74498	340,9626	443,9578
Meranti	160	273,8602	25,74498	222,3626	325,3578
Meranti	180	297,7336	25,74498	246,2360	349,2312
Meranti	200	260,5982	25,74498	209,1006	312,0958
Meranti	220	401,7158	25,74498	350,2182	453,2134

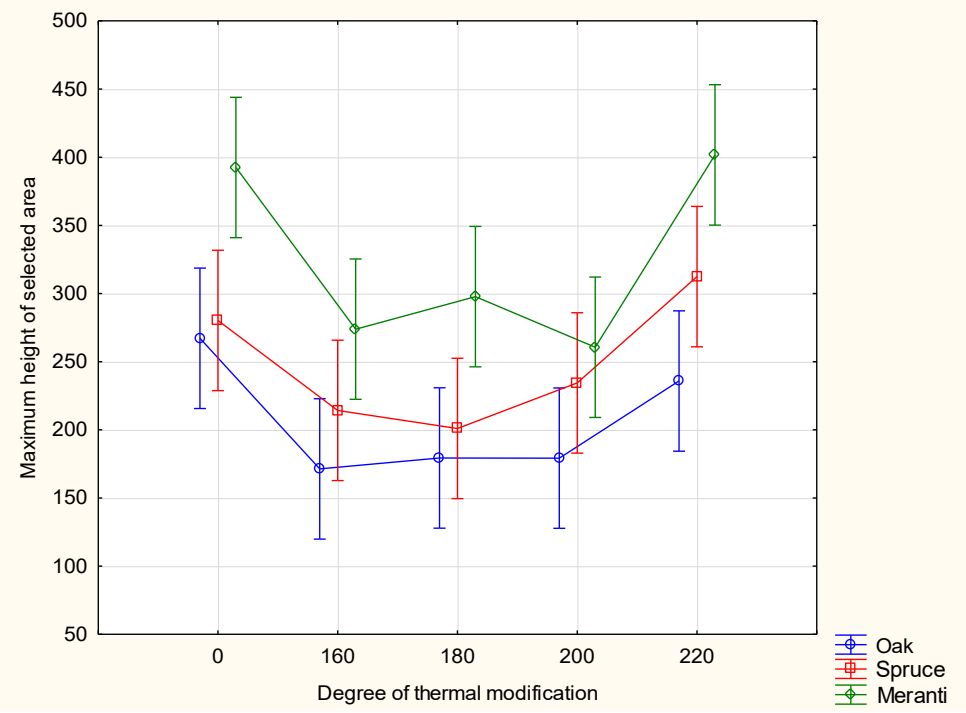


Figure 7: The effect of thermal modification on the quality of the created surface during sanding

Like other technologies for processing thermally treated material, an increase in quality due to thermal modification can also be observed during grinding. This increase is manifested only up to a certain degree of thermal modification, beyond which the quality deteriorates again. In our case, the temperature of 220°C can be considered critical, where the quality of the created surface deteriorates, and this is the case for all investigated woods. However, this deterioration is approximately at the level of the surface quality of non-thermally treated wood.

CONCLUSIONS

In the article, we focused on the comparison of the quality of the ground surface of native woods oak, spruce and meranti and we compared how it is affected by thermal modification at different temperatures of 160°C, 180°C, 200°C and 220°C. We found that with increasing treatment temperature, the quality of the surface of all woods is better, but only up to a certain limit, which in this case is the treatment temperature of 220°C. We consider this temperature to be critical, as it deteriorates the surface quality of all types of wood. At this treatment temperature, the surface quality of all woods returned to the original level of native wood. It is assumed that this can be caused by an increase in brittleness and a decrease in some mechanical properties, as chemical reactions of lignin occur.

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REDUCTION OF FORMALDEHYDE EMISSION FROM WOOD-BASED PANELS BY MODIFICATION OF UF ADHESIVES WITH NATURAL BIOPOLYMERS

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ABSTRACT

At present, polycondensation urea-formaldehyde (UF) resins are the most widely used wood gluing adhesives, but their main disadvantage is their low resistance to water and moisture, which causes the subsequent release of formaldehyde emissions from finished products. The aim of the study was to reduce the release of formaldehyde from wood materials by developing and testing new, more effective modifiers that bind formaldehyde or form more stable methylene bonds during polycondensation. Research was focused on the biopolymer collagen and keratin. For this study collagen samples were modified with hardener RODA M 210 (manufacturer Duslo Šaľa) and sulphur additive. From biopolymer keratin, which can be found in hair, feather, wool, nails, hoofs, horns, etc., were prepared samples by thermal heating during for 1 hour at various temperatures from 150°C to 197°C. XPS Ray photoelectron spectroscopy analyse was used to identify changes in their surface chemical structure. The XPS spectrum of keratin samples has been shown to depend on the temperature of their thermal degradation, with the total amount of carbon, nitrogen and sulphur increasing with increasing temperature. For sulphur, the total amount of its reduced form expressed as sulphide also increases, while the total amount of oxygen decreases with increasing temperature. Technical applications have focused on the application of keratin samples to modify mixtures of UF resins to reduce the release of formaldehyde from glued wood-based panels. Formaldehyde emissions were assessed from five-layer plywood according to EN ISO 12460-4. Measured values of extinctions of tested samples confirmed the decrease of formaldehyde emissions for each concentration of collagen and keratin samples in comparison with the reference sample.

Key words: UF adhesive, modifier, keratin, collagen, UF resin, plywood, gluing, formaldehyde emission.

INTRODUCTION

In woodworking industry, at present, polycondensation urea-formaldehyde (UF) resins are the most used adhesives for wood-based panels. Annual European production of UF adhesives achieves about 4.8 million tons, of which 60% is consumed for production of particleboard

30% for production of medium density fibreboards (MDF), and 10% for adhesive bonding in production of furniture, interior doors, and plywood (Maminski *et al.* 2006).

Glutaraldehyde (GA) is chemical matter, which is often tested for modification of hardeners, there is the assumption, which is completely cross-linked into the structure of the adhesive. Maminski *et al*. 2006 investigated melamine-urea-formaldehyde (MUF) adhesive, they added GA into the hardener in form of 50% water solution. Shear strength of birch samples glued with modified adhesive was significantly higher in comparison with the reference sample. Also, there is a direct bond of GA with chemical compounds of wood, what significantly increases the strength of glued joint. The percent of fibre destruction was much higher, modified adhesive proved stronger interaction adhesive-wood.

Their wide utilisation is allowed by their relative low price, high reactivity, availability of raw material and easy applicability, after hardening they provide transparent, but fragile bond. UF adhesives are thermo-reactive resins hardening in wide interval of temperatures with short time of condensation and they are resistant against micro-organisms. A major disadvantage is their low water and moisture resistance and consequent toxicity caused by the hydrolysis and release of formaldehyde (fd) from finished products. Much contemporary research describes emission of formaldehyde mainly from three sources: the residual formaldehyde present in the resin, formaldehyde formed by the polycondensation reaction between hydroxymethyl groups and formaldehyde released by hydrolytic degradation of hardened resin, especially under conditions of increased humidity and increased temperature.

Formaldehyde adversely affects the respiratory system, eyes, skin, genetic material, reproductive organs, and has a strong effect on the central nervous system (Příhoda 1988).

The research of modification of adhesives is aimed on utilisation of products, which are easily accessible, and their application save the costs for resin production. On the market, there is large number of biopolymers, which as secondary raw material can be used for modification of adhesives with the aim to keep and/or increase the quality of adhesives and glued joints. Leather and food industry produces amount of different biopolymer waste, which pollutes the environment (Pünterer 1995, Buljan *et al.* 1997, Matyašovský *et al.* 2011).

The shear strength of glued joint directly depends on the resistance against humidity. Suitable modification of adhesive mixtures can reach better cross-linking of the structure of hardened adhesive, increase of durable chemical bonds and lowering of the hydrolysis of adhesive. The research aimed not only on the study of properties of wood and adhesives, but as glued products are also the subject exposed to the environment in which they are located, and to study their interactions (Šmidriaková *et al.* 2011).

Langmaier *et al.* 2004 in his experiments used hydrolysate of chromium waste from leather industry obtained by enzymatic hydrolysis. Non-isothermal thermogravimetric method (TGA) was used at investigation of condensation reactions of dimethylol-urea (DMU) and its mixtures with different weight content of urea, hydrolysate, or acid hardener.

Thermo-oxidative stability of different materials and biopolymers was tested by differential scanning calorimetry (DSC). The method is based on determination of the end of induction period, or the beginning of the main oxidation process (Šimon *et al.* 2001, Šimon *et al.* 2006).

Literary research and practical requirements indicated the existence of a potential to apply modifiers of protein hydrolysates for adjusting parameters of wood adhesives, particularly polycondensation UF resins. Biologically active natural products are suitable to be used for new applications in the technology of polycondensation adhesives. (Ružiak *et al.* 2017, Sedliačik *et al.* 2011, Zhao *et al.* 2012).

Collagen and keratin are renewable materials, and their sources are almost unlimited. Therefore, there is an effort to constantly improve existing products and find new options for their application and processing (Matyašovský *et al.* 2014).

Experimental research was aimed on preparation of adhesive mixtures and testing their influence on formaldehyde emission and strength of glued joint. The aim of the

study was to reduce the release of formaldehyde from wood materials by developing and testing new more effective keratin-based environmental modifiers that bind formaldehyde and form more stable methylene bonds and their effect on the bond strength of wood-based panels.

EXPERIMENTAL METHODS

MATERIALS AND CHEMICALS

Collagen of type I was prepared from pig skins by hydrolysis of fibril structure through the application of proteolytic enzymes, alkalis, acids or lyotropic agent. This type of collagen was applied to experimentally test the reduction of formaldehyde emissions from UF cured adhesive mixtures. Concentrating and subsequent drying can extend stability of biopolymer for more than 12 months. Chemical and physical parameters of dried collagen are described in Tab 1.

Table 1: Physical and chemical parameters of dry collagen No.1 hydrolysate

Total nitrogen	14.9%
Size of particles	60 Mesh or 0.25 mm
Bloom at concentration 6.67% and temperature 10 °C	191
Viscosity at concentration 6.67% and temperature 60 °C	2.6 mPa.s
pH	5.2
Dry content matter	90.8%
Ash	< 2%

To increase the efficiency, collagen was modified with hardener RODA M 20 (manufacturer Duslo Šaľa, Slovakia), with the following parameters: pH = 7.4, total nitrogen as N – wt. 21.5% and amide nitrogen as NH_2 – mass 4.5 and sulphur additive.

In the experimental work, UF glue KRONORES CB 1639F was applied and hardener DAM 390 containing 30% nitrogen with a ratio of ammonium, nitrate, and amide nitrogen of 1: 1: 2 = (7.5%: 7.5%: 15%) were applied as a standard, (manufactured by Duslo Šaľa – Slovakia). Formaldehyde emissions in the bonded material were determined by the desiccator method according to EN ISO 12460-4 Wood-based panels. Determination of formaldehyde release. Part 4: Desiccator method.

Adhesive mixtures for modification UF resin were prepared according to following scheme:

Reference: 100% KRONORES CB 1639F + 20% technical flour+ 5% DAM 390 hardener,

Sample No.1: 100% KRONORES CB 1639F + 20% technical flour + (0.0; 0.2; 0,5; 1.0; 3.0)% collagen No.1 prepared from pig skin + 5% RODA M 210 hardener,

Sample No.2: 100% KRONORES CB 1639F + 20% technical flour + hardener 5% RODA M 210 modified with (0.0; 0.2; 0,5; 1.0; 3.0)% collagen No.1 prepared from pig skin,

Sample No.3: 100% KRONORES CB 1639F + 20% technical flour + hardener 5% RODA M 210 + modified 0,5% sulphur additive and subsequently modified (0.0; 0.2; 0,5; 1.0; 3.0)% collagen No.1 prepared from pig skin.

Modification of urea-formaldehyde adhesives was also solved by preparation and application of four samples of keratin, which were prepared from crushed horn by its thermal degradation at temperatures from 150°C to 197°C for one hour. The samples were characterized by XPS and FTIR-ATR spectroscopy and technical applications were fo-

cused on their application to urea-formaldehyde (UF) resins in order to reduce formaldehyde emissions from glued wood-based boards while maintaining the quality of the glued joint. Formaldehyde emission was tested according EN ISO 12460-4 and bonding quality according to standards EN 314-1 and EN 314-2.

Description and labelling of prepared samples No:

1. Keratin K-1 (a) – prepared by thermal degradation for 1 hour at 150°C,
2. Keratin K-2 (b) – prepared by thermal degradation for 1 hour at 170°C,
3. Keratin K-3 (c) – prepared by thermal degradation for 1 hour at 190°C,
4. Keratin K-4 (d) – prepared by thermal degradation for 1 hour at 197°C.

After modification, the samples were crushed in a ball mill, homogenized by sieving, and their chemical composition was determined by X-ray photoelectron spectroscopy and FTIR-ATR spectroscopy. Adhesive mixtures for modification UF resin were prepared according to following scheme:

0: 100% UF adhesive – KRONORES CB 1639F + 20% technical flour + 5% DAM 390 hardener – Reference,

1–5: 100% UF adhesive – KRONORES CB 1639F + 19.5% technical flour + 0.5% – Keratins (K-1(a) K-2(b) K-3(c) K-4(d)), modifications by thermal degradation at (150; 170; 190; 197)°C + 5% DAM 390,

6-10: 100% UF adhesive + 19.0% technical flour + 1.0% – Keratins (K-1(a) K-2(b) K-3(c)

K-4(d)), modifications by thermal degradation at (150; 170; 190; 197) °C + 5% DAM 390,

11-12: 100% UF adhesive + 17.0% technical flour + 3.0% – Keratins (K-1(a) K-2(b) K-3(c)

K-4(d)), modifications by thermal degradation at (150; 170; 190; 197)°C + 5% DAM 390.

MEASUREMENTS METHODS

X-Ray photoelectron spectroscopy

XPS signals were recorded following a previously described procedure using a Thermo Scientific K-Alpha XPS system (Thermo Fisher Scientific, UK) equipped with a micro-focused, monochromatic Al Kα X-ray source (1486.6 eV). An X-ray beam of 400 μm size was used at 6 mA×12 kV. The spectra were acquired in the constant analyser energy mode with pass energy of 200 eV for the survey. Narrow regions were collected using the snapshot acquisition mode (150 eV pass energy), enabling rapid collection of data (5 s per region). A version 5.988 of the *Thermo Scientific Avantage* software was used for the data acquisition and processing. Spectral calibration was determined using the automated calibration routine with the use of internal standards of Au, Ag and Cu provided with the K-Alpha system.

ATR-FTIR spectroscopy measurements

FTIR-ATR (Fourier Transform Infrared Attenuated Total Reflectance Spectroscopy) was used to investigate the surface chemical composition. Spectra were recorded on a NICOLET 8700™ by ThermoScientific instrument (Madison, WI, USA) in the middle infrared region in transmission mode. KBr pellet technique was used to expand the examined spectral region bellow 650 cm^{-1} circumvent the optical material used in ATR measurements (germanium crystal) limit. This process should allow detection of the sulfidic vibrations, which occur in region between 700 cm^{-1} – 500 cm^{-1}. Transparent tablets were prepared from the samples by pressing individual substances up to 2 mg into KBr.

Plywood strength testing

Quality of gluing was tested according to standards EN 314-1 and EN 314-2. Three-

layer plywood of birch (*Betula pendula*) veneer was prepared for determination of physical and mechanical properties at following conditions: pressing (laboratory hydraulic press FONTIJNE) pressure 1.8 MPa, temperature 105°C, time 5 resp. 6 min. Plywood were conditioned at the temperature of 20 ± 2°C and relative humidity 65 ± 5%. Tested pieces were pre-treated for the class 1:

- immersion in water 20°C for 24 hours,
- constant rate loading,
- disruption after 30 ± 10 seconds,
- accuracy of 1 N.

Formaldehyde emissions

Formaldehyde emissions from five-layer plywood were tested according to the test method EN ISO 12460-4 according to following conditions:

- volume of desiccator: 9–11 dm^3,
- loading coefficient: 1800 cm^2,
- temperature of 20 ± 0.5°C,
- test duration 24 h,

The concentration of formaldehyde absorbed in distilled water was evaluated by acetyl-acetone method with spectrophotometric evaluation using the ultraviolet spectrophotometer UviLine SI 5000 at 412 nm wavelength.

RESULTS AND DISCUSSION

Influence testing of samples of UF adhesive mixtures with collagen No. 1 and its modifications with concentrations (0.0, 0.2, 0.5, 1.0, 3.0%) calculated on the weight of the adhesive for the life of the adhesive mixtures is described in Tab. 2.

Table 2: Influence of samples No. 1,2,3 for the lifetime of UF adhesive mixtures at room temperature

Sample No.	Life of the adhesive mixture at 20 ° C
0 – Reference	> 1 week
1	> 1 week
2	> 1 week
3	> 1 week

All adhesive mixtures have a comparable service life to the reference UF adhesive sample.

Results of measurements of the effect of the amount of collagen No. 1 and its modification to the condensation time of the UF adhesive mixture are shown graphically in Fig. 1. The condensation time determined in a test tube at a temperature of 100° C was calculated from an average of 5 measurements.

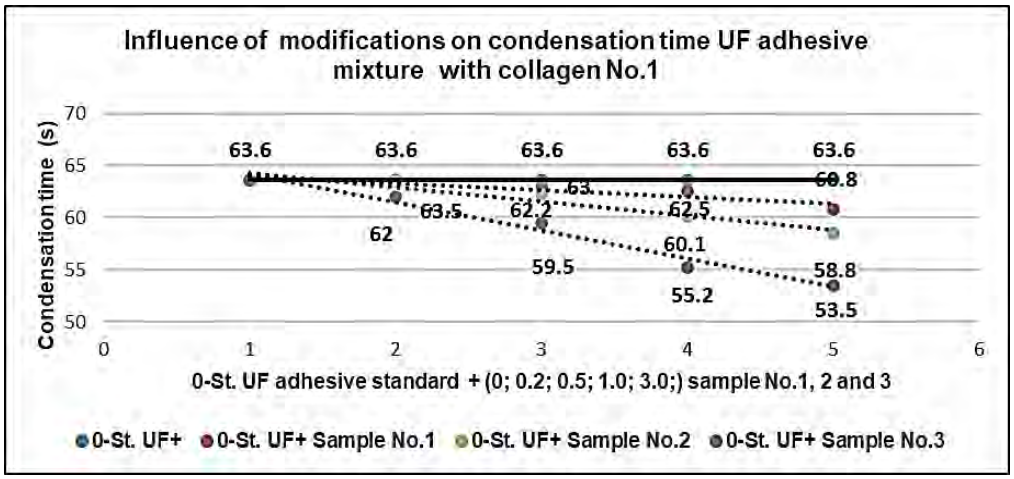


Figure 1: Influence of samples No. 1, 2, 3 for the condensation time of UF adhesive mixtures

The measured data show that the condensation time of UF adhesives is affected by the modification and concentration of collagen No.1 in the adhesive mixture. Sample No. 3 collagen No. 1 modified with hardener RODA M and sulphur additive most significantly accelerates the condensation time, while this effect increases with its increasing concentration from the value of the reference sample 63.6 to 53.5 s.

Testing the effect of collagen No.1 and its modifications on formaldehyde emissions of UF adhesive mixtures: UF adhesive KRFORES CB 1639F and its modifications were condensed at 90°C for 45 minutes. The results of measurements of the effect of UF adhesive modifications on the free formaldehyde content in% are shown graphically in Fig. 2.

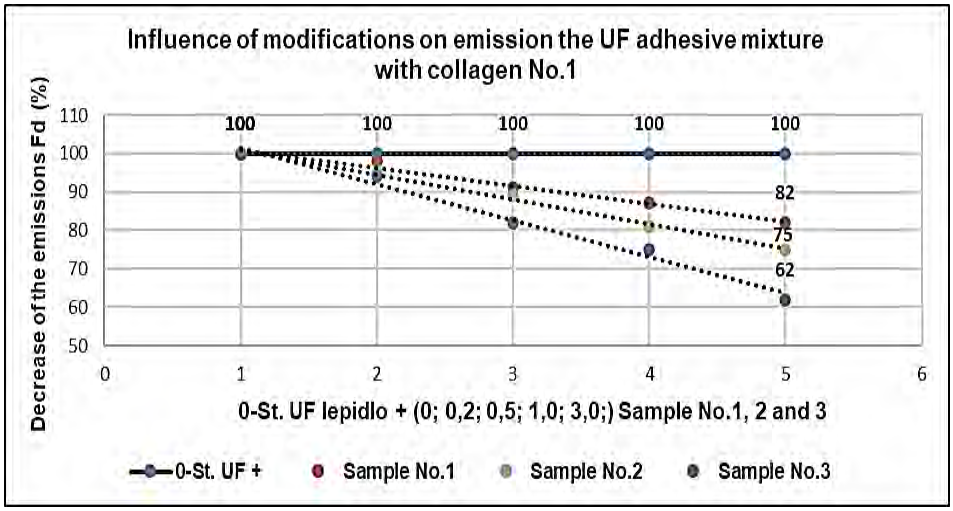


Figure 2: Impact of samples No. 1, 2 and 3 on formaldehyde emissions of UF adhesive

The measured values show that collagen and its modifications are suitable for reducing formaldehyde emissions in cured UF adhesive mixtures. Sample No. 3 modified with hardener RODA M 20 and sulphur additive most significantly reduces formaldehyde emissions, while this effect increases with its increasing concentration. Formaldehyde emissions were tested by the desiccator method according to EN ISO 12460-4, while a reduction in emissions of 38% was achieved by comparison with a reference sample – (0- St. UF adhesive KRONORES CB 1639F + 20% technical flour + 5% DAM 390).

Testing the effect of collagen No.1 and its modifications on the viscosity of UF adhesive mixtures: The results of the measurements of the effect of the modifications of the UF adhesive on the viscosity of the UF adhesive mixture are shown graphically in Fig. 3.

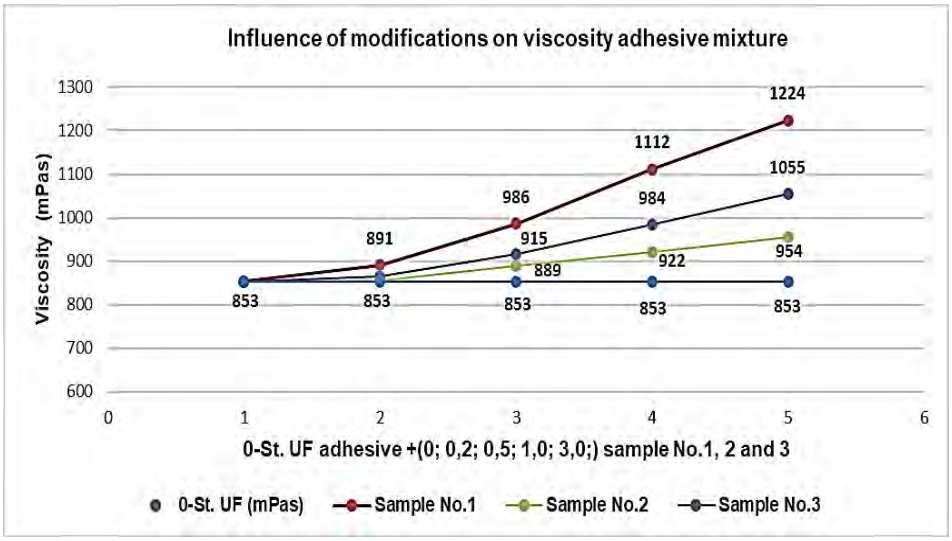


Figure 3: Influence of collagen modifications on the viscosity of UF adhesive mixtures

The measured values indicate that collagen is a suitable modifier to adjust the viscosity. Collagen No. 1 prepared from pork skins further unmodified most significantly increases the viscosity of the UF adhesive composition, this effect increasing with its increasing concentration from the value of the reference sample 853 [mPa.s] to 1224 [mPa.s] at its 3% concentration. The measured values show that collagen and its modifications are suitable. UF adhesive viscosity modifiers are suitable

X-Ray photoelectron spectroscopy (XPS) was used for qualitative and quantitative determination of basic elements prepared samples of biopolymers keratin and the results are summarized as follows: overall carbon (C1s signal at ~ 285 eV), oxygen (O1s signal at ~ 532 eV), nitrogen (N1s signal at ~ 400 eV), natrium (Na1s signal at ~ 1072 eV), chlorine (Cl2p signal at ~ 198 eV), and sulphur as C–S (S2p signal at ~ 163 eV) and SO3 (S2p signal at ~ 168 eV). Analysis of sample surfaces determined by X-Ray photoelectron spectroscopy can be seen on the Tab. 3.

Table 3: Apparent surface chemical composition samples of keratin as determined by XPS

Surface chemical composition of samples prepared from keratin [%]						
Sample No.	C1s	O1s	N1s	S2p	Sulphide (C-S)	Oxide (SO_2)
K-1 [(a)]	65.1	20.7	11.5	1.2	54.6	44.5
K-2 [(b)]	66.5	19.3	11.7	1.2	61.3	38.7
K 3 [(c)]	68.0	17.2	12.1	1.3	67.6	32.4
K-4 [(d)]	69.7	13.4	14.1	1.4	76.2	23.8

The differences between the spectra of prepared samples are visible mainly in the amount of sulphur and in the ratio of the reduced state C-S (signal S2p at -163 eV) and the oxidized state SO2 (signal S2p at 168 eV).

Analyses have confirmed that the XPS spectrum of keratin samples depends on the temperature of their thermal degradation, with the total amount of carbon, nitrogen and sulphur increasing with increasing temperature. In the case of sulphur, the total amount of its reduced form, expressed as sulphide, also increases, while the total amount of oxygen decreases with increasing temperature.

Examination of the surface chemical composition of thermally treated samples of keratin powders prepared from crushed horn was further characterized by the FTIRTM Spectrometer NICOLET is shown in Tab. 4. and graphically shown in Fig. 4.

Table 4: Comparison of positions of maximum wavelengths for the area of valence vibrations

Sample	-CO-NH	-CH	Amide I	Amide II	Oxides (SO_2)	Sulfide (SH)	di-Sulfide (SH)
Keratin-1[(a)]	3316	2960	1654	1514	1169	866	605
Keratin-2[(b)]	3391	2960	1652	1516	1079	859	562
Keratin-3[(c)]	3302	2960	1654	1516	1170	858	699/613
Keratin-4[(d)]	3302	2960	1656	1518	1170	854	611

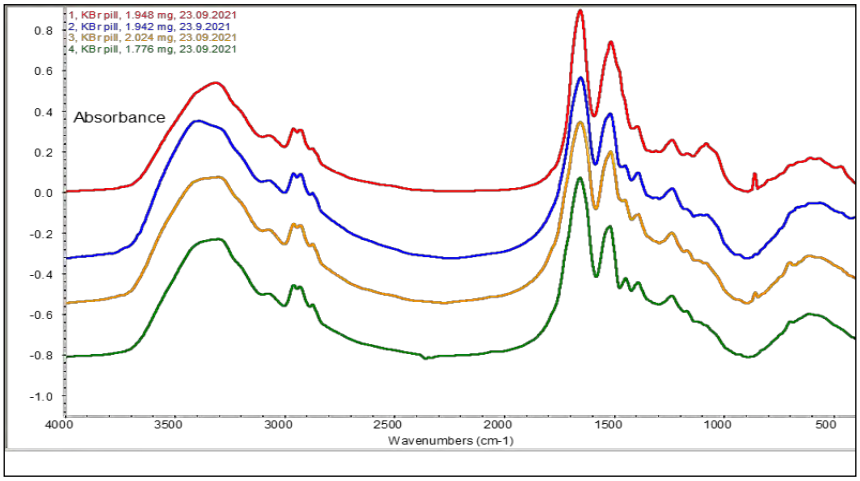


Figure 4: FTIR-ATR spectra samples of various temperature-treated crushed horns

The band approximately with a maximum at 1170 cm^{-1} is characteristic for sulphur oxides (SO_2) stretch vibration.

The band in the spectral range of 500–700 cm^{-1}can be assigned to the alkyl- and dialkyl sulphide (C-S) stretch vibrations.

Keratin samples No. K-1 (a) K-2 (b) K 3 (c) K-4 (d) were tested to determine their influence on release of formaldehyde and quality of gluing from wood-based panel bonded with UF resins. Results evaluation of the influence of modifications on the release formaldehyde and shear strength of the plywood test pieces are shown in Figs. 5 and 6.

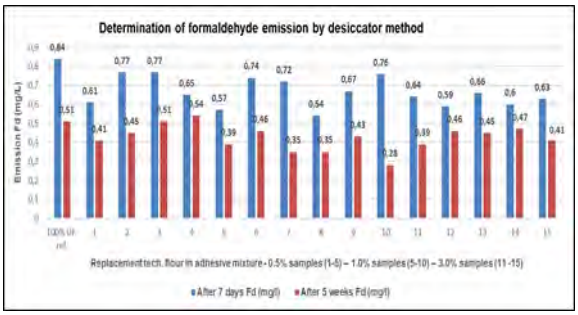


Figure 5: Results of formaldehyde emission by desiccator method [mg/L]

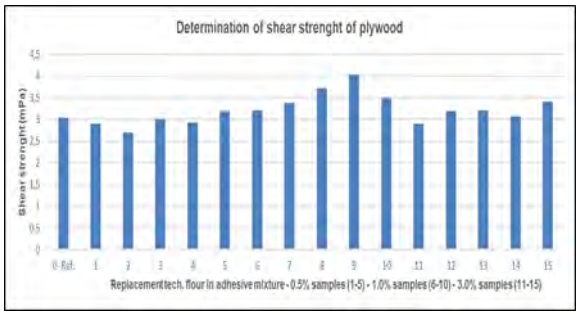


Figure 6: Shear strength of the plywood [MPa]

The measured values of formaldehyde emissions of the tested samples of UF adhesive mixtures are graphically shown in the figure and confirmed the decrease of formaldehyde emissions for all keratin additives compared to the reference one. The most significant reduction in formaldehyde emissions of up to 35% determined after 7 days was achieved with the modification of sample No. 8 – prepared by application of 1.0% concentration (keratin modified at 180°C for 1 hour). The most significant reduction in formaldehyde emissions of up to 45% determined after 5 weeks was achieved with the modification of sample No.10 – prepared by applying a 1.0% concentration of keratin (modified at 197°C for 1 hour).

Bonding quality was tested according to bonding class 1. The highest shear strength of 4.0 MPa was achieved in sample No. 9 – prepared by applying 1.0% concentration (keratin modified at 190°C for 1 hour).

CONCLUSIONS

Modern research and development in the field of wood polycondensation adhesives is aimed at finding new materials and technologies, or at targeted modifications of existing technologies. The stability of amino plastic adhesives and the problem of toxicity of UF adhesives have been addressed by the addition of biopolymers that bind the released formaldehyde or form more stable methylene bonds more resistant to back hydrolysis of the adhesive, thus achieving reduced formaldehyde emissions. The aim of this study was focused on the biopolymer collagen and keratin. Testing the effect of collagen – type 1, prepared from pig skin and its subsequent modifications to the service life, condensation time, formaldehyde emissions and viscosity of UF adhesive compositions have confirmed that collagen is a suitable modifier of these properties of UF adhesive compositions.

The measured values of formaldehyde emissions of the tested samples of UF adhesives confirmed the decrease of formaldehyde emissions for all keratin additives compared to the reference sample. Bonding quality was tested according to bonding class 1. The European standard EN 314-2 requires a value of the shear strength of the glued joint of 1.0 MPa and all prepared samples far exceed this required minimum. The tested plywood boards were suitable for gluing class 1 – use in a normal indoor environment.

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POSSIBILITIES OF DETERMINING THE CHARACTERISTICS OF WOODCHIPS USING IMAGE ANALYSIS IN THE MATLAB PROGRAM

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ABSTRACT

This article deals about the possibilities of obtaining information from a sawdust sample using the Matlab program. Using sawdust analyzing during chip machining, it makes it possible to determine unsuitable conditions by cutting and woodworking, such as dulling of the tool, unsuitable cutting conditions, overheating of the tool and others. Such conditions can have negative effects on the operation and economics of the company.

Commonly used sawdust sizing methods, such as sieving, obtain only partial information about a given sample. On the other hand, by means of image analysis of a sawdust sample, it is possible to find out much more, for example the largest and smallest dimension of each single particle, its circularity, area, perimeter, eccentricity, convex hull major and minor axis length, or color of the particle. For some other particle analysis methods, it is not appropriate to repeat the experiment with the same sample, because it may occur damage of the sample during the measurement. This can happen during sieving, where the sample is mechanically stressed and can crumble. In the image analysis, the sawdust is scattered on the substrate and a digital image of these sawdust is create. Therefore, there is no mechanical damage on the sample.

Key words: sawdust, image analysis, dimensions measurement, Matlab.

INTRODUCTION

The development of industry and the economy puts pressure on the speed of production of products and goods. In addition to the advantages, this trend also has many negative aspects, for example, excessive production of waste material that can be largely recycled. Waste in the form of chips is also generated during the production of semi-finished products. It is mainly sawdust and dust that must be removed so that they do not affect the production process and the operators.

The size of the generated sawdust and dust can tell different information about the production process, as well as about the safety of work in a dust-polluted environment. Nowadays woodworking with CNC technologies is an integral part of thewoodworking industry. The range of used CNC machines is very wide in the so-called CNC-machining centers (Korčok et al. 2018, Kos et al. 2004). Even with these modern computercontrolled machines, we cannot avoid the problem of removing secondary material, whicharises during machining – chip (Kučerka, 2022).

Evaluates the carcinogenic risk to humans posed by occupational exposures to wood dust and formaldehyde. A number of occupational situations that involve exposure to wood dust also entail exposure to formaldehyde, as in plywood and particle board manufacture, during furniture and cabinetmaking, and during parquet floor sanding and varnishing. The highest occupational exposures were noted to occur in wood furniture and cabinet manufacture, especially during machine sanding and similar operations, in the finishing departments of plywood and particle-board mills, and in the workroom air

of sawmills and planer mills near chippers, saws, and planers. Citing findings from several recent well-designed case-control studies, the monograph concludes that occupational exposure to wood dust is causally related to adenocarcinoma of the nasal cavities and paranasal sinuses (International Agency for Research on Cancer, 1995).

The aim of the article is the design and testing of an optical method for the analysis of fractional particles produced during chip woodworking.

MATERIALS AND METHODS

The measurement of dimensions was performed on a milled birch lumber (Figure 1). This samples were milled on a lower spindle milling machine FVS(Czechoslovakia Music Instruments, Hradec Králové, Czech Republic) and feedingmechanism ZMD 252/137 (Frommia, Fellbach, Germany) at the Technical University in Zvolen.

Subsequently, the sawdust was photographed using a Nikon D550 camera (Koleda, 2021).



Figure 1: Sample of Birch wood chips

This image is subsequently processed in the proposed program in Matlab (Figure 2).

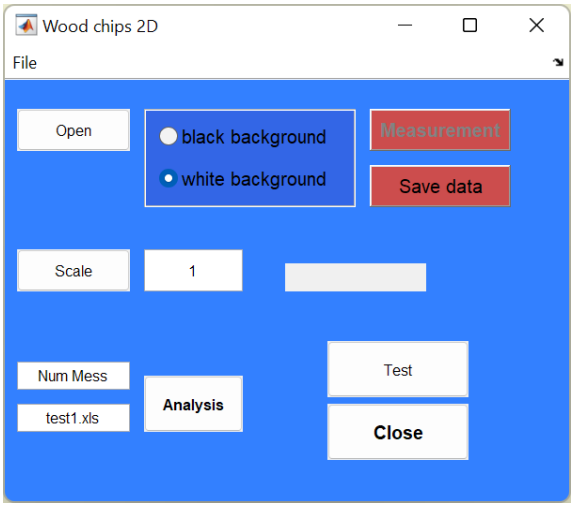


Figure 2: Created program in matlab

This program allows you to open processed images with sawdust. Before analyzing the images, it is necessary to determine the conversion coefficient for converting pixels to the metric system (milimeters). This is

determined by taking a single image containing a known distance – 100 mm on the ruler (Figure 3).

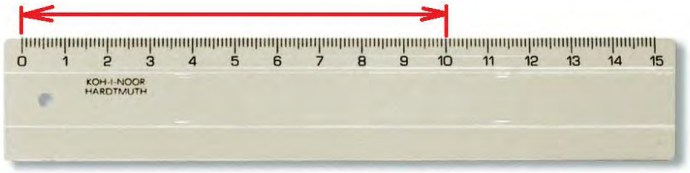


Figura 3: Determining the conversion factor to metric dimensions

In this image are selected by clicking 2 points that are 100 mm apart. The program determines how many pixels represent this distance, which determines the conversion coefficient for measuring dimensions in mm.

Subsequently, the analyzed image is opened, in which it is necessary to select the background color of the sawdust, whether there are light sawdust on a black background, or dark sawdust on a white background. These combinations are suitable for the contrast between the searched sawdust and the background, so that they can be easily identified. In the case of a background with a similar color to the searched objects, particles may be incorrectly assigned to the background, or false objects may be created.
For next analysis, this image is converted into binary form using a function:

$$im2bw(I, \text{graythresh}(I)) \quad \textbf{(1)}$$

I – a variable representing the loaded image.

Function *im2bw* converts the input image to a binary form in which the pixels belonging to the sawdust have the value 1 (white), the other pixels have a value 0 (black). The decision level for this transfer is calculated using a function *graythresh*(*I*). This computes a global threshold T from grayscale image I, using Otsu's method. Otsu's method chooses a threshold that minimizes the intraclass variance of the thresholded black and white pixels (Otsu, 1979). The result of binarization is shown in the figure 4.



Figure 4: Binarized picture

During this binarization may be fictitious holes created, due to the structure of the sawdust. These are subsequently removed using the function:

$$imfill(BW,'holes') \quad \textbf{(2)}$$

BW – input binary image, *'holes'* – parameter of the *imfill* function.

Function *imfill(BW,'holes')* fills holes in the input binary image *BW*. Using parameter *'holes'* are removed only holes in objects (Figure 5). Hole is a set of background pixels that cannot be reached by filling in the background from the edge of the image.

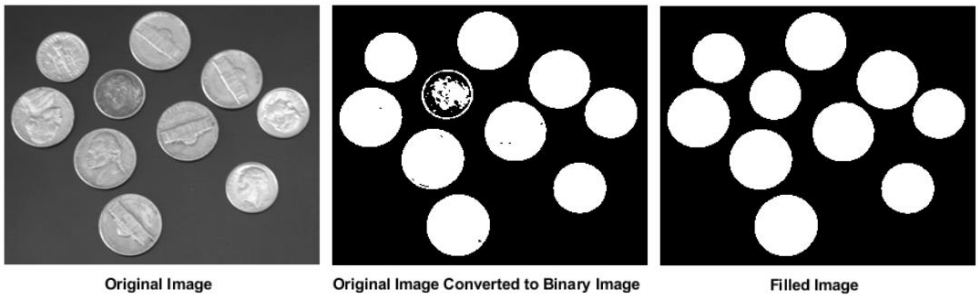


Figure 5: Removing holes in objects

In the thus modified binary image, the dimensional characteristics of the sawdust are subsequently detected by pressing the „Measurement“ button.

It is possible to determine the dimensional parameters of the sawdust in the digital image modified in this way. In Matlab program were to determine sawdust parameters used functions

$$\begin{matrix} regionprops(BW,properties) \\ bwferet(BW,properties) \end{matrix} \quad \textbf{(3)}$$

BW – input binary image,

properties – specified required calculated properties.

Using *regionprops* function are calculated the required characteristics of the found objects – sawdust. The list of these characteristics is specified as *Properties* in the function *regionprops*. To dimensions measure of the sawdust, the following were determined: Area, Perimeter, Centroid, Orientation, Circularity, Eccentricity and Bounding Box.

Function *bwferet* measures the Feret properties of objects in an image and returns the measurements in a table. The input properties specify the Feret properties to be measured for each object in input binary image *BW*. The measured Feret properties include the Major and Minor axis length, Feret angles, and endpoint coordinates of Feret diameters.

Area of individual sawdust is determined with a parameter *‘Area’*. This parameter counts all pixels belonging to individual sawdust in the binary image.

The Perimeter measurement of sawdust is determined using a parameter *‘Perimeter’*. Function *regionprops* computes the perimeter by calculating the distance between each adjoining pair of pixels around the border of the region.

The position of the center of sawdust is determined by a parameter *‘Centroid’*, this detects the horizontal and vertical coordinates of the position of the center of particle in the image.

The rotation of sawdust in the image is detected by a parameter *‘Orientation’*. It represents an angle between the x-axis and the major axis of the ellipse that has the same second-moments as the region, returned as a

scalar. The value is in degrees, ranging from -90 degrees to 90 degrees.

Roundness of objects, returned as a structure with parameter *'Circularity'*. The structure contains the circularity value for each object in the input image. The circularity value is computed as

$$(4*\text{Area}*\text{pi})/(\text{Perimeter}^2) \quad \textbf{(4)}$$

For a perfect circle, the circularity value is 1. The input must be a label matrix or binary image with contiguous regions.

Eccentricity of the ellipse that has the same second-moments as the region, is detected with parameter *'Eccentricity'*. The eccentricity is the ratio of the distance between the foci of the ellipse and its major axis length. The value is between 0 and 1. (0 and 1 are degenerate cases. An ellipse whose eccentricity is 0 is actually a circle, while an ellipse whose eccentricity is 1 is a line segment).

Position and size of the smallest box containing the region, detected with parameter *'BoundingBox'*. It's returned as a 1-by-(2*Q) vector. The first Q elements are the coordinates of the minimum corner of the box. The second Q elements are the size of the box along each dimension. For example, a 2-D bounding box with value [5.5 8.5 11 14] indicates that the (x,y) coordinate of the top-left corner of the box is (5.5, 8.5), the horizontal width of the box is 11 pixels, and the vertical height of the box is 14 pixels.

The largest and smallest dimensions of each sawdust are determined using parameters *'MajorAxisLength'* and *'MinorAxisLength'*.

RESULTS

The determined dimensional sawdust parameters are stored in an Excel table for further processing. Some of them can be graphically represented in a modified binary image with sawdust (Figure 6): bounding box (blue rectangles), major axis length and minor axis length (blue lines with displayed length), orientation (red ellipse), and position of sawdust center (green star).

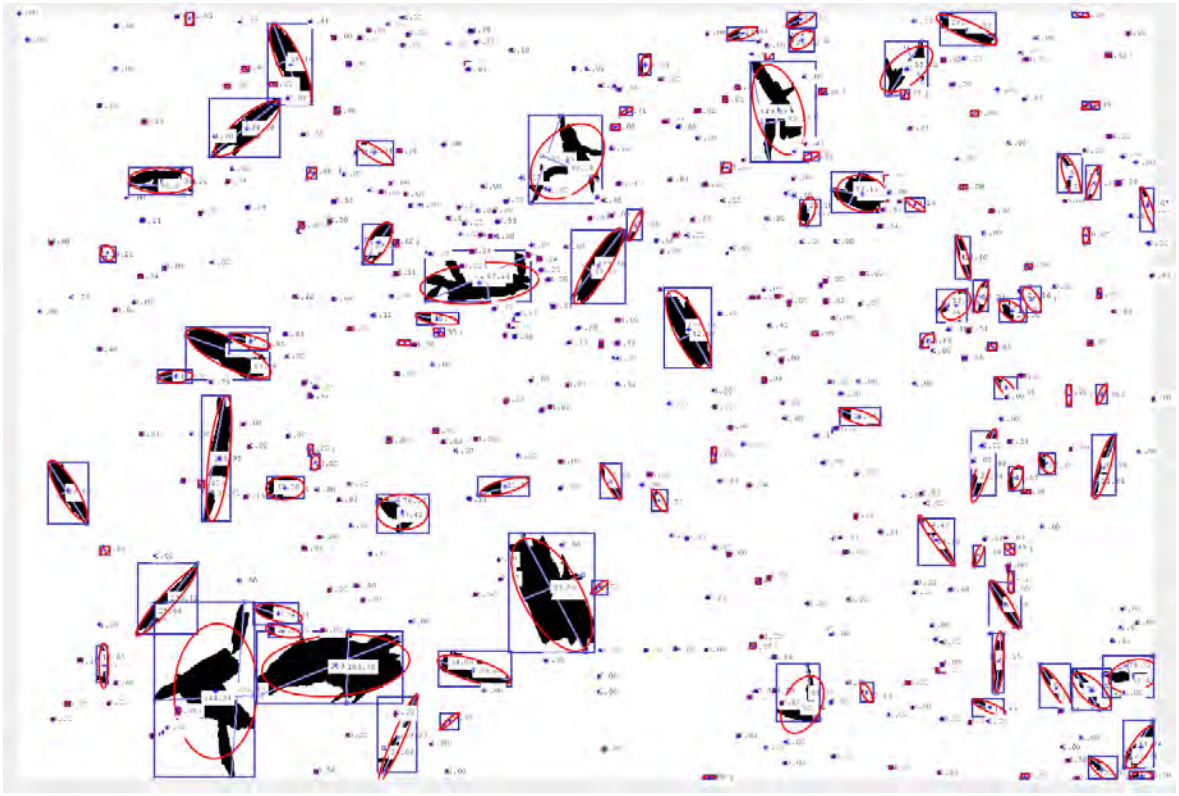


Figure 6: Graphic representation of the detected sawdust

Multiple images with analyzed sawdust can be processed for one measurement. If multiple images are being processed, after the measurement, the next image is simply opened and the next measurement is started in the same way. After the last analyzed image, all measured data are saved in an Excel table by pressing the "Save data" button in the program. Data stored in table can be further processed, for example, in statistical software. Some analyzes such as histogram, ANOVA and others, can also be run in the designed application using a button "*Analysis*". The obtained histograms from the test image are shown in the Figure 7.

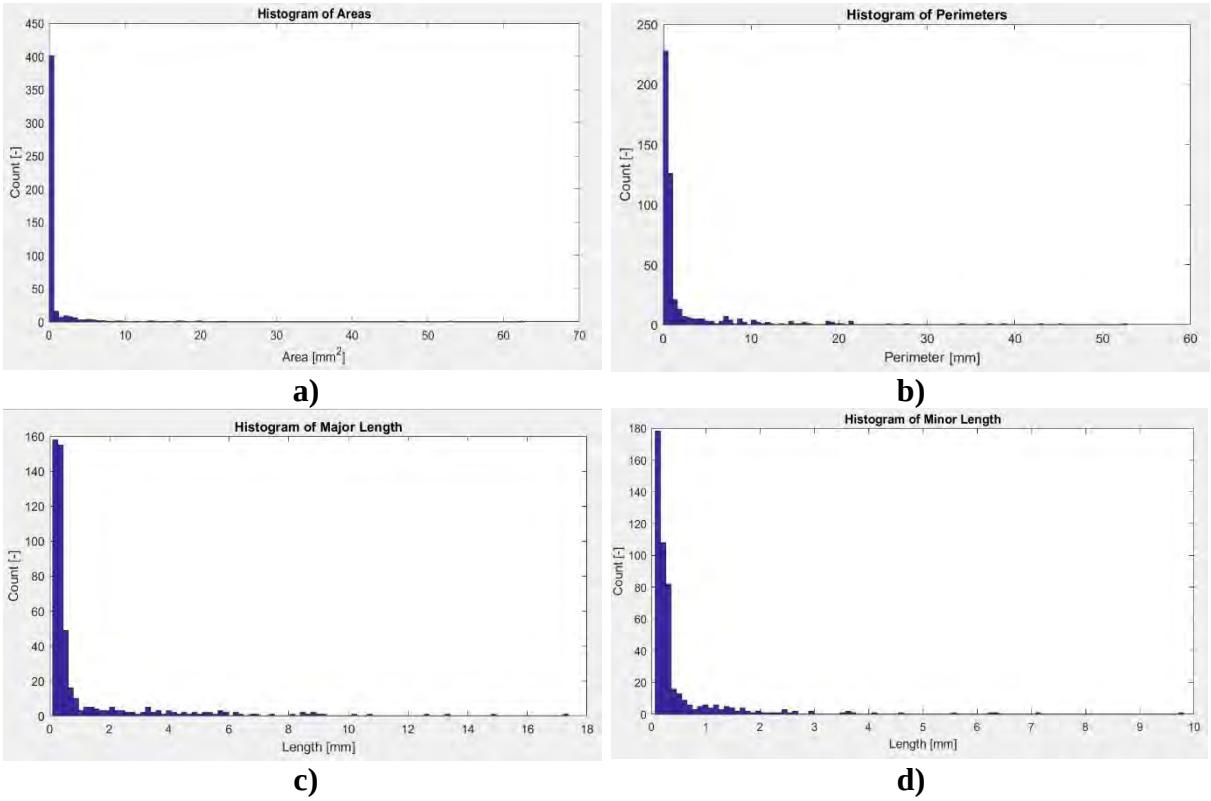


Figure 7: Histograms: a) Areas, b) Perimeters, c) Major Length, d) Minor Length

CONCLUSION

As described in this article, detailed information of the dimensional characteristics of sawdust can be obtained using image analysis in Matlab. Compared to other methods, such as sieving, this method is non-destructive. However, the disadvantage is the need to separate the scanned sawdust from each other, otherwise they may overlap together. Such overlapped sawdust is subsequently evaluated as a one separate sawdust, what introduces error into the measurement. In addition to the obtained information in tabular form, matlab itself enables to statistical evaluation of the measured samples, for example using histograms. Also, it provides the basic knowledge on image analysis that can be implemented to maximize the executed information from the analysis and minimize the magnitude or error (Jahari, 2021).

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DEVELOPMENT OF COMPOSITE TIMBER GIRDERS

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ABSTRACT

The paper presents a research for development of composite timber girders made of residual waste sheathing boards obtained in the prefabrication process of light-frame timber building kits, to be used in prefabricated timber buildings enabling a more sustainable construction. The proposed research project solution is a composite girder constructed of solid timber frame (flanges and web stiffeners) with webs of waste boards (cement-particle and oriented strand boards) attached to the solid frame in various ways. Main motivation, design concepts and some experimental test results are presented in the paper.

Key words: composite timber girders, residual waste, oriented strand boards, cement-particle boards, conceptual design, experimental tests.

INTRODUCTION

Modern architectural design of prefabricated timber buildings increasingly comprises of wide and open spaces in the ground floors with limited supporting elements, of large wall openings and sometimes of large span cantilevers. In these cases, timber girdersare often replaced by steel girders due to large static heights and architectural boundaries. On the other hand, in prefabrication process of timber buildings, a substantial amount of residual waste is created when cutting sheathing boards for light-frame timber wall /floor/ roof panels. This material cannot be further used in the regular production structural elements.

To overcome the exposed issues in the production of prefabricated timber building kits an applicative research project entitled “Timber Composite Girders made of Residual Waste Materials Obtained in Prefabrication of Timber Houses”, conducted in collaboration of research institute (ZAG Ljubljana) and industry partner (Jelovica hiše d.o.o.), tackled the research for development of the concept of using waste sheeting boards for construction of composite timber girders, which could replace commonly used glued-laminated timber or steel girders. The basic concept of the proposed solution is a composite timber girder (Figure 1, left) constructed of solid timber flanges and webs made of waste sheathing boards which result from the manufacturing process of prefabricated timber building kits of the industry partner company, i.e. oriented strand boards (OSBs) or cement-particle boards.

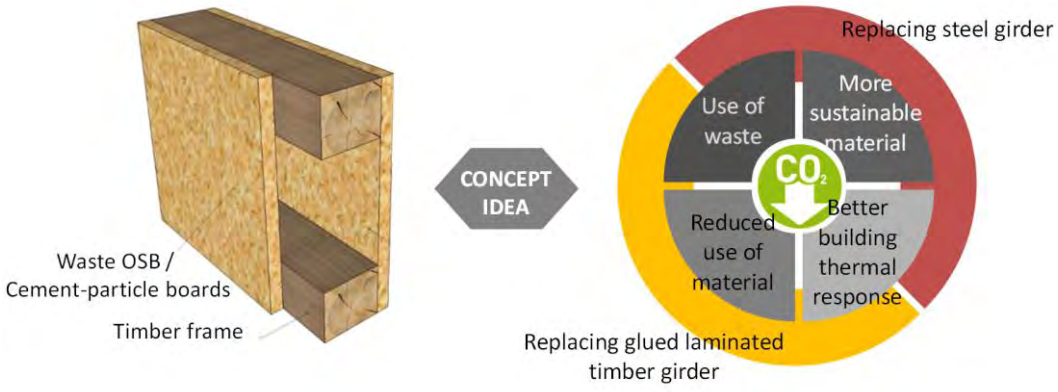


Figure 1: Design concept of composite timber girders with "box" cross section and its positive effects on the prefabricated timber buildings' sustainability

The solution of composite timber girders made of waste material will increase sustainability of prefabricated timber structures in various ways (Figure 1, right). Its main advantages over glued-laminated timber girders are lower material consumption and a greater possibility of "tailoring" their mechanical characteristics. In comparison to steel girders, besides timber being a more sustainable material, with composite timber girders the occurrence of thermal bridges is avoided, therefore also the thermal response of the building envelope is improved. The development of composite timber girders within the project considers all the basic work requirements (BWR) for construction products relevant for the intended use, with an emphasis on mechanical resistance and stability, fire safety and the sustainable use of natural resources. Furthermore, the design concept considers the limitations of the industry partner's manufacturing technology process as well as its financial aspects.

The research and development work in the project was iterative; the design of the girders was optimized by conducting experimental investigations and numerical analyses, whereas the selected solutions were properly validated on real-size composite timber girders. The paper presents a part of experimental research within the project, focused on development and mechanical performance of composite timber girders constructed with mechanical fasteners only. Industry already produces various timber composite web girders, which are however in most cases glued (many of them are patented). Another specific feature of the presented developed girders is the use of cement-particle boards for webs. This material is not commonly used in the timber prefabricated buildings and therefore performance of products based on cement-particle boards cannot be found in the literature.

THE DEVELOPED DESIGN CONCEPT WITH MATERIALS AND EXPERIMENTAL METHODS

Developed design concept of composite timber girders

The design of the composite timber girders is as already mentioned based on the materials used in the production of prefabricated timber building kits of the industry partner and manufacturing technology available. It also follows the demands for timber prefabricated buildings of the industry partner and geometrical limitations following their buildings' designs. Due to the expected improving performance in dependence of the girders' height, girders of 420 mm height were constructed and studied within the experimental

campaign. The developed design of the composite timber girders, the variations tested, and the results are presented further in the paper.

Timber frame

Two variations of the timber frame were adopted for the composite timber girders and furthermore tested. For basic variation, the timber frame consists only of timber flanges and web stiffeners, while with the other timber frame variation the diagonals were added to increase the stiffness of the girders. All timber frame members of the tested girders (flanges, web stiffeners and in some girder variations diagonals) were constructed of 140/80 mm solid glued laminated "duo" beams of strength class GL 24h. The web stiffeners in the timber frame are in both timber frame variations arranged at 625 mm, which is also a module in the manufacture of light-frame timber panels, the distance between the end stiffeners is adjusted to the length of the girder. In variations with diagonals, the diagonals were oriented in compression direction (Figure 2) and were therefore only inserted in the timber frame (without mechanical fixing).

The dimensions (length / height) of the tested girders were 5660/420 mm, with width differing in dependence of the type of boards; 172 mm or 184 mm for cement-particle boards or OSBs, respectively.

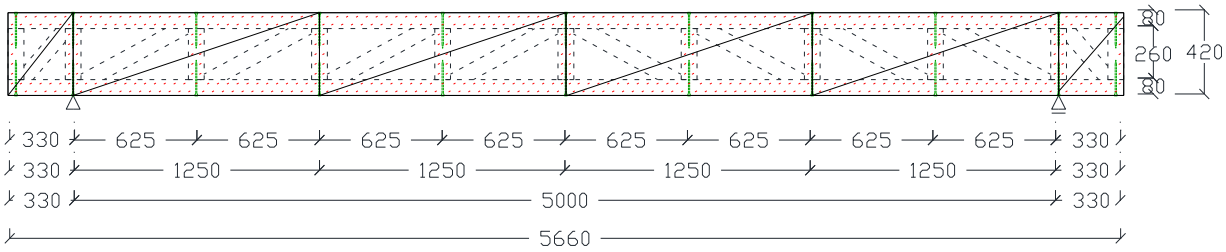


Figure 2: Composition and geometry of the tested girder (with diagonals)

Webs (wood-particle boards)

Composite timber girders were constructed with one of two types of waste boards: cement-particle boards (Figure 3, left) or OSBs (Figure 3, right). The mechanical characteristics of cement-particle boards in the plane of the board, specified in the technical data sheets of the manufacturer, are as follows: flexural strength $f_{m,k}$ = 9.0 MPa, tensile strength $f_{t,k}$ = 2.5 MPa, compressive strength $f_{c,k}$ = 11.5 MPa, modulus of elasticity $E_{m,mean}$ = 4500 MPa; of OSBs (in the plane of the board) are as follows: flexural strength $f_{m,k}$ = 14.8 MPa, tensile strength $f_{t,k}$ = 7.4 MPa, compressive strength $f_{c,k}$ = 14.8 MPa, modulus of elasticity $E_{m,mean}$ = 3800 MPa.

The length of the boards used for the composite timber girders webs was 1250 mm, which is the nominal width of the wood-particle boards and thus a common length of waste board pieces. The thickness of cement-particle boards was 16 mm, and of OSBs 22 mm. The wood-particle boards were in the girder attached to both sides of the timber frame (“box” cross section).



Figure 3: Composite timber girder with cement-particle boards fastened to timber frame by metal staples (left) and with OSBs fastened to timber frame by nails (right)

Boards-to-timber-frame connection

The cement-particle boards were fastened to the timber frame with 2.0 x 11.76 x 50 mm staples, while the OSBs with 2.5 x 65 mm nails. To study the behaviour of the cement-particle-boards-to-timber connections by staples, preliminary experimental tests of connections were conducted (Kržan et al., 2020). Both types of boards were along its perimeter attached to the frame by mechanical fasteners at 50 mm longitudinal spacing (Figure 3). This distance has in preceding tests of sheathing-to-timber connections proven to be suitable for the cement-particle boards despite the higher distance recommendations by the board manufacturers. The characteristic tensile strength of galvanized steel for staples is $f_{u,\,k}$ = 800 MPa, and of nails $f_{u,\,k}$ = 600 MPa. For the staples, a layer of thermo-adhesive is applied on the legs to increase the fastening.

Timber-flange-to-web-stiffener joint

Preliminary numerical studies have shown a higher load-bearing capacity of the girders if shear force transfer is not enabled only through board-to-timber staple connections. Thus, in the basic girder variations (timber frame with no diagonals), web stiffeners are fixed to the flanges with three screws on each side (partially threaded screw TG 8 x 180 mm in the middle and two fully threaded screws (VG) 7 x 180 mm at the side; Figure 4, labelled Joint 1).

For girders with diagonals, the web-stiffeners-to-flange joint was changed to TG 8 x 180 mm screw in the middle and two VG 7 x 220 mm screws at side inserted at an angle of approximately 10° to the web stiffener longitudinal axis to increase the withdrawal capacity of the screw connections and enable higher tensile forces in stiffeners (Figure 4, labelled Joint 2). One variation of the girder with diagonals but with weaker web-stiffeners-to-flange joints (without inclined screws, Joint 1) was also tested to experimentally evaluate the influence of the joint (Specimen 1.5 in in Table 1).

Table 1).

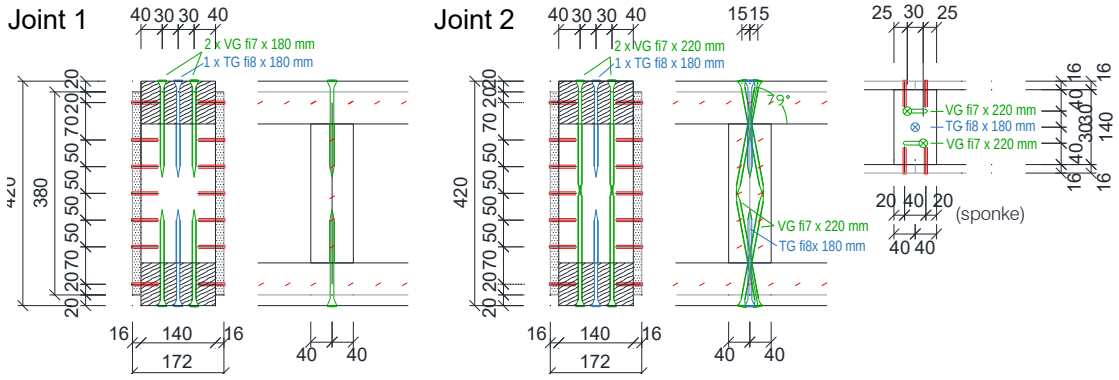


Figure 4: Web-stiffener-to-flange joints; Joint 1 – without inclined screws (left), and Joint 2 – with inclined screws (right)

Experimental bending tests of the developed girders

The developed girders were tested for bending behaviour. The characteristics of the individual tested variations are summarized in Table 1.

For each variation, three girders were constructed and tested. For comparison, timber frame with diagonals and no webs was tested too.

Table 1: Different variations of girders experimentally tested

Specimen	Diagonals in Timber frame	Type of boards	Mechanical fasteners	Timber flange-to-web-stiffener joint
1.1-V1-CPB	/	Cement-particle	Metal staples	Joint 1
1.3-V2D-CPB	Yes	Cement-particle	Metal staples	Joint 2
1.5-V1D-CPB	Yes	Cement-particle	Metal staples	Joint 1
2.1-V1-OSB	/	OSB	Nails	Joint 1
2.3-V2D-OSB	Yes	OSB	Nails	Joint 2
0.1-V1D	Yes	/	/	Joint 2

As no standard for the type of girders under investigation exists, the experimental tests were based on standards for similar structural elements, namely EN 13377:2002 (Prefabricated timber formwork beams – Requirements, classification and assessment (CEN, 2002)), SIST EN408: 2010+A1:2012 (Timber structures – Structural timber and glued laminated timber – Determination of some physical and mechanical properties (CEN, 2010)) and SIST EN 595:1995 (Timber structures – Test methods – Test of trusses for the determination of strength and deformation behaviour (CEN, 1995)).

The girders were supported at a distance l_0 = 5000 mm between the supports. They were laterally supported in two positions – the test setup is presented in Figure 5. Overhang length of the girder equals 330 mm and it is higher than the length defined in standard SIST EN 13377:2002 equal to half of the module (distance between web stiffeners in lattice girders). The girders were loaded with distributed load introduced in 8 points at a distance of l_0 / 8 in accordance with SIST EN 13377:2002. The loading protocol for the bending test had several phases: – Phase 1 – loading in the elastic range (loading, 30 min constant load, unloading); – Phase 2 – constant load for creep analysis conducted for one of the three test specimens of each variation (loading, 18h constant load, unloading); – Phase 3 – loading to failure.

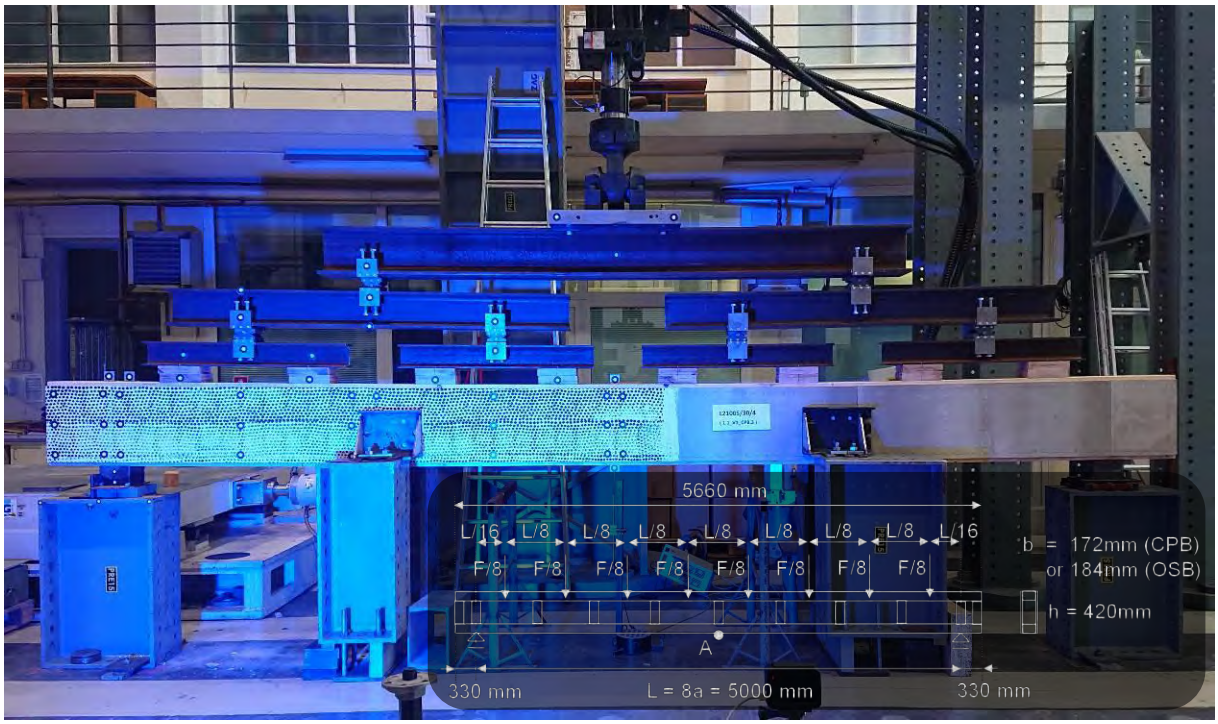


Figure 5: Test setup for bending test of girders

Vertical displacements in the middle of the girder (in the upper and bottom flange) were measured with LVDT. Additional discrete points (seen in Figure 5 as black and white dots) were measured with GOM optical measuring system. In addition, the girders had on about half of the length pained boards' surface or, in the case of girders with no web, timber frame (Figure 5), which allowed monitoring the deformations in the painted area.

RESULTS AND DISCUSSION

The performance of girders under bending load differed in dependence of the girders' design. For girders with cement-particle boards, several cracks in the tensile area of the boards occurred, which resulted in lower load-bearing capacity compared to girders with OSB beams, where the tensile-bending timber failure of the bottom flange occurred without cracks in sheathing boards. Figure 6 shows the GOM-measured deformations before failure (above) and damage at failure (below) of the girder with cement-particle boards and no diagonals, while Figure 7 of the girder with OSBs and no diagonals, respectively.

In quite a few tests (i.e. 5), the timber failure of the bottom flange occurred at finger joint, mostly in the lower lamella of the glued "duo" laminated timber flange.

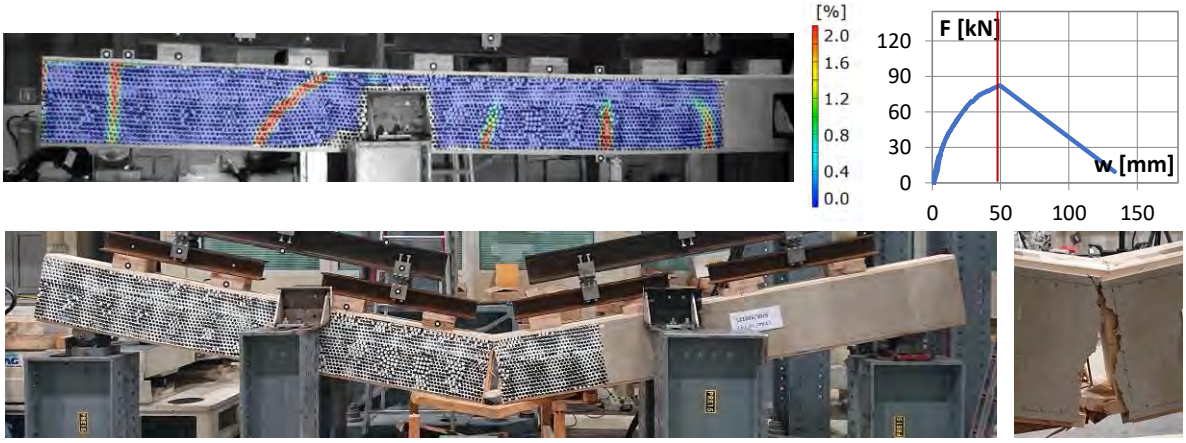


Figure 6: Measured deformations before failure with corresponding vertical force – vertical displacement diagram (above) and damage after failure (below) of the girder with cement-particle boards sheathing and no diagonals

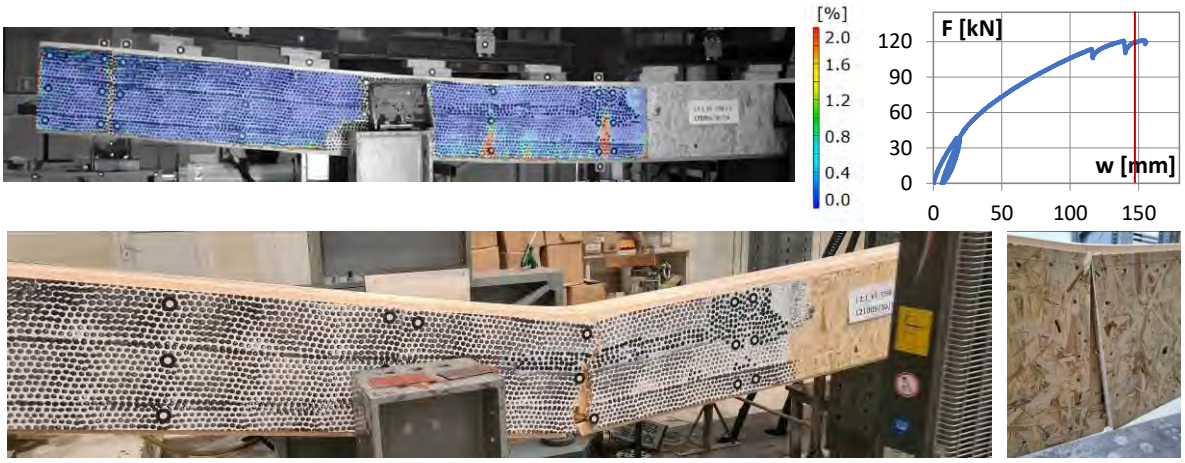


Figure 7: Measured deformations before failure with corresponding vertical force – vertical displacement diagram (above) and damage after failure (below) of the girder with OSBs sheathing and no diagonals

The vertical force – vertical displacement (in the middle of the girder) diagrams in Figure 8 show the influence of the type of boards for the web and the timber frame design on the load-bearing capacity and stiffness. The average values of the most important results, i.e. the maximum force achieved and the corresponding vertical displacement in the middle of the girder (F_{max} and d_{Fmax}) and the elastic stiffness, determined as secant stiffness between 10% and 40% of the bending capacity ($K_{10\text{-}40}$), are for the tested girder variations compared in Figure 9.

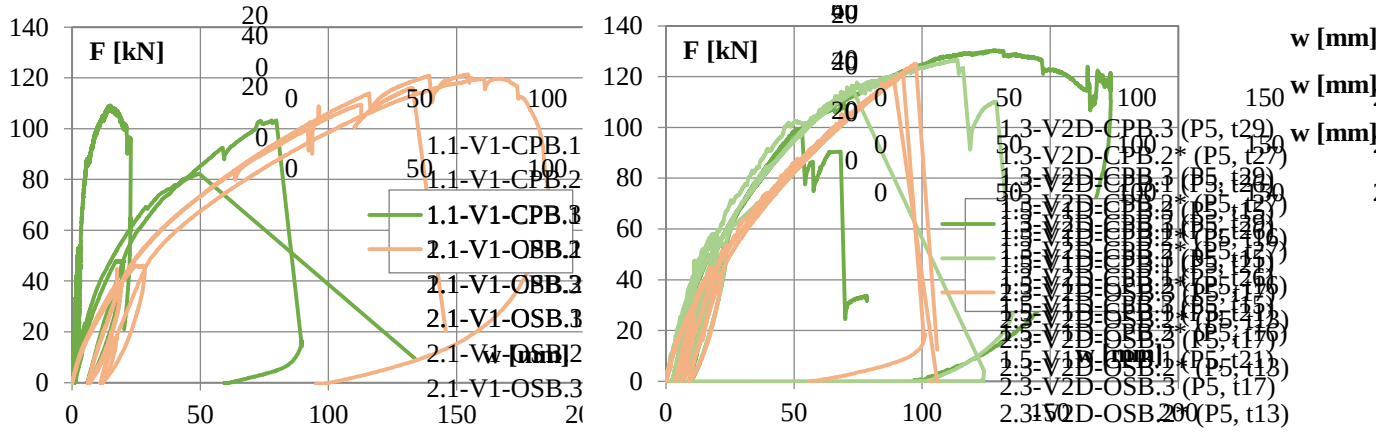


Figure 8: The vertical force – vertical displacement (in the middle of the girder) diagrams of the tested girders; girders without (left) and with diagonals (right).

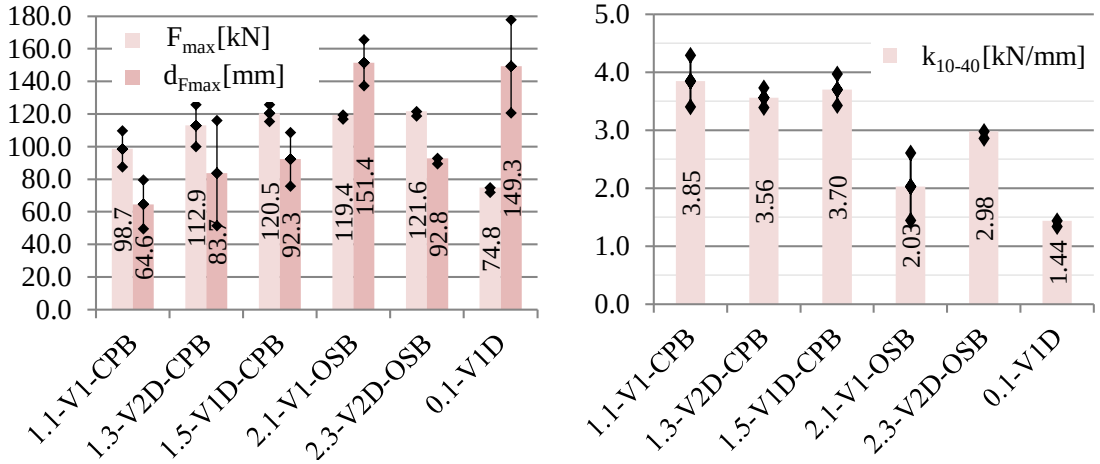


Figure 9: Average result of load-bearing capacity, ultimate displacement, and elastic stiffness for various variations of the girders

Comparisons show that girders with diagonals exhibited increased bending capacity in case of girders with cement-particle boards (girder variations 1.3 and 1.5), as the diagonals reduced the tensile stresses in the boards (compared to girder variation 1.1 at identical girder loading) and allowed cracking of the boards at higher forces and therefore bending capacity closer to that achieved in girders with OSBs (girder variations 2.1 and 2.3), where in all cases the tensile-flexural failure of the bottom flange was critical. For girders with OSBs, the average load-bearing capacities of girders with and without diagonals (girder variations 2.3 and 2.1, respectively) were similar with less than 2% difference. In the case of girders with cement-particle boards and diagonals, a higher average load-bearing capacity was achieved in girders with weaker web-stiffener-to-flange joints (in terms of withdrawal capacity, girder variation 1.5), which can be explained by higher scatter of results for girders with stronger joints (girder variation 1.3). In two specimens, the flange failed at finger joint in the bottom lamella.

In the case of girders with OSBs, the diagonals proved to be favorable in terms of stiffness, as their average elastic stiffness was 47% higher than of the girders without diagonals. The stiffness was however still almost 20% smaller than of girders with cement-particle boards. The lower stiffness can mainly be attributed to the lower slip modulus (K_{ser}) of the OSB-to-timber nailed connection com-

pared to cement-particle-board-to-timber stapled connection. It is unusual that the results of girders with cement-particle boards show higher elastic stiffness for variations without diagonals, as according to numerical analyzes (the results of both girder variations with average values of mechanical characteristics according to experimental tests (Kržan et al., 2020) adopted) diagonals should increase the stiffness of the beams. Since here, too, the scatter of the results is much higher than for the girders with diagonals, the results can be explained by a small number of samples (the difference in average stiffnesses is relatively small). In the case of girders without diagonals, the stiffness of the girders depends in a greater extent on K_{ser}, which however has, due to the higher scatter of hardness / strength of cement-particle boards (because of different age), again higher scatter.

Regarding the ultimate displacements, it should be noted that with some girders with cement-particle boards and diagonals, the residual load-bearing capacity was observed – in contrast to other variations where a sudden failure was obtained. It was achieved through cracking of the boards and redistribution of internal forces within the girder until the final tensile-flexural failure of bottom flange occurred.

SUMMARY AND CONCLUSIONS

The paper presents the development of composite timber girders constructed of waste timber-based particle boards fastened to timber frame by mechanical means only. After introducing the structural details of the developed and investigated variations of the girders, the experimental tests and results in term of load-bearing capacity and stiffness are presented in dependence of the tested girder variations.

Investigations have shown that girders with 16-mm cement-particle boards fastened with metal staples are more rigid than girders with 22-mm OSBs fastened with nails, which is most probably to be attributed to the larger slip modulus (K_{ser}) of the OSB-to-timber nailed connection in comparison to the cement-particle board-to-timber stapled connection (cement-particle boards have only an 18% higher modulus of elasticity). Due to the inferior material characteristics (tensile strength) of cement-particle boards in comparison to OSBs and consequent earlier cracking of the boards, the girders with cement-particle boards sheathing without diagonals achieved lower load-bearing capacity.

Diagonals, which were added mainly to improve stiffness, had a favourable effect on load-bearing capacity of cement-particle-boards-based girders, as they decreased the tensile stresses in the boards and thus enabled higher load-bearing capacity of the girders. The average stiffness of girders with cement-particle boards contrary to the predictions and results of numerical analyses did not improve with adding diagonals, which is most likely due to the small statistical sample and high dispersion resulting from high dispersion of cement-particle board-to-timber stapled connections' slip modulus K_{ser}. Unlike for girders with cement-particle boards, diagonals improved the stiffness for girders with OSBs. They did however not affect the load-bearing capacity, as both OSB girders with and without diagonals failed with tensile-flexural failure of the bottom timber flange without any visible damage on the boards.

It should be noted that the presented conclusions are based on only three tests for each variation, with the relatively large dispersion of the results for certain mechanical characteristics in some girder variations. The flexural capacity of the developed and tested girders is in the case of tensile-flexural failure of the bottom flange equivalent to flexural capacity of glued laminated timber

girder GL 24h of dimensions 140/334 mm (assuming that the mean bending strength is 20% higher than the characteristic). Due to the relatively small stiffness, the presented girders are however suitable for use at low loads only or where serviceability demands are low. For more demanding use, higher stiffness of the board-to-timber connections should be achieved, which is within the project being further investigated.

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COMPARATIVE STUDY OF HEATING TECHNOLOGY AND INERT ATMOSPHERE AFFECTING LIGNOCELLULOSIC BIOMASS THERMOCHEMICAL MODIFICATION

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ABSTRACT

Climate changes, biomass utilization and bioenergy recovery are among the biggest world challenges. Wood is considered as a renewable and sustainable material. However, wood needs to be upgraded for future utilization. Exposure of wood to temperatures in the range of 180–280°C, in low concentrations of oxygen, confers new properties. Many technologies for wood thermochemical modification have been developed using nitrogen, steam, smoke, hot oil, pressurized water, and vacuum. This work aims at furthering the knowledge of the influence of inert atmosphere on thermodegradation reactions.

Key words: heat treatment, durability, preservation, wood, material.

INTRODUCTION

Wood is one of the most widely promoted building materials. However, when exposed to outdoor conditions, unprotected wood undergoes degradation, induced essentially by fungal activity. Wood heat treatment by torrefaction, with temperatures ranging from 180°C to 240°C, under inert atmosphere, can be used as a preservation process with a weak environmental impact. Wood preservation by heat treatment is fast-growing in many European countries, with several processes having been developed since 1980. Despite the fast-industrial development, there is a deficiency of fundamental knowledge about the torrefaction mechanism, which results in a lack of process control and problems with the final properties of the treated material. It is exceedingly difficult to obtain heat treated woody biomass with consistent quality, even for well-known wood species, which can render the final product unfit for commercial use. Treatment conditions are determined, in most cases, by empiricism, without fully understanding the individual contributions of key factors, such as reaction atmosphere.

In order to lower the environmental impact of human activities, there is a need for the development of value-added products from woody biomass. It is possible to enhance some properties of wood biomass through the use of a controlled heat treatment at lower temperatures (<250˚C) in the absence of oxygen (torrefaction). Torrefied wood can be more easily processed, leading to more homogeneous products with hydrophobic character (Chen *et al.,* 2018), typically brown in color (Tumuluru *et al.,* 2011). In addition, wood heat treatment by torrefaction results in products with a low environmental impact since only heat is introduced in the process. It is an interesting alternative to chemical impregnation for the valorization of low-cost, local wood species, improving their dimensional stability (Militz 2002, Korkut *et al.,* 2012), durability (Allegretti *et al.,* 2012), and their economic potential

(Yan-Jun *et al.,* 2002). At the end of its life, this material without added chemical products can be easily re-used or recycled. In such applications, it is desirable that the treatment be applied to biomass with bigger particle size, ideally in the form of lumber.

On a chemical level, torrefaction promotes crosslinking and condensation reactions at higher temperatures, while degradation reactions of lignin predominate at lower temperatures (Kubovský *et al.,* 2020). It has also been reported that, while hemicelluloses undergo complete degradation upon severe torrefaction (Li *et al.,* 2015), with hemicelluloses from hardwood being more susceptible to thermal degradation than those of softwood (Poletto *et al.,* 2012), the crystallinity of cellulose increases slightly at low torrefaction temperatures and experiences a sharp decrease with increasing torrefaction temperatures (Wang *et al.,* 2017). This observed behaviour has been attributed to a competitive degradation between crystalline and amorphous cellulose (Wang *et al.,* 2017). Overall, the products obtained from wood torrefaction can be classified in non-condensable volatiles (gases and low molecular weight hydrocarbons), solid products (biochar and charcoal precursors), and condensable volatiles (acetic acid, furfural, and tar) (Chih *et al.,* 2019).

Despite the vast literature on torrefaction (Pelaez-Samaniego *et al.*, 2013) of wood products and ligno-cellulosic biomass for specific applications (Suliman *et al.,* 2017), there is a deficiency of fundamental knowledge about chemical processes occurring at different inert atmospheres. Subsequently, this study focusses on the effect of the inert atmosphere on the degradation of the main biomass polymers (hemicelluloses, cellulose, and lignin) during a mild pyrolysis process. Experiments were performed on poplar in semi-industrial scale reactors under nitrogen, superheated steam, air, and several low-pressure conditions ranging from 200 hPa to 600 hPa (vacuum). All experiments were carried out with a treatment temperature of 235°C. Mass loss was recorded for each experiment and was chosen as a representative indicator of the degradation reaction, since it has been reported in the literature as a reliable marker for fungi resistance. Colors of each sample were measured before and after the heat treatment. Indirect TGA and DTG were applied to untreated and treated woods in order to assess chemical modification during the treatment. The study highlighted that even if mass loss was slightly affected from the treatment conditions, thermo-chemical degradation was not identical, leading to differences in the final product properties.

MATERIALS AND METHODS

Raw material and heat treatement conditions

The wood used in this study is a well-known European hardwood, poplar (*Populus nigra*). This species is commonly used in the wood industry. Its averaged density is in the range of 400–500 kg m^{-3}. The wood samples have been cut into 2.0 × 10.0 × 30.0 cm^3 (tangential x radial x longitudinal directions, respectively, according to wood fiber orientation). The samples were dried in an oven at 103°C until mass stabilization. All the samples were collected from the same initial board to prevent any variation due to the initial properties of the material. The thermal treatments have been performed in two semi-industrial experimental devices: a conductive reactor operating under vacuum, presented in Figure 1, and a convective, multi-atmosphere (nitrogen, superheated steam, and air) oven, shown in Figure 2.

In Europe, the industrial production of thermally modified wood is carried out in the

temperature range of 200–240°C, until reaching a target mass loss of treated wood of 8-10 wt.% (Esteves *et al.* 2009, Sandberg and Kutnar, 2016). For this reason, the heat treatment of wood samples was performed at 235°C. For all heating stages, a heating rate of 0.2°C min^{-1} was applied. The temperature increased from room temperature to 105°C. An isothermal plate of 30 min is maintained to achieve mass stabilization in order to remove the moisture absorbed during the experiment's setting, and precisely determine the anhydrous woody mass. Anhydrous mass is then recorded. Subsequently, the temperature is raised to 170°C and held for 30 min, like in the industrial processes (Petrissans *et al.* 2014). Finally, the temperature in the reactor is increased to 235 °C and held for 1000 min. The mass loss (*ML*)of the wood samples was recorded. *ML* is defined as:

$$ML\ (\%) = \frac{M_i - M_{treated}}{M_i} \times 100 \quad \textbf{(1)}$$

where M_i is the initial weight of wood sample (dry basis), and $M_{treated}$ is the weight of the sample after the thermal treatment.

Experimental pilot scale conductive reactor

The conductive experimental system is shown on Figure 1. It is composed of a wood heat treatment unit, a vacuum pump, and a control unit. Wood boards are thermally treated between two electrically heated metal plates. K-type thermocouples are installed inside the heating plates and in the center of the wood sample. In the control and recording unit, a computer with a monitoring software is adopted to control and record the sample's temperature during the treatment.



Figure 1: Conductive vacuum reactor

Experimental pilot scale convective reactor

The convective unit is shown in Figure 2. This reactor can simultaneously treat 10 boards with dimensions of 30.0 × 10.0 × 3.0 cm^3. For this study, only two boards were processed in each test. The treatment pilot enclosure is electrically heated and can be swept by either air, nitrogen, superheated steam, or a mixture of these gases. The gas used is also pre-heated at the treatment temperature before being injected into the reactor. A sensor at the reactor outlet allows the measurement of the oxygen concentration in order to prevent possible combustion of the boards. The volatiles issued from wood degradation, mixed with the sweeping gases, are bubbled through water in order to eliminate the main volatiles.



Figure 2: Convective multi atmosphere reactor.

Color measurements

Before and after treatment, colorimetric measurements were made using a chromameter (CR-410, Konica Minolta) according to the CIELAB standard. The measurements were carried out on 3 locations for each board (Figure 3) and the results presented are the mean values. Parameter a^* represents the color between green and red, parameter b^* represents the color between blue and yellow, and parameter L^* represents the clarity of the sample (100 = white and 0 = black).



Figure 3: Color measurement sampling

Following this colorimetric determination on treated and non-treated samples, it is possible to calculate the color variation due to the treatment according to Equation 2.

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad \textbf{(2)}$$

Where ΔL^*, Δa^* and Δb^* are the differences observed before and after treatment for parameters L^*, a^*, and b^*, respectively.

Thermogravimetric analysis

Finally, the treated and untreated boards were ground and then thermogravimetrically analyzed in order to identify the decomposition phases of the main wood compounds. The thermodegradation behavior was analyzed by a thermogravimetric analyzer (TGA 2 (LF), Mettler Toledo), shown in Figure 4.



Figure 4. Thermogravimetric equipment

The instantaneous weight of the sample over the course of the analysis was detected and recorded at a frequency of 2 Hz. To ensure the quality of measurements and analyses, the temperature and weight in the TG were periodically calibrated using zinc (Zn), calibration weights, and sapphire glass, respectively. Prior to the experiments, the powdered woody samples were dried at 105°C for 24 h.

TGA was performed on all torrefied wood samples to determine if the inert atmosphere (vacuum, nitrogen, air, or steam) during the torrefaction process changes the amount of hemicellulose degradation. The TGA method starts under nitrogen atmosphere with a flow rate of 20 mL min^{-1} in the balance and furnace. After loading a 5 mg sample, there is a 20°C min^{-1} ramp from room temperature to 105°C, and then the temperature is kept isothermal for 30 minutes to remove any water from the sample. The temperature is then raised at a heating rate of 20°C min^{-1} to 800°C with a gas change to air at 600°C. The air is used to burn off any residue from the Platinum pan for the next TGA run.

RESULTS AND DISCISSIONS

Thermodegradation mass loss

It has been reported in the literature (Chaouch *et al.,* 2012) that a good durability is achieved, and mechanical properties are preserved (Candelier *et al.,* 2011), when the mass loss due to the thermal degradation of wood samples is in the range of 10-15 wt.%. For this reason, the averaged mass losses of all treatments investigated is recorded and summarized in Table 1. It can be seen that all treatment atmospheres allow for the samples to reach the target degradation level. Statistically, it is not easy to draw conclusions about the influence of the reaction atmosphere on the global biopolymers' degradation. Examining the results of experiments conducted under reduced pressure, one can see that even if the higher pressure allows the presence of a higher oxygen concentration, no clear trend can be observed. As a matter of fact, the effect of pressure on the thermodegradation reaction is quite complex. Higher vacuum extracts small volatile molecules from wood's pores and vessels, and avoids polymerization reactions. Lower vacuum removes only lower molecular weight volatiles, and allows

the presence of higher oxygen concentration, significantly modifying the transformations occurring during the treatment.

It has been already reported that small molecule volatiles produced from hemicelluloses degradation, such as acetic acid, have a catalytic effect on thermal degradation of biomass. Vacuum treatment is supposed to remove rapidly produced volatiles. It is possible that the increased mass loss observed when the treatment is performed under nitrogen is the result of the presence of acetic acid by-product in the system under inert atmosphere. When the treatment is performed under air, it was expected that the presence of oxygen would induce oxidation of wood components, accelerating the overall process, and consequently the mass loss evolution. The results obtained didn't confirm this expectation. It is important to highlight that the difference between the recorded mass losses is statistically not persuasive with respect to the results' dispersion.

Table 1: Averaged mass loss of poplar wood samples recorded under each heat treatment

Treatment conditions	Initial mass (g)	Mass loss (%)
Conductive vacuum oven		
200 hPa	1837.39	15.16±0.12
300 hPa	1410.60	13.44±0.06
400 hPa	1359.56	13.22±0.41
500 hPa	1340.23	13.30±0.52
600 hPa	1359.62	14.24±0.26
Convective multi-atmosphere oven		
Nitrogen	452.35	16.48±0.59
Super-heated steam	486.12	14.97±0.98
Air	484.78	12.81±0.24

Color changes

The wood color change occurs with depolymerization of cellulose and lignin, causing chemical changes inside and on the surface of the wood sample. Color changes measured for samples treated at different pressures are shown in Figure 5 while color changes measured for experiments performed under nitrogen, steam, and air are displayed in Figure 6. The results for low pressure treatments show that the values of ΔL* decreases as the pressure increases (ΔL* = -46.99 at 200 hPa and ΔL* = -51.36 at 600hPa). Negative values represent the black color, thus the more negative the value, the darker the sample. Similar results are obtained for the Δb* values, which represented the green-blue color. They decrease from -12.13 to -14.14 as the pressure increases from 200 hPa to 600 hPa, respectively. Here again the more negative the values, the more the sample color tends towards blue. The Δa* values change from negative (-1.79 at 200 hPa – representing the green color) to positive (0.25 at 600 hPa – representing the red color) thus collaborating for the wood samples to have a darker brownish tone. It can be observed that the total color change ΔE, calculated according to Equation 1, increases as pressure increases. The values increase from 48.58 to 53.28, as pressure increases from 200 hPa to 600 hPa, respectively.

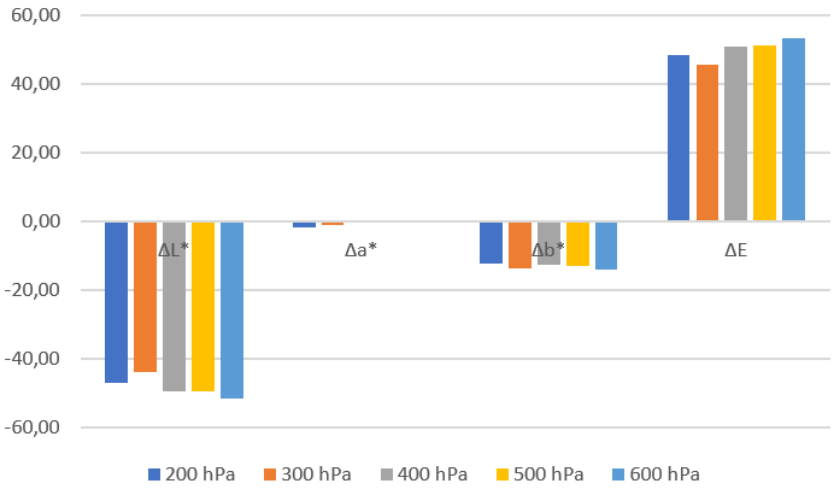


Figure 5: Color change for conductive vacuum oven treatments

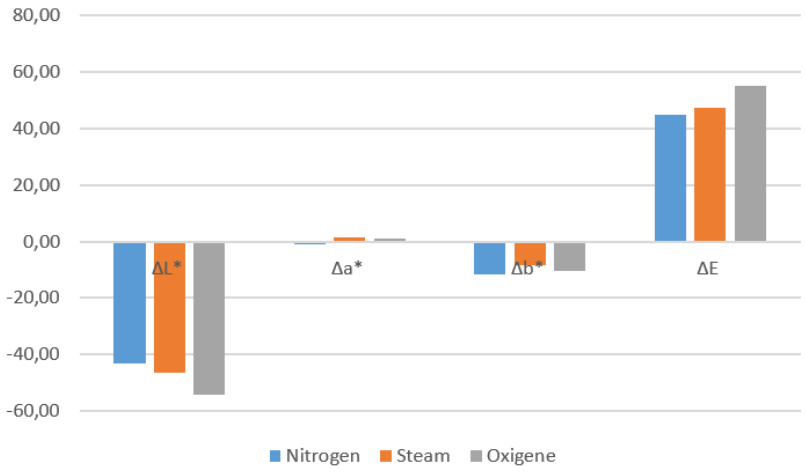


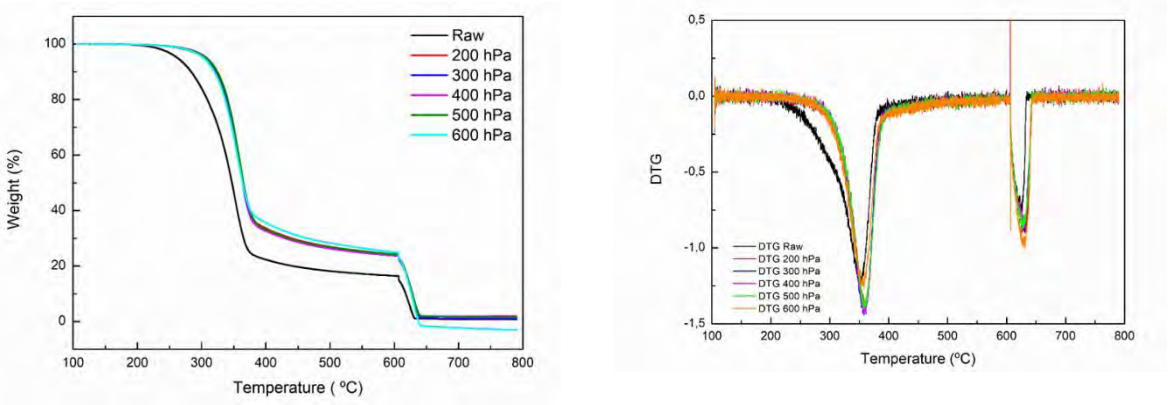
Figure 6: Color change for convective multi-atmosphere oven treatments

A similar behavior is observed in Figure 6. The total color change (ΔE) for wood samples treated in a convection heating oven increases with changing atmospheres. The value is 44.45 under nitrogen, 47.26 under steam, and 55.1 under oxygen. This occurs because nitrogen is a non-reactive gas, making some chemical reactions difficult in the heart and on the surface of the wood. With steam and oxygen, this does not occur, as they are naturally oxidizing atmospheres, allowing for chemical reactions and color change to happen. According to Yanni Xi et al., oxidizing atmospheres can generate more chromophores, colored quinoid compounds, and increased oxygen content can accelerate the depolymerization and degradation of macromolecules in biomass (Xi *et al.,* 2021). The change in wood color under heat treatment is attributed to the decrease in hemicelluloses (mainly in pentosanes) and lignin, which has been suggested as being more responsible than polysaccharides for color change in heat treated wood (Sivrikaya *et al. 2020*). Sun *et al*. 2015 suggest that linkages within the lignin structure break during the thermal treatment to form ketones.

Indirect TGA-DTG composition analysis

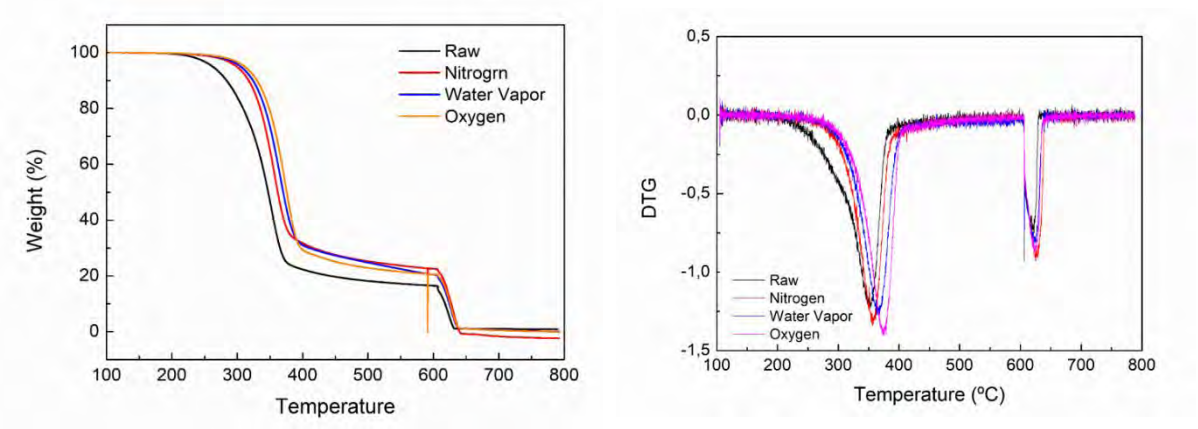
In order to investigate the influence of inert atmosphere on the chemical decomposition of woody biomass and degradation reaction pathways, indirect methods have been performed by thermogravimetric analysis

(TGA) and its derivative (DTG). Results of conductive vacuum oven and convective multi-atmosphere oven are shown in Figures 7 and 8, respectively.



a) **b)**

Figure 7: a) TGA experiments for samples treated at different pressures. b) DTG experiments for samples treated at different pressures.



a) **b)**

Figure 8: a) TGA experiments for samples treated at different atmospheres. b) DTG experiments for samples treated at different atmospheres.

A first examination of Figures 7 and 8 allows to highlight the differences of the degradation rate as a function of the atmosphere employed. Raw poplar wood degrades significantly faster than any of the treated samples. That marked difference can be attributed to the continuous degradation and removal of volatiles and lower molecular weight (Mw) degradation products still present in the sample. For any of the thermally treated samples, these materials (volatiles and low Mw by-products) have already been partially removed during the treatment, therefore a lower weight loss is observed during TGA.

When specifically evaluating the effect of reduced pressure on the thermally treated samples (Figure 7), their TGA degradation profiles are very similar between 100˚C and 600˚C (Figure 7a). The only observable difference between these samples is on the intensity of the major DTG signal at approximately 370˚C (Figure 7b). This signal is correlated to the degradation of cellulose (Colin et al. 2021). With the exception of the sample treated at 200 hPa, the DTG peak is more intense, in absolute numbers, for samples treated at lower pressures. The intensity of the DTG peak is attributed to the homogene-

ity of the sample, more specifically to the relative content in crystalline cellulose (Safar et al., 2019). It is possible that at lower pressure (higher vacuum), the volatile by-products from the degradation of hemicelluloses and amorphous cellulose are more efficiently removed, resulting in a sample that is richer in crystalline cellulose.

The effect of different atmospheres on the TGA profiles of poplar can be seen in Figure 8a. Contrary to initial expectations, the sample treated under nitrogen degrades faster than the one treated under water vapor, which in turn degrades faster than the one treated under air. That trend translates into a shift of the temperature of the main DTG signal. Samples that start degrading at a lower temperature display a DTG maximum at a lower temperature. It is possible that, under oxidative atmospheres (steam and air), fragments of the sample can be more easily oxidized and potentially re-polymerized under the more reactive environment, forming by-products that are more thermally stable and therefore harder to degrade.

CONCLUSIONS

In this study, the influence of inert atmosphere on thermodegradation kinetics and pathway is explored. Experiments in mild pyrolysis conditions (235°C) are performed in semi-industrial scale conductive and convective reactors under vacuum, nitrogen, superheated steam, and air. Recorded mass loss does not seem to be affected by the inert conditions. Contrariwise, measurements of color evolution and indirect analysis of composition show that the thermochemical degradation reactions are not identical and influence the final product qualities. For a better understanding of wood thermal degradation during a mild pyrolysis process, deeper analysis is planned, including: Fourier Transform Infra-Red spectroscopy (FTIR), X-Ray diffraction (XRD), elemental, proximate, and fiber analysis. The results of this investigation could be useful for industries producing heat treated wood for furniture and construction.

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EXPERIMENTAL STUDY AND MODELING OF THERMODEGRADATION DURING TORREFACTION OF ROW AND POTASSIUM IMPREGNATED BEECH WOOD

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ABSTRACT

Wood is promoted as renewable energy source. Row wood presents some drawbacks like a high moisture content, low energy density, bad grindability. Wood torrefaction in temperature ranged between 180–280°C in poor oxygen atmosphere upgrades wood properties. Process can be optimized by impregnation with potassium. An accurate modelling of the process is helpful for industrials to predict process duration and final quality of the product.

Key words: biomass, torrefaction, renewable energy, modelling.

INTRODUCTION

Demand for bioenergy is growing at a rapid pace as the world seeks to reduce its dependence on fossil fuels. At the same time, while bioenergy markets are expanding in terms of volumes traded, they are also expanding geographically (Olsson and Hillring, 2012). Biomass has become an important energy source, accounting for 14% of the world's energy. It ranks among the world's largest fuel sources after coal, oil and natural gas (Patel, 2012). Woody biomass is the most important source of bioenergy, accounting for 87% of bioenergy production and has become a focus for research (Figure 1) (Manzano-Agugliaro *et al.,* 2013).

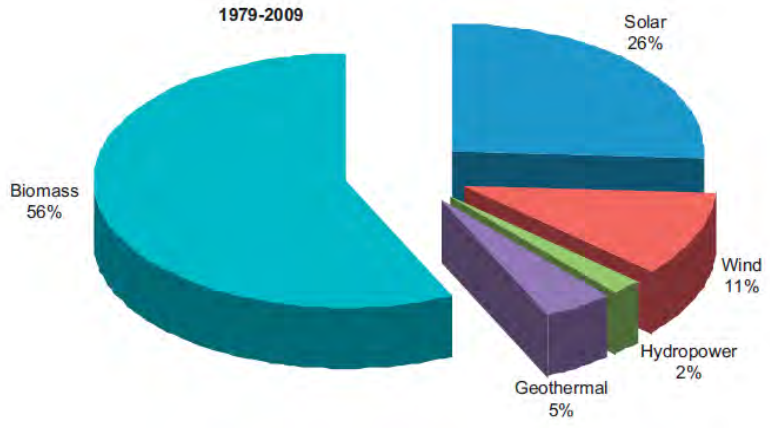


Figure 1: Distribution of scientific publications on renewable energies (1979–2009)

At the same time, the market needs for wood-based products are increasing exponentially, especially in Europe. It requires the use of bio-based energy sources including wood to reduce the carbon impact. Thus, "new" technologies, such as thermal modification, have been successfully introduced into the market and demonstrate potential for improving wood properties of (Sandberg *et al.* 2017). Wood heat treatment (torrefaction)

can efficiently recover biomass and improve the quality of solid fuel derived from biomass (biochar) (Sandberg *et al.* 2017, Chen *et al.* 2021).

Torrefaction is a thermal treatment of wood in an inert environment at 200–300°C. Torrefaction results in three types of products: gas, liquid and solid, the latter being the primary product (Bergam and Kiel, 2007). Product yields change with increasing treatment temperature. Bio-oil decreases while biochar increases rapidly. In addition, the acid yield decreases as the phenols increase, leading to a higher calorific value. As for the gas phase, more CH_4 and H_2 are produced, which also increases the calorific value of the non-condensable gas (Chen *et al.* 2021).

Torrefaction is recommended as a pretreatment for biomass use in the energy sector. Despite the fact that wood is a clean source with low sulphur and nitrogen content, its reduced thermal stability leads to tar formation in gasifiers. Prins *et al.*, 2006 proposed a new method of using torrefied wood in gasification to increase process efficiency. Torrefaction effectively reduces moisture content and O/C and H/C. In addition, it increases the calorific properties of the wood and allows for better crushability (Chen *et al.* 2021).

Wannapeera and Worasuwannarak, 2012 found that by pre-treatment of wood by pressurized torrefaction, pyrolysis and combustion properties were improved. Coal efficiency increases with pyrolysis to 800°C and the rate of coal combustion increases considerably during combustion. In addition, bio-oils produced by pyrolysis have improved O/C ratios when torrefied wood is used compared to untreated wood. This improvement strongly depends on the intensity of the torrefaction.

Torrefied wood has properties similar to those of bituminous coal, so it can be used in existing coal boilers without major modifications. Li *et al.* (2012) developed a model that determined that the pulverized coal boiler could be fuelled solely with torrefied biomass with no significant impact on boiler efficiency, while reducing NO_X and CO_2 emissions in the system.

The literature shows that the thermal conversion rate of biomass is strongly influenced by the presence of potassium (Nowakowski and Jones, 2008). Potassium is the most abundant of the metals present in the biomass. It is in ionic form K^+ with a content that varies according to species and growing conditions (Clery *et al.,* 2018). Analyses of the rapid pyrolysis of potassium-impregnated poplar wood show that the presence of K impacts the properties of bio-oils including viscosity and water content, but also the thermochemical reactions by promoting the disappearance of levoglucosan and the increase of lignin-derived phenol (Hwang *et al.,* 2013).

The literature reveals that the thermal conversion rate of biomass with the variability in the chemical composition of wood and its potassium content, the behaviour of wood thermodegradation is unpredictable. Hence the importance of developing a kinetic model that can predict the degradation profile of lignocellulosic biomass. The modelling of thermodegradation process considering the presence of potassium is the main purpose of this study.

MATERIALS AND METHODS

Wood sampes and potassium impregnation

The wood species chosen is beech (Fagus sylvatica), due to its abundance in Europe and the lack of its use on the market in order to valorise.

Its averaged density is in the range of 640 kg m^{-3}. Experiments have been performed on two size samples: on power and wood block.

Powder preparation: the raw sample was powdered and sieved, and the particle sizes were controlled within 60–120 mesh. To avoid the effect of the moisture, the powder was dried at 105 °C in an oven.

Blocks preparation: the wood samples have been cut into 2.0 × 7.0 × 7.0 cm^3 (tangential x radial x longitudinal directions, respectively, according to wood fiber orientation). All the samples were collected from the same initial board to prevent any variation due to the initial properties of the material

Impregnation were performed only on powders in order to investigate the influence on thermodegradation pathway. The samples were oven dried at 105 C till mass stabilization before impregnation. Then 2.0 g of the dried sample are stirred with a magnetic stirrer with 20 mL of a solution of potassium carbonate for 1h at ambient conditions. Samples are labelled according to the concentration of potassium in which they are immersed (0.004 M, 0.008 M or 0.012 M K_2CO_3). The impregnated samples are recovered by vacuum filtration (Büchner with Whatman filter papers, without ash, d = 42.5 mm) and dried at 105 C for 24 hours.

Thermogravimetric analysis

The thermodegradation behaviour of row and impregnated samples was analysed by a thermogravimetric analyser (TGA 2 (LF), Mettler Toledo, Figure 2). A heating rate of 20°C min^{-1} is applied from room to treatment temperature (300°C) followed by an isothermal plate at 300°C for 120 min.

The instantaneous weight of the sample over the course of the analysis was detected and recorded at a frequency of 2 Hz. To ensure the quality of measurements and analyses, the temperature and weight in the TG were periodically calibrated using zinc (Zn), calibration weights, and sapphire glass, respectively.

The mass loss (*ML*) of the wood samples was recorded. *ML* is defined as:

$$ML\% = \frac{m_i - m}{m_i} \times 100 \quad \textbf{(1)}$$

where m_i is the initial weight of wood sample (dry basis), and m is the weight of the sample during the thermal treatment.



Figure 2: Thermogravimetric equipment

Torrefaction shimadzu reactor.

The thermal treatment of wood blocks has been performed in the Shimadzu convection oven, presented on Figure 3.

For each batch, three samples were put into a hermetically closed Shimadzu reactor (Figure 3). The reactor was swept with a nitrogen flow rate of 100 mL min^{-1}. A heating rate of 20°C min^{-1} was applied. The treatment temperature was 300°C. The samples were kept in treatments isothermal conditions with residence time from 10 to 20 min in order to reach a different ML%. The gases produced during the treatment were condensed in a water trap. All samples have been weighed and the dimensions were measured before and after the treatment to assess mass loss (Eq. 1) and dimensional changes under anhydrous conditions.

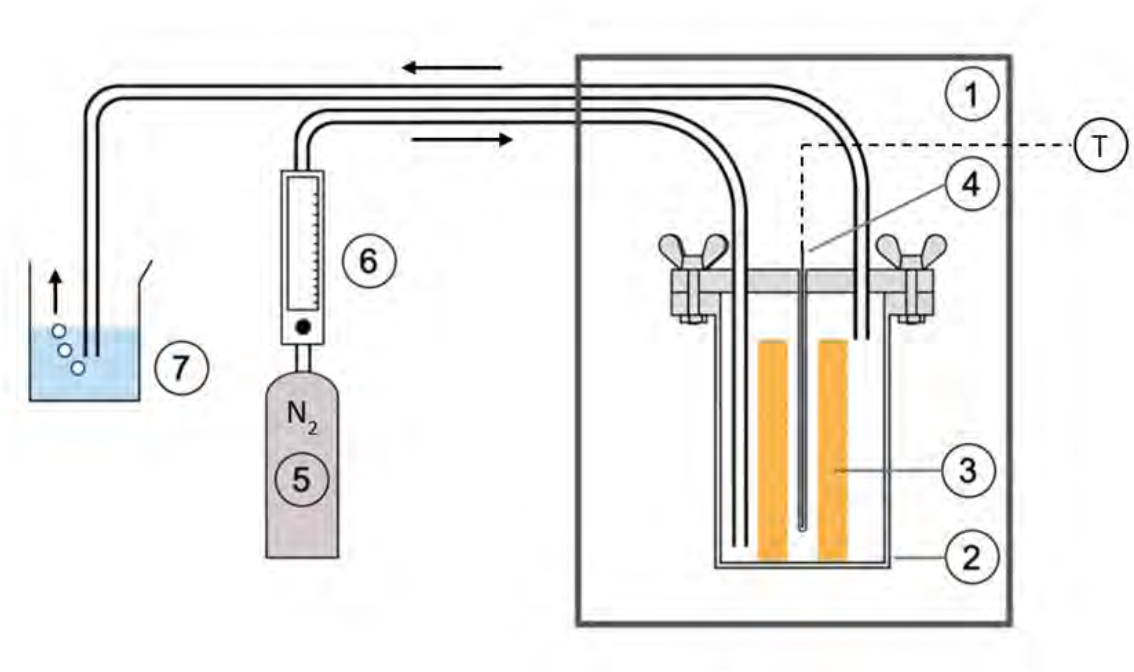


Figure 3: Shimadzu convection oven

Wood specific gravity (ρ, kg m^{-3}), thermal conductivity (λ, W m^{-1} K^{-1}), heat diffusivities (m^2 s^{-1}) before and after the torrefaction have been measured and analyzed. This part is important for the modelling of the heat transfer during the torrefaction process.

Thermal conductivity measurements with Hot-Disk.

Native and heat-treated beech wood samples were characterized using a Hot Disk TPS 1500 (Hot Disk AB, Sweden). This is a transient plane source method that consists of a resistive probe (nickel sensor coated with Kapton film) used as both a heat source and a temperature sensor. The probe is clamped between two twin samples and slightly heated by an electric current pulse. The temperature of the sensor changes as the heat flux diffuses through the sample, perpendicular to the surfaces facing the probe. Thermal conductivity can then be inferred from these temperature changes over time, which are precisely estimated from records of the voltage variations of the probe.

Since wood is an anisotropic material, the heat transfer behavior varies with the direction of the measurement. Given the configuration of the beech wood samples, thermal conductivity was measured in the radial direction using a 6.4 mm radius disk-shaped probe (Kapton 5501). The measurement parameters were set at 33 mW of power and during 80 s. The ambient temperature was 23°C. Three replicates were performed for each sample with a time interval of 10 minutes between them. The thermal conductivity was calculated by means of the anisotropic module of the instrument software.

Mathematical formulation.

Wood thermodegradation is a complex set of degradation and polymerization reactions giving several reaction products. Mathematical modeling is based on coupled heat (Eq. 2) and mass (Eq. 3) transfers and remain a simplified approximation of real phenomena.

$$\rho Cp \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + Hp \frac{\partial \rho}{\partial t} \qquad \textbf{(2)}$$

$$\frac{dm}{dt} = \sum_i c_i \frac{d\alpha_i}{dt}, \quad i = 1,2,3 \ldots, N \qquad \textbf{(3)}$$

where: $\rho = m/V$ is the averaged anhydrous wood density, V is the sample's volume., *T* is the local temperature, *Hp* is reaction enthalpy. The instantaneous sample's weight *m* is calculated following the Eq. (3), where $\frac{dm}{dt}$ is the mass evolution, c_i is the mass fraction of i^{th} component, α_i is the conversion rate of i^{th} component.

Variety of methods based on the thermal analysis of polymer thermodegradation has been developed. Among the models that exist to represent wood degradation as a function of time and temperature, the model of Di Blasi and Lanzetta (1997) seems to be one of the most relevant. He considers wood as homogeneous biomass A, which decomposes into an intermediate product B and volatiles V1. Intermediate B then breaks down into a solid product C and volatiles V2 (Figure 4). Degradation and formation reactions are supposed 1st order, obeying an Arrhenius low (Eq. 4).

$$\frac{d\alpha_i}{dT} = \frac{A_i}{\beta} \cdot \exp\left(-\frac{Ea_i}{RT}\right) \cdot (1-\alpha_i)^n \qquad \textbf{(4)}$$

Where A_i is the pre-exponential factor (s^{-1}) Ea_i is the activation energy of i^{th} component (KJ mol^{-1}), β is the heating rate (°C.s^{-1}), T is the absolute temperature (K).

To our knowledge, no model in the literature incorporates the presence of potassium.

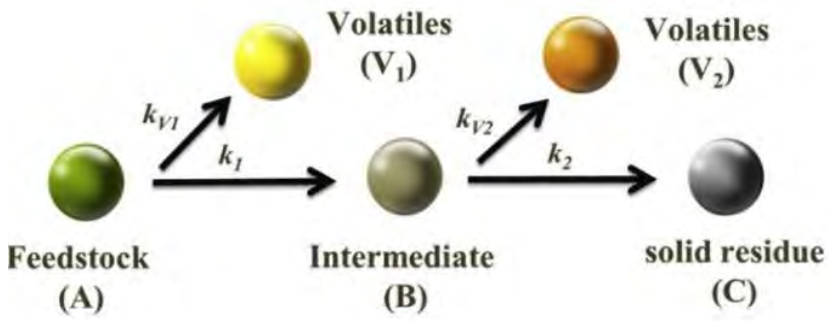


Figure 4: Decomposition of biomass during torrefaction according to the model of Di Blasi and Lanzetta (1997).

RESULTS AND DISCUSSIONS

Thermogravimetric analysis.

The TGA curves of beech for 300°C torrefaction temperature are shown in Figure 5. The potassium significantly impacted the kinetics at the isothermal step at 300°C. At 82 minutes, the weight was 8.47% lower when K increased from raw to 0.012M. At the end of the torrefaction, the curves intersected at the same mass yield (32-34 wt%), after which K switched from catalysing the degradation of wood to favouring char formation. The potassium acts as a catalyst, the increase of K leads to more char. However, the results obtained in this study showed that the effect does not depend on temperature solely but on the torrefaction time as well. In fact, the reaction time and temperature are observed to have strong influences on the torrefaction. Therefore, it is logical that the effect of potassium on the torrefaction depends on these two variables as well.

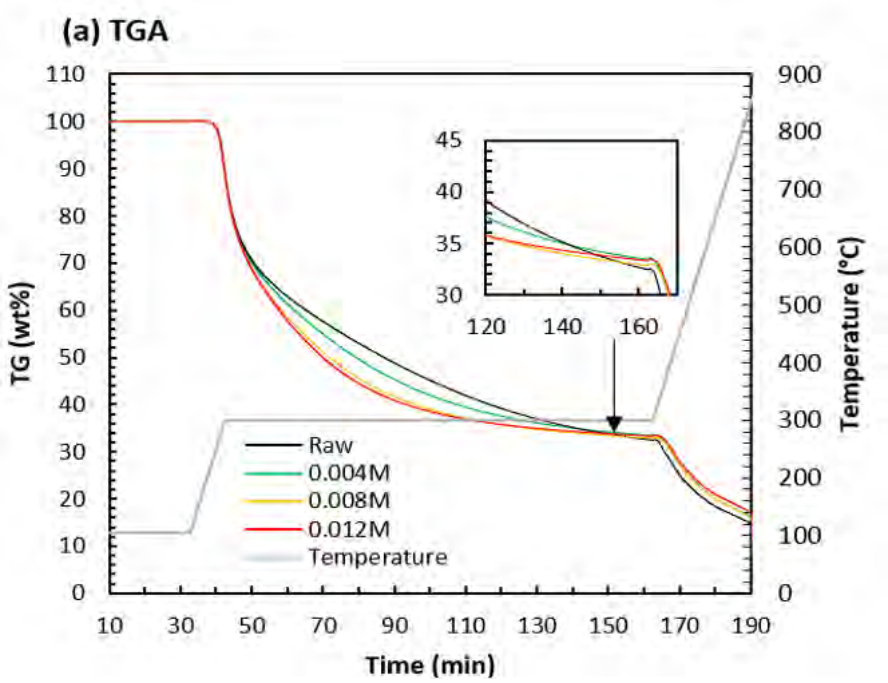


Figure 5: TGA of beech wood

Evolution of phisical properties.

The evolution of wood specific gravity (ρ, kg m^{-3}), thermal conductivity (λ, W m^{-1} K^{-1}), heat diffusivities (m^2 s^{-1}) are summarized in Table 1.

Table 1: Physical properties evolution

Sample	Density raw wood	Density treated wood	Weight loss	Axial thermal conductivity	Axial thermal diffusivity	Radial thermal conductivity	Radial thermal diffusivity
	kg m^{-3}	kg m^{-3}	%	W m^{-1} K^{-1}	mm^2 s^{-1}	W m^{-1} K^{-1}	mm^2 s^{-1}
1	625	605	0,53	0,170	0,218	0,203	0,226
2	634	600	3,75	0,172	0,209	0,211	0,253
3	628	575	9,21	0,170	0,215	0,226	0,249
4	633	573	11,83	0,174	0,241	0,209	0,251
5	625	568	14,41	0,177	0,208	0,250	0,256

As expected, wood density after treatment decreases as mass loss increases. Thermal conductivity and thermal diffusivity both in radial and axial direction are not affected by the thermodegradation in this degradation range. Frequently, in the literature these properties are considered constant.

Further experiments are necessary to determine how these properties change when temperature increases. More severe treatments are also scheduled in order to have a larger range of wood degradation.

Kinetic parameters and simulation.

Kinetic parameters are determined for each treatment case individually. Pre-exponential factors and activation energies were initialized using data from the literature [38] and upgraded by the minimization of the error function using a multidimensional unconstrained nonlinear minimization solver Nelder-Mead (Matlab® software) with admitted convergence criterion of 10^{-4}.

This part of the study is still under construction.

Simulation obtained using the model (Eq. 2-4) are show in Figure 6. Agreement between experimental and numerical data is not achieved.

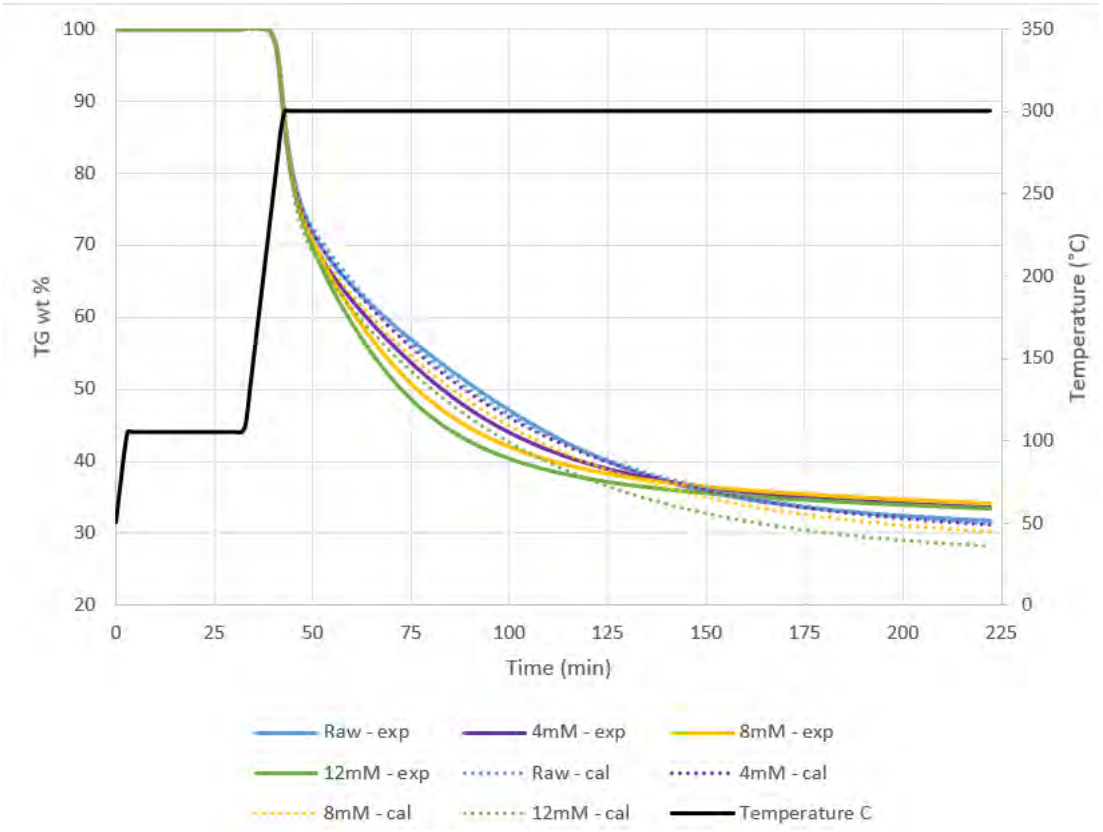


Figure 6: Experimental and simulation results of torrefaction of raw and impregnated beech wood under 300°C treatment temperature.

CONCLUSIONS AND PERSPECTIVES

In this study, the influence of the impregnation with potassium carbonate of thermal degradation during a torrefaction process has been investigated. The experiments at 300°C highlighted that potassium acts like catalyst till a certain level of degradation. This trend is inversed for more important residence time and K behaves like an inhibitor.

The investigation of physical properties did not show a pronounced modification of thermal conductivity and thermal diffusivity.

Further experiments are required to measure the heat released by the exothermic degradation reactions. Analysis using Differential scanning calorimetry are ongoing.

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MODIFICATION OF VARIOUS WOOD SPECIES BY BARRIER DISCHARGE PLASMA

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ABSTRACT

The barrier discharge plasma (BDP) modification represents an appropriate method for the polarity increasing of the wood surfaces. The surface properties of various wood species (beech, maple, birch) were pre-treated using BDP at atmospheric pressure in air were evaluated by contact angle measurements. The FTIR spectrum of the three tested species of wood is a mixed spectrum (composition) of cellulose and lignin with characteristic peaks corresponding to –OH bonds (with a maximum at about 3400 cm^{-1}) and fingerprints assigned to the –CO, –COO and $–CH_2–$ bonds typical for polysaccharides.

Key words: barrier discharge plasma, beech, maple, birch, chemical composition.

INTRODUCTION

The using of the low-temperature plasma for wood modification leads to an improvement of the wood adhesion to various substrates by adhesives (Hünnekens *et al.* 2018). The discharge plasma in air significantly increases hydrophilicity of the wood because of formation various polar groups (e.g. hydroxyl, carbonyl, carboxyl, etc.), and the wood macromolecules are also cross-links (up to a few microns), what leads to the increase in scratch resistance, and to the improvement in barrier properties of the wood. After discharge plasma modification of the wood we can observe an increase of adhesion in adhesive joint between wood substrate and adhesive due to growth of wood hydrophilicity, important for industrial applications. The low-temperature plasma represents a mixture of various excited particles, such as ions, atoms, electrons, and radicals, and plasma created particles have sufficient levels of energy to break chemical bonds in the wood substrate (Novák *et al.* 2016). The treatment of the wood by discharge plasma is limited to a few nanometres without affecting the bulk properties of the wood (Acda *et al*. 20012). The increased surface polarity due to oxidations reaction during modification of wood by RF plasma improves its wettability and hydrophilicity (Ciolacu *et al*. 2011). The wettability helps in establishing a molecular scale contact with the wood surface and critical to the development of strong adhesion at the adhesive/wood interface. Great efforts have been made in developing various kinds of furniture using wood or plastics veneers in adhesive joints wood-adhesive-veneer (Kúdela *et al.* 2017). The barrier discharge plasma (BDP) at atmospheric pressure is currently an efficient method for modification of surface and adhesive properties of the wood, and is considered as a "green" and ecological friendly modification method (Moghadamzadeh *et al.* 2011). This paper is focused on a study of the surface properties of selected wood species as well as on changes in chemical composition of the plasma modified wood.

EXPERIMENTAL METHODS

MATERIALS

Beech (*Fagus Sylvatica* L.), birch (*Betula Pendula* L.), and maple (*Acer Pseudoplatanus*) wood plates with dimensions 50 × 15 × 5 mm (Technical University in Zvolen, Slovakia) with 8% of humidity, twice distilled water as a testing liquid for contact angles measurement.

BARRIER DISCHARGE PLASMA TREATMENT

The surface of selected wood species was pre-treated by barrier discharge plasma (Fig. 1). The BDP set-up was operated at 350 W under atmospheric pressure in air. Two parallel banded systems of electrodes made of Ag paste (1 mm wide and 50 μm thick, with 0.5 mm spacing between the strips) generated the low-temperature plasma in an effective manner. The electrodes were embedded in 96% Al_2O_3, which protected the electrodes from direct contact with the plasma and thereby prolonged their lifetime. The plasma panel was also connected to a cooling system to prevent overheating. A high-frequency sinusoidal voltage (~15 kHz, with a U_m of ~10 kV) applied to the electrodes led to macroscopically homogenous plasma generation and uniform surface treatment.

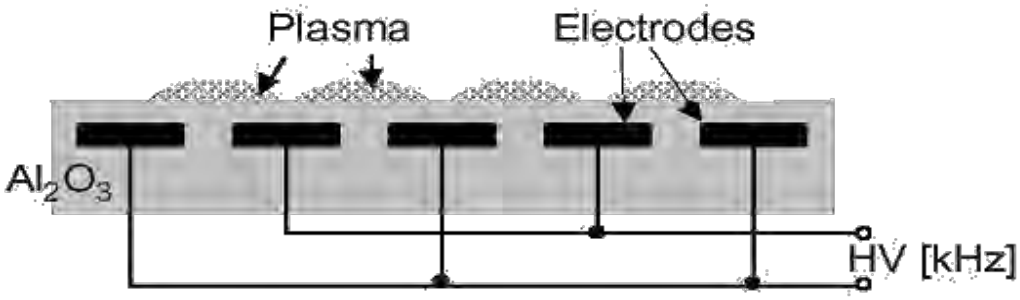


Figure 1: Barrier discharge plasma set-up

FTIR-ATR

Fourier Transform Infrared Spectroscopy with Attenuated Total Reflectance (FTIR-ATR) measurements were performed with an FTIR Nicolet 8700 spectrometer (Thermo Scientific, UK) using a single bounce ATR accessory equipped with a Ge crystal. For each measurement, the spectral resolution was 2 $cm^{-1}$and 64 scans were performed.

RESULTS AND DISCUSSION

The results of water contact angles on the surface of the investigated three wood species versus time of modification by BDP is shown in Fig. 2. The contact angles of water in the investigated wood surfaces diminished with the time of modification by BDP, and showed a steep decrease from 72° (beech wood) to 50° after modification by plasma for 120 s. The hydrophilicity (polarity) of the wood surface depends on the polar oxygenic functional groups formation during plasma treatment of wood in air. After saturation (from 60 s of the plasma treatment) of the wood surface with polar groups, the wood hydrophilicity was stabilized. The deeper decrease (from 70° up to 30°) of contact angles was observed for birch and maple wood modified by BDP.

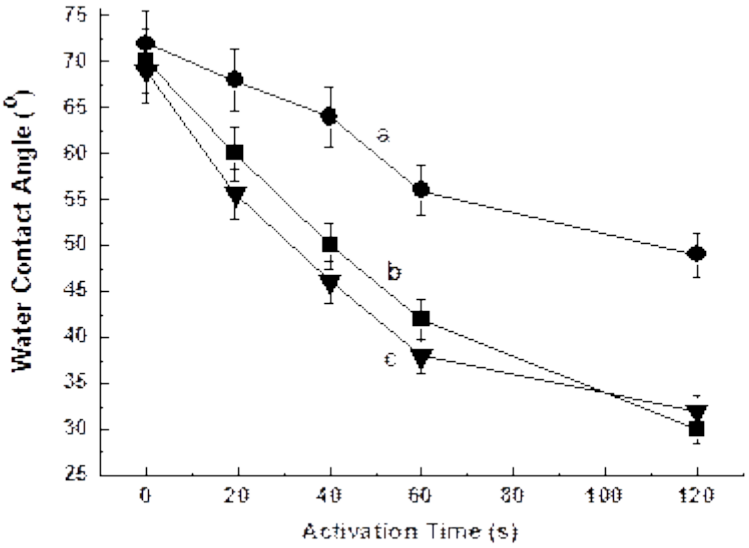


Figure 2: Water contact angle of selected wood species wood surface treated by BDP in air vs. plasma activation time: a – beech wood, b – birch wood, c – maple wood

The FTIR spectrum of selected wood species represents a mixed spectrum of cellulose and lignin with characteristic peaks in –OH bonds with a maximum at about 3400 cm^{-1}, so as in the area of fingerprints, which is reflected oxygen bonds in groups in C–O–C, COO, and unpolar CH_2 bonds typical for polysaccharides. The peak (C–O–C) appears for each of them as typical representative. Ratios of integrated intensities of oxygen bonding groups (with the majority contribution of –OH groups) with their maximum at 3400 cm^{-1} and integrated intensities at the 2985 cm^{-1} (CH_2)sym were determined. However, this is only semi quantitative information, Table 1 shows ratios of integrated intensities P(–OH)/P(–CH_2), where the vibration of –CH_2– was chosen as an internal standard with the assumption that the plasma treatment does not affect this area.

Table 1: The ratio of integrated peaks for P (2895, CH_2 stretch) and P (3400, OH stretch) calculated from FTIR for selected wood species treated by BDP

BDP treatment time (s)	P(OH)/P(CH_2) Beech	P(OH)/P(CH_2) Birch	P(OH)/P(CH_2) Maple
unmodified	8.474	6.627	5.948
20 s	13.973	10.135	11.914
40 s	20.624	14.690	14.046
60 s	22.986	18.632	16.960

In Table 1 we can observed an increase of P(OH)/P(CH_2) ratio with plasma treatment time, that shows also an increase of the polarity of selected wood species. The largest increase was observed in the case of beech wood (from value of 8.474 for the untreated beech wood up to 22.986 for the 60 s plasma treatment. The ratio P(OH)/P(CH_2) for untreated types of woods ranges from 5.948 to 8.474, which indicates approximately the same hydrophilicity, that is, the content of –OH groups on the surface of all types of wood before any treatment was the same. It can be concluded that FTIR-ATR measurements confirmed that the plasma treatment causes some changes at the surface of all types of wood, which are dependent on the time of exposition by plasma and it can be

said that there is an increased content of hydrophilic groups compared to the untreated samples. Conclusions from the FTIR-ATR spectroscopy could be complemented by measuring of contact angles of plasma treated wood species as well.

CONCLUSIONS

The contact angle of water of selected wood species modified by BDP in air decreased significantly with plasma treatment time, Results of ATR-FTIR spectra measurement confirms the increase of the wood polarity and hydrophylicity after BDP treatment due to growth in – OH group amount. The content of oxygenic polar groups on the surface of wood after plasma treatment increased, but the amount of carbon conversely decreased. The concentration of –C–O, COOH, and C=O polar groups after treatment by BDP significantly increased.

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TECHNOLOGIES FOR UTILIZATION OF WASTE FROM CUTTING OF WOODEN MATERIALS

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ABSTRACT

When performing technological operations for cutting of wood materials, any waste is inevitably produced. Some of the waste is technologically reusable for furniture or other products. The relatively high share of the material costs in the cost of furniture sold is the reason why the problem of efficient utilization of its waste is always relevant for the furniture manufacturers. The aim of the present study is to present rational technologies for utilization of the furniture waste. Proposals have been made for effective utilization of small pieces of deciduous and coniferous tree species, as well as of furniture board materials. In conclusion, specific examples of wood products that can be successfully fabricated from technologically reusable waste are provided.

Key words: wood, wooden materials, technological waste, utilization.

ТЕХНОЛОГИИ ЗА ОПОЛЗОТВОРЯВАНЕ НА ОТПАДЪЦИ ОТ РАЗКРОЯВАНЕТО НА ДЪРВЕСНИ МАТЕРИАЛИ

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РЕЗЮМЕ

При изпълнение на технологичните операции за разкрояване на дървесни материали, неминуемо се получават отпадъци. Част от тях са технологично оползотворими за мебели или други изделия. Високият относителен дял на материалните разходи в себестойността на мебелите е причина проблемът за ефективно оползотворяване на отпадъците да бъде винаги актуален за производителите на мебели. Целта на настоящото изследване е да се представят рационални технологии за оползотворяване на отпадъци от мебелното производство. Направени са предложения за ефективно оползотворяване на малогабаритни парчета от дървесина, както и от плочести материали. В заключение са дадени насоки за разширяване на обхвана на съществуващите практики за оползотворяване на технологични отпадъци от мебелните производства.

Ключови думи: дървесина, дървесни материали, технологични отпадъци, оползотворяване.

УВОД

Независимо от полаганите усилия досега практически не е създадена технология за разкрояване, при която да не се получават отпадъци. Значителното увеличение на цените на дървесните материали и високият относителен дял на материалните разходи в себестойността на мебелите е причина проблемът за ефективно оползотворяване на отпадъците да бъде все по-актуален за производителите на мебели. От друга страна, в световен мащаб продължава да се отчита намаляване на дървесните ресурси, особено на тези от висококачествена дървесина, която е основна суровина за производство на мебели. Последните години се отчита тенденция за все по-голям недостиг на мате-

риали за производство на мебели и значително удължаване на срока за доставката им.

Отпадъците от дървесина може да бъдат потенциално ценен ресурс за производството на различни материали и продукти (Lykidis and Grigoriou, 2008). Видът и обемът на отпадъците, генерирани по време на производството на мебели, са се променяли с времето в зависимост от различни фактори. Един от тези фактори е увеличаването на обема на ползваните за производство на мебели плочести материали, спрямо обема на влаганата в мебелното производство масивна дървесина. Съгласно официални данни средно 90% от общото количество на образуваните дървесни отпадъци са в сектора на дървообработващата и дървопреработващата промишленост;

Рециклирането на всички дървесни отпадъци е теоретично възможно, но на практика има фактори, които ограничават практиките за рециклиране (Top, 2015). Те включват събиране и транспортиране на отпадъци, типа и производствените обеми на производствата, количеството и вида на произведените отпадъци, екологичните разпоредби и нивото на развитие на конкретната държава. Вследствие на ремонтни дейности, домакинствата изхвърлят отпадъци от дървесина и дървесни производни, но в повечето случаи е икономически неизгодно те да се ползват повторно в мебелните производства. Основна причина за това е наличието на захабени защитно-декоративни покрития, обемно замърсяване и омазняване, както и наличието на множество метални елементи в дървесните отпадъци, които задължително трябва да бъдат отстранени. Плочести детайли във видимо добро състояние, могат да бъдат повторно облагородени в мебелни предприятия, но това ще бъде за сметка на завишени разходи на труд и енергия, което поставя под въпрос икономическата ефективност на този технологичен процес. Основно по тази причина, понастоящем в България са слабо развити технологиите за рециклиране на дървесните отпадъци.

В зависимост от размерите, конфигурацията и възможностите за тяхното рационално ползване, отпадъците от дървесина и дървесни материали биват: технологично оползотворими за мебели, оползотворими за други цели, най-често за изгаряне с цел отопление и неоползотворими. Обект на настоящото разглеждане са само отпадъците от първата група т.е. технологичните отпадъци от мебелните производства. Цел на изследването е представяне и разработване на рационални технологии за оползотворяване на технологичните отпадъци от разкрояването на дървесни материали. Съществените различия в подхода и начините за оползотворяване на технологичните отпадъци от масивна дървесина и от плочи налагат те да се разглеждат поотделно.

ТЕХНОЛОГИИ ЗА ОПОЛЗОТВОРЯВАНЕ НА ОТПАДЪЦИ ОТ РАЗКРОЯВАНЕТО НА МАСИВНА ДЪРВЕСИНА

Приема се, че технологично оползотворими отпадъци от масивна дървесина са всякакъв вид парчета, оставащи след разкрояване, които имат дължини над 150 mm, а по-малкият размер от напречното им сечение е равен или превишава съответен размер на някои от масово произвежданите в дадено предприятие детайли (например летви за пълнежни плочи или ламелни детайли, вложки, водещи или крепващи летви и др.).

С оглед настоящата икономическа ситуация и настъпващата глобална рецесия,

е перспективно кооперирането на фирми ползващи голямо габаритни заготовки от дървесина с производители на изделия от дървесина със сравнително малки габарити. Примери за такъв тип изделия са декоративни елементи от дървесина, детски играчки, лайсни, первази и др. (Фиг. 1).



Фигура 1: Изделия от масивна дървесина, подходящи за изработване от технологични отпадъци

Друг вариант на икономически ефективно кооперирането на мебелни предприятия е технологичните отпадъци от масивна дървесина да се събират в общо депо и в последствие да се ползват за изработване на летви, греди и плочи чрез клинозъбно снаждане по дължина и/или широчина. За изработване на плот от технологични отпадъци от масивна дървесина, е рационално да се ползва следната технология: начално грубо сортиране по размери; окрайчване по дължина с оглед премахване на чепове, заобленост, отчупвания и други недопустими недостатъци; базоформиране на страна и кант (освен ако те са точни бази); доразкрояване по широчина и дебелина (при необходимост); снаждане по дължина и формиране на непрекъснат фриз; снаждане по широчина и формиране на еднослойна плоча от

масивна дървесина; калибриране по дебелина; задаване на точна дължина и широчина на плота от масивна дървесина.

За изпълнението на гореспомената технологията е необходимо да се ползват специализирани преси (фиг. 2) и подходяща околопресова механизация. Основна слабост на разгледаното направление за оползотворяване на отпадъците от масивна дървесина е големият брой операции със значително участие на ръчен труд и/или скъпо машинно оборудване. Това е причина технологиите, разработени на тази основа, да са по-рядко разпространени в практиката. Друг съществен недостатък на представената технология е необходимостта от съчетаване на различни по текстура и цвят парчета от масивна дървесина.



Фигура 2: Преси и машини за клинозъбно снаждане на технологични отпадъци от масивна дървесина

Ползването на подобни технологии изисква наличие или закупуване на специализирани машини за клинозъбно снаждане и специализирани пресови съоръжения (фиг. 2). Производственият опит показва, че прилагането на поточни линии от този тип е икономически целесъобразно за предприятия със средно и голямо по обем производство на мебели и други изделия от дървесина на иглолистни дървесни видове. Тъй като, инвестицията е икономически оправдана при годишно обработване на не по-малко от 2000 – 2500 m^3 масивна дървесина (Кавалов и Ангелски, 2014), тази технология е рационално да се ползва при кооперирание на сродни мебелни предприятия със значителен обем на технологичен отпадък.

Друг вариант е да се ползва под наем специализирано оборудване за клинозъбно снаждане и/или изработване на плочи от масивна дървесина. Това означава, че технологично оползотворимите отпадъци могат да се съхраняват за определен период от време, след което да се транспортират и снаждат във фирма с налично за целта оборудване. В тази връзка, може да се ползват съществуващи интернет базирани платформи за споделяне на активи между бизнеспартньори (business-

to-business) и да се кооперират български производители на мебели и изделия от дървесина (https://timber-b2b.bg/).

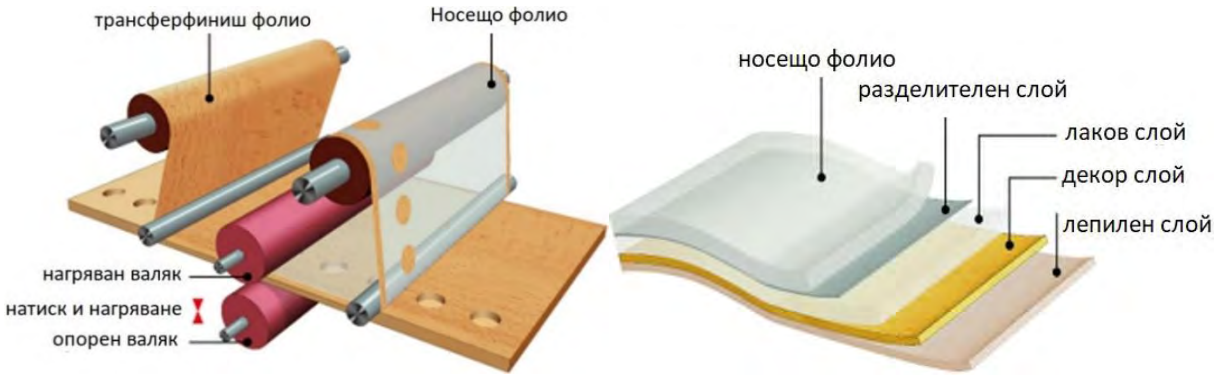
ТЕХНОЛОГИИ ЗА ОПОЛЗОТВОРЯВАНЕ НА ОТПАДЪЦИ ОТ РАЗКРОЯВАНЕТО НА ПЛОЧЕСТИ МАТЕРИАЛИ

Към технологично оползотворимите отпадъци от плочести материали (плочи от дървесни частици, плочи от дървесни влакна, шперплат и др.) се отнасят тези, чиято широчина е по-голяма от 20 mm. Отпадъците с широчини от 20 до 50 – 60 mm са подходящи за формиране на пълнежни слоеве на облицовъчни плочи. Отпадъчните ивици с по-голяма широчина се използват предимно за формиране на композирани плочи, които се подлагат на калибриране и задължително двустранно облицоване, изпълнявано най-често с фурнирни платна. Ивиците в този тип се съединяват чрез слепване по прав кант с помощта на карбамидформалдехидно лепило. Снаждането по кантовете се осъществява на специализирани едноетажни тактови преси с двупосочно упражнявано налягане: по кантовете и по направление перпендикулярно на равнината на плочата (вж. фиг. 2). Този тип преси са с нагреваеми плотове. По направени груби изчисления се приема, че оползотворяването на този тип технологични отпадъци е икономически оправдано, ако годишно отделяният обем на отпадъците е не по-малък от 550–700 m^3 (Кавалов и Ангелски, 2014). Необходимостта от закупуване на специализирано пресово оборудване и осигуряването на значителен обем на технологичен отпадък е отново предпоставка за кооперирane на мебелни производители със сродна дейност.

Голямоформатните отпадъци с размери по широчина над 200–250 mm е икономически ефективно да се използват като полуфабрикати за други производства, например: за изработване на скелети на тапицирани мебели, за направа на каси за опаковане на остъклени мебелни конструктивни елементи и др.

Характерно за мебелните производства е наличието на складове с множество парчета от разкроени плочи, които най-често са с декори излезли от производство. От една страна тези складове намаляват ефективната производствена площ, а от друга затрудняват производствения процес. Тяхното разчистване, може да е икономически ефективно при ползване на технологията „трансферфиниш“, което на практика означава да се смени декора. Същността на метода, се изразява в пренасяне на предварително формиран върху носещо фолио декор към гладко обработена повърхнина на конструктивен елемент. Декор-слоят е в комбинация с топлинно-разтопяем лепилен слой от едната си страна и лаково покритие – от другата. Чрез едновременно нагряване и притискане към облагородяваната повърхнина те заедно се отделят от носещото фолио и в резултат на термоактивиране на лепилния слой, залепват за нея (фиг. 3). Предназначеният за трансферфиниш материал представлява навита на руло лента, състояща се от следните пет слоя: прозрачно носещо фолио, разделителен слой, лаков слой, декор-слой, лепилен слой (фиг. 3). Носещото фолио е с дебелина между 15 и 25 μm. Разделителният слой представлява високовискозно течно лепило. При повишаване на температурата вискозитетът му рязко спада, благодарение на което става лесно разделяне на носещото фолио от лаковия слой. Адхезионните свойства на ле-

пилото са подбрани така, че при разделянето лепилото остава само на носещото фолио. Лаковият слой от трансферфиниш-ната лента обикновено е с дебелина до 30 μm. Методът се прилага без да се използват мокри процеси, а облицоването е с отлично качество, при това проходно и следователно високопроизводително. Лепилният слой е от необратимо втвърдяващи се след стопяване и контакт с плочестия детайл еднокомпонентни полиуретанови лепила. Те притежават висока термоустойчивост при експлоатационни условия (до 140°C). Пренасянето на декор-слоя и лаковия слой от носещата лента към облагородяваната повърхнина става най-често чрез прекарване на обекта между двойка валяци, като този, който участва пряко в трансфера е нагрят до определената по режима температура. Декора се пренася само в участъците, където е осъществено нагряване и притискане между лентата и плочата. В съседство с контактната зона декорът остава върху носещото фолио. Непрозрачността на декоративния слой създава допълнителна възможност за повторно облицоване в случаите, когато са допуснати дефекти по вече декорирани повърхнини. Дебелината на лентите от рулата за трансферфиниш не превишава 100-150 μm. Вследствие на това нанесените покрития по метода трансферфиниш са толкова тънки, че въобще остават незабележими по ръбовете на облагородяваните плочи или при наслагване на няколко слоя един върху друг.



Фигура 3: Технология “трансферфиниш“ – принципна схема и руло лента на трансферфиниш фолио

Технологията „трансферфиниш“ се характеризира с високи, ненадминати от друг метод за облагородяване производителност и технологичност. Изразяват се преди всичко в: кратък производствен цикъл без технологични престои; липса на мокри процеси, включително лакиране; отсъствие на буферни складове; необходимост от малки производствени площи за прилагането му; липса на надмерки и операции за тяхното отстраняване. Освен това липсват проблеми по отношение на охраната на труда, вероятността за възникване на пожари, по замърсяване на околната среда. Липсват традиционните за други подобни методи вредни емисии, неприятни миризми, изпарения. Значително по-малко са технологичните отпадъци. Рулата от носещо фолио по принцип са годни за повторна употреба и подлежат на рециклиране. Тези факти нареждат методът трансферфиниш на едно от първите места сред технологично чистите производства. Въпреки това трябва да се има предвид че, той е неприложим за груби или недостатъчно добре подготвени мебелни повърхнини. Освен това трябва да се отбележи високите цени на рулонните

многослойни ленти за трансферфиниш. Този факт, в съчетание с относително ниския процент на оползотворяване на рулата по дължина и особено по широчина (средният рандеман е около 70% и рядко надхвърля 80%), е една от основните причини за ниската популярност на метода сред производителите на мебели. Въпреки това, споменатите по-горе предимства са предпоставка за внедряване на този метод за облицоване в мебелните производства. Необходимостта от ползване на специализирано оборудване и материали, предполага по-голяма икономическа ефективност при кооперирание на няколко мебелни фирми и ползване на споделен производствен ресурс.

Подобни резултати и икономически ефект може да се постигне чрез инвестиране в машина за дигитално печатане на декори. При този тип печатарска техника се постига директно пренасяне на изображението от цифрово описание (компютърен файл) към физически носител. Използват се няколко системи за отпечатване на цветни изображения, като принципа при всичките е наслагване на растерните решетки на отделните цветове.

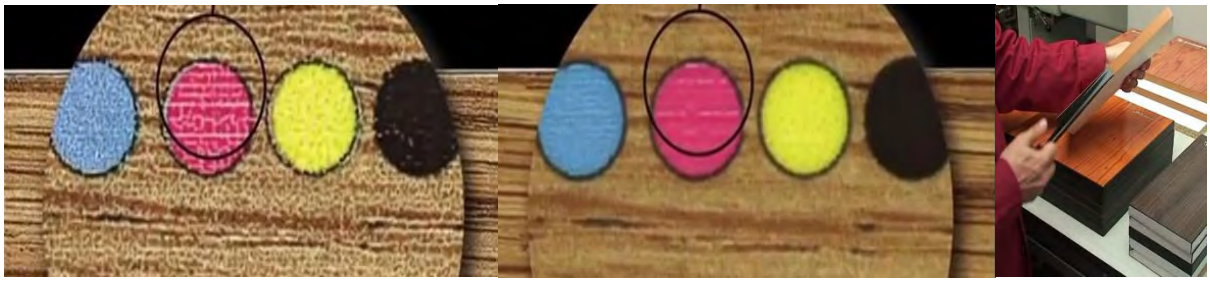


Фигура 4: Промишлен принтер за цветен печат върху плочести детайли

Най-разпространената система за цветен печат е, така наречената CMYK (абревиатура от основните цветове – Cyan, Magenta, Yellow и BlacK). При мастиленоструйният печат, няма необходимост от междинен носител (печатна форма, клише) за пренасяне на мастилото върху повърхността на детайлите и изображението се формира безконтактно, директно върху печатния материал. Печатащите машини представляват промишлени мастилено-струйни принтери с дюзи, които изпускат фини капчици течно мастило с висока скорост, чрез деформиране на пи-

езокристал (фиг. 4). На практика посредством тази технология се постига неограничено разнообразие на визуалните ефекти. Всяка висококачествена снимка може да се пренесе върху плочестия детайл. Като основен недостатък може да се отбележи високата цена на промишлените принтери и скъпите печатарски консумативи.

Качествено дигитално отпечатване на декори (Фиг. 5) върху детайли получени от отпадъчни парчета от разкроя на ламинирани плочи се получава при спазване на следната технология: облицоване с бял ламинат (грунд фолио); нанасяне на праймер; нанасяне на 1-ви слой грунд; нанасяне на 2-ви слой грунд; защитно облепяне на кантовете с фолио; шлифоване; дигитално принтиране; нанасяне на финиш покритие (лакиране).



Фигура 5: Сравнение между некачествен и качествен дигитален печат

Боядисването на плочестите детайли е значително по-евтина алтернатива, но тя има ограничени възможности за постигане на висококачествени защитно-декоративни ефекти. Основен проблем на технологията е необходимостта от полагане на грижи за съгласуване на цветовата характеристика на предходните покрития с основното лицево (видимо) покритие. На практика, това означава да се вземат мерки за най-точно спазване на изискванията за получаване на равномерно и с предписаната дебелина покритие. В противен случай се получи нюансиране в наситеността на цвета, с което се понижава качеството на повърхнините. Примерна технология за оползотворяване на разнообразни по вид и декор отпадъци от разкрояването, чрез боядисване е следната: задаване на точни размери по дължина и широчина; китване и шлифоване на повърхнините за боядисване; полагане на грунд; сушене на грунд; коректурно китване; местно шлифоване; нанасяне на боя, първи слой; сушене на първи слой боя; нанасяне на боя, втори слой; сушене на втори слой боя.

С оглед настоящо създалата се икономическа ситуация, характеризираща се с многократно увеличени цени на плочестите материали, особено на шперплата и фурнированите такива, при завишени срокове за доставка, може да се окаже рационално да се рециклират дървесни отпадъци от фурнировани детайли и шперплат. Такъв тип плочести материали, често се изхвърлят от домакинствата на местата за събиране на отпадъци. Разбира се, за нормално протичане на този процес, е необходимо да се развие система за регулирано събиране и/или изкупуване на дървесни отпадъци от заинтересованите лица на определени за целта места. При липса на откъртвания и отчупване на фурнированите плочести материали, е необходимо да се изпълнят технологични операции за отстраняване на лаковите покрития (посредством шлифоване) и нанасяне на нови

такива. Съществени недостатъци на такъв тип технология на оползотворяване на дървесни отпадъци са: сравнително малки габаритни размери на отпадъчните детайли и наличие на отвори; повишена вероятност от прошлайфане на фурнира при отстраняването на лаковото покритие; замърсяване на околната и работната среда със шлайфпрах; висока енергоемкост и значителна продължителност на технологичните операции. Освен това, на повторна технологична обработка могат да се подлагат само неизметнати плочести детайли.

Детайли от шперплат без съществени дефекти, могат да бъдат технологично обработени чрез шлифоване, почистване и при необходимост облицовани.

За рециклиране на плочести детайли облицовани с фолиа или ламинати е рационално да се ползва описаната по-горе технология за снаждане чрез слепване по прав кант. В този случай, е задължително плочестите детайли да са с еднаква дебелина и да се извърши шлифоване на фолиата или ламинатите преди тяхното повторно облицоване. За предпочита е да се ползват сравнително дебели облицовъчни материали, които да ограничат видимостта на снадките. Задължителното двустранно облицоване може да се извърши на хидравлични и/или вакумно-мембранни пресови съоръжения. Практическите затруднения по осигуряването на еднаква дебелина на снажданите плочести елементи, е основана причина за ограниченото приложение на технологията.

Често ползвана практика е малки производители и занаятчии да закупуват материали от обяви на граждани, публикувани в специализирани за целта сайтове. В тази връзка, друга насока за ефективно оползотворяване на технологичните отпадъци е съставянето и поддържането на обща база данни на мебелни предприятия, където да са вписани с габаритни размери и особености всички налични парчета и заготовки. Този подход може да се разшири при включване на всички складови материали в база данни. Това на практика означава да се създаде общ виртуален склад на кооперираните мебелни предприятия.

ЗАКЛЮЧЕНИЕ

Технологиите за оползотворяване на технологичните отпадъците от мебелното производство имат потенциал за превръщането им в ценен ресурс за производството на различни материали и продукти. Понастоящем мебелните фирми подържат множество буферни складове с голямо количество технологичен отпадък от разкрояването на дървесните материали. Значителното увеличение на цените на дървесните материали и намаляване на дървесните ресурси в световен мащаб са неоспорим факт. През последните години се отчита тенденция за все по-голям недостиг на материали за производство на мебели и значително удължаване на срока за доставката им. Тази икономическа ситуация може да се окаже благоприятна за предприемчиви производители на мебели и изделия от дървесина, склонни да инвестират в технологии за оползотворяване на дървесни отпадъци. Кооперирането на мебелни фирми има значителен потенциал, както за ползването на общи ресурси, така и за развиването на съвместни бизнеси свързани с оползотворяването на технологични отпадъци или рециклирането на дървесни отпадъци. Правилният избор и рационалното използване на технологиите за оползотворяване на технологични отпадъци е предпоставка за регенериране на годни за употреба конструктивни еле-

менти със сравнително ниска себестойност. Освен това, оползотворяването на застоялите материали и отпадъци ще доведе до разчистване на производствените помещения и освобождаване на буферните складове. На практика това ще има не само финансов ефект, а и ще доведе до намаляване на пожароопасността на мебелните производства.

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SUITABLE OF LOCUST TREE WOOD FOR PRODUCE FURNITURE

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ABSTRACT

The wood of the Locus tree as timber is very suitable for produce furniture. From timber after drying and fashion can be produce details and plate with very nice flathers and tons. It is suitable for produce of table details for bed and parquets, but may be drying to 8–10% moisture.

ПРИГОДНОСТ НА ДЪРВЕСИНАТА НА АКАЦИЯТА ЗА ПРОИЗВОДСТВО НА МЕБЕЛИ

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РЕЗЮМЕ

Дървесината на бялата акация като фасониран материал е много подходяща за производство на мебели от материал бичен след изсушаване на детайли и получаване на еднослойни плочи , които се характеризират с много красива текстура и цвят. Тя е подхадяща за изработване на столове, маси, детайли на легла и паркетни настилки, но при условие, че предварително се изсуши камерно до влажност: 8–10 %.

ВЪВЕДЕНИЕ

Акацията е пренесена в миналото в Европа от Северна Америка за украса на паркове и градини. Тя е цъфтящ бързорастящ дървесен вид. Цветовете й излъчват приятен аромат и могат да се консумират безопасно от хората и домашните животни. Дървесината е ядрова. Тя е много устойчива на фунгицидни вредители (5). Първоначално е използвана за производство на колове за лозя и градини, но постепенно намира приложение в индустрията за производство на изделия с различно предназначение (4). Този вид е бързо растящ фиг 1. За 15–20 години прави ствол с височина 20 метра и диаметър 20–30 см на гръдна височина. Дървесината на този вид е с много високи технически показатели, които я правят конкурентна на другите бързо растящи видове. Средната й плътност е много голяма: 750 /650 – 900/. Дървесината е ядрова. Беловината се отличава със светло-жълтеникаво-зеленикъв цвят, а ядрото преминава от жълто-зеленикав до кафеникав цвят (1; 2).



Фигура 1: Насаждение от правостъблена акация от района на гр. Свищов.

Пригодност на дървесината на акацията за производство на мебели.

Поради високата ѝ плътност дървесината на бялата акация съхне при атмосферни условия сравнително бавно – за няколко месеца. При наличните съвременни сушилни камери и разработените рационални режими за сушене тя става много подходяща и за производство на мебели и други технически изделия. Пионери в Европа относно използването на тази дървесина за производство на мебели са Унгария и Румъния. В тези страни са интродуцирани бързорастящи видове по поречието на река Дунав. У нас в последната половина на миналият век са създадени плантации от учените на Станцията по бързорастящите видове в Свищов както в поречието на река Дунав така и по поречията на реките: Марица, Искър, Вит, Росица и Янтра (2;4). Стволът на този вид за около 20–30 години достига подходяща височина за получаване на секции пригодни за производство на фасониран материал (дъски), шперплатен и мебелен фурнир (фиг.1). За целта са разработени и подходящи режими за пропарване и сушени. През началото на 21 век се разработиха камери и режими за термотретиране на тази дървесина при високи температури: 180–200ºС. При тези температури цветът на този вид дървесина от зеленикаво-жълтеникав става тъмно кафеникав и наподобява този на ореха и екзотичния тик. Именно така обработена тази дървесина става много пригодна за изработване на оригинални мебели от елитен клас. Дървесината на акацията е ядрова и кръговопореста. В табл. 1. са представени качествените показатели на 10 клона.

Table 1: Mean arithmetic values of mechanical properties of Locust tree wood (4).

Index	Hardness MPa			Compr. MPa		Shear MPa		Splitting kN/m		Bending, MPa Modulus, MPa			Impact KJ/m^2	
	D_{12}	H_{yq}	H_{yl}	D_{12}	R_c	D_{12}	R_{st}	D_{12}	R_{cl}	D_{12}	B_s	E_s	D_{12}	R_r
P10	710	51.5	68.4	708	61.7	645	11.3	710	32.3	649	102.5	13690	666	47.3
C4	918	83.4	113.3	924	80.2	924	13.6	925	52.1	925	170.0	14020	884	121.4
B4	724	50.1	65.8	762	58.8	762	12.4	762	47.5	762	112.2	11980	729	49.8
C27	885	88.7	107.9	863	75.8	863	12.9	864	44.0	863	168.6	17070	825	79.7
H27	826	75.2	83.1	847	71.9	855	14.1	845	49.3	855	127.4	10780	822	70.2
C33	795	78.4	81.2	778	70.5	776	12.6	780	39.1	780	141.1	13910	798	72.2
B33	760	67.9	72.9	844	58.5	844	13.1	845	41.3	845	142.3	12880	761	52.7
C54	920	87.4	93.8	880	77.9	880	15.9	883	68.2	885	174.6	15580	933	147.2
B54	764	72.7	79.8	762	50.1	761	13.0	765	49.8	763	117.7	13090	765	58.5
D5	718	60.4	82.7	732	86.5	744	12.0	734	47.1	745	149.9	15840	760	50.4
H12	724	64.5	80.1	736	54.1	735	12.7	735	53.2	736	109.9	10490	820	91.6

Плътността на хабитатните клонове варира от 718 до 920 kg/m^3 докато на естествено растящата е 710 kg/m^3 добита от района на гр. Бяла (Рс). Тази дървесина е много твърда (760-918 MPa) поради което се износва по-трудно и за това се предпочита за производство на елементи за подови настилки (паркет, паркетни дъски, дюшуме). По този показател дървесината на акацията е равностойна на тази на дъба като при някои клонове я превъзхожда. Именно за това дървесината на акацията е много пригодна за изработване на елементи на подови настилки (дюшеме, паркет), паркови и градински мебели (пейки), дървени набраздени паркови, градински и плажни пътеки с набраздена повърхност (стил рустик), както и за обзавеждане на детски площадки (катерушки, гърлушки, оградки), тъй като е много трайна на атмосферни въздействия и на гъбни нападения (5). Особено високи са показателите на статично и динамично огъване на тази дървесина, което я прави незаменима за производство на спортни уреди (успоредки, трамплини), както и за подови елементи за спортни салони. Дървесината на акацията е вного пригодна за изработване на елементи на дървени беседки, оградни елементи, тъй като бавно гние дори и при контакт с почва и вода. В Дървесината се отличава с много високи стойности на якостта на удар (765–933 KJ/m^2 – Табл. 1) Именно за това се използва за израбатване на паркови и градински мебели- пейки, столове, маси. термотретиран вид дървесината на акацията се оказа много пригодна за изработване на декинг елементи за баня и сауни и много добър заместител на екзотични дървесни видове като тик, ироко, мерба, сапели и бамбук. В средна Европа (Унгария, Словакия, Австрия), където акацията е много разпространене много дървопреработващи фирми усвоиха производството на подови елементи за тротоари и открити тераси от термотретирана дървесина на акация (3; 5).

ЗАКЛЮЧЕНИЕ

В заключение трябва да се отбележи, че тази дървесина е много подходяща за производство на градински мебели както в натурален така и в термо модифициран вид, тъй ката има много богата цветова окраска и е много устойчива на дърворазрушаваши гъбни вредители.

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IMPROVEMENT OF THE TECHNICAL-ECONOMICAL AND ECOLOGICAL INDICATORS OF WOODWORKING AND FURNITURE ENTERPRISES THROUGH AIR RECUPERATION IN THEIR VENTILATION INSTALLATIONS

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ABSTRACT

The importance of the use of equipment for heat recovering of the outgoing exhaust air from the ventilation installations of the enterprises of the woodworking and furniture industry is grounded. It is emphasized that, as a rule, they have serious emissions of dust and harmful substances, the evacuation of which from the production premises requires intensive artificial ventilation. At it, the exhaust (polluted) air leaves the working area with its temperature, and the same amount of fresh (clean) air is introduced as compensation. If it is fed in the relevant room with environmental parameters, during the winter season its subsequent heating is associated with significant heat costs, as well as the discomfort of service personnel. Therefore, combining forced ventilation with the site's heating system is more common.

The inclusion in the described scheme of a heat utilizing unit, representing a recuperative heat exchanger, in which the enthalpy of the heated exhaust air decreases at the expense of growing that of the incoming cold flow from it can lead to significant energy savings.

Thermal calculations of possible real situations have been performed. Based on them, an analysis of the annual capital investment for the initial construction of each option for the implementation of the utilizing unit, as well as the operating and total costs for its functioning.

Practically oriented conclusions have been formulated, which would contribute to the improvement of the technical-economical and ecological indicators of the enterprises from the woodworking and furniture industry.

Key words: ventilation systems, dust emissions, harmful substances, forced ventilation, heating system.

INTRODUCTION

Improving the energy and environmental efficiency of the economy of each member state of the European Union (EU) is subject to a detailed, constantly updated and increasingly stringent regulatory base.

The European Strategy for Smart, Sustainable and Inclusive Growth Europe 2020 has set targets to reduce carbon dioxide emissions by at least 20% until 2020 compared to the levels of the 1990s, the share of renewable energy sources (RES) in final consumption to increase to 20%, and energy efficiency to improve also by 20% [1].

The European Green Deal poses even more serious challenges to the economies of the Old Continent [2, 3]. It is a new growth strategy that focuses on making the EU a just and prosperous society with a modern, resource efficient and competitive economy that will have no net greenhouse gas emissions in 2050 and growth will not be dependent on use of resources.

The Deal also aims to protect, preserve and increase the EU's natural capital, as well as to protect the health and well-being of citizens from environmental risks and impacts. This transition must be fair and inclusive.

The European Green Deal provides an action plan for:

- increasing the efficient use of resources by moving to a clean, circular economy;
- restoring biodiversity and reducing pollution.

This document indicates the necessary investments and the available financial instruments for the implementation of its tasks.

The EU aims to be climate neutral in 2050. Proposing European legislation in this area must make this political commitment a legal obligation.

Achieving this goal will require action in all sectors of the economy, such as:

- investing in environmentally friendly technologies;
- support for industrial innovation;
- introduction of cleaner, cheaper and healthier forms of private and public transport;
- decarbonisation of the energy sector;
- increasing the energy efficiency of buildings;
- work with international partners to improve environmental standards worldwide.

It is no coincidence that the first two positions list tasks concerning the industry. Minimizing the problems it causes requires the most serious concentration of material and intellectual resources.

Under the Deal, the EU will also provide financial support and technical assistance to help reorganize the sectors most affected by the transition to a green economy. This will be done through the Fair Transition Mechanism. It will help target at least 100 billion EUR for the period 2021 – 2027 to the most affected regions.

These ambitious tasks require the adoption of an entirely new approach to the problems of complex assessment of industrial devices and systems. The analysis of their effectiveness in the three main aspects – technical, economic and environmental, should be carried out when considering each constructive option for their implementation in the phase of feasibility studies, and not postponed to a later stage, when next phases of the investment process have already begun [4].

Another important aspect of the listed priorities of the European Green Deal is the decarbonisation of the energy sector. In addition to a major overhaul of large power plants, this large-scale task can be supported by diversifying of the production of electricity into generating units, which are smaller, flexible and based on state-of-the-art environmentally friendly technologies. Finding suitable sites for their location is often associated not only with financial and technical, but also with significant infrastructure, logistics, urban, social and others. difficulties [5].

There is no doubt that the fulfillment of the listed commitments to the national economies of the EU member states will have to be fairly distributed among the individual economic entities. Thus, seemingly abstract and overly global goals and objectives spread very quickly in a vertical direction to the level of each separate enterprise. In order for it to be adequate to the listed requirements, it is necessary for the problems of energy and ecological efficiency of the main technological and auxiliary activities carried out in it to be a constant object of monitoring and optimization.

One of the significant expenditure items in the balance sheet of each company and organization, which is characterized by continuous growth at a higher rate than those of its other components, are the means to provide

the necessary energy resources for its activities. Minimizing them requires that the problems associated with reducing the cost of ensuring the necessary microclimate in the workplace, as well as reducing the level of greenhouse gas emissions in the environment, be a constant focus of attention of every industrial enterprise. They are becoming especially relevant with the drastic and uncontrollable rise in energy prices in early 2022.

The woodworking and furniture industry is characterized by relatively high levels of particulate matter and chemical compounds that adversely affect human health in the individual production operations. It is assumed that dust concentration at levels above 5 mg/m^3 significantly increases the disease incidence. Levels of 1-5 mg/m^3 indicate higher risk and only at concentrations below 0.5 mg/m^3 there is no increased risk of disease [6]. At present, the EU occupational exposure limit for hardwood dust is 5 mg/m^3 [7]. The same norm is defined in Ordinance № 13 of 30 December 2003 as the limit value of wood dust in the air of workplaces. As it is not always possible to identify and isolate high-emission areas to which more concentrated measures should be applied to evacuate the emissions, forced ventilation is often required with a significant air exchange rate of entire production halls. This is related to capital investments for the initial construction and depreciation of the respective installations, as well as to current operating costs to ensure their exploitation. In the latter, the electricity needed to transport the exhaust (polluted) air evacuated from the room and to compensate for it with the same amount of fresh (clean) air has a significant and growing share. During the winter season, its necessary subsequent heating is associated with significant heat costs, as well as the discomfort of service personnel. Therefore, combining forced ventilation with the site's heating system is more common.

In view of the above, the aim of this study is to conduct technical and economic calculations based on a real situation typical of the woodworking and furniture industry, grounded on which to analyze the annual capital investment for the initial construction of possible options for the implementation of the heat utilization facility, as well as the operating and total costs for its functioning, while taking into account also the environmental impact of the proposed measures.

TECHNICAL-ECONOMICAL CALCULATIONS, RESULTS AND DISCUSSION

An installation for artificial (mechanical) ventilation of an industrial site from the woodworking or furniture industry with the following parameters has been selected as an object of consideration:

- hall in the shape of a regular parallelepiped, with horizontal dimensions 40 m x 15 m and height 8 m;
- continuous 24 hours mode of work without days off;
- heated and ventilated volume V = 4800 m^3;

The following preconditions are introduced when performing the calculations:

- winter mode of operation is considered, when the air temperature $T^a = 291$ K is maintained in the site by means of a local heating installation, working with natural gas;
- to simplify the reasoning, a combination of the forced ventilation with the heating system of the site is considered;
- since the average temperatures of the two streams are close to those at normal conditions ($T_0 = 273$ K),

the thermal expansions of the gases are neglected, i. e. their velocities and volumetric flow rates are not adjusted to their actual temperatures;

- the computational temperature of the outside air at an average uncertainty of the installation of 20 hours/year (h/a) is $T^c = 257$ K [8];
- the heat losses per unit volume when taking into account, on the one hand, the growing requirements for the effectiveness of the thermal insulation of enclosing walls, and on the other – the frequent introduction in the room of cold raw materials, the entry of vehicles for them and related to it and to the export of finished products opening of the doors, are q = 40 W/m^3 [9].

The power required to compensate for the losses from the hall in question is:

$$Q = qV = 40 \cdot 4800 = 192000 \text{ W} = 192 \text{ kW}. \quad \textbf{(1)}$$

The transport of the same heat flow must be able to provide the recuperator, which is used to heat the fresh air supplied to the room. Its construction is shown schematically in Fig. 1. In Table 1, its main characteristics are systematized, together with the symbols and measures used for them.

In order to carry out the design heat-technical sizing of the required apparatus, an own software product was used, which is based on the generally accepted methodology for performing such calculations [10 ÷ 13]. The main results of the calculations are also presented in Table 1.

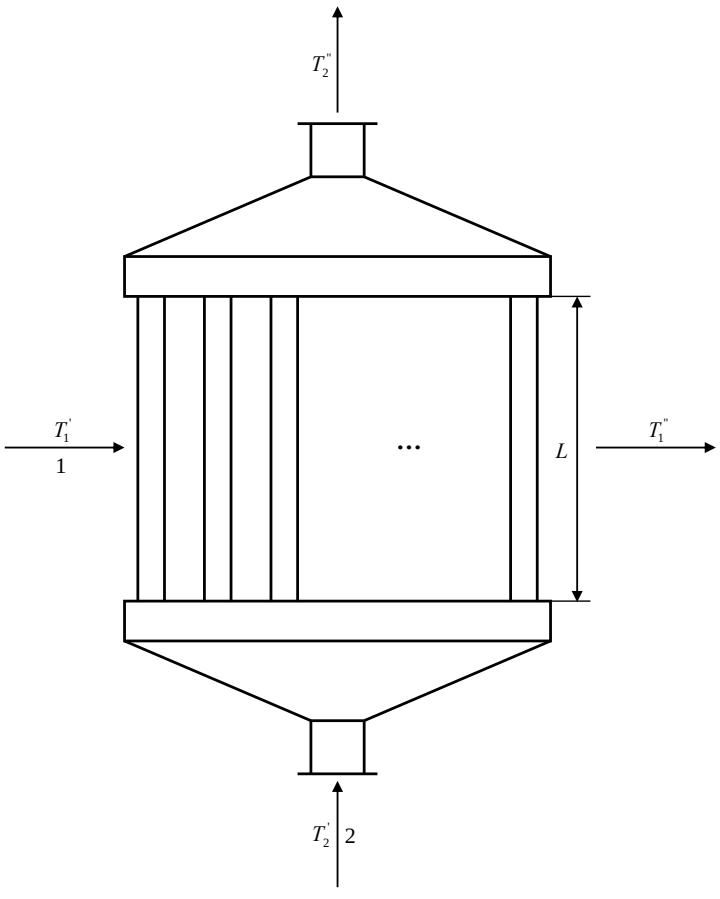


Figure 1: Scheme of the considered recuperator 1 – hot (exhaust, polluted) air; 2 – cold (fresh, clean) air

As can be seen, if you work with a tube metal recuperator, typical of high-temperature hot medias, such as flue gas leaving an industrial furnace, a significant value of the area of the heat transfer surface area of the facility is obtained.

In order to assess the feasibility of implementing this option, we use our own methodology, which is presented in detail and successfully applied in our previous studies [4, 14]. It provides for the determination of the annual costs (respectively of the depreciation deductions) for the recovery of the initial investments (the capital inputs) in the construction of each facility, E_{cap}, EUR/a, as well as the annual operating costs to ensure its functioning, E_{expl}, EUR/a.

The accurate identification of these two items in the financial balance of an industrial enterprise is a time-consuming task. In addition, it is related to the need for information on current prices of materials, labor and energy carriers, which are changing quite dynamically.

Table 1: Basic characteristics of the considered recuperator

No.	Parameter	Symbol	Value	Measure
1	**Type**	–	With one section and straight, smooth, in-line steel tubes	–
2	Motion scheme of the two fluids	–	Cross flow	–
3	Temperature of the warm (exhaust, polluted) air entering in the recuperator	$T_1^{'}$	291	K
4	Temperature of cold (fresh, clean) air entering in the recuperator	$T_2^{'}$	257	K
5	Temperature of heated (clean) air outgoing from the recuperator	$T_2^{''}$	288	K
6	Exhaust air velocity at normal conditions [4]	$w_{1,0}$	18.9	m/s
7	**Fresh air velocity at normal conditions [4]**	$w_{2,0}$	7.3	m/s
8	Pitch between the tubes in the direction of the exhaust air movement	$S^{\perp}$	0.08	m
9	Pitch between the tubes across the movement of the flue gases	$S^{\parallel}$	0.08	m
10	Outer tube diameter	d_o	0.04	m
11	Inner tube diameter	d_i	0.033	m
12	Length (height) of the tubes	L	1.65	m
13	**Heat transfer surface area**	F_0	124.81	m^2
14	Number of the tubes in a row	Y	22	–
15	Number of the rows of tubes	R	30	–

The proposed approach to evaluating a steel recuperator includes the steps listed below.

- Calculation of the mass of the metal inserted in the tubes

The determination of this parameter is done by the formula:

$$m^{'} = F_0 \delta \rho_{st}\text{,} \qquad \textbf{(2)}$$

where with $m^{'}$, kg, is marked the required mass of the material inserted in the tubes, with δ, m, – the tube wall thickness, and with $\rho_{st} = 7800$ kg/m^3 [13] – the density of the steel from which it is made.

- Ascertainment of depreciation deductions

In order to quantify the annual costs (respectively the depreciation deductions) for the recovery of the made initial investments (the capital investments) in the construction of the facility, the following preconditions have been introduced:

1. The mass of the collectors, the flanges, the mantle and all other metal elements of the recuperator is equal to 10% of that of the tubes inserted in it, in which the total mass *m*, kg, of the equipment becomes:

$$m = 1{,}1m' . \qquad \textbf{(3)}$$

2. According to indicative data, the price of recuperative heat exchangers is $E^* = 30$ EUR/kg.
3. The depreciation period (the redemption term) of the facility is $A =$ 10 years (10 a) upon acceptance of a linear, i. e. evenly distributed over time repayment of the funds invested in it.

In this case, the annual depreciation deductions amounts to:

$$E_{cap} = \frac{E^* m}{A} = \frac{30m}{10} . \qquad \textbf{(4)}$$

- Determination of the annual operating costs

For the assessment of this type of costs, a three-shift continuous working mode of the recuperator is considered, which, taking into account certain downtime for current repairs, etc. reasons corresponds to approximately 8000 hours in a calendar year.

The calculations pass through the following steps:

1) It is assumed that the only item from which the operating costs are formed is the value of the consumed electricity for driving the air fans on both tracts, i. e. the prices of the facilities themselves are neglected as insignificant.
2) The total pressure drop on the side of the heated air, $\Delta p_t \equiv \Delta p_{t,2}$, Pa, is formed as the sum of that of friction Δp_f, Pa, and of shape pressure losses, Δp_s, Pa, i. e.:

$$\Delta p_t = \Delta p_f + \Delta p_s , \qquad \textbf{(5)}$$

where:

$$\Delta p_f = \lambda \frac{\rho_0 w_{2,0}^2}{2} \frac{L}{d_i} \qquad \textbf{(6)}$$

and

$$\Delta p_s = \xi \frac{\rho_0 w_{2,0}^2}{2} . \qquad \textbf{(7)}$$

The following symbols are used for the first time in the above expressions:

ξ is the shape pressure loss coefficient of the corresponding element,

$\lambda = 0.03$ – the friction pressure loss coefficient of the tube [15],

$\rho_0 = 1.293$ kg/m^3 – the air density at normal conditions [15].

The other symbols are presented in Table 1.

3) The shape pressure losses are formed by the inflow into the inlet and the outflow from the outlet collectors of the recuperator, representing spaces with significantly larger dimensions than those of the tubes.

In accordance with the methodology proposed in [15], the determination of the shape pressure loss coefficient in case of sudden expansion (ξ_1) and sudden narrowing (ξ_2) is done according to the formulas:

$$\xi_1 = \left(1 - \frac{f}{F}\right)^2 \qquad \textbf{(8)}$$

and

$$\xi_2 = 0.5\left(1-\frac{f}{F}\right)^2 \qquad \textbf{(9)}$$

where f and F denote the cross-sectional areas respectively in the narrower and wider parts of the channel, m^2.

From the above two formulas, assuming that the value of the ratio f/F is above 0.01, it turns out that $\xi_1 \approx 1$, and $\xi_2 \approx 0.5$.

4) It is assumed that due to the significantly easier passage of exhaust air, the aerodynamic drop in its path amounts to 20% of this of the fresh gas. In this case, the total pressure losses of the regenerator Δp_t^{Σ}, Pa, are calculated as the sum of those in the path of fresh air $\Delta p_{t,1}$, Pa, and exhaust one $\Delta p_{t,2}$, Pa, i. e.:

$$\Delta p_t^{\Sigma} = \Delta p_{t,1} + \Delta p_{t,2} = 0.2\Delta p_{t,2} + \Delta p_{t,2} = 1.2\Delta p_{t,2}\,. \qquad \textbf{(10)}$$

5) The indicator obtained under (10) is increased by 20% to the final value Δp_t^* in order to cover respectively possible unreported losses on the other parts of the two tracts, accepted for a maximum of 10%, as well as the additional arose such in the amount also of not more than 10% from the originally calculated value.

6) The total power P, kW, of the two identical in design and connection way electric motors of the fans for transporting of the air flows is calculated by the formula [16]:

$$P = K\frac{\Delta p_t^* V_{2,0}}{1000\eta\eta_b} \qquad \textbf{(11)}$$

where K is the stock coefficient, the value of which is usually 1.2,

$V_{2,0}$ – the volume flow rate of fresh air at normal conditions, m^3/s.

η – the average coefficient of performance (c.p.) of the fan, the value of which can be assumed to be 0.7,

η_b – c.p. of the belt drive, in the absence of such, i. e. in the case of direct coupling of the engines, as is customary in this case, $\eta_b = 1$.

7) The annual operating costs E_{expl}, EUR/a, are calculated as follows:

$$E_{expl} = 8000PZ\,, \qquad \textbf{(12)}$$

where $Z = 0.2$ EUR/kWh indicates the average price of electricity for industrial needs at the beginning of 2022. It is subject to the same reservations about volatility and difficult predictability that were made in relation to that of natural gas.

The indicator E_{sum}, EUR/a, represents the total (the summary) annual costs for the recuperator:

$$E_{sum} = E_{cap} + E_{expl}\,. \qquad \textbf{(13)}$$

The values of the parameters listed above are presented in Table 2 as a variant No. 1.

It is obvious that if a heat exchanger is constructed whose tubes have larger diameters and distances between them, the velocities of the two fluid flows would decrease. According to our in-depth studies with recuperators designed for metallurgical furnaces, published in [4], this can lead to a reduction, even by a whole order of magnitude, of the pressure losses through the respective facility and of the associated with their overcoming operating costs for electricity. Such a measure would make the apparatus significantly less expensive, i. e. the expected increase in

capital investments and related annual depreciation costs would be within tens of percent. Therefore, depending on the specific design assignment, one can look for optimization of the structure in this direction. However, such changes are limited, as too large a recuperator would create inconveniences in its delivery, finding a suitable location in the engine room, installation and operation, so for each specific situation must be carried out a preliminary study, technical-economical analysis and precise calculation of all the characteristics of the facility and the installation of which it is an element.

Table 2: Results from the technical-economical comparison between the different variants for composing of the recuperator

Variant	m	E_{cap}	Δp_t^*	P	E_{expl}	E_{sum}
No.	kg	EUR/a	Pa	kW	EUR/a	EUR/a
1	3748	11244	1496.4	28	44800	56044
2	no data	1777	528	9.7	15520	17297

The steel smooth-tube heat exchanger described so far is obviously not the only possible type for the considered purpose, therefore the attention was focused also on a completely different in terms of design option. This refers to a plate heat exchanger, the schematic diagram of which is shown in Fig. 2 [17].

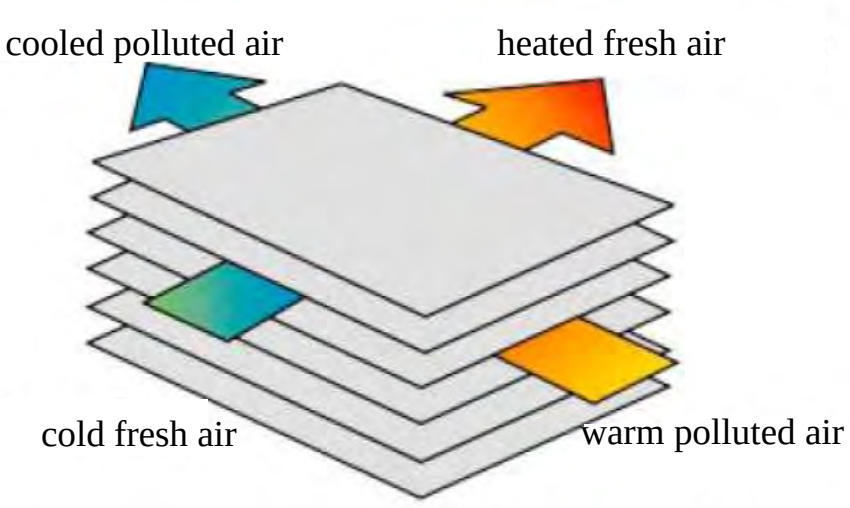


Figure 2: Scheme of plate heat exchanger [17]

In recent years, the market has seen increasing diversity in the supply of these products [18] presents a series of such devices intended specifically for the case under discussion. As this is a specific company product, the cited source does not provide details about the design and the method of calculating its parameters. The largest apparatus offered there is dimensioned for air flow from 19000 to 22000 m^3/h.

As an appropriate value for the air exchange rate in the considered room can be chosen n = 8 times/hour (h^{-1}) [19]. In this case, the volumetric flow rate of fresh air at normal conditions would amount to:

$$V_{2,0} = nV = 8 \cdot 4800 = 38400\ m^3/h = 10{,}667\ m^3/s. \quad \textbf{(14)}$$

The obtained result exceeds 6 times the capacity of the most high-performance standard heat exchanger offered in [18]. The parallel connection of several apparatuses is hardly an appropriate design solution. It would be better for the case to construct and manufacture a facility consisting of one block, using the same elements (slats) to build the plate heat exchange surface. The cited source indicates prices only for devices with lower performance, which further leads to the conclusion that the more powerful ones are subject to special negotiation and are performed only at the request of the customer. However, taking into account both the conditionality of such price extrapolation and the inability to predict their movement in conditions of high inflation and at the same time of fluctuations in economic activity and respectively in the demand for this type of engineering products on the market, the estimated value of the required apparatus for the present case it can be determined as follows.

The offered plate heat exchanger HA 1000, whose productivity is about 4.5 times lower than the required one for the discussed hall, has a price of 3216.70 BGN without value added tax (VAT), i. e. 3860 BGN with VAT, or about 1974 EUR.

In order to consider a less favorable option for investment, it is assumed that:

- this number has doubled in the meantime because of inflation,

- it is not reduced due to the repeated participation in it of the values of collectors, fittings and other elements of the recuperator, the number of which does not increase to the same extent, but only increases their size, and

- for the same reason, there is a serious decline in the input materials for the cage of the common, larger facility, compared to the mechanical sum of the areas of the outer walls of the individual devices, which is also not considered as a factor for cheaping.

Thus, the expected price of the required recuperative heat exchanger for the needs of the room in question can be indicated:

$$4.5 \cdot 2 \cdot 1974 = 17766\ EUR. \quad \textbf{(15)}$$

With the same depreciation period (redemption term) of the facility $A = 10$ years (10 a) and acceptance again of a linear, i. e. evenly distributed over time repayment of the funds invested in it, the annual depreciation deductions would amount to:

$$E_{cap} = \frac{17766}{A} = \frac{17766}{10} = 1777\ \text{EUR/a}. \quad \textbf{(16)}$$

To this sum must be added and the operating costs related to the pressure drops on the routes of the two air streams in total, the value of which is estimated according to data from [18] and taking into account the precondition introduced in step 5) of the calculations already presented:

$$\Delta p_t^* = 2 \cdot 1.2 \cdot 220 = 528\ Pa. \quad \textbf{(17)}$$

The following computations until the determination of the indicators E_{expl}, EUR/a, E_{sum}, EUR/a, were performed according to the algorithm already shown in accordance with formulas (11) ÷ (13).

Repeating the calculations according to formula (11) under the same preconditions leads to the total power of the two identical in design and connection way electric motors of the fans for transporting of the air flows.

In the same way, the annual operating costs according to the dependency (12) are determined, as well as the indicator E_{sum}, EUR/a, for the case under consideration in compliance with equation (13).

The calculated values of the parameters listed above are presented in *Table 2* as a variant No. 2. From the results shown there it is impressive that compared to the annual basis, the second recuperator is 3.24 times cheaper than the first considered option. Independently from its obvious advantage, it should be borne in mind that both in its choice and in the technical and economic calculations of its construction, bolder and more radical preconditions were introduced, which hide more risks of deviating from the actual conditions. In addition, the adopted also in this case depreciation period (redemption term) of the facility $A = 10$ years (10 a) may be commensurate with the actual duration of its trouble-free use, while with proper operation and maintenance, the first considered heat exchanger could work smoothly at least three decades.

Other design solutions can be sought in the direction of existing modern compact devices, whose heat exchange surface per unit volume exceeds 700 m^2/m^3 [20]. Providing good cleaning of the exhaust air, which is necessary due to the presence in them of nozzles and ducts with small bright openings, their use would ensure even lower capital investments and depreciation deductions with a negligible increase in operating costs due to increased speeds of gaseous media through them.

The results of the presented calculations should be weighed against the expected favorable effects of undertaking heat utilization. Starting from the above considerations of reliability and durability, as well as to consider a less favorable investment case in order to ensure greater certainty of the formulated conclusions grounded on the technical-economical calculations, as a basis for calculating the expected benefits of applying recuperation the first option is chosen.

In accordance with the already introduced precondition, to ensure the required temperature in the hall in question during the cold period of the year there is a local heating system, which is powered by its own hot water boiler running on natural gas. In the presence of recovery of the heat of the exhaust air, its productivity must be reduced by the thermal power that would be provided from the utilization facility. The estimation of this decrease can be obtained by taking into account the energy efficiency of the recuperator ε,%, which shows what part of the available heat from the heating gas flow is transferred to the heated fluid. This indicator for well-functioning facilities is over 60% [18, 21], but in this case, again for reasons of choosing a less favorable investment option in the technical-economical calculations, it will be accepted for 45% (this value practically coincides with the lowest result for the heat exchangers offered in [18]). In this case, the „saved" heat output would amount to:

$$Q' = \frac{\varepsilon Q}{100} = \frac{45 \cdot 192}{100} = 86.4 \text{ kW}. \qquad \textbf{(18)}$$

Assuming that the natural gas has a lover specific heating value $Q_l = 47000$ kJ/kg and a density $\rho = 0.78$ kg/m^3 [13], and its volumetric flow rate to the burner for covering only this heat output is marked with B, m^3/s, the last indicator is determined as follows:

$$B = \frac{Q'}{Q_o^p \rho} = \frac{86.4}{47000 \cdot 0.78} = 0.0023566 \text{ m}^3/\text{s}. \qquad \textbf{(19)}$$

At first glance, the result obtained seems modest, but at a continuous production cycle of the industrial site and taking into account only the already mentioned short-term downtime, it corresponds to an annual consumption of fuel used for this purpose, amounting

to:

$$0.0023566 \cdot 3600 \cdot 8000 = 0.0023566 \cdot 3600 \cdot 8000 = 67870 \text{ m}^3.$$

With all the reservations already made for the rapid and largely uncontrollable development of the political and resulting from them economic processes after the beginning of February 2022, as a relatively representative and realistic at the time of the current calculations can be considered the approximate price of natural gas 1000 EUR/1000 m^3. Therefore, using a recuperator for one year would save the company 67870 EUR.

According to the data from Table 2, the more expensive variant No. 1 is characterized by $E_{sum} = 56044$ EUR/a, i. e. during the first

$$\frac{56044}{67870} 12 = 0.8257551 \cdot 12 = 9.91 \approx 10$$

months of each year the savings resulting from the use of this heat exchanger manage to cover all related to it costs, including operating ones for November and December, and in the last two months this energy saving measure brings a net financial benefit to the company of over 11800 EUR.

After the expiration of the redemption term (the depreciation period) of the facility, the expected benefits would increase to the sum $67870 - 44800 = 23070$ EUR/a. Even if the company decides to cover 100% of the investment with its own funds, which in the current unstable financial situation and at the same time low rates on loans would not be recommended, calculations show that the full amount of capital investment would pay off in just under 1 year and 10 months, after which only the operating costs will have to be covered, i. e. from the second year until the end of the use of the recuperator a profit of over 23070 EUR/a would be realized.

It should be noted that the latter statements are valid while maintaining the same price of natural gas. Its forecasting for a period of 10 to 20 or 30 years is impossible, but it is obvious that the trend of its appreciation will continue, which would further increase the real economic effect of heat recovery.

The choice of the natural gas as a fuel is not the only opportunity, nor is it the most typical situation for an enterprize where there are significant quantities of wood waste suitable for heating purposes. This option is discussed because for the indicators of that energy carrier there is the most massively announced and widely recognized information, which is why it can be considered objective and universally valid. In addition, the good heat engineering, fuel-technical and environmental characteristics of natural gas, as well as its relatively affordable price in the recent past, have made it a preferable to use. This process was also supported by the started gasification, including in less populated areas in the country.

Of course, the conclusions drawn from the results of the technical-economical calculations presented here would be valid to a similar extent for heating based on fuel oil, as for the prices of petroleum products there are similar trends to increase rapidly due to the appreciation of the raw material for their production.

If solutions are sought related to a use of local fuels, the value of which is more advantageous, their reduced fuel-technical characteristics must be taken into account, while at the same time their environmental performance deteriorates sharply. The latter circumstance would create more and more serious legislative problems and costs for their avoidance by construction and operation of treatment plants, or for covering the imposed sanctions in the absence of sufficiently effective ecological measures.

In view of the options briefly described, it may be recommended that each individual

site have at least two alternative energy sources, and even better, three. A good combination, for example, is a local heating boiler running on traditional (solid, liquid and/or gaseous) fuel and electricity. Naturally, through the use of RES, a variety of modern and very efficient combinations become acceptable, guaranteeing not only reduced current costs, but also higher energy independence. In the specified category for heating purposes are suitable heat pumps (with possible options for combinations of heat carriers), solar collectors for hot water or hybrid modules for electricity and heat production from sun radiation), systems that otherwise utilize geothermal energy, such as direct heating with enough hot mineral water, etc.

It should be emphasized that the adoption of any variant leads to a facility with significant dimensions and space necessary for its maintenance, which requires the provision of a sufficiently large engine room.

In all cases, the choice of a specific engineering solution must be preceded by an in-depth technical-economical analysis conducted on the basis of a preliminary research and a comprehensively prepared assignment by the potential investor.

CALCULATIONS FOR THE IMPACT ON THE ENVIRONMENT, RESULTS AND DISCUSSION

The environmental impact of the flue gases coming out of the furnace should also not be neglected. If typical values are chosen for the volume of smoke emitted at the completely combustion of 1 m^3 of gaseous fuel at normal conditions and supplying the actually necessary amount of air to maintain the process $V_{sm} = 12.83$ m^3/m^3 and its carbon dioxide content $CO_2 = 9.00\%$ [4], the volume of this greenhouse gas emitted into the atmosphere in one year turns out to be: $67870 \cdot 12.83 \cdot 0.09 = 78370$ m^3/a. Taking into account that the density of this environmentally harmful compound at 273 K is 1.9767 kg/m^3 [4], the mass of its annual emission will amount to $78370 \cdot 1.9767 =$ 154914 kg/a or close 155 t/a.

The „green effect”of the introduction of heat recuperation of polluted exhaust air from this room can be illustrated by the following example [4]. If a modern car has emissions of CO_2, equal to 150 g/km and an annual run 20000 km, achieving the above-mentioned natural gas savings from the furnace would lighten the atmosphere in the same way as the simultaneous stopping from movement of $154914/(0.15 \cdot 20000) = 51.6$ personal motor vehicles. This value could exceed the number of all cars in the car park of the woodworking or furniture enterprize in question. In other words, the effort of the company's management to install a suitable recuperator would have the same impact on the environment as such a drastic measure, in that without any deprivation and discomfort on the part of its staff. Of course, parallel efforts to reduce emissions from the use of personal transport, which undoubtedly also have ecological, social and educational effects, should not be underestimated.

CONCLUSIONS

The analysis of the results of the conducted calculations on the change of the technical-economic and environmental indicators of the enterprises from the woodworking and furniture industry due to the introduction of heat recuperation of the exhaust (polluted) air from their ventilation installations gives grounds for the following summary.

- While maintaining the currently accepted as actual prices, the construction of a heat recovery facility would save the selected company 67870 EUR/a throughout its period of use.

- The comparison of this economic effect with the capital, operating and total costs even for the more expensive version of the recuperator layout with the economic effect of its inclusion in the installation shows that in each of the 10 years for the payment of the heat exchanger, financial benefits manage to cover all related expenses in the first less than 10 months, including operating such for November and December, and in the last two months the adoption of this energy saving measure brings a net profit of the enterprize over 11800 EUR.

- The expected advantages after the expiration of the redemption term (the depreciation period) of the facility increase to the amount of 23070 EUR/a.

- After the full repayment of the capital investments for the recuperator, the benefits of heat utilization would amount to the already mentioned level 23070 EUR/a. Even if the company takes the inadvisable decision to finance 100% of the investment with its own funds, the entire amount for capital inputs would be paid in just under 1 year and 10 months, after which only operating costs will have to be covered, i. e. from the second year until the end of the recuperator's use a profit of 23070 EUR/a would be realized.

- The environmental impact of the introduction of a facility for utilization of heat from the polluted exhaust air from the considered room is to reduce of the carbon dioxide emissions by nearly 155 t/a, which is equivalent to stopping from movement of more than 50 average personal motor vehicles.

- Other options for choosing a recuperator and an energy source to provide heating of the studied site were also treated.

- The formulated recommendations based on the alternatives regarded, as well as the conclusions proposed above based on the analysis of the heat exchanger examined in detail, have a practical focus and would contribute to improving the technical-economical and environmental performance of wood and furniture enterprizes.

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OPTIMIZATION OF WAREHOUSE AREAS FOR FINISHED PRODUCTS IN FURNITURE INDUSTRY ENTERPRISES

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ABSTRACT

The main elements in a warehouse structure are the area, volume and arrangement. These main factors influence the necessary capacity for storage of finished products, and hence the logistical competitiveness of furniture industry enterprises.

The paper discusses the issues and possibilities for applying a mathematical model for managing warehouse stock of finished products in furniture companies, taking into account the estimated size of packaging, the number of packages per product and the number of products produced in enterprises. To find the optimal area for storage of finished products, an innovative method for finding a solution was used. In this way, a local and global information advisory module was created for a rational decision-making by the warehouse staff in production enterprises of the furniture industry regarding the warehouse area arrangement.

Key words: Multi-item EOQ with storage limitation, optimal storage, stock availability.

ОПТИМИЗИРАНЕ НА СКЛАДОВИТЕ ПЛОЩИ ЗА ГОТОВА ПРОДУКЦИЯ В ПРЕДПРИЯТИЯ ОТ МЕБЕЛНАТА ПРОМИШЛЕНОСТ

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РЕЗЮМЕ

Основни елементи в структурата на складовите комплекси са площта, обемът и начина на подреждане. Тези основни фактори оказват влияние върху необходимият капацитет за складиране на готовата продукция, а от там и върху логистичната конкуренто способност на предприятия от мебелната промишленост.

В статията се разглежда въпроса и възможностите за прилагане на математически модел за управление на складови наличности на готовата продукция в мебелни предприятия, като се взимат предвид габаритните размери на техните опаковки, броя опаковки комплектуващи едно изделие и броя на изделията произвеждани в предприятията. Чрез разработване на математическия модел с нелинеен подход за търсена оптималната площ за складиране на готовата продукция. По този начин се създава локален и глобален информационен съветващ модул за вземане на рационални решение от складовия персонал в производствените предприятия от мебелната индустрия относно подреждането на складовите площи.

Ключови думи: Многопродуктов количествен модел с ограничение капацитет на склада Multi-item EOQ with storage limitation, оптимално складиране, складова наличност.

УВОД

Основна част от всяка верига на доставки е складовата логистика. Терминът „логистика“ произхожда от древногръцката дума „logistike”, означаваща „мислене, разчет, целесъобразност“[8]. Обикновено, преди транспортиране на готовата продукция от предприятията в мебелната промишленост до търговската мрежа, стоките се съхраняват в складове. Склад е помещение за съхранение на големи количества стоки и материали. В тях постоянно пристигат стоки, съхраняват се за определен период от време, след което се експедират до адрес [4], [5]. В днешно време складовете стават все по-търсени до степен, че дори понякога се стига до недостига им в определени райони в страната. Добро управление на складовите площи в предприятията от мебелната промишленост осигурява икономия на разходи по поддържане на складова наличност. Това от своя страна им осигурява по-голяма конкурентноспособност на мебелния пазар.

ТЕХНИКО-ИКОНОМИЧЕСКИ ИЗЧИСЛЕНИЯ, РЕЗУЛТАТИ И ДИСКУСИЯ

В мебелно предприятие се произвеждат и съхраняват на склад 5 продукта. Готовите продукти се събират в кашони [6] с размери представени в табл. 1. От предприятието са направили анализ и са определили месечното търсенето в проценти за всеки един продукт складиран в склада, данните са въведени в последната колона на таблица 1. Работния обем на склада е 1500 m^3. От фирмата са установили, че не могат да съхраняват запаси от продуктите, които да отговарят на максималното търсене. Това налага да се проведе изследване чрез което да се намери количеството съхранявано за всеки един продуктите произвеждани в предприятието.

Таблица 1: Входни данни

Продукт	Дължина [m]	Ширина [m]	Височина [m]	Минимално месечно търсене [брой]	Максимално месечно търсене [брой]	Търсене на продукта [%]
1	1,16	1,1	1,2	120	780	60
2	1,20	0,8	1	50	95	7
3	1,10	1,1	0,5	60	85	6
4	1,10	1,1	1,2	60	120	10
5	0,80	1,03	0,83	80	200	14

Описание на задачата

В мебелните предприятия, като всички други производства се стремят изцяло да отговорят на изискванията на своите клиенти. Това налага да се поддържат нужните запаси от суровини, изправни машини и инструменти, налични работници, финансови капитали и др. От друга страна е необходимо много добро организиране на доставките на суровини, на готова продукция, оптимизирането на складовите наличности и използване на максималния капацитет на съоръженията. Анализирането и управлението на всички тези параметри на производство изисква използването на голямо количество данни и информационни системи за обработване и съхранението им.

Поради факта, че фирмата ни е предоставила, ограничено количество данни и ясно е формулирала конкретен проблем, изследването се ограничава до намиране на количествата от продуктите, необходими да се съхранявани в склада, при известен обем на склада и обема на всеки отделен кашон готова продукция . От наличните данни може да се изгради мате-

матически модел, чрез които да се определят не известните количества за всеки един от продуктите [1], [7].

Описание на математическия модел

Целта на изследването е да се разработи математически модел, чрез които да се определят количествата от всеки един от продуктите съхранявани в склада. При известни данни за размерите на кашоните, в които се съхранява готовата продукция и работен обем на склада [2].

Параметри на математическия модел

i – индекс на продукта;

L_i – Дължина на кашона за съхранение на продуктите;

W_i – Ширина на кашона за съхранение на продуктите;

V_i – Обем на кашона за определен продукт;

H_i – Височина на кашона за съхранение на продуктите;

D_i – Търсене на продукт i;

CD_i – изчислена наличност за продукт;

A – Обем на склада m^3;

Amax – Необходима площ m^3;

UA – използван обем от склада UA = $\sum v_i x_i$;

Diff – разлика между необходимата площ и използвания обем от склада;

Целевата функция на математическия модел

Diff= min(Amax-$\sum v_i x_i$)

X_i – търсеното количество съхранявано в склада

Ограничение на модела

Ограничение относно използваната площ в склада

$\sum v_i x_i \leq$ A

Ограничение относно наличността на продуктите

CDi ≥ Di

Ограничение относно количеството на продуктите

Xi -цели числа

$X_{mini} \leq X_i \leq X_{maxi}$

X_{mini} – минимално търсене на продукт i

X_{maxi} – максимално търсене на продукт i

X_T – Общ брой продукти съхранявани в склада

Числово представяне на задачата

Целева функция на модела

Търси се минимум на функцията

Diff = 1,5312*(780-X_1) + 0,96*(95- X_2) + 0,605*(85-X_3) + 1,452*(120-X_4) + 0,68392*(200-X_5) (1)

Ограничения на задачата

Ограничение относно площта на склада

1,5312*X_1 + 0,96*X_2 + 0,605*X_3 + 1,452*X_4 + 0,68392*X_5 ≤ 1500 (2)

Ограничения относно количества съхранявани в склада за всеки един от продуктите

$120 \leq x_1 \leq 780$ (3)

$50 \leq x_2 \leq 95$ (4)

$60 \leq x_3 \leq 85$ (5)

$60 \leq x_4 \leq 120$ (6)

$80 \leq x_5 \leq 200$ (7)

x1, x2, x3, x4, x5 – цели числа

Ограничения относно процентната наличността на продуктите

$x_1/x_T \geq 0,6$ (8)

$x_2/x_T \geq 0,07$ (9)

$x_3/x_T \geq 0,06$ (10)

$x_4/x_T \geq 0,1$ (11)

$x_5/x_T \geq 0,14$ (12)

ИЗЧИСЛЕНИЯ , РЕЗУЛТАТИ И ДИСКУСИЯ

Решение на задачата

Входните данни на задачата се въвеждат в работения лист на MS Excel. На фиг. 1 е представена задачата в работния лист на Excel

С намиране на решение на задачата се определя минималната разлика между необходимата площ за съхранение на продуктите в момент на най-голямо търсене и използваната площ за съхранение на определените оптимални количества от продуктите. Оптималните количества на работния лист се представят на фиг. 1, маркирани с жълт цвят. Резултатите от изчислението на целевата функция Diff се представят в клетка E19 маркирана в зелено на фиг. 1.

Стойността за необходимата площ за съхранение на продуктите при максимално търсене се изчислява в клетка A19, чрез функцията

=SUMPRODUCT(B12:F12;B7:F7),

а в клетка C19 се изчислява използваната площ за съхранение на оптималните количества на продуктите, като използва функцията

=SUMPRODUCT(B10:F10;B7:F7).

Стойността в клетка C15 се изчислява използваната площ за съхраняване на продуктите, която е по-малка от 1500 m^3. Това е ограничението за работната площ на склада.

Стойностите в клетките за търсените количества B10:F10, трябва да са по-малки или равни от стойностите за максимално търсене, B12:F12 и също така да са в по-големи или равни от стойностите за минимално търсене, B8:F8.

В клетката B13 се изчислява стойността за процентно количество за продукт 1, чрез формулата =B10/$E$21, която се копира и за другите продукт в клетките от B14 до F13.

	A	B	C	D	E	F
1						
2	**Входни данни**					
3	Продукт	1	2	3	4	5
4	Дължина [m]	1,16	1,20	1,10	1,10	0,80
5	Ширина [m]	1,1	0,8	1,1	1,1	1,03
6	Височина [m]	1,2	1	0,5	1,2	0,83
7	Обем [m3]	1,5312	0,96	0,605	1,452	0,68392
8	Минимално търсене [брой]	120	50	60	60	80
9		<=	<=	<=	<=	<=
10	Оптимална стойност [брой]	698	95	71	120	179
11		>=	>=	>=	>=	>=
12	Максимално търсене [брой]	780	95	85	120	200
13	Изчислена наличност [%]	0,600	0,082	0,061	0,103	0,154
14		>=	>=	>=	>=	>=
15	Търсене на продукта [%]	0,6	0,07	0,06	0,1	0,14
16						
17	***Решение***					
18	Необходима площ [m3]		Използван обем на склада		Разлика	
19	1647,985	-	1499,59428	=	148,3907	
20			>=			
21	Капацитет на склада [m3]		1500	Общ брой артикули	1163	

Фигура 1: Представяне на задачата в работен лист на Excel

Решение на задачата с Solver

На фиг. 2 е представен панела за решаване на задачата с инструмента Solver н MS Excel.

В полето *Set Objective* се въвежда клетката на целевата клетка, която е минималната разлика между необходимата и използваната площ. клетка E19 на работния лист. Уравнение 1 от числото представяне на задачата.

В полето *By changing Variable Cells* се въвеждат клетките, които ще се променят за да се намери количеството за всеки продукт съхраняван в склада. Това са клетките на работния лист на Excel от B10 до F10.

Ограничения на задачата се въвеждат в полето *Subject to constraints*

Чрез израза

$B$10:$F$10=>$B$8:$F$8 се въвежда ограничението за минималното търсене на продуктите.

Чрез израза

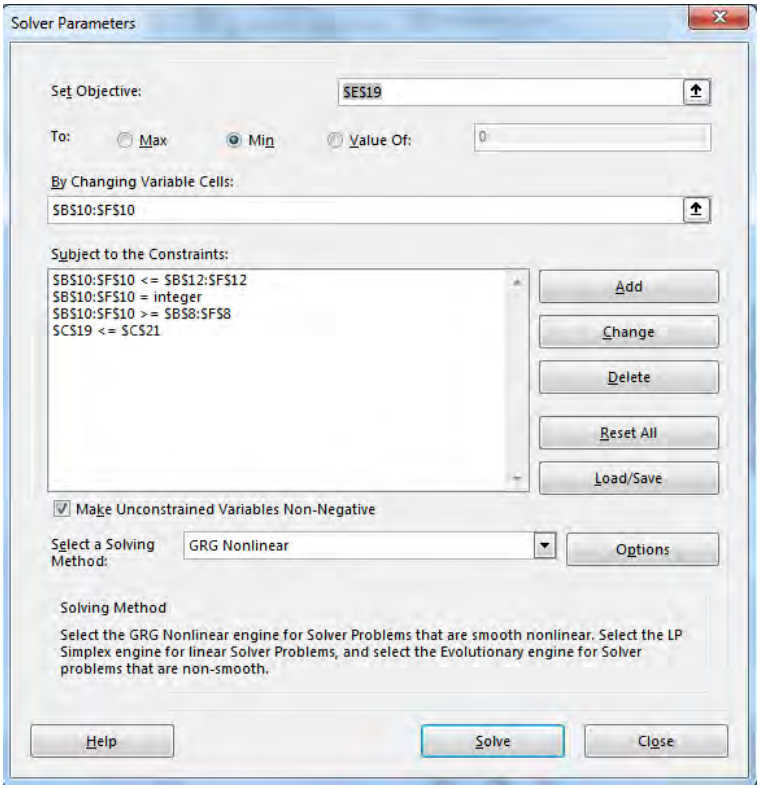
$B$10:$F$10<=$B$12:$F$12 се въвежда ограничението за максимално търсене на продуктите.

С ограничението

$B$10:$F$10= integer се ограничава намерените стойности за продуктите да са цели числа.

C19<=C21 се въвежда ограничението за относно площта на склада

Метода, чрез който се търсят оптималните количества за всеки един продукт е GRG Nonlinear.



Фигура 2: Панел на инструмента Solver

Анализ на получените резултати

След решаване на задачата с Solver е намерено, че минималната разлика е 148,39072 m^3, т,е това е недостигащата площ за съхранения на продуктите в момент на пиково търсене на продуктите. И също така е установено, че оптималното разпределение на продуктите е x_1=698;

x_2=95; x_3=71; x_4=120; x_5=179, при цялостно запълване на работната площ на склада.

Резултатите от полученото решение графично са представени на фиг. 3. На фигурата със син цвят е представено минималното, със сив цвят максималното, а с оранжев цвят оптималното търсене на продукта. От нея ясно се вижда, получените резултати са много близки до максималните.



Фигура 3: Разпределение на количествата по продукти

В табл. 2 са представени в проценти запасите за всеки един продукт от максималното търсене. От нея се вижда, че наличността за продукти 2 и 4 е 100%, а за всички останали е над 83%

Таблица 2: Наличност на продуктите в%

Оптимално търсене	698	95	71	120	179
Максимално търсене	780	95	85	120	200
Наличност%	89,49	100,00	83,53	100,00	89,50

ЗАКЛЮЧЕНИЕ

В статия се представя оптимизационен модел за склад на мебелно предприятие, чрез които се определя оптималните количества за всеки един от продуктите складирани в помещението. Чрез него се предлага конкретно решение за разпределение на продуктите при спазване на предварително определението ограничения на задачата относно наличност и площ на помещението.

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APPLICATION AND TRENDS IN CNC MACHINES IN THE FURNITURE INDUSTRY IN BULGARIA

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ABSTRACT

The report examines some of the main trends in the development of furniture industry in Bulgaria and provides a brief overview of the development of CNC technologies in it. Some of the most important advantages and disadvantages of digitalized technological equipment are analyzed. Specific examples of some of the most modern, efficient and technologically advanced CNC machines implemented in the production processes of Bulgarian furniture enterprises are presented. A brief classification of CNC milling and drilling machines is made depending on the number of interpolated axes of movement and the characteristics of the worktable. In conclusion, some of the challenges facing industry and university professors in the field of furniture and wood products manufacturing are formulated.

Key words: CNC machines, CNC woodworking centers, furniture industry.

ПРИЛОЖЕНИЕ И ТЕНДЕНЦИИ ПРИ CNC МАШИНИ В МЕБЕЛНАТА ИНДУСТРИЯ В БЪЛГАРИЯ

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РЕЗЮМЕ

В работата са разгледани някои тенденции в развитието на мебелната индустрия в България и е направен кратък обзор на развитието на CNC технологиите. Разгледани са някои основни предимства и недостатъци на цифровизираното технологично оборудване. Представени са конкретни примери на някои от най-съвременните, ефективни и технологични CNC машини внедрени в производствените процеси на български мебелни предприятия. Направена е кратка класификация на CNC фрезово-пробивни машини в зависимост от броя на интерполираните оси на движение и характеристиките на работната маса. В заключение са формулирани някои от предизвикателствата пред индустрията и преподавателите в областта на производството на мебели и изделия от дървесина.

Ключови думи: CNC машини, дървообработващи центри, мебелна индустрия.

ВЪВЕДЕНИЕ

Мебелната индустрия в България е с дългогодишни традиции, а по-голямата част от произведената продукция през последните петдесет години традиционно е реализирана на външните пазари. Днес мебелната и дървообработващата промишлености формират близо 4% от БВП на България, заетите в сектора са над 45000 души, а над 85% от продукцията е предназначена за износ (по данни на БКДМП). Всички тези добри показатели свидетелстват за това, че през годините, мебелната индустрия в България се е развивала съобразно последните техноло-

гични тенденции и днес е конкурентноспособна на световните пазари. Механизацията и автоматизацията в дървообработващата и мебелната промишленост на България както в условията на планово стопанство и държавна собственост на предприятията, така и в условията на пазарно стопанство и частна собственост винаги е била добре развита за времето си (Шехтов 2020a, Шехтов 2020b). Днес всички индустриални мебелни предприятия в България разполагат с технологично оборудване с CNC (Computer Numerical Control) управление. Макар абревиатурата CNC да е заимствана от английския език, през последните 15–20 години се е налага и измества традиционното българско съкращение ЦПУ (Цифрово Програмно Управление). Поради широкия спектър от възможности за изпълняване на различни технологични операции, като рязане, пробиване, гравиране, шлифоване, кантиране и др. в практиката тези машини са придобили наименованието CNC центрове. Най-общо индустриалните машини с цифрово управление се състоят от работна маса, работен орган, с или без възможност за софтуерно управляема смяна на режещия инструмент, и пулт за управления. CNC машините работят с кодирана информация за всички действия, при която и да е обработка на материалите. Компютърна система управлява задвижването на инструментите, режимите на работа на двигателя, смяната на режещия инструмент и др. При този вид машини ръчните операции са сведени до минимум, като те се отнасят най-вече до поставянето и свалянето на обработваните материали и детайли от машината. Използването на CNC технологично оборудване е предпоставка за обработване на детайлите с висока геометрична точност, ниска грапавост на обработените повърхнини и висока производителност (Кавалов 2014, Гочев 2018). Като недостатък при внедряването и използването на този вид високотехнологично оборудване може да се отбележи необходимостта от квалифицирани оператори, които притежават високи дигитални умения, съчетани с добри познания за характеристиките на материалите, режещите инструменти и режимите на рязане, при които се обработват. В стремежа за осигуряване на все по-голяма производителност и качество на обработените детайли. CNC машините и тяхната работа са обект на редица научни публикации свързани с: i. тяхното софтуерно осигуряване; ii. динамичното им поведение по време на работа; iii. подобряване характеристиките на режещите инструменти и режими на рязане (Karagoz 2011, Pinkowski 2013, Kminiak 2016, Palubicki 2016, Kminiak 2017a, Kminiak 2017b, Nemec 2017, Вичев 2020).

Настоящата статия има за цел да представи кратък обзор на развитието, състоянието и тенденциите на CNC технологиите и машините в мебелната индустрия в България, като едновременно с това се направи и класификация на CNC машините, намерили най-широко приложение при обработването на дървесина и материали на дървесна основа в нашата страна.

Кратък исторически преглед на развитието на CNC технологиите в България

*Първите системи за ЦПУ в България са произведени в средата на 7*0-те години на миналия век и са компилирани в металообработващи стругове с ЦПУ, произвеждани в тогавашния завод „Електра“. Цифровизирането е по лиценз на фирмата *Fanuc* (Япония), която работи по

цифровизация на машини още от 1956 г. *В началото на осемдесетте години е придобит нов лицензна ЦПУ от Fanuc* 5 и 6, който е внедрен в Завода за изчислителна техника (ЗИТ). В началото на 80-те години не се е предлагало програмно управление, вградено в хардуера. В началото на 90-те години на двайсети век е създадена българската фирма „Микротел“, която през годините се доказа като производител на надеждни и прецизни CNC машини за разкрояване, фрезоване, гравиране, направа на отвори и др. Част от продукцията на фирмата се реализира на външните пазари. *Друга българска фирма, наложила се на пазара, е* “АДП – Смолян” ООД. Дейността ѝ е ориентирана в проектиране и производство на автоматично оборудване за промишлеността и по-конкретно в производството на стандартни и нестандартни CNC машини.

Една от първите CNC машини в дървообработващата и мебелната промишленост в България е внедрена през 1986 г. във фирма „Бряст-Д“ АД, гр. Добрич, която е специализирана в обработката на масивна дървесина (Гочев 2018). Инсталираната машина е фрезов център на световно известния концерн SCM (Италия). По-късно през годините постепенно и в други мебелни предприятия се внедряват високотехнологични фрезово-пробивни CNC машини (Шехтов 2020b). Днес в българската мебелна индустрия са внедрени разнообразни дървообработващи CNC машини на редица водещи европейски производители, в т.ч. Homag Group (Германия), Weinig (Германия), Holzher (Германия), IMA Klessmann (Германия), SCM (Италия), Biesse (Италия), Paolino BACCI (Италия), Pade (Италия), FELDER (Австрия) и др. Важно е да се отчете, че всички посочени фирми имат представителства в България и осигурен сервиз за предлаганото от тях технологично оборудване.

Класификация на някои внедрени CNC мебелни машини в България

Разнообразието на CNC машини внедрени в българската мебелна индустрия е изключително голямо според тяхното предназначение, в т.ч. фрезови машини, циркулярни машини, пробивни машини, универсални банцизи, шлайфмашини и др. През годините в практиката е възприето, към групата на CNC машините да се причисляват предимно фрезово-пробивни машини. Най-вероятно това схващане е в резултат на това, че чрез фрезоване се оформят най-сложните геометрични контури. Машините с цифрово управление използват правоъгълна и полярна координатна система за програмиране на преместванията. Съкращението CNC се отнася специално за компютърен контролер, който чете инструкции на *G*-код и управлява машинния инструмент – устройство, захранвано с електрически ток, с което се създават компоненти чрез селективно отнемане на материал (Гочев 2018).

Технологичните възможности и сложността на детайлите, които могат да бъдат обработвани на дадена CNC машина зависят от прецизното управление на преместването по различни оси на движение. Първите внедрени CNC машини в български мебелни предприятия са с 3 софтуерно управляеми оси на движение на движение (*X, Y, Z*) – извършващи праволинейни премествания на работния орган или масата на машината. С развитието на CNC технологиите към цифровизацията на машините се добавят още две допълнителни оси (*A, B*), т.е. машината е с 5 интерполирани оси на управление. Двете

допълнителни оси осигуряват извършването на въртеливи движения на машинния инструмент. Днес при някои CNC машини освен линейното преместване на работния орган на машината има възможност и за линейно преместване на работната маса, с което управляемите оси на машината се увеличават с още 1 или 2 в зависимост от броя на работните маси. Днес, предимно от икономически съображения, на пазара се предлагат CNC машини с различен брой на софтуерно интерполираните оси на придвижване.

Освен според технологичното им предназначение и броя на цифрово управляемите оси на движение, CNC машините в дървообработващата и мебелната промишленост (ДМП) могат да се класифицират и в зависимост от конструкцията си. В конструктивно отношение фрезово-пробивните CNC машини използвани в мебелната индустрия могат да се представят най-общо в четири основни групи (Халим, 2022):

- CNC машини с гредова (конзолна) работна маса (фиг. 1.А);
- CNC нестинг машини (фиг. 1.Б);
- CNC машини с портална конструкция (фиг. 2);
- Преносими CNC машини (фиг. 3).

При CNC машините с гредова (конзолна) работна маса, обработвания детайл се поставя върху вакуумни захващащи устройства, които са поставени върху греди, формиращи работната маса на машината (фиг. 1.А). Разстоянието между отделните греди (по ос *x*) и разстоянието между вакуумните захващащи устройства (по ос *y*) може да се променят в зависимост от размерите и геометрията на обработвания детайл. Този тип CNC машини са сред първите, които навлизат през годините в мебелната индустрия. Използват се предимно при производство на мебелни детайли и такива за врати и прозорци. Днес основните изпълнявани технологични операции са свързани с фрезоване по кант и страна, направа на отвори, кантиране и др. Подобен тип технологично оборудване, на различни европейски производители, е внедрено в редица малки, средни и големи мебелни предприятия в България, сред които: Булдекор, Ирим, Ергодизайн, Мебелор, Мебели Валди, Ретро М, Валиян, Колорадо, Интериор И, Фантастико мебел, М2 Пром и мн. др.



***А*)** **Б)**

Фигура 1: Общ вид на CNC фрезово-пробивни машини (Homag, Германия):
***А*) с гредова работна маса, модел Centateq R110;**
***Б*) с нестинг работна маса, модел Centateq N500**

При CNC нестинг машините работната маса е изработени от листов композитен материал на базата на фенолни смоли и синтетични влакна (фиг. 1.Б). Повърхността на работната маса е разделена от глухи канали под формата на решетка,

към която се подава вакуум през специални отвори. Този тип CNC машини са подходящи за обработване на едрогабаритни плоски материали от плочи от дървесни частици (ПДЧ), плочи със средна плътност (MDF), шперплат и др., а основните изпълнявани технологични операции са направа на отвори и фрезоване. През последните години този тип машини намират по-широко приложение при производството на мебели, поради по-доброто оптимизиране на плочестите материали и възможността за обработка на детайли с малки размери.

CNC машините с портална конструкция (фиг. 2) са предимно със специално предназначение, например детайли за производство на столове, прозорци и др. Представената като пример CNC машина е предназначена за обработване на линейни детайли, например крака на столове и др. Тя е конструирана с общо дванадесет интерполирани софтуерно управляеми оси и на нея могат да се извършват редица операции като: пробиване, фрезоване, рязане, направа на длабове и чепове. Машината е оборудвана с две оперативни глави (фиг. 2.А), всяка от които може да бъде оборудвана с един или два електрически шпиндела, на всеки от които могат да се монтират съответно два или четири режещи инструмента (фиг. 2.Б). Машината разполага с две работни маси, които могат са работят както независимо, така и в синхрон, като една маса.



Фигура 2: Специализирана CNC фрезово-пробивна машини, модел Double Jet (BACCI, Италия): *А*) Общ вид – машина и захранваща станция; *Б*) Работна глава с четири режещи инструмента; В) Работна маса и захващане на детайлите

Детайлите се фиксират на работната маса посредством пневматични скоби, които могат автоматично да се движат линейно по осите *X* и *Z* (фиг. 2.В). Детайлите, подлежащи на обработка се подреждат в захранваща станция, а вече обработените в разтоварна станция (фиг. 2.А). Автоматизираното захранване и разтоварване на детайлите значително повишава производителността на машината. CNC машина, модел Double Jet (фиг. 2) е внедрена в технологичния процес на фирма ЕЛИМЕКС, гр. Троян, която специализирана в производството на маси и столове. Подобен тип CNC машини са внедрени в производствата на фирми Средна Гора (гр. Стара Загора), Рико Стил (гр. Троян), ЕТ Катя Стойнева (гр. Велинград) и др.

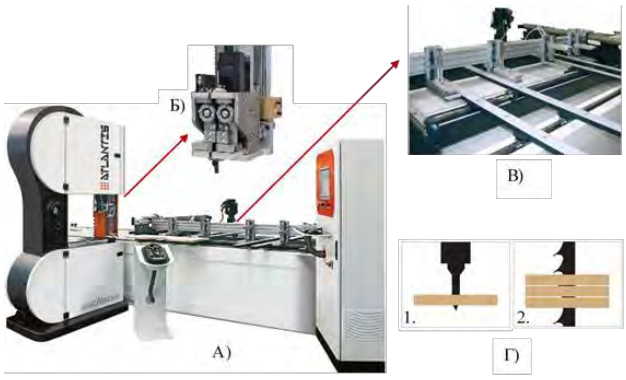
Цифровизацията на машините се е развило до такава степен, през последните 6-7 години, че освен при индустриалните машини вече се произвеждат ръчни оберфрези със CNC управление (Халим 2022). Този тип машини намират приложение при по-малки производства, при довършителни и монтажни работи или за изработване на шаблони и прототипи. Като пример за такъв тип машина може да бъде представена една от първите ръчни CNC оберфрези, модел Shaper Origin (фиг. 3).



Фигура 3: CNC оберфреза модел Shaper Origin: А) общ вид;
Б) екранна снимка на дисплея на машината в процес на рязане

Машината разполага с три софтуерно управляеми оси – *X, Y* и *Z*, като преместването по оси *X* и *Y* е интерполирано. Движението на шпиндела по ос *Z* определя дълбочината на обработване, която се задава софтуерно при създаване на програмата за управление. В процеса на рязане движението по ос *Z* не може да се променя. В процеса на обработване, на дисплея на машината се визуализира геометрията на рязане, оста на въртене на режещия инструмент и зоната на самокоригиране на шпиндела по оси *X* и *Y* (фиг. 3.Б). В случай че в процеса на водене на машината, операторът излезе от геометрията на рязане, повече от зоната на саморегулиране, шпинделът на машината се прибира автоматично. Обработваните детайли могат да бъдат поставени върху всяка хоризонтална равна повърхност, т.е. няма изисквания към конкретна работна маса. Машината се самоориентира в пространството благодарение на предварително залепени върху обработвания детайл хартиени ленти (Shaper Tape), разработени и предлагани от фирмата производител (фиг. 3). Върху лентите е отпечатан произволен уникален код, който се разчита от сканиращата камера, разположена на предния панел на машината. Сканираната информация се подава към софтуера на машината. Към този момент е известно, че в България са въведени в експлоатация три машини от този тип, като едната от тях е в катедра „Дървообработващи машини“ на Лесотехническия университет и се използва за учебния процес със студентите.

Друга съвременна CNC машина въведена в производството на няколко мебелни фирми в България, сред които „Средна гора“ АД, Стара Загора (производство на маси и столове) и „Руди-Ан“, Варна (производство на тапицирани мебели) е цифровизирания универсален банциг модел Atlantis (Veneta Machina, Италия), който разполага с три интерполирани софтуерно управляеми оси на движение (фиг. 4).



Фигура 4: CNC банциг модел Atlantis (Veneta Machina, Италия): А) общ вид – банциг, работна маса, пулт за управление; Б) лентоводител; В) работна маса; Г) сравнителна графика във височината на рязане между челен фрезер 1. и лентов трион на Atlantis 2.

Най-общо машината се състои от: i. вертикален банциг с възможност за завъртане на лентовия трион от ±0 до ±90 градуса; ii. работна маса, която осигурява подаване на детайлите за обработка по оси *X* и *Y* (фиг. 4.В); iii. оперативен компютър за въвеждане на управляващата програма. Банцигът е предназначен за рязане по праволинеен и криволинеен контур на детайли от масивна дървесина и материали на дървесна основа.

Едно от основните предимства на тази машина е голямата височина на рязане до 150 mm, малката широчина на прореза и възможността за обработване на детайли с малка широчина (фиг. 4.Г). За сравнение, други машини за криволинейно рязане с цифрово управление имат дълбочина на рязане от около 60 mm при по-голяма широчина на прореза. Устойчивата работа на лентовия трион и възможността му за завъртане по време на рязане до ±90° се осигурява от два огледално разположени сервозадвижвани лентоводителя (фиг. 4.Б). Въртящият се лентов трион може да реже контури и форми до минимален радиус от 50 mm. Цифровизираният банциг модел Atlantic може да бъде компилиран като част от по-голяма CNC фрезово-пробивна машина.

ЗАКЛЮЧЕНИЕ

Представената по-горе информация не изчерпва разнообразието и видовете CNC машини внедрени в мебелната индустрия в България. Тя е само пример на базата на който може да се обобщи, че развитието на мебелните предприятия в страната по отношение цифровизацията на машинния парк е на много високо ниво. Благодарение на различните си модификации, приложение и характеристики различни CNC машини са намерили своето широко приложение в българската мебелна и дървообработваща индустрия и са се превърнали в неизменна част от съвременното индустриално производство. Едновременно с това не спира стремежът за непрекъснато подобряване на възможностите им както в технологично отношение, така и в програмното им осигуряване.

С въвеждането на CNC технологиите коренно се променя производствената индустрия в т.ч. мебелната и дървообработващата. Значително се увеличава автоматизацията в производствените процеси, обработват се детайли със сложна геометрия при това с повишено качество и значително съкратено време за обработка. Улеснява се също и изработването на сравнително сложни 3D обекти, което при стандартна структура на изработка би отнело много време и усилия, същевременно се променя и броя на машинните операции, които изискват човешка намеса. Наличието на различни софтуерни функции при CNC машините дават възможност за виртуално моделиране на обработката директно на самата машина, като представят анимация на процеса на обработка.

Като недостатък при внедряването на CNC машини в производствени условия може да се посочат: високата цена на подобен тип технологично оборудване; необходимостта от квалифицирани оператори както с добри дигитални умения, така и със знания необходими за производството на мебели; високо квалифицирани сервизни техници.

В отговор на развитието на технологичното оборудване в мебелната индустрия и в частност в областта на CNC технологиите, през годините в Лесотехническия университет регулярно са се актуализирали учебните програми в специалност „Технология на дървесината и мебелите“,

а от две години е разкрита и нова специалност „Компютърни технологии в мебелната индустрия“. Учебния план на новата специалност е в контекста на четвъртата индустриална революция – Индустрия 4.0 (Industry 4.0). Днес високото ниво на автоматизация и дигитализация на производствените процеси е настоящето безспорно предизвикателство както пред мебелната индустрия в България, така и пред преподавателите в професионалните гимназии и висшето образование в областта на производството на мебели и изделия от дървесина.

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THE INFLUENCE OF WOOD PELLET EXPOSURE TO DIFFERENT MICROCLIMATIC CONDITIONS ON THEIR MECHANICAL AND DIMENSIONAL PROPERTIES

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ABSTRACT

Wood pellet's mechanical properties, as an important quality parameter, are directly affected by moisture content (MC). This study investigated the effect of increased MC on certified pellet's mechanical and dimensional properties. In order to increase their MC, baseline samples were exposed to intense conditions inside a climate chamber for various residence periods, and then tested for mechanical durability (DU) by both standardised tumbler method and non-standardised Holmen ligno tester. Pellet's diameters were also recorded for each residence time. Even though increased MCs negatively affected these properties, their values mainly stayed within the certification quality requirements.

Key words: moisture content, mechanical durability, dimensional stability, tumbler, ligno tester.

INTRODUCTION

Demand to reduce greenhouse gas emissions, pollution and CO2 has been increasing in the last couple of decades. Major pollutants are industrial facilities that are still mainly relying on fossil fuels and oils, in the first place coal. In addition, global spike in the price of heating energy sources, especially gas and electricity, has lead both industrial and domestic users to search for alternative fuel solutions for power and heat generation. These alternatives must provide similar utilization properties (storage, handling, transportation, energy outputs) as previously mentioned conventional power and heating sources, while releasing less harmful gases into the atmosphere and being economically viable at the same time.

Solid biomass has imposed itself as one of the main alternative options. Solid biomass, such as residuals from the forestry operations or wood processing and agricultural industries, is mechanically and/or chemically processed and turned into solid biofuels, which are considered a renewable energy source (Ellabban et al., 2014). These biofuels, when utilized, are emitting less greenhouse gases than fossil fuels. They can also be more affordable and practical in some cases, especially when other types of fuels come with increased prices or limited or no availability.

One very common type of solid biofuels are wood pellets. They are produced from woody feedstock that is reduced in size and compressed through cylindrical openings of the die, making pellets of uniformed shape and size, low moisture content and high energy density (Mobini et al., 2014). These quality properties make wood pellets competitive with other fuels available on the market. Quality properties are often prescribed by various certification schemes in Europe, North America and other parts of the world, guaranteeing to end users expected quality that provides desired utilization performance.

Mechanical properties, such as mechanical durability (DU) and dimensional stability

(DS), are an important quality parameter, which has a direct impact on their utilization performance. DS is simply presented by the change in pellet's dimensions when they are exposed to certain atmospheric conditions for a period of time. DU represents wood pellets mechanical strength and resistance to disintegration into smaller pieces, and/or loss of their original shape, when being exposed to the external physical forces which force pellets to hit and bounce from surfaces surrounding them, as well as to being hit against each other. These forces happen during various stages of pellet handling – storage and transportation from the production facility to the end user. The poorer/lower the DU of pellets is, the higher amount of smaller particles and fines is generated from the breakage of pellets during handling procedures. This leads to lower utilization performance due to increased amount of fine particles that are lost during the handling process and can't be efficiently utilized, resulting in pellets losing their value as a whole. Pellets DU is affected by numerous factors such as feedstock's quality and pre-production state, pre-treatment and preparation (e.g. sizing), feedstock's moisture content (MC) and its consistency during the drying process, species, additives, state and set up of the equipment (screens, rollers, die, knives, hammers, ventilation, pressing temperature and compression, etc.). Also, it is impacted by the post-production (final) MC, which can vary depending on the process parameters, as well as on storage and transportation conditions. Increase in wood pellet's MC has shown to have a negative impact on their dimensional stability (Craven et al., 2015) and DU (Obernberger and Thek 2010, Hartmann 2004).

Increase in post-production MC can happen during storage and transportation, when it's exposed to adverse external influences, such as increased air humidity, wind, rain or sun. As such, it is important to preserve the up to standard quality even after longer periods of storage.

This paper has investigated the impact of increased post-production MC on wood pellets mechanical properties, as well as differences between standardised and non-standardised testing methods.

EXPERIMENTAL METHODS

Samples were sourced from 6 certified wood pellet producers from central Croatia, in a form of 15 kg commercial bags. These producers are exclusively producing pellets that are 6mm in diameter and mainly for domestic use. Feedstock wood species used for the production of these pellets vary between producers but they can be categorized into the group of pure softwoods (fir (*Abies alba*), spruce (*Picea abies*)), pure hardwoods (oak (*Quercus robur*), beech (*Fagus sylvatica*), hornbeam (*Carpinus betulus*)) and a mixture of the latter two. Producers are utilizing debarked round wood and sawmill residuals as a feedstock. Details on sample groups (producers) can be found in Table 1.

Table 1: List of sample groups (producers)

producer #	feedstock	certification class	quality requirement		
			moisture content (%)	mechanical durability (%)	diameter (mm)
1	hardwood	1	≤ 10	≥ 98.0	6 ± 1
2	softwood	1			
3	softwood	1			
4	hardwood/softwood	1			
5	hardwood/softwood	1			
6	hardwood	2		≥ 97.5	

Experimental part of the study was conducted at the University of Zagreb, Faculty of Forestry and Wood Technology, Institute of Processes Engineering, Laboratory for Energy Measurements.

Firstly, initial mechanical durability (DU), moisture content (MC) and diameters were tested for all 6 producers and these values were used as a starting baseline. Then, all samples were placed into the conditioning chamber for various residence periods, in order to increase their MCs. After each residence period, samples were tested for DU, MC and diameters, and these values were compared to baseline values as well as to each other, in order to understand their correlations and trends.

Each producer (sample) had 3 testing repetitions for DU and MC parameters. Diameters were tested on 10 single pellets for each producer, after each residence period.

Mechanical durability (DU)

DU was tested as per standardized tumbler method (HRN EN ISO 17831-1:2016) as well as with non-standardized Holmen NHP 100 (ligno tester) device. Initial (baseline) samples were all screened through 3.15 mm sieve prior to DU testing. The rest of the samples that were conditioned inside the chamber were screened prior to placing them into the chamber, and were not screened after conditioning. They were tested for DU as-is.

Tumbler

Kern EMS scale with 0.1g precision was used to weigh the screened sample. 500 g of a pellet sample was then exposed to controlled collisions and frictions between the surfaces of tumbler's (Figure 1.a and .b) chamber and the sample itself, for 500 rotations (10 min), in order to imitate full scale handling procedures. This test resulted in pellet breakage and consequently forming of fines and smaller particles that got detached from the main body of a pellet during the testing procedure. Generated fines were screened through 3.15 mm sieve and the final weight of a sample without generated fines was then divided with the initial weight of the tested sample, with final value representing the percentage of mechanical durability of a said sample. Equation was as follows:

$$DU = \frac{m_A}{m_E} X\ 100$$

where:

DU – mechanical durability (%)

m_A – initial sample weight before testing (g)

m_E – final sample weight after the test and screening (g)

Holmen NHP 100 (ligno tester)

This device (Figure 1.c) is testing pellet's DU but on a different principle than tumbler. Ligno tester blows air into the funnel shaped chamber, which is made of 3.15 mm perforations. Screened samples were weighed with A&D scale with the precision of 0.1 g. 100 g of a pellet sample was then placed into ligno tester and the device was started. Device blows air into the chamber at 70 mbar for 60 sec, causing pellets to collide into each other and bounce of the sides of the chamber, resulting in pellet breakage and fines formation. Fines that pass through the chamber's perforated sides are automatically separated from the sample and collected at the bottom of the device. Tested sample is then weighed and equation (see 2.1.1. Tumbler) is used to calculate the DU value.

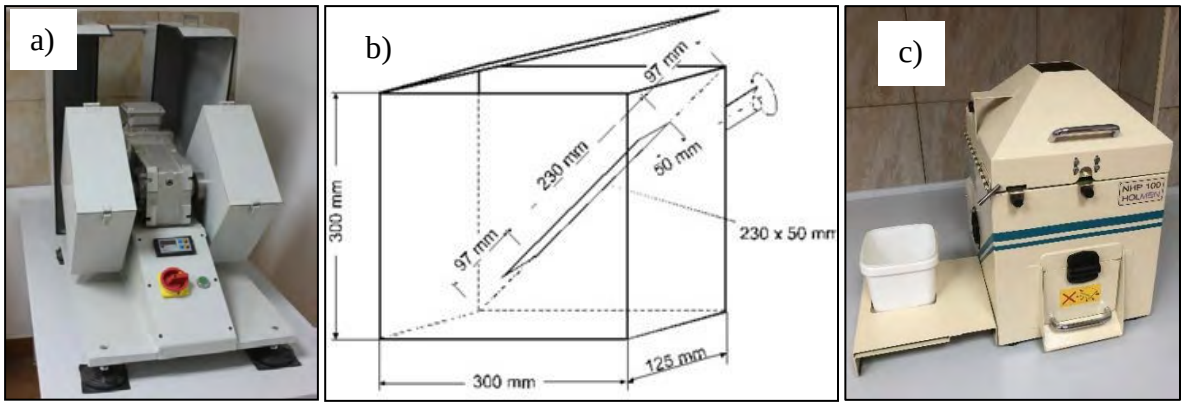


Figure 1: a)Tumbler device; b) Tumbler device's dimensions; c) Holmen NHP 100 (Ligno Tester)

Moisture content

Moisture content was tested as per HRN EN ISO 18134-3:2015. Samples were weighed on Sartorius's analytical scale with the precision of 0.0001 g. Each repetition, weighing 1±0.1g, was placed into the drying oven at 103±2°C, until the constant mass was achieved. After drying, samples were placed into the desiccator to cool down to room temperature. The samples were then weighed and moisture content values were calculated based on the following equation:

$$MC = \frac{(m_2 - m_3)}{(m_2 - m_1)} X\ 100$$

where:

MC – moisture content (%)

m_1 – weight of dried empty glass container with its cover (g)

m_2 – weight of glass container with its cover and sample before drying (g)

m_3 – weight of glass container with its cover and sample after drying (g)

Diameter measurements

Due to pellet's various lengths and rough/irregular ends, all single pellet samples were cut to the same length in order to achieve uniformed volumes for homogenized wetting effect. Circular saw with fine grade teeth was used, and all single pellet samples were reduced to the length of 10 ± 01 mm (Figure 2.). Diameters were measured by Mitutoyo IP 65 Digimatic Micrometer with the precision of 0.001 mm.

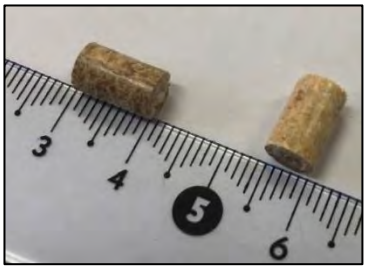


Figure 2: Single pellet samples cut to uniformed dimensions

Conditioning

Memmert's HCP105 conditioning chamber (Figure 3.a) was used as a humidifier to increase wood pellet's MC. Chamber was set up to temperature of 30°C and relative air humidity of 90%. 2.5 cm thick layers of pre-screened and pre-weighed samples were placed into plastic trays (Figure 3.b), which were then placed into the chamber at the mentioned conditions. Each tray was designated for a specific residence period. Additional trays with pre-cut and pre-measured single pellet samples were also placed into the chamber (Figure 3.c). Trays with samples were taken out for MC, DU, and diameters testing after following residence periods: 1h, 2h, 4h, and 8h. When the chamber was being opened to retrieve the samples for a specific period, the rest of the samples for MC and DU tests were slightly stirred in order to homogenize the wetting effect.

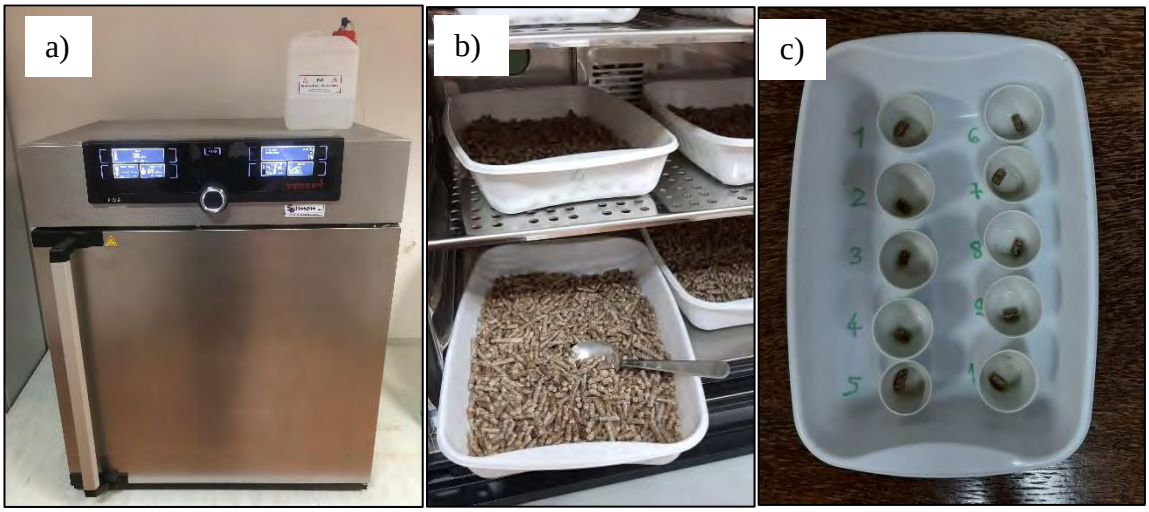


Figure 3: a) Conditioning chamber; b) Pellet samples in trays inside the chamber for MC and DU tests; c) single pellet samples for dimensional stability test

RESULTS AND DISCUSSION

Regarding baseline values (Figure 4), MCs ranged from the lowest 6.2% for producer #5 to the highest 8.4% for producer #4. All baseline MC values were within the quality requirement. Tumbler's baseline DUs ranged from the highest 99.3% for producer #6 to the lowest 97.5% for producer #4. Ligno tester's baseline DUs ranged from the highest 99.2% for producer #6 to the lowest 97.4% for producer #4. Producer #4 was the only producer whose baseline DU was not within the quality standard according to both testing methods.

Expectedly, intense humidification caused an increase in wood pellets MCs (Figure 4). Within the study's humidification timeframe, samples with lower baseline MCs had a higher water increase than the ones with higher baseline MCs. Producer #6, which had the lowest amount of water to start with, had a highest water increase (+ 3.38%), while Producer #4, which was on the opposite end to start with, had the lowest water increase (+1.94%). Observed hygroscopicity trends are in the accordance with previous research (Greinöcker *et al*., 2006). Furthermore, when additional water was absorbed into the wood pellet structure, cell walls were increasing, causing pellets to swell (Craven *et al*., 2015). The swelling effect can be seen in Figure 5, where sample's diameters, after 8 hours of humidification, were increased between +2% and +3% from the baseline values.

Since pellets are made from a large number of small particles bound together, swelling negatively affects their structure (Craven *et al*., 2015), causing degradation of their mechanical properties. This can be seen from both tumbler and ligno tester DU value trends for all 6 producers (Figure 4). These results are in accordance with the previous research, where it was also found that increased MC causes increased abrasion (decreased DU) (Greinöcker *et al*., 2006).

After 8 hours of humidification, total average MC increase was found to be 2.8%, while the total average decrease of DU was found to be 0.4% (tumbler) and 0.7% (ligno tester). Similar trends were reported by Obernberger and Thek (2010), where they presented Hartmann's (2004) data. This data showed an approximate 0.3% abrasion increase correlating to MC increase from 6% to 9.5%.

Ligno tester, even though it was mostly following the same trend, was showing lower DU values than tumbler. Except for producer

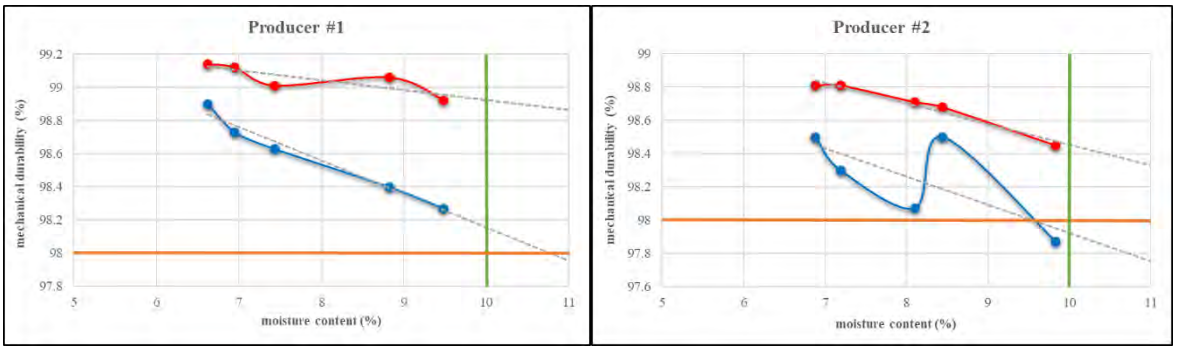
#6, where only the final value was irrelevantly higher than tumbler's final value. Ligno tester was on average showing 0.4% lower DU values than tumbler. As opposed to tumbler, ligno tester showed more variation and a couple of peak DU values (producer #2 and #5) that were equal to or even higher than the baseline value.

The latter case was also present in Abdulmumini *et al*. (2020) study, where they compared ligno tester against tumbler and rotary impact tester. Ligno tester was consistently creating more fines as opposed to the other two methods, hence showing lower DU values. It also showed three times larger variation in results. The difference between the results of these two methods can be explained by tumbler's lower impact velocity of the tested pellets. Comparable findings were presented by Temmerman *et al.* (2006), where they concluded that tumbler method gives more repeatable and reproducible results, when compared to ligno tester. Even though a good portion of their results showed how ligno tester gave lower results than tumbler, they concluded how there is no clear correlation between the results, and how comparisons between these two methods are not advisable.

All tumbler's DU values stayed within the standard's quality requirements, while for ligno tester only final values for producer #2 and #5 slightly dropped under the requirement. Producer #4 was the only one with below requirement values from the start, for both tumbler and ligno tester. As for MC, 8 hours of intense humidification did not cause substantial increase, hence values stayed below the allowed maximum of 10%. Again, only producer #4 exceeded the allowed maximum, due to relatively high baseline MC (8.4%).

Pellet samples preserved relatively satisfactory DU values even after intense humidification. This might be due to relatively low increase of MCs that were obtained within the applied humidification timeframe. According to literature, more rapid (even exponential (Greinöcker *et al*., 2006)) decrease of DU would be observed only when MC rises above 10% (Hartmann, 2004,). Similar results were reported by Lee *et al*. (2020) as well, where MCs >10% resulted in DUs < 96.5%. When they increased the MC up to 20%, DU followed further steep decrease to 80%.

This paper also showed that hardwood pellets (producer #1 and #6) generally had higher baseline DU values when compared to softwood ones, with less emphasized decline after humidification. This was present especially for producer #6. When it comes to DU, the data suggests that hardwood pellets are slightly superior to softwood pellets. Related data was obtained by Šafran *et al*. (2018), where their fir/oak (softwood/hardwood) pellets mechanical properties performed better than their fir/pine (pure softwoods) pellets.



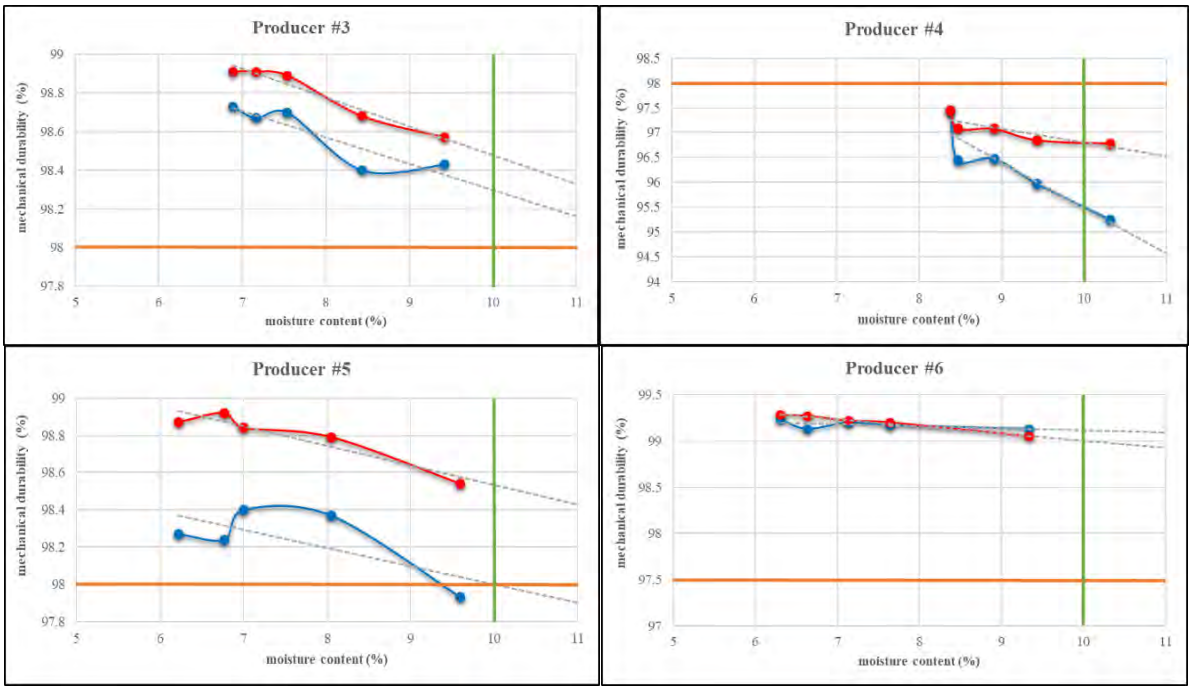


Figure 4: Correlation between moisture content and mechanical durability tested as per standardised tumbler method (red) and non-standardised ligno tester (blue), for 6 certified producers. Orange line – mechanical durability (%) lower limit, as per certification quality requirement; green line – moisture content (%) upper limit, as per certification quality requirement; grey intermittent lines – trend lines.

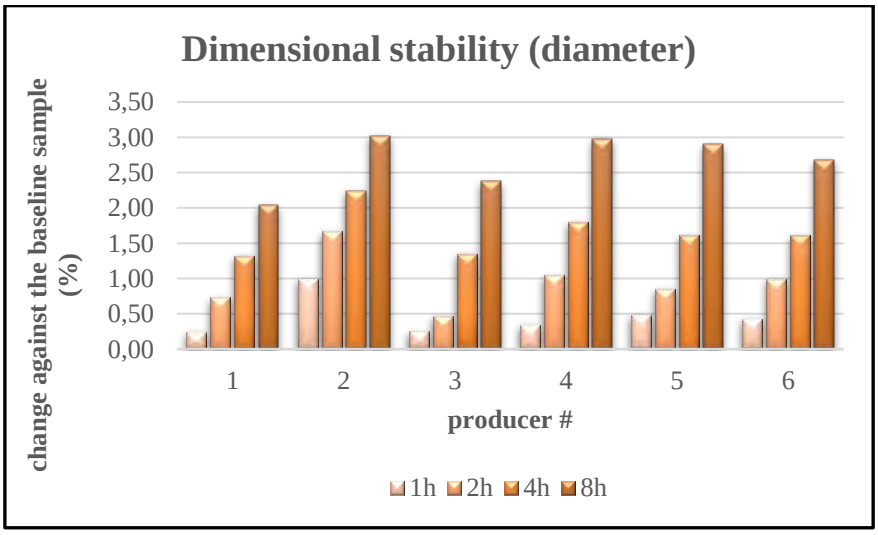


Figure 5: Dimensional stability of pellets in radial direction, after each residence period inside the conditioning chamber

CONCLUSIONS

Intense humidification conditions inside the chamber expectedly caused wood pellets to absorb water and their cells to swell. Cell swelling de-stabilized pellets dimensions, expanding them in radial direction. This resulted in pellets degradation, negatively affecting their mechanical durability. However, 8 hours of humidification at applied conditions did not show sufficient to increase their MCs above 10% allowance (as per standards obligatory quality requirement) or enough for pellets to lose their mechanical structure. Without losing their structure, pel-

lets mechanical properties (both DUs and diameters) also mainly stayed within the requirements.

Considering that applied conditions inside the chamber were on the higher end of intensity, longer humidification period is evidently necessary to obtain higher MCs. According to literature, this would induce more severe negative changes in wood pellets structure.

Tumbler showed more consistent results, while ligno tester was almost systematically showing lower results. According to this paper's results and literature, there is no clear correlation in results between these two methods. However, there are definitely somewhat suggestive trends, making non-standardised ligno tester an acceptable testing option or reference for regular quality checks at production facilities. Especially when consistently lower values, simplicity and testing duration are taken into the account.

Hardwood pellets, when compared to softwood pellets and pellets made from a mixture of softwood and hardwood feedstock, had better mechanical properties to start with. Also, their degradation trend lines were generally less pronounced (except producer #1 tested with ligno tester) after the applied humidification conditions.

Even though tested quality parameters mainly stayed within the obligatory requirements, it was shown that even short periods of increased temperature and humidity negatively impacts wood pellets properties. It is evident, from both this paper and cited literature, that longer periods of unfavourable storage conditions could significantly endanger these properties, hence it is important to handle wood pellets in controlled conditions.

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IDENTIFICATION OF THE COLOR FALSE HEARDWOOD OF *FAGUS SYLVATICA L.* IN THE COLOR SPACE CIE L*A*B*

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ABSTRACT

The paper presents the differences in the color of native beech wood between the false heardwood and sapwood in the color space CIE L*a*b*. The visual evaluation of the differences in the color of beech wood between the false heardwood and sapwood clearly shows that the color of the false heardwood of beech wood has a reddish-brown color with values on the coordinates L* = 67.5, a* = 12.7, b* = 20.3 compared to sappwood, the color of which is a light white-gray color with a yellowish tinge with values on the coordinates L* = 77.1, a* = 9.5, b* = 18.4. The degree of color difference at the individual coordinates of the CIE L*a*b* beech wood color space between the false heardwood and sapwood indicates the fact that while the brightness of the false heardwood relative to the sapwood is ΔL* = -9.6 smaller, the red values Δa* = +3.2 and yellow Δb* = +1.9 in color are higher in the false heardwood in penetration with sapwood beech wood. A comparison of the values of the standard uncertainty of the measurement of the color of the false headrwood with the values of the relative standard uncertainty of the sapwood shows that the variability of the color shades of the brown-red color of the false heardwood is greater than the variability of the sapwood beech wood.

Key words: beech wood, false heardwood, color wood, color space CIE *L*a*b**.

INTRODUCTION

Beech wood belongs to the scattered-porous woody species of coreless wood with the possibility of forming a false heardwood. Beech wood of sapwood is medium-heavy, flexible, easy to split. It has good mechanical properties, plasticizes very well, bends and is machined. Thanks to its high permeability, it impregnates well, stains and paints. Beech wood is used for the production of furniture, floors, sports equipment, toys and small household items. Beech sapwood dried by low-temperature drying modes has a light white-gray color with a touch of yellow. In the color space CIE *L*a*b*,* the sapwood beech color is by the authors: Babiak et al. (2004) identified by values on the coordinates *L** = 75.96; *a** = 6.62; *b** = 17.63. Similar values for the color of sapwood are also given by the authors: Tolvaj et al. (2009), Dzurenda (2014), Meints et al. (2017), Dzurenda – Dudiak (2021).

The false heardwood of beech is a growth error caused by the reaction of air with wood in the zone of sapwood. The primary cause of a false heardwood is an injury to the trunk or branches of the tree, which allows air to enter the trunk of the tree. Oxygen contained in the air causes oxidation of soluble carbohydrates and starch (contained in living or partially dead parenchymal cells), resulting in brown colored polyphenolic compounds that penetrate and stain neighboring tissues Bauch – Koch (2001), Račko – Čunderlík (2010). According to the occurrence of the false heardwood in the trunk of the tree and its shape on the cross section of the trunk, the false heardwood is divided into: Round, Mosaic Star, Flame (eccentric, centric) Mahler – Höwecke (1991). False heardwood has a lower moisture content in a growing tree compared to white and green wood

and, according to Babiak et al. (1990), a lower fluid permeability. The color difference between false heardwood and sapwood is the reason for the elimination of sawmill blanks for the production of bentwood furniture, sports equipment, as well as construction and carpentry products.

The reason for the different color of beech wood are the chromophores, i.e. functional groups of the type: > C = O, -CH = CH-CH = CH-, -CH = CH-, kernels found in chemical components of wood (lignin dyes, tannins, resins and other extractive substances found in sappwood and false heardwood) which absorb electromagnetic radiation in the UV-VIS area of daylight radiation. The reflected electromagnetic radiation entering the human eye creates in the human mind a psychophysiological sensation manifested in the vision of the color of the object observed by the human eye. Wilson – Keil (1999), Kubovský – Urgela (2004).

The aim of this work is to identify the color of false heardwood in the color space CIE *L*a*b** and to quantify the degree of total color difference Δ*E** between the color of beech wood of false heardwood and sapwood.

MATERIALS AND METHODS

Beech wood in the form of blanks with a false heardwood measuring 27 × 75 × 320 mm was dried to moisture content w_p = 10.0 ± 0.5%.

The wood color of beech blanks in the color space CIE *L*a*b** was measured with a Color reader CR-10 colorimeter (Konica Minolta, Japan). A D65 light source was used and the diameter of the optical scanning aperture was 8 mm.

The measurement of the brightness values *L** a of the basic chromatic coordinates red *a** and yellow *b** of the color space CIE *L*a*b** of white and false heardwood was performed on a set of n = 58 blanks. The measured values are given in the form of a record $x = \bar{x} \pm u_C$ i.e., average measured value and combined standard measurement uncertainty.

The calculation of the average values $\bar{x}_L, \bar{x}_a, \bar{x}_b$ from the measured values L_i, a_i, b_i on the coordinates of the color space CIE *L*a*b** is given by the equations:

$$\bar{x}_L = \frac{\sum L_i}{n}; \quad \bar{x}_a = \frac{\sum a_i}{n}; \quad \bar{x}_b = \frac{\sum b_i}{n}; \tag{1}$$

Where: L_i, a_i, b_i – measured values on coordinates color space CIE *L*a*b**, n – number of measurements.

The combined standard uncertainty takes into account type A and type B uncertainties.

$$u_C = \sqrt{u_A^2 + u_B^2} \tag{2}$$

Where: u_A – standard uncertainty type A, u_B – standard uncertainty type B.

The calculation of the combined standard uncertainty for the values at the individual coordinates of the color space CIE *L*a*b** is given by the equations:

$$u_{C_L} = \sqrt{\frac{\sum(L_i - \bar{x}_L)}{n\cdot(n-1)} + u_{B_L}^2}, \quad u_{C_{La}} = \sqrt{\frac{\sum(a_i - \bar{x}_a)}{n\cdot(n-1)} + u_{B_a}^2}, \quad u_{C_b} = \sqrt{\frac{\sum(L_i - \bar{x}_b)}{n\cdot(n-1)} + u_{B_b}^2}, \tag{3}$$

Where: L_i, a_i, b_i – measured values on coordinates color space CIE $L^*a^*b^*$, $\bar{x}_L$, $\bar{x}_a, \bar{x}_b$ – average values of sets of measured values on color space coordinates, n – number of measurements, u_{BL}, u_{Ba}, u_{Bb} = 0.1 standard deviations of the Color reader CR-10 from the nominal value.

The degree of scatter of the determined values in the color space CIE $L^*a^*b^*$ of the false heardwood and sapwood beech is evaluated by means of the relative standard uncertainty $_{rel}u_C$. The relative standard uncertainty values for each color coordinate describe the equations:

$$_{rel}u_{C_L} = \frac{u_{C_L}}{\bar{x}_L}.100\ [\%], \quad _{rel}u_{C_{a^*}} = \frac{u_{C_{a^*}}}{\bar{x}_{a^*}}.100\ [\%], \quad _{rel}u_{C_{b^*}} = \frac{u_{C_{b^*}}}{\bar{x}_{b^*}}.100\ [\%] \qquad \textbf{(4)}$$

Where: u_{Ci} – the combined standard uncertainty of the value at the appropriate coordinate color space, $\bar{x}_i$ – average value.

The calculation of the total color difference ΔE^* of the difference between the color of sapwood and false heardwood beech is described by the following equation:

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2} \qquad \textbf{(5)}$$

Where: L^*_1, a^*_1, b^*_1 average values on the coordinates of the color space of sapwood, L^*_2, a^*_2, b^*_2 average values on the coordinates of the color space of the false heardwood.

RESULTS AND DISCUSSION

The visual difference in the colors of the wood of the false heardwood beech from the sapwood beech is shown in Fig. 1.



Figure 1: Examples of beech wood color with false heardwood formation

The values of brightness L^*, red color a^* and yellow color b^* on the coordinates of the color space CIE $L^*a^*b^*$ color of the sapwood wood and false heardwood on the planed surface of the loading surfaces of beech blanks with moisture content w = 10.0 ± 0.5% are given in the Table 1. and sapwood Table 2.

Table 1: Values on coordinates color space CIE *L*a*b describing the false heardwood of beech**

False heardwood of beech blanks	Coordinates of color space CIE *L*a*b**		
	L*	***a****	***b****
number of measurements [-]	58	58	58
coordinate value [-]	67.5 ± 4.2	12.7 ± 2.3	20.3 ± 1.9
relative standard uncertainty [%]	6.2	18.1	9.3

Table 2: Values on coordinates color space CIE *L*a*b describing the sapwood of beech**

Sapwood of beech blanks	Coordinates of color space CIE *L*a*b**		
	L*	***a****	***b****
number of measurements [-]	58	58	58
coordinate value [-]	77.1 ± 2.9	9.5 ± 1.3	18.4 ± 1.1
relative standard uncertainty [%]	3.7	13.6	5.9

The degree of color difference at the individual coordinates of the color space CIE *L*a*b** between the false heardwood beech and the sapwood beech is shown in Fig. 2.

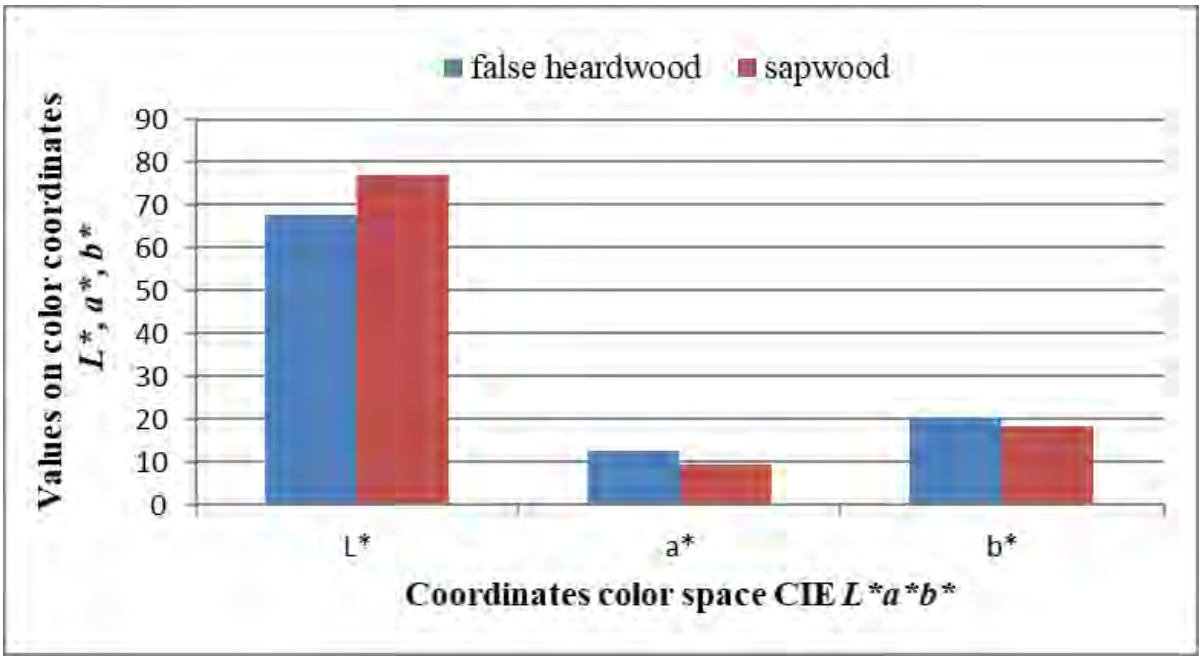


Figure 2: Graphic evaluation of colors on individual coordinates of the color space between the false heardwood and sapwood beech.

In Fig. 2 shows the degree of color difference on the individual coordinates of the color space CIE *L*a*b** beech wood between the false heardwood and the sapwood. They point to the fact that while the brightness of the false heardwood compared to the brightness of sapwood is ΔL^* = -9.6 smaller (the wood is darker), the value of the red

color a^* of the false heardwood is $\Delta a^* + 3.2$ higher than the value red color a* of sapwood and the value of yellow color b^* in the false heardwood is higher by $\Delta b^* = + 1.9$ higher compared to sapwood. This is due to the increased number of chromophores in polyphenolic compounds formed by the oxidation of air-oxygen-soluble carbohydrates and starch contained in living or partially dead parenchymal cells, as reported by Bauch – Koch (2001), Račko – Čunderlík (2010).

Higher values of relative standard uncertainties of the false heardwood brightness of the $_{rel}u_{CL}$ = 6.2% of the red color of $_{rel}u_{Ca}$ = 18.1% and of the yellow color of $_{rel}u_{Cb}$ = 9.3% of the wood given in Table 1 in comparison with similar values of sapwood beech wood given in Table 2 show a greater variability in the color shades of the brown-red color of the false heardwood compared to the homogeneous color of the sapwood.

CONCLUSION

The paper presents the coordinates of the color of the false heardwood of beech in the color space CIE $L^*a^*b^*$. The red-brown color of the false heardwood beech, based on the statistical processing of the measured values, has a brightness $L^* = 67.5 \pm 6.8$ and values on chromatic coordinates: red color $a^* = 12.7 \pm 2.3$ and yellow color $b^* = 20.3 \pm 1.3$.

Higher values of relative standard uncertainty of $_{rel}u_{CL}$ = 6.2%, red color of $_{rel}u_{Ca}$ = 18.1% and yellow color of $_{rel}u_{Cb}$ = 9.3% of false heardwood compared to values of relative standard uncertainty of sapwood beech $_{rel}u_{CL}$ = 3.7%, $_{rel}u_{Ca}$ = 13.6% and $_{rel}u_{Cb}$ = 5.9% indicate a greater variability of color shades of brown-red color of the false heardwood.

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IMPACT OF THE SAMPLE DIMENSIONS ON MEASURED WOOD COMPRESSIVE PROPERTIES ON THE LONGITUDINAL DIRECTION

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ABSTRACT

The paper analyses the compressive elastic and plastic properties of wood samples in the longitudinal direction based on different sample dimensions. The samples of the type of wood most commonly used in Croatia were used (oak, beech and fir). The following properties of the samples were determined: maximum and final stress; the modulus of elasticity; specific energy of deformation. The results showed that the change in the dimensions of the samples has no effect on the elastic properties, while the analysed plastic properties show a clear tendency to change with the change in the dimensions of the samples.

Key words: modulus of elasticity, stress, strain, energy of elastic and plastic deformation.

INTRODUCTION

Mechanical properties represent the response of wood to the action of external forces, and have been the subject of study for many years. However, increasingly strict technological requirements in production, the ecological component of the use of wood, and the development of experimental setups make this research attractive even today. Given the long history of research into mechanical properties, several relevant papers are listed below.

From beginning of last century mechanical properties were corelated with density (Newlin and Wilson, 1919). With increasing wood density mechanical properties increase (Zhang, 1994) but density will not be such prior factor in longitudinal direction (Krauss, 2009). Effect of loading rate on beech wood in longitudinal direction showed that as loading rate increase MOE increase (Radmanović et al., 2021). Moisture content (MC) decreases compression straight, increasing 1 % of MC decreased for 3,1 % compression in range 8 – 20 % of MC in micro size oak samples (Korkmaz and Büyüksarı, 2019). Positive corelation between micro size samples and standard size samples were examined on *Quercus Petraea* for mechanical properties. (Büyüksarı et al., 2017). Size effect of *Quercus robur* in radial direction for samples 10x10x10 mm and 25x25x25 mm showed small differences in advantage for smaller samples (Afshar, 2022). Compression in longitudinal direction of wood effects easier bending. Most hardwood with 20 % MC can be compressed for wood modifications (Báder, 2015). The influence of the dimensions and geometry of wood on the mechanical properties were announced by (Wolcott et al., 2007). Influence of samples height on Young' s module (ε) was established by Boding and Kunesh acc. (Wolcott et al., 2007). *E* increase as sample height increase.

In this paper, the influence of the change in the dimensions of wood samples on the compressive properties in the longitudinal direction is studied. Certain compressive prop-

erties are: modulus of elasticity (*E*), maximum stress (σ_{max}), strain at the maximum stress (ε_{max}), final stress (σ_{final}), strain at the final stress (ε_{final}), energy (*W*) and density of strain energy (*e*).

EXPERIMENTAL METHODS

MATERIALS

Some of the most common species from Croatia were selected for experiment. Beech (*Fagus sylvatica),* oak (*Quercus robur) and fir (Picea abies).* Samples from each species were cut on a circular saw in 3 groups of dimensions. First group was volume 1 cm^3, second 8 cm^3 and third 27 cm^3, (Fig. **Error! Reference source not found.**). Samples of each species were selected from one plank and were free from visual defects and uniform texture. Planks were naturally dried for more than 2 years in facility of Faculty of forestry and wood technology. For each group 10 samples were prepared. Samples were conditioned for 2 weeks in climate chamber at constant temperature of 30°C and 90 % of relative air humidity. Each sample was marked according to group and dimension. Two weeks after conditioning samples were weight to precision of 0.0001 g, dimensions were measured to precision of 0.01 mm and densities were calculated (Table 1).

Table 1: Dimensions, mass and density of samples. O1 – Oak volume 1 cm^3, O2 – Oak volume 8 cm^3, O3 – Oak volume 27 cm^3, B1 – Beech volume 1 cm^3, B2 – Beech volume 8 cm^3, B3 – Beech volume 27 cm^3, F1 – Fir volume 1 cm^3, F2 – Fir volume 8 cm^3, F3 – Fir volume 27 cm^3, *L* – dimension of the samples in longitudinal direction (mm), *R* – dimension of the samples in radial direction (mm), *T* – dimension of the samples in tangential direction (mm), m – mass of the samples (g), ρ – density of the samples (g/cm^3)

Wood type	Samples	*L* (mm)	*R* (mm)	*T* (mm)	*m* (g)	ρ (g / cm^3)
Oak	O1	10,03 ± 0,07	10,03 ± 0,09	10,08 ± 0,05	0,67 ± 0,02	0,66 ± 0,02
	O2	20,14 ± 0,11	20,15 ± 0,17	20,44 ± 0,08	5,53 ± 0,11	0,66 ± 0,01
	O3	29,89 ± 0,13	30,46 ± 0,07	30,55 ± 0,14	18,58 ± 0,59	0,66 ± 0,02
Beech	B1	9,90 ± 0,05	10,04 ± 0,02	10,23 ± 0,04	0,74 ± 0,01	0,73 ± 0,01
	B2	20,16 ± 0,06	20,19 ± 0,14	20,71 ± 0,10	6,08 ± 0,14	0,72 ± 0,02
	B3	29,97 ± 0,10	30,34 ± 0,21	30,96 ± 0,22	19,66 ± 1,17	0,69 ± 0,04
Fir	F1	9,94 ± 0,11	9,96 ± 0,07	10,15 ± 0,09	0,38 ± 0,01	0,38 ± 0,01
	F2	20,20 ± 0,03	20,26 ± 0,07	20,36 ± 0,23	3,42 ± 0,10	0,41 ± 0,01
	F3	30,18 ± 0,06	30,22 ± 0,12	30,61 ± 0,25	11,52 ± 0,56	0,41 ± 0,02

Table 2: Standard deviation of the measured values of modulus of elasticity (*E*), strain energy (*e*) and density of strain energy (*w*). O1 – Oak volume 1 cm^3, O2 – Oak volume 8 cm^3, O3 – Oak volume 27 cm^3, B1 – Beech volume 1 cm^3, B2 – Beech volume 8 cm^3, B3 – Beech volume 27 cm^3, F1 – Fir volume 1 cm^3, F2 – Fir volume 8 cm^3, F3 – Fir volume 27 cm^3.

Samples	Samples	Standard deviation of the measured values		
		E (MPa)	*e* (J)	*w* (MJ/m^3)
Oak	O1	186,8732	1,1	0,3058
	O2	278,5722	3,8	0,1240
	O3	163,9527	2,9	0,0766
Beech	B1	193,4538	1,4	0,1857
	B2	213,4560	3,9	0,2061
	B3	219,8757	4,3	0,3092
Fir	F1	96,2627	1,2	0,1711
	F2	223,3614	2,7	0,1326
	F3	224,6759	4,6	0,1472

Table 3: Standard deviation of the measured values of maximal stress (σ_{max}), strain at maximal stress (ε_{max}) final stress (σ_{final}), strain at final stress (ε_{final}). O1 – Oak volume 1 cm^3, O2 – Oak volume 8 cm^3, O3 – Oak volume 27 cm^3, B1 – Beech volume 1 cm^3, B2 – Beech volume 8 cm^3, B3 – Beech volume 27 cm^3, F1 – Fir volume 1 cm^3, F2 – Fir volume 8 cm^3, F3 – Fir volume 27 cm^3.

Samples	Samples	Standard deviation of the measured values			
		σ_{max} (MPa)	ε_{max}	σ_{final} (MPa)	ε_{final}
Oak	O1	2,14	0,00107	3,45	0,00523
	O2	1,65	0,00115	2,34	0,00728
	O3	2,34	0,00103	4,21	0,00655
Beech	B1	2,15	0,00226	2,85	0,00551
	B2	1,15	0,00231	4,81	0,00980
	B3	2,76	0,00260	4,03	0,00705
Fir	F1	0,94	0,00531	2,74	0,00656
	F2	1,11	0,00270	2,14	0,00453
	F3	0,65	0,00168	3,05	0,00509

METHODS

Compressive properties of samples in longitudinal directions were determined depending on size of samples. During the test loading rate was constant, 2 mm/min. Test was performed by Shimadzu testing machine with load cell of nominal forces of 10 kN for samples volume 1 cm^3 and 100 kN for samples volume 8 cm^3 and 27 cm^3. Displacement ($\Delta L = L - L'$) were programmed in software Trapezium X, Shimadzu until the moment of cracking of the sample (Fig. 1). Forces were measured in 0,001 N. Data's of the measured force and displacement was processed in Sigma Plot (Version 10.0).

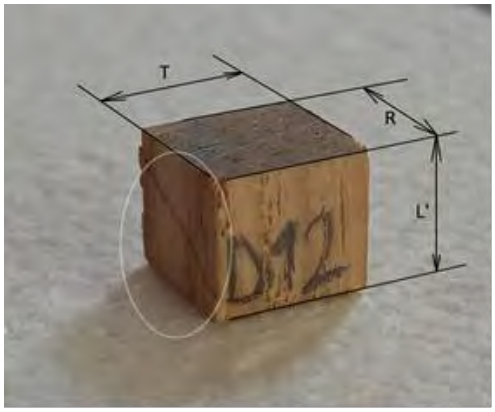


Figure 1: Cracked wood sample. L' is length of sample after test compression, R is dimension in radial direction, T is dimension in tangential dimension and oval mark is place of collapse.

Compressive stress was recorded as Eq. 1.

$$\sigma = \frac{F}{R \cdot T} \qquad (1)$$

where σ is the compressive stress (Pa), F is the force (N), R is the sample length (m), T is the sample width (m). The corresponding strain was determined according to Eq. **Error! Reference source not found.**.

$$\varepsilon = \frac{\Delta L}{L_0} \qquad (2)$$

where ε is the relative strain, ΔL is a change in the dimensions of the samples (m), a L_0 is the initial dimension of the samples (m). After the calculated stresses and associated relative strain, stress strain diagram was made (Fig. 2).

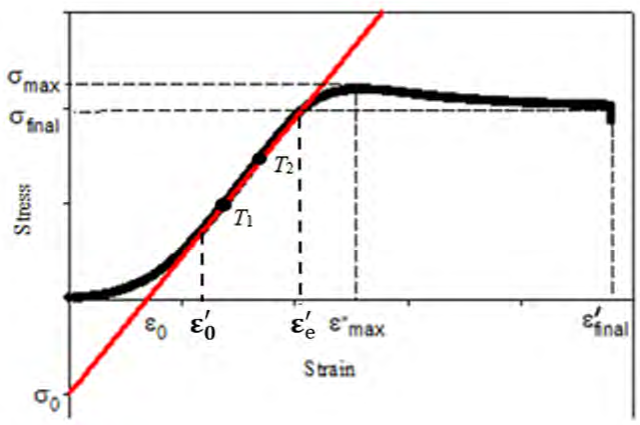


Figure 2: Stress – strain diagram in longitudinal direction, σ_0 – section of the linear function on the ordinate axis, σ_{max} – maximum stress, σ_{final} – final stress, ε_0 – *initial strain*, ε'_0 *and* ε'_e – elastic strain, ε'_{max} – strain at maximum stress, ε'_{final} – strain at ultimate stress

Considering the strain axis, the stress strain diagram can be divided into four parts. In the first part of the diagram when ($0 < \varepsilon < \varepsilon'_0$), the relationship between stress and strain is nonlinear. This non-linearity is the result of the fact that in the initial part, in addition to the pressing of the samples, there is also the adjustment of the samples on the cutter due to surface micro-unevenness's. In the second part of the diagram when ($\varepsilon'_0 < \varepsilon < \varepsilon'_e$), the relationship between stress and strain is linear (elastic area). Deformations from that area are reversible. In the third part of the diagram when ($\varepsilon'_e < \varepsilon < \varepsilon'_{max}$), the relationship between stress and strain is non-linear (plastic region). Deformations in that area are irreversible. In the fourth part of the diagram, when ($\varepsilon'_{max} < \varepsilon < \varepsilon'_{final}$), the relationship between stress and deformation is non-linear, material yielding occurs, stresses decrease, and finally when ($\varepsilon = \varepsilon'_{final}$), cracking of samples occurs.

In the first part of the stress strain diagram, the strain ε ($0 < \varepsilon < \varepsilon'_0$), is the sum of the deformation caused by the initial setting of the sample on the cutter and the initial elastic stress. With the aim of determining the deformation caused by setting the samples on the cutter, in the area of the stress strain diagram where the relationship between stress and strain is linear (elastic area), two points (T_1 and T_2) were selected through which the linear function of the shape was determined:

$$\sigma_{el} = \sigma_0 + E \cdot \varepsilon'_e \,, \qquad (1)$$

where σ_{el} is the elastic stress (Pa), ε'_e is the elastic strain and E is the modulus of elasticity (Pa). The modulus of elasticity is determined according to the expression:

$$E = \frac{\sigma(T_2) - \sigma(T_1)}{\varepsilon(T_2) - \varepsilon(T_1)} \,, \qquad (2)$$

where $\sigma(T_1)$ is the stress at the point T_1, $\sigma(T_2)$ is the stress at the point T_2, $\varepsilon(T_1)$ is the strain at the point T_1, $\varepsilon(T_2)$ is the strain at the point T_2. By equating the linear function (3) to zero, the initial strain is determined:

$$\varepsilon_0 = -\frac{\sigma_0}{E} \,, \qquad (5)$$

where ε_0 is section of linear function on abscissa. The deformation in the interval $[0, \varepsilon_0]$ is the result of the adjustment of the sample (Radmanović at all). So that the setting of the samples on the cutter would not affect the measured values, the initial deformation was equalized to zero (5), and stress-strain diagram was translated to left:

$$\varepsilon_0 \to 0, \sigma_0 \to 0, \varepsilon_{max=} \varepsilon'_{max} - \varepsilon_0 \text{ and } \varepsilon_{final=} \varepsilon'_{final} - \varepsilon_0. \qquad (6)$$

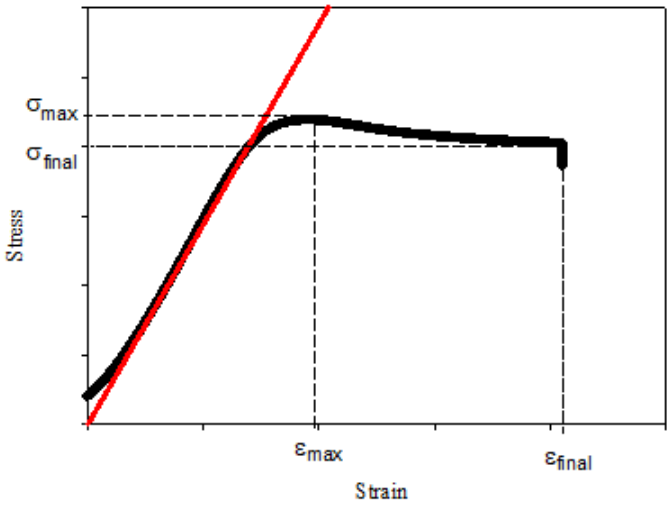


Figure 3: Stress – strain diagram in longitudinal direction, σ_{max} – maximum stress, σ_{final} – final stress, ε_{max}– strain at maximum stress, ε_{final} – strain at ultimate stress

The maximum (σ_{max}) and final (σ_{final}) stress values with associated strain (ε_{max} and ε_{final}) are read from the diagram (Figure 3). By applying the first law of thermodynamics to the compression of samples at constant temperature, it follows:

$$\Delta U = W, \tag{7}$$

where ΔU is change in internal energy of the sample, W – work performed on the sample. The common name for the change in internal energy during compression of samples is the strain energy (e). It is evident from the expression (7) that during the compression of the samples there is an increase in the strain energy. At the moment when the strain energy takes on a critical value (ε_{final}), the samples crack. Strain energy (e) and its density (w) is determined by:

$$e = \int_{\varepsilon_0=0}^{\varepsilon_{final}} \sigma \cdot \mathrm{d}\varepsilon \tag{3}$$

$$w = \frac{e}{V} \tag{9}$$

where e is the strain energy, σ is stress, ε_0 is the initial strain, ε_{final} is the final strain, w is the density of strain energy.

RESULTS AND DISCUSSION

Experimentally measured values were processed in the SigmaPlot v.10.0 software package. Then, the mean value of the modulus of elasticity (E), maximum stress (σ_{max}), strain at the maximum stress (ε_{max}), final stress (σ_{final}), strain at the final stress (ε_{final}), energy (W) and density of strain energy (e) with the associated standard deviation was determined. In the "Results" chapter, the mean value of the measured compressive properties for three different groups of samples is presented, Group 1: samples with dimensions (10 x 10 x 10) mm, group 2: samples with dimensions (20 x 20 x 20) mm, group 3: samples with dimensions (30 x 30 x 30) mm and the standard deviations of the measured values are presented in the appendix of this paper. Figure (4) shows the mean value of the modulus of elasticity for three different groups of samples of oak, beech and fir. The figure shows that the highest mean value of the modulus of elasticity for all samples is from group 2. However, due to the large value of the standard deviations (attachment), it cannot be concluded that the dimensions of the samples affect the elastic compressive properties.

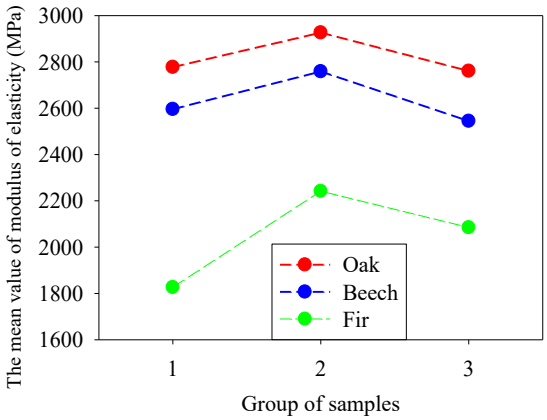


Figure 4: The mean value of modulus of elasticity for three groups of samples of oak, beech and fir. Group 1: samples with dimensions (10 x 10 x 10) mm, group 2: samples with dimensions (20 x 20 x 20) mm, group 3: samples with dimensions (30 x 30 x 30) mm

Figure (5) shows the mean value of the maximum (σ_{max}) and final stress (σ_{final}), as well as the strain at the maximum (ε_{max}) and final stress (ε_{final}) for three different groups of samples of oak, beech and fir. The figure shows a clear decreasing trend of measured mean values of maximum stress (σ_{max}), strain at maximum stress (ε_{max}) and strain at final stress (ε_{final}) with increasing sample dimensions, while no trend can be established for mean values of final stress (σ_{final}). The properties shown in Figure (5) are properties that describe the behaviour of the samples after the elastic limit, and it can be concluded that the dimensions of the samples affect these properties.

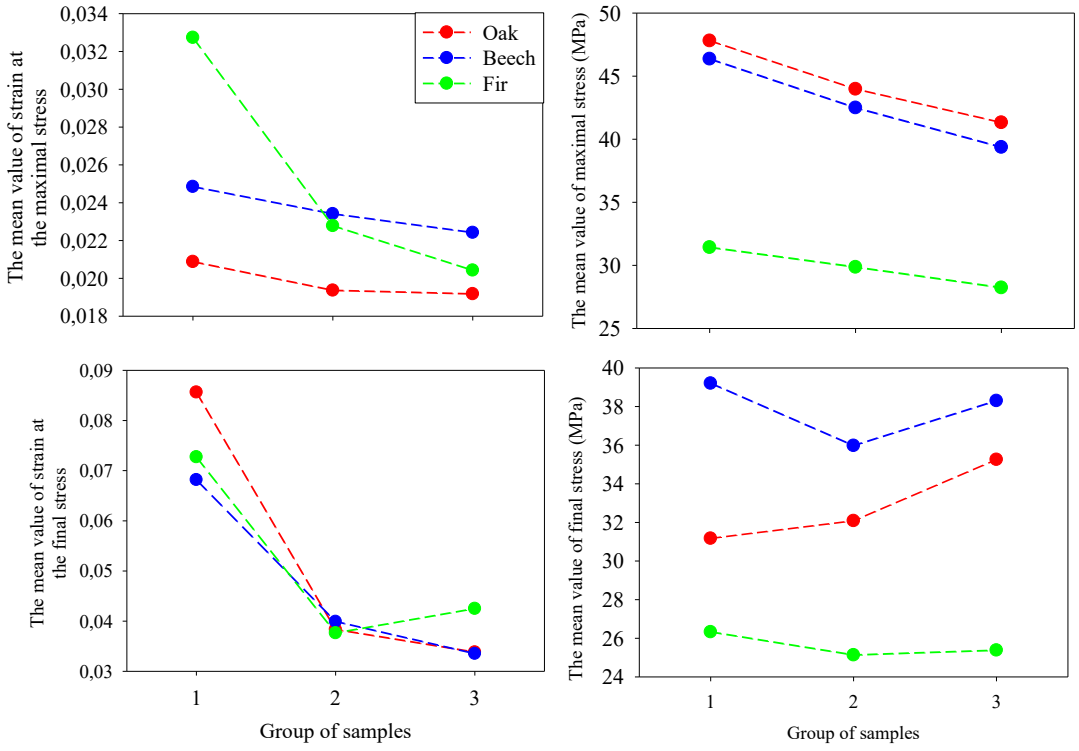


Figure 5: The mean value of the strain at maximal and final stress and the mean value of the maximal and final stress for three groups of samples of oak, beech and fir. group 1: samples with dimensions (10 x 10 x 10) mm, group 2: samples with dimensions (20 x 20 x 20) mm, group 3: samples with dimensions (30 x 30 x 30) mm

Figure (6) shows the mean value of energy (e) and density of strain energy (w) for three groups of samples of oak, beech and fir. The figure shows a clear trend of growth in the mean energy value (*e*) and decrease in the mean value of the density of strain energy (*w)*.

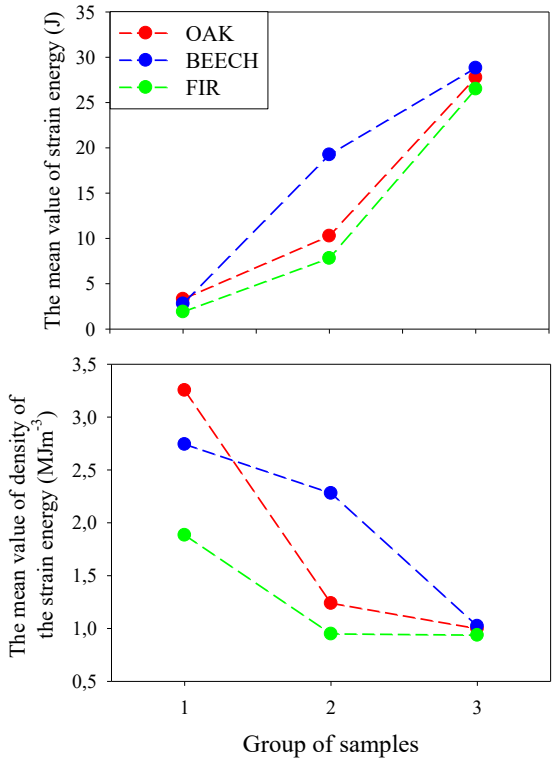


Figure 6: The mean value of strain energy and density of strain energy for three groups of samples of oak, beech and fir. Group 1: samples with dimensions (10 x 10 x 10) mm, group 2: samples with dimensions (20 x 20 x 20) mm, group 3: samples with dimensions (30 x 30 x 30) mm

CONCLUSIONS

The following conclusions can be drawn from the presented research results

1. The size of the samples does not affect on the modulus of elasticity of the tested samples of oak, beech and fir

2. By increasing the dimensions of the samples, the values of the maximum and ultimate stress are reduced, as well as the strainat the maximum and ultimate stress

3. By increasing the dimensions of the samples, the absorbed energy increases, but the energy density decreases, which means that the volume of the samples grows faster than the absorbed energy.

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DIGITAL EDUCATION IN THE FACULTY OF „FOREST INDUSTRY" IN THE CONTEXT OF INDUSTRY 4.0

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ABSTRACT

European trends in the field of higher education and the Strategy for Development of Higher Education in the Republic of Bulgaria for the period 2021 – 2030 determine the framework through which universities and colleges are to be supported in the processes related to determining opportunities and ways of application of digital technologies, to further develop their concepts related to traditional learning. Thanks to up-to-date tools for assessing the state and prospects related to digitalization processes and innovation in education, close cooperation with businesses, as well as the increasing accessibility and functionality of ICT, universities have the opportunity to devise optimal opportunities for deriving maximum benefits when traditional activities and processes in a university environment are carried out. The Faculty of Forest Industry has traditions in this area and has trained specialists, thanks to which, in recent years, the faculty has managed to further develop its strategy in line with the new technological requirements. Through a clear and widely shared vision, outlining the main priority areas for developments, as well as goals and measures to achieve them, the faculty follows a sustainable line to improve both the quality of educational processes and its attractiveness to students and businesses. As a result of a self-assessment analysis, the faculty further developed its digitalization strategy in the context of Industry 4.0 and virtual engineering, improved business relations, identified key competencies and priorities for the future development of students, related to their professional realization. Discipline curricula have been renewed, and most of them have the opportunity for digital use of resources or access through digital educational content management systems. As a result, one of the specialties at the faculty was declared a "protected specialty by profession", and as an independent, a new specialty "Computer technology in the furniture industry" was created in the last two years, as a result of efforts and visions for education development in the faculty in the context of the Industry 4.0 concept. In addition, in order to meet the requirements set in this development framework, as well as to provide the basis for a quality learning environment, modern laboratories have been built, thanks to cooperation between the faculty and the businesses, who later benefit from the prepared trainees. Future developments in the long-term strategy include the introduction of digital design and prototyping in furniture factories, continued use of virtual reality, engineering simulations in the furniture industry with CAD/CAE/CAM and CNC technologies and the ability to digitize and automate processes. In additionq there are plans to update the technological support of disciplines through the introduction of specialized software for design and manufacturing of furniture, and interior design with the ability to plan, present and implement in the production of individual or complete solutions.

Key words: digital education, industry 4.0, CNC, CAD/CAE/CAM.

ДИГИТАЛНО ОБРАЗОВАНИЕ ВЪВ ФАКУЛТЕТ „ГОРСКА ПРОМИШЛЕНОСТ" В КОНТЕКСТА НА ИНДУСТРИЯ 4.0

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РЕЗЮМЕ

Европейските тенденции в областта на висшето образование, Стратегията за развитие на висшето образование в Република България за периода 2021 – 2030 година определят рамката, чрез която университетите и висшите училища да бъдат подпомогнати в процесите, свързани с определяне възможностите и начините за използване на дигиталните технологии, за да доразвият своите концепции, свързани с традиционното обучение.

Благодарение на актуални инструменти за оценка на състоянието и перспективите, свързани с процесите на дигитализация и иновациите в образованието, тясното сътрудничество с бизнеса, както и все по-достъпните и функционални ИКТ, университетите имат възможност на намерят оптималните възможности за извличане на максимални ползи при провеждане на традиционните дейности и процеси в университетска среда.

В това направление факултет „Горска промишленост", има традиции и разполага с подготвени специалисти, благодарение, на което през последните години успя да доразвие своята стратегия в унисон с новите технологични изисквания. Чрез ясна и широко споделена визия, очертаваща основни приоритетни области за развитие, целите и мерките за постигането им, факултетът следва устойчива линия за подобряване, както качеството на образователните процеси, така и на своята привлекателност по отношение на студентите и бизнеса.

В резултат на проведен анализ за самооценка, факултетът доразви своята стратегия за дигитализация в контекста на Индустрия 4.0 и виртуалното инженерство, подобри връзките с бизнеса, набеляза ключови компетентности, приоритетни за бъдещото развитие на обучаемите, свързани с тяхната реализация. Бяха обновени учебните програми по дисциплините, като голяма част от тях са с възможност за дигитализирано ползване на ресурси или за достъп, чрез системи за управление на дигитално образователно съдържание.

Като резултат, една от специалностите към факултета е обявена за „защитена специалност от професия", а като самостоятелна, от последните две години е създадена и нова специалност „Компютърни технологии в мебелната индустрия", резултат от усилията и вижданията за развитие на образованието във факултета в контекста на концепцията Индустрия 4.0.

Наред с това, за да се отговори на изискванията, заложени в тази рамка на развитие, както и да се осигури основата за качествена среда за обучение, са изградени модерни лаборатории, благодарение на сътрудничество между факултета и бизнеса, имащ отношение към подготвяните кадри.

Бъдещото развитие, заложено в дългосрочната стратегия включва въвеждането на дигитално проектиране и прототипиране в мебелните фабрики, продължаване на използването на виртуалната реалност, инженерни симулации в мебелната индустрия с CAD/CAE/CAM и CNC технологиите и възможностите за дигитализация и автоматизиране на процесите. Предвидено е и обновяване на технологичната обезпеченост на преподаваните дисциплини, чрез въвеждането на специализиран софтуер, предназначен за проектирането и производството на мебели и интериорното обзавеждане с възможност за планиране, представяне и въвеждане в производството на индивидуални или цялостни решения.

Ключови думи: дигитално образование, индустрия 4.0, CNC, CAD/CAE/CAM.

ВЪВЕДЕНИЕ

Европейските тенденции в областта на висшето образование, Стратегията за развитие на висшето образование в Република България за периода 2021 – 2030[2] година определят рамката, чрез която университетите и висшите училища да бъдат подпомогнати в процесите, свързани с определяне възможностите и начините за използване на дигиталните технологии, за да доразвият своите концепции, свързани с традиционното обучение. Технологичният напредък, от последните години оказващ влияние върху обществото и неговите структури засяга и образованието като една от областите, в които технологията предоставя свободен достъп до повече информация и следователно повече знания [1]. Фундаменталните промени в начина на производство свързани с Индустрия 4.0, характеризираща се с цифровизация, автоматизация и Интернет на нещата (IoT), водят до икономика базирана на знанието. Големите масиви от данни и развитието на технологиите за тяхната обработка, развитието на технологиите за науките за живота, биотехнологиите, екоиновациите и другите свързани с Индустрия 4.0, според редица автори поставят въпроса за необходимостта от развитие на адекватно образование. Образование 4.0 с възможност за сливане на дигиталното, биологичното и физическото, основано на нови образователни методи и процеси ориентирани към подготовката на индивида с необходимите умения свързани с динамиката в технологичното развитие. Благодарение на актуални инструменти за оценка на състоянието и перспективите, свързани с процесите на дигитализация и иновациите в образованието, тясното сътрудничество с бизнеса, както и все по-достъпните и функционални ИКТ, университетите имат възможност на намерят оптималните възможности за извличане на максимални ползи при провеждане на традиционните дейности и процеси в университетска среда.

АНАЛИЗ НА ВЪЗМОЖНОСТИТЕ ЗА ИНТЕГРИРАНЕ НА ДИГИТАЛНОТО ОБРАЗОВАНИЕ КЪМ ИНДУСТРИЯ 4.0

Парадигмата на Индустрия 4.0 и свързаните с нея технологии (Големи данни, Интернет на нещата, Изкуствен интелект, Облачни изчисления, Машинно обучение, Разширена реалност и т.н.) са ключови по отношение на техническите възможности на икономическите субекти, като „дигиталната промяна“ е съществено изискване за тяхната конкурентоспособност [2]. Това налага въвеждането на подходящи промени в компетенциите и уменията на подготвяните специалисти, чрез инициативи и програми фокусирани върху дидактически методологии. В тази насока на европейско ниво и с насоченост към образование в контекста на Индустия 4.0 вече са налице редица инициативи, като една такава е проекта HEIn4[3]. Данните от производството и техният анализ, като основа за практическо обучение и като примери за официални учебни симулации, могат да послужат при изграждането на модели за внедряване на обучение основано на по-тясна интеграция на учебните дейности към кибер-физическата производствена система [3]. Такива модели комбиниращи интегрирано ИКТ обучение и хибриден модел на интелигентност човек/машина, въз основа на анализа

[2] https://www.strategy.bg/StrategicDocuments/View.aspx?lang=bg-BG&Id=1399
[3] https://hein4.net/

на данни, симулации и комуникация между участниците са основа, както за създаване на умения за вземане на обосновани решения, но и за непрекъснато обучение и подобряване на знанията. Четвъртата индустриална революция използваща изкуственият интелект и цифровизацията, при което взаимодействието човек-машина става още по-гъвкаво променя изискванията към образователната система. Фокусът е върху превръщането на обучението в по-лично, интелигентно, преносимо, глобално и виртуално [4], чрез използването на подходяща информация и умения от преподавателите, с използването на образователни иновации отговарящи на съвременните изисквания. Висшето образование в контекста на индустрия 4.0, е изправено пред големи възможности и предизвикателства. Настъпилите промени и тяхното въздействие следва да бъдат отразени в обучителните дейности на институциите за висше образование, по отношение съдържанието на учебните програми, методите на обучение, осъвременяване на учебната среда, оборудването, както и в подбора на обучаеми [5]. Оценката за въздействието на Индустрия 4.0 по отношение на образованието на база холистичен анализ дава възможност за предприемане на действия и мерки в подкрепа за допълнителни консолидирани препоръки, позволяващи развитието на висшето инженерно образование по актуализирани учебни програми отчитащи приложението Индустрия 4.0 в рамките на дигиталните вериги за доставки, като подготвят добре обучени специалисти за смарт организациите и индустриални компании [6]. Трансформацията на бизнес процесите през последните години, под влияние на технологичните иновации свързани с Индустрия 4.0, наред с подобреното икономическо позициониране на икономическите субекти и ползи за обществото води и до редица социални и културни промени отразяващи се и върху висшето образование [7]. Това се обуславя от новите тенденции свързани с необходимостта да се обучават хора с дигитални умения, посредством методи на преподаване в крак със съвременните изисквания на пазара на труда. Подходите предприемани от висшите училища посредством повсеместното използване на технологиите, насочени към подобряването, оптимизирането и персонализирането на широко-обхватно иновативно образование следва да отчитат възможностите за автоматично проследяване на напредъка на обучаемите по отношение придобиването на нови знания или умения [8]. Процесите на непрекъснати подобрения в начините и методите на преподаване е необходимо да бъдат преосмислени, като за постигането на максимални резултати от обучаемите свързани с техните знания е необходимо трансформиране на модела на интегриране на технологиите в преподаването. Предизвикателствата и възможностите на Индустрия 4.0, налагат образованието във висшите училища да се фокусира върху формирането на знания и умения необходими в ерата на големите масиви от данни, изкуственият интелект, интернет на нещата и информационната сигурност, за да се приспособи към индустриалното развитие [9]. Това налага разработването на нови стратегии за трансформация отчитащи ключови компетенции необходими за овладяване от обучаемите. Според изследване проведено от [10], относно Образование 4.0: като основни компоненти могат да се разглеждат отвореният достъп, индивидуализирано образование, интегрирането на цифрови технологии в образованието, модерната учебната среда, ученето през целия живот,

както и мултидисциплинарното образование; основните качества, които се очакват от студентите, са умения за сътрудничество и комуникация, технологични умения, умения за учене и лични характеристики; технологични умения, умения за насочване, умения за учене през целия живот и лични характеристики са определящи за преподавателите. Цифровизацията налага дълбоки промени в образователната система в отговор на недостига на висококвалифицирани, специализирани и квалифицирани работници [11], което налага неговата хармонизация в съответствие с новите изисквания на пазара на труда и повишаване на осведомеността. Това включва обновяване на учебните програми и методите на преподаване, повишаване квалификацията на преподавателите, както и развиване на модерни лаборатории, които да подпомогнат връзката между университетите и предприята. Индустрия 4.0 променя всички области от общественият живот, като по отношение на образованието връзката е силно двупосочна, поради факта, че от неговото състояние зависи напредъкът и развитието на обществата, както и тяхната способност да се конкурират икономически [12]. За да се постигнат добри резултати от технологичният напредък в индустрията учебните програми във висшите училища трябва да са съобразени с международните стандарти.

Динамичните промени в обществото продиктувани от повсеместното използване на новите технологии засяга значително и образованието, като в голяма степен Висшите училища следва да преначертаят своите стратегии в съответствие с изискванията на Индустрия 4.0.

ДИГИТАЛНО ОБРАЗОВАНИЕ ВЪВ ФАКУЛТЕТ „ГОРСКА ПРОМИШЛЕНОСТ“ В КОНТЕКСТА НА ИНДУСТРИЯ 4.0

В резултат на проведен анализ за самооценка, факултет „Горска промишленост“ при Лесотехнически университет – София, доразви своята стратегия за дигитализация в контекста на Индустрия 4.0 и виртуалното инженерство. Целта на този анализ е създаването на рамка, която да подпомогне факултета в процесите свързани с развитието на специалности насочени към подготовката на специалисти с адекватни умения свързани с допълнителните предимства предоставяни от технологиите използвани и характеризиращи Индустрия 4.0.

Обновяване на учебните програми във факултет „Горска промишленост“ и тяхното интегриране с цифровите технологии

Въз основа на анализа се вижда, че от ключово значение за успешна стратегия по отношение хармонизирано обучение в контекста на Индустрия 4.0 са учебните програми и застъпеното в тях съдържание. През 2020 г., в унисон със заложените цели в оперативния план към Стратегията за развитие на висшето образование в Република България за периода 2021 – 2030 година[4] към факултета беше разкрита пилотна специалност „Компютърни технологии в мебелната индустрия“ за ОКС бакалавър. Учебните програми на дисциплините от учебния план на специалност КТМИ могат да се систематизират в две групи: дългогодишно утвърдени и многократно актуализирани от учебните планове на специалностите „Технология на дървесината и мебелите“ и „Инжинерен дизайн“; изцяло нови дисциплини пряко

[4] https://www.strategy.bg/PublicConsultations/View.aspx?lang=bg-BG&Id=6307

свързани с индустрия 4.0. Обединяващо за всички учебни дисциплини е че, обучението на студентите е пряко насочено към уменията и знанията, които ще са им необходими в съвременната работна среда на мебелната индустрия. При съставяне на учебния план беше възприет принципът във всеки семестър да се въвежда минимум една нова дисциплина пряко свързана с индустрия 4.0 и/или изучаване на приложен софтуер. Последователно през семестрите се заложени да се изучват дисциплини/приложен софтуер: основи на CAD проектирането (AutoCAD, Corel Draw); Компютърна анимация и виртуална реалност (CINEMA 4D; Vray; Unreal Engine); Компютърно оразмеряване и симулационни процеси (CAD/CAE: Solid Works; Autodesk Inventor); Онлайн търговия (imos NET/PLAN); облачни технологии (Tapio.one; iFurn.net); ценообразуване (imos CAD/CAM – Calculation Manager); CAD/CAM/CAE системи в мебелното производство (imos CAD/CAM, NX CAM); Компютърно управление на транспортни операции; Индустриални роботи и манипулатори, CNC машини и инструменти. Разработените учебните програми на дисциплините подпомагат студентите да придобият необходимите им познания в областта на системите за автоматизираното проектиране, инженерни изчисления и спецификата за работата в мебелните производства. В повечето дисциплини са заложени практически задачи и проектно-базирано обучение на студентите в реална производствена среда. Въз основа тях студентите натрупват практически умения за работа със съвременни CAD/CAE/CAM системи и могат да решават задачи, свързани с проектирането и подготовката за производство на типични мебелни изделия. Добрите резултати от проведеното пилотно обучение през първите 2 години в резултат на добре структурираните учебни програми, както и насоките на университетско ниво за актуализиране на всички учебни програми и от другите специалности във факултета поставиха основите наред с въвеждането на споменатите по-горе нови дисциплини, през последните години да се направят съществени актуализации на учебните програми от учебните планове на специалностите ТДМ и ИД. Те са свързани преди всичко с въвеждането в учебния процес на съвременни софтуерни продукти за проектиране и производство на мебелни изделия.



Фигура 1: Увеличение на дисциплините в две от специалностите на факултет „Горска промишленост" по отношение включеното в тях изучаване на информационни технологии

За последните две години са актуализирани 36 учебни програми, с учебен материал свързан с автоматизираното проектиране на мебели и изделия от дървесина. Въз основа на споменатите актуализации

за специалност ИД увеличението на учебния материали свързан с информационните технологии е 31%, а за специалност ТДМ 23% (Фиг. 1).

Подобряване методите на преподаване във факултет „Горска промишленост“, чрез иновативни технологии и средства с свъзможност за проследяване напредъка на обучаемите

Системите за управление на учебно съдържание с тяхното развитие и усъвършенстване през последните години намират все по-широко използване в академичните среди, благодарение на лесната им интеграция с останалите системи на институциите и поддържаната информационна система за участниците в образователните процеси. Наред с това те предлагат и богат инструментариум по отношение каналите за комуникация, начините за дигитализирано представяне на учебното съдържание свързано с дисциплините и възможност за проследяване напредъка на обучаемите. Използваната до момента подобна система от преподавателите в Лесотехнически университет, и в частност от тези от тях свързани с обучението във факултет „Горска промишленост“ е BlackBoard[5]. От въвеждането и през 2014 г. преподавателите от факултета се включват активно в процеса към създаване или мигриране към електронни форми на обучение, като данни за тяхното участие са показани на фиг. 2.

На база анализа от използването на системата през годините и нейната пригодност по отношение на предприеманите промени в стратегията на факултетно ниво насочени към хармонизиране на учебното съдържание в съответствие с Индустрия 4.0 се очертаха необходими промени в технологичната инфраструктура, за обезпечаване нормалното функциониране на процесите и запазването на положителните нагласи от страна на потребителите.



Фигура 2: Брой модули/учебни програми разработени от преподаватели от факултет „Горска промишленост“ с възможност за дигитализирано ползване на ресурсите в платформата BlackBoard

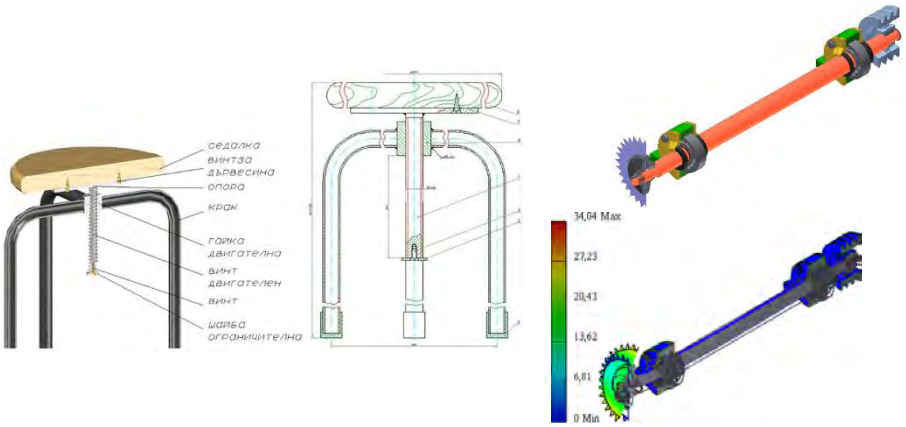
За постигането на максимален ефект от предимствата, които тези системи предоставят по отношение на централизирано обучение, неограничен достъп до учебни материали, намаляване разходите за развитие и обучение, лесното проследяване на напредъка е необходимо използването на интегриран подход по отношение на уеб-приложенията за онлайн комуникация [13]. От друга страна дублирането на SCORM съдържанието в алтернативна система от подобен тип но с отворен код, ще даде възможност за диферсификация

[5] https://www.blackboard.com/

на процесите свързани с изграждането на дигитализирани ресурси и ще осигури устойчивост по отношение създаните ресурси. За тази цел в стратегията на факултета за образование в контекста на Индустрия 4.0 е заложено от 2023 г. да се осигури възможност за използване от преподаватели на факултета на системата MOODLE[6].

Индивидуализирано обучение във факултет „Горска промишленост"

Като добри практики свързани с индивидуализираното обучение и заложени в стратегията за насоченост на образованието във факултета в контекста на Индустрия 4.0 са определени кръжочната форма на обучение, включването на обучаемите в подготовката и организирането на участия в специализирани изложения, както и в конкурси предполагащи развиването у тях на дигитални умения. С традиции във факултет „Горска промишленост" от 2008 г. се провежда кръжок „3D обектно компютърно моделиране и инженерен анализ". С насоченост към студенти от специалностите „Технология на дървесината и мебелите" и „Инженерен дизайн", ОКС „Бакалавър" и ОКС „Магистър", както и към докторантите от факултета посредством индивидуализиран подход се обучават в контекста на конкурентния иженеринг и новите способи на конструиране (Фиг. 3) – конкурентен инженерен дизайн, основан на 3D моделирането и произтичащите от това повишени изисквания към графичните и дигиталните познания на инженерите.



3D и 2D моделиране на сглобена единица – табуретка с двигателно винтово съединение

3D модел на циркулярен механизъм и изследване на собствените трептения по МКЕ

Фигура 3: Представени резултати в областите на ефективно 2D документиране и нови 3D способи на конструиране от студенти кръжоцници

Целта на кръжока е да запознава студентите с методите на твърдотелното 3D моделиране на реални обекти от дървообработващата и мебелната промишленост, както и с някои от софтуерните CAD/CAE системи за 3D моделиране и инженерен анализ по метода на крайните елементи (МКЕ) – Solid Works Simulation, Autodesk Inventor Professional и Autodesk Simulation Mechanical в контекста на концепцията Индустрия 4.0 и инженерните симулации в мебелната индустрия. Една част от задачите за упражнения се разработват колек-

[6] https://moodle.org/

тивно, други – самостоятелно, като резултатите от изследванията са представени под формата на над 17 доклада на Национална студентска конференция “Управление и устойчиво използване на биологичните ресурси“, която се организира от ЛТУ и провежда от 2008 г. и други международни научни конференции и публикации в списания.

Като ключово по отношение на професионалното развитие на обучаемите е индивидуализираното им обучение свързано с участия в конкурси организирани от представители на частни компании имащи нужда от кадри с подходящи дигитални умения за тяхната дейност. Добра практика в това отношение е традиционно провежданият конкурс „ИЙМС“, организиран от фирма “М2 ПРОМ“, с подкрепата на мебелна компания "Lindera" и Фонд за Капиталови Инвестиции АД, и факултет „Горска промишленост“ при Лесотехническия университет. Конкурсът се провежда в три етапа градиращи уменията на студентите: определяне на основни материали, проектирнане на мебел по зададен модел и проектиране на мебел по зададен обем, като всички мебели, проектирани в етап втори, се произвеждат впоследствие в базата на фирмата и служат за нагледно обсъждане на избраните конструктивни решения. Изготвянето на проектите от последните два етапа става в среда на AutoCAD.

Изграждане на модерни лаборатории, които да подпомогнат връзката между университетите и предприята

Добре известно е, че в днешното динамично ежедневие и непрекъснато технологично развитие, обновяването на материалната база на университета е от изключително голямо значение за качествено и съвременно обучение. В тази връзка ФГП изгради редица учебно-демонстрационни центрове и лаборатории, с цел подобряване практическата подготовка на студентите и развиването у тях на необходимите дигитални умения отговарящи на съвременните изисквания на пазара на труда.

През 2019 г. към факултет „Горска промишленост“ бе открит нов учебно-демонстрационен център по електроинструменти (Фиг. 4). Центърът разполага със зала за теоретична подготовка с 16 лекционни места и зала за практическа работа, оборудвана с последно поколение ръчни електроинструменти FESTOOL, предназначени за учебния процес на студентите. Учебният център е изграден с подкрепата на фирмите FESTOOL, TEKA, IKEA, JAF, Консулт Инженеринг – КИМ.



Фигура 4: Учебно-демонстрационен център по електроинструменти (Festool)

През 2020 г. с подкрепата на фирмите Julius Blum GmbH (Австрия) и Интериор И (България) в лицето на управителя ѝ инж. Владимир Димитров към факултет „Горска промишленост" бе изграден нов учебно-демонстрационен център BLUM, оборудван с учебни образци на съвременен мебелен обков и технологично оборудване за неговия монтаж (Фиг.5). Залата е оборудвана с 16 лекционни места и зона за практическа работа.



Фигура 5: Учебно-демонстрационен център BLUM

През 2021 г. към факултет „Горска промишленост" бе изграден нов учебно-демонстрационен център за врати и прозорци.



Фигура 6: Учебен център по „3D визуализации Redvertex"

Залата е оборудвана с 16 лекционни места, зона за практическа работа и гама от учебни образци, а през 2022 г. с подкрепата на фирма Redvertex (България) към факултет „Горска промишленост" е изграден нов учебен център по „3D визуализации Redvertex"(Фиг.6). Залата е оборудвана с 15 работни места с необходимата компютърна техника и софтуер. В нея студентите имат възможност да се запознаят с най-новите тенденции при създаването на фотореалистични 3D изображения, които са неделима част от представянето на всеки съвременен дизайнерски проект.

Наред с новоизградените учебно-демонстрационни центрове и лаборатории към катедра „Дървообработващи машини" в рамките на няколко научно-изследователски проекта беше закупено и ново технологично оборудване, подпомагащо учебния процес на студентите в областта на CNC технологиите и машините, а именно: CNC 3D координатна фреза,

CO_2 лазер за рязане и гравиране, CNC ръчно водима оберфреза модел Shaper Origin.

РЕЗУЛТАТИ

В резултат на създадената рамка от изследването и въз основа на добрите практики придобити от пилотното въвеждане на ориентираната към Индустрия 4.0 специалност КТМИ разкрита към факултета, се премина към надграждане и осигуряване на устойчивост на постигнатите резултати. Насочено към адекватни учебни програми, съответсващи на нуждата от придобиване на специализирани дигитални умения, индивидуализирано обучение с възможност за използване на съвременни методи за преподаване във факултета започна подготовката за въвеждане в образователния процес на специалност „КТМИ“ и за ОКС „Магистър“. Дицсиплините от учебния план предвиждат да доразвият способностите за обучение през целия живот от страна на студентите, като надградят познанията в области близки или имащи отношение към Индустрия 4.0. В допълнение факултет „Горска промишленост“ е участник и в проект „Модернизация на висшето образование в областта на природните ресурси“ финансиран по оперативна програма. В тази насока, като резултат от създадената рамка от изследването, факултетът доразви своята стратегия, като съвместно с друг университет от България, стартира процеса по организиране и въвеждане в процеса на обучение на специалност „Мебелна Индустрия 4.0“, ОКС „Магистър“, професионално направление 5.13 – „Общо инженерство“. Предвидените допълнителни курсове за преподавателите насочени към развитие на дигиталните им умения и свързани начини за преподаване, както и специализираните софтуерни пакети и оборудване ще осигурят технологичната инфраструктура за успешното обучение на студентите. По този начин, чрез завършване цикъла на обучение за специалност КТМИ посредством ОКС „Магистър“, и след въвждането на специалност „Мебелна Индустрия 4.0“ ще се осигури до голяма степен конкурентоспособността на факултета, като се отговори на съвременните изисквания за дигитално обучение в контекста на Индустрия 4.0.

ЗАКЛЮЧЕНИЕ

За да бъдат успешни, както по отношение подготовката на висококвалифицирани кадри притежаващи необходимите за реализация в настоящата обстановка дигитални умения, така и по отношение на тяхната конкурентоспособност в рамките на глобалицазия стратегиите за хармонизирано образовение в контекста на Индустрия 4.0 следва да бъдат насочени към: обновяване на учебните програми и тяхното интегриране с цифровите технологии; подобряване методите на преподаване, чрез иновативни технологии и средства свъзможност за проследяване напредъка на обучаемите; индивидуализирано обучение; повишаване квалификацията на преподавателите и осигуряване на отворен достъп до ресурси; развиване на модерни лаборатории, които да подпомогнат връзката между университетите и предприята. Това трябва да става хармонизирано в съответствие с новите изисквания на пазара на труда и международните стандарти, което ще доведе до развитието на специалности отговарящи на стандартите за обучение в контекста на Индустрия 4.0.

В това направление факултет „Горска промишленост“, има традиции и разполага с подготвени специалисти, благодарение, на което през последните години

успя да доразвие своята стратегия в унисон с новите технологични изисквания. Чрез ясна и широко споделена визия, очертаваща основни приоритетни области за развитие, целите и мерките за постигането им, факултетът следва устойчива линия за подобряване, както качеството на образователните процеси, така и на своята привлекателност по отношение на студентите и бизнеса.

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OPPORTUNITIES FOR OPTIMIZATION OF PRODUCTION ACTIVITIES AND COST OF PRODUCTION IN THE FURNITURE INDUSTRY

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ABSTRACT

The article discusses key points in the management of business processes of companies in the furniture industry in Bulgaria. Similar problems have been identified, related to difficulties in calculating the planned price of the products, as well as the lack of information on the planned and actual price of the individual production processes. Overstocking of raw materials or late ordering due to lack of synchronization between procurement and production schedule is another key point that could be addressed with appropriate tools. One of the most serious problems underestimated by producers in the sector is the lack of production planning mechanisms. Various business cases from practice show that the automation of production planning leads to better load of production facilities, which directly affects the cost of production. In this regard, the calculation of the real cost of individual semi-finished and finished products, companies report as labor-intensive, which leads to averaging the cost of production and misstatement of information. In this regard, the article aims to provide clear mechanisms and approaches based implementation of the appropriate IT product, which manufacturers in the furniture industry would increase their efficiency and productivity.

Key words: SAP, furniture manufacturing, cost of good sold, automation manufacturing, ERP – systems.

ВЪЗМОЖНОСТИ ЗА ОПТИМИЗИРАНЕ ПРОИЗВОДСТВЕНИТЕ ДЕЙНОСТИ И СЕБЕСТОЙНОСТТА НА ПРОДУКЦИЯТА В МЕБЕЛНАТА ИНДУСТРИЯ

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РЕЗЮМЕ

В статията са разгледани ключови моменти в управлението на бизнес процесите на предприятия от сектора на мебелната промишленост в България. Установени са сходни проблеми, свързани със затруднения при изчисляване на плановата цена на продукта, както и липсата на информация за планова и реална цена на отделните производствени процеси. Презапасяването със суровини или късното им заявяване, поради липса на синхронизиране между снабдяване и производствен график е друг ключов момент, който би могъл да се разреши с подходящи инструменти. Един от най-сериозните проблеми, който се подценява от производителите в сектора е отсъствието на механизми за планиране на производството. Практиката показва, че автоматизацията на производството води до по-добро планиране на производствените мощности, което пряко влияе върху себестойността на продукцията. В тази връзка изчисляването на реалната себестойност на отделните полуфабрикати и готови изделия, компаниите отчитат, като трудоемко, което води до осредняване на цената за производството и изкривяване на информацията. В тази връзка статията има за цел да даде ясни механизми и подходи на база внедряването на подходящ

„ИТ продукт“, с което фирмите производители в сферата на мебелната промишленост, биха повишили ефективността и производителността си.

Ключови думи: SAP, мебелно производство, себестойност, автоматизация на производството, „ERP“ – системи.

ВЪВЕДЕНИЕ

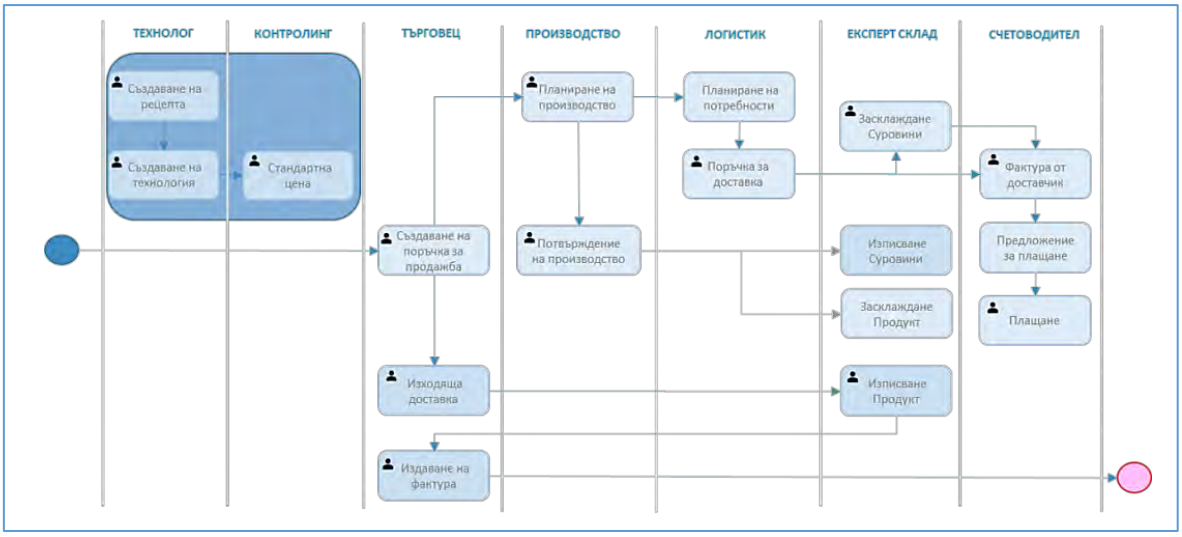
През последните години в мебелната промишленост в България, се наблюдава значителен ръст на инвестициите в софтуерни решения, с което се цели оптимизиране на производствените дейности и себестойността на продукцията. При избор на решение за управление на бизнес процесите, често водещ фактор се явява ниската цена. Този избор обикновено е сведен до решения покриващи финансово-икономическите изисквания на компаниите, но не и производствените нужди. Друго често срещано разбиране е, че за покриване на всички свои нужди, компанията трябва да работи с множество софтуери, всеки специализиран в определена област, с което се оценяват недостатъчни ползи от внедряването им, а същевременно служителите губят много време за сравняване на данни от една система спрямо друга, извеждането на отчети се превръща в трудоемка задача, а информацията е ненавременна и ненадеждна. Всичко това би могло да се избегне с помощта на утвърдени „ERP“ – системи (Enterprise Resource Planning – планиране на ресурсите на предприятието), които са насочени към управление на бизнес процесите в компаниите в единна интегрирана система.

ERP СИСТЕМИТЕ

За да установим принципа на работа на „ERP“ – системите, ще се спрем на конкретна интегрирана информационна система за управление на бизнес процесите – „SAP S/4HANA“. Решение, като „SAP S/4HANA“ е не само софтуер за управление на бизнес процеси, но и знания как да извършим това, базирайки се на най-големите компании в различни индустрии. „SAP“ (Systems Applications and Products in data processing – Системни приложения и продукти в обработката на данни) разполага с разработени добри практики, които дават възможност на малките и средни компании в мебелната промишленост да внедрят решението в кратки срокове, с разумен бюджет, позовавайки се на световния опит (https://www.sap.com/products.html). Използвайки „SAP S/4HANA“ всеки клиент има възможност да избира, кои добри практики са приложими за него, съобразявайки проекта си с целите, които си е поставил (https://help.sap.com/docs/SAP_S4HANA_ON-PREMISE). Голяма част от компаниите в сектора имат ясни цели, от една страна да обхват всички бизнес процеси в една интегрирана информационна система, за да оптимизират и автоматизират част от тях, а от друга да подобрят отчетността си, за да получат бърза и надеждна информация в реално време.

С внедряване на интегрираната информационна система „SAP S/4HANA“ очакванията на предприятията, са сведени до оптимизиране процесите по планиране на суровините, което от своя страна би довело до оптимизиране складовете запаси. Друг очакван резултат е автоматизиране и оптимизиране процеса по изчисляване на планови и фактически цени на продуктите, с което компаниите в сектора биха могли да реагират адекватно на пазара и да покажат гъвкавост при ценообразуване.

Пример от добрите практики в мебелната индустрия, прилагайки решенията на „SAPS/4HANA“ е показаният интегриран бизнес модел на фиг. 1 (https://www.stemo.bg/bg/service/category/s4factory).



Фигура 1: Процес на производство по „клиентска поръчка“

За да стартира дадено производство, би следвало да е налице потребността от продукт. Потребността може да бъде породена от заявка от клиент или от решение за производство на продукти за склад. На фигура 1 е представен схематично процес на генериране на потребност от „клиентска поръчка“. Независимо от това каква потребност стартира процесът, основен момент е да бъдат дефинирани изискванията към продукта и желаните дати за производство. От водещо значение за постигане на очакваните резултати от системата е изискванията към продукта и неговото производство да бъдат представени. Основни техники за това са създаването на технологични карти и „рецепти“. „Рецептата“ представя количествата от суровините и полуфабрикатите, които са необходими за производството на единица краен продукт. Всяка суровина в система е представена като основен запис съдържащ информация както за наименованието, единицата за измерване, така и данни за нейната доставка – срок и минимално количество на доставка, доставчици, цена, на която може да се закупи. За да е налице достатъчно гъвкавост при планирането, е необходимо в „рецептата“ да бъдат планувани и заместители на основните суровини. Това е особено полезно за продукти при, които цените се променят често или имат много дълги срокове на доставка. Следващият задължителен елемент в системата е построяването на технологията на производство. Технологията на производство описва поредицата от операции и тяхната продължителност за производство на крайния продукт. Всяка операция се изпълнява на конкретна машина или производствена линия, като важен момент за оптимизиране на планирането на производство е да се определят капацитета на отделните машини и необходимия квалифициран персонал, който да изпълни операциите на тях. „Рецептата“ и технология са в основата на последващите процеси в системата, те съдържат всички необходими данни за автоматизиране процесите по планиране на производството и изчисляване на себестойността. Много често, говорейки за себестойност, голяма част от

предприятията свързват това понятие единствено и само с изчисляване материалната себестойност. Това се оказва твърде недостатъчно, за да може компанията да бъде конкурентна на пазара и да определя своите продажни цени на база реални разходи.

Технологията на производство е обекта в системата, която съдържа цялата необходима информация за изчисляване материалната и пълната себестойност. Този процес реализиран в S/4HANA – системата следва конкретен алгоритъм. Машините в системата са свързани с носител на разходи – разходен център, където би могло да бъдат планирани разходите свързани с амортизация на машините, ремонтни дейност, заплати на служителите и т.н. Всяка машина има конкретен капацитет и план за натоварване. На база планираните разходи и часове работа системата разполага с налична информация за един час планово на всяка машина, както и необходимото време за производство в часове, за всеки един продукт и машината, през която преминава за обработка. По този начин, на база на технологичната карта, бихме могли да изчислим колко производствени разходи, свързани с производствените операции, планираме.

Базирайки се на технологията и „рецептата“, разполагаме с информация за разходите за материали и производствени операции за всеки един продукт, като бихме могли да добавим непреките производствени разходи, като разходи осветление, амортизации на производствените помещения, разходи за качествен контрол, разходи за поддръжка на складови пространства и други. Тези разходи, добрата практика препоръчва да бъдат планирани по отделни разходни центрове. На база на предварително дефиниран алгоритъм те се включват, като част от плановата цена на продуктите. Най-често използваните методи за планово разпределение на тези разходи са на база себестойността на преките материали или на база времето за обработка на продукта. Често компаниите разпределят тези разходи и поравно между всеки един продукт, който се произвежда, тъй като в повечето случаи ги третират, като постоянни разходи независимо от обема на производство.

Използвайки технологията и „рецептата“ и алгоритмите за разпределение на непреките разходи, бихме могли да изчислим плановата цена на продукта и на тази база да определим конкурента продажна цена. Системата предоставя възможност да се разиграват различни версии на изчисляване на планова цена, например ако използваме алтернативен материал или алтернативна производствена линия.

От представената схема на фиг. 1 се вижда, че на база регистрирана клиентска поръчка, системата генерира производствени поръчки. Това е възможно поради два факта – от една страна желана дата на производство е известна, а от друга е съставена технологичната карта за производство на изделието. Тръгвайки от желаната дата на производство системата връща назад поредността на технологичните операции и определя времето, в което да стартира съответното производство. За всяка машина или производствена линия системата резервира определен капацитет. В резултат на което, още при постъпване на клиентското запитване, би могло да се прецени дали е налице необходимия капацитет, за да бъде произведено даденото изделие за датата, изискуема от клиента. В случай, че това е невъзможно системата определя, първата възможна дата на база на свободните ресурси. Следващият етап след определяне на производствения план е осигуряване на необходимите суровини

за производството. Всяка технология на производство е свързана с конкретната „рецепта“ за производство на изделието, а за съответната операция са определени необходимите суровини. По този начин, на база определения план за производство, системата генерира автоматично потребности от суровини. На този етап би могло да възникне ситуация, в която създадения план за производство не е съобразен със сроковете на доставка, като специалист от компанията би трябвало да избере едно от двете готови решения: да използва някои от алтернативните суровини при възможност или да промени производствената програма на база сроковете, в които може да бъде доставена суровината. Всяка система, включително и „SAP S/4HANA“ има множество вградени алгоритми, целящи автоматизиране на процесите, като във всяка автоматизация има случаи, за които е необходимо и човешко решение. Системата трябва да предоставя и интуитивен интерфейс, който позволява на потребителя лесно да се ориентира във възникналата ситуация, за да вземе решение. „SAP S/4HANA“ има нов модерен потребителски интерфейс „SAP Fiori“, който позволя да се работи както от десктоп машини, така и от мобилен телефон (https://www.sap.com/products/technology-platform/fiori.html).

ЗАКЛЮЧЕНИЕ

В гореизложеното представихме нагледен пример, как бихме могли да постигнем автоматизация на себестойността и автоматизация и оптимизация на планирането следвайки възможностите на „SAP S/4HANA“ – система, с което фирмите производители в сферата на мебелната промишленост, биха могли да повишат активността и производителността си.

ИЗТОЧНИЦИ

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THE DEEP TECH: NEXT BIG THING IN INNOVATION ECOSYSTEM

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ABSTRACT

Additional information about Deep Tech: We define deep technology as companies founded on a scientific discovery or meaningful engineering innovation. This is where you're asking, "Aren't all technology companies founded on these principles?" Partly yes, but mostly no. Most technology companies these days are built on business model innovation or offline to online business model transition using existing technology. Take Uber for example – Uber is built on the concept of a "sharing economy" – a business model innovation enabling individuals to share existing resources. Deep technology companies on the other hand, are built on tangible scientific discoveries or engineering innovations. They are trying to solve big issues that really affect the world around them. For example, a new medical device or technique fighting cancer, data analytics to help farmers grow more food, or a clean energy solution trying to lessen the human impact on climate change. Continuing the Uber reference, deep-technology companies in the transportation business would include autonomous vehicles, flying cars or other similar transformative technologies. (Quotation)

PROCEEDINGS OF ELEVENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE "INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN" – INNO 2022, 3-5 OCTOBER, HOTEL RILA, BOROVETS, BULGARIA, P. 255

MODELING OF METAMATERIALS FOR FURNITURE HONEYCOMB PANELS

Prof. Dr. Jerzy Smardzewski (Keynote Lecturer)
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ABSTRACT

The properties of conventional honeycomb panels depend mainly on the mechanical properties of the facings. However, metamaterials, especially with a negative Poisson ratio, can significantly improve the properties of the core and the properties of the whole honeycomb panel. Modeling various auxetic metamaterials for furniture honeycomb panels are discussed.

CHALLENGES AND OPPORTUNITIES FOR THE FURNITURE INDUSTRY IN BULGARIA AFTER THE KOVID CRISIS, WAR AND RAW MATERIAL SHORTAGES

Prof. Dr. Vassil Jivkov (Keynote Lecturer)
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ABSTRACT

In the last 2–3 years, the furniture industry has faced several challenges globally and nationally. First, the Covid crisis started, followed by a global shortage of raw materials, transport problems, the rising cost of energy resources and finally, the war in Ukraine. This brought furniture companies several difficulties and challenges, but on the other hand, it also opened up new opportunities. Processes of optimisation, automation and robotisation of production, search for new raw materials, new energy sources, and energy efficiency improvement started. Increasingly, companies will pay attention to innovation and human capital.

STUDENTS' WORK DIARIES: VISUAL IMPRESSIONS OF A DESIGN PROJECT STUDY MODULE

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ABSTRACT

The object of the present article is a summary of Students' Work Diaries, prepared by every team participating in the "Design Project", a study module of "Engineering Design (Interior and Furniture Design)" Bachelor Program.

In the article, authors are looking at the information obtained from the diaries. The following questions are considered: Are students paying enough attention to these diaries as a tool to present their work? To what extent is the submitted information sincere and complete? Can students' work diaries actually be an effective way of grading a team's work and its individual members?

Based on the analysis made of students' diaries from "Design Project" module in four successive years, conclusions and recommendations are made. The aim is to improve the requirements for the preparation of student diaries, so that teachers can use them for grading the work done by teams and their individual members.

Key words: Team Project-Based Learning (TPBL), design education, sketchbook.

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SMALL SPORT ZONES IN HOME AND IN OFFICE: INTERIOR AND DESIGN

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ABSTRACT

The report examines a growing phenomenon: (sport) exercising at home and in small offices. The reasons for the ever-wider spread of this, can be found in the consequences of the Covid pandemic, but also in the changed everyday culture of society (including the digital revolution and the possibilities for remote work).

The purpose of the research is to track the current needs and appropriate solutions in the creation of sports areas in small spaces, or in zones not originally meant for exercising processes. Comparative analysis and survey research are used.

The expected outcomes are in the fields of design theory, contemporary design and architecture.

Key words: sports at home, sports equipment, home furnishings, design for sports, home office.

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COMPOSITION IN THE 21ST CENTURY: GESTALT AND INTUITIVE DESIGN

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ABSTRACT

The research is focused on some new compositional approaches in the interior design of the 21st century. The aim is to highlight important trends in modern design creation and reveal the advantages and disadvantages. Popular examples from various world practices are analyzed. An evaluation and comparative analysis is carried out, the degrees of sustainability and future potential of the considered solutions are tracked.

The expected results are in the field of theory and history of design, composition and architecture.

Key words: gestalt design, intuition, intuitive design, new compositional approaches, contemporary design, 21st century.

PROCEEDINGS OF ELEVENTH INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE "INNOVATIONS IN FOREST INDUSTRY AND ENGINEERING DESIGN" – INNO 2022, 3-5 OCTOBER, HOTEL RILA, BOROVETS, BULGARIA, P. 260

THE TRIPOD: A RARELY MENTIONED FURNITURE TYPE T

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ABSTRACT

In the article, a rarely mentioned in publications furniture type is considered: the tripod. The functional and symbolic meaning of this ancient artefact are researched aiming at revealing its role for the emergence of other furniture types in the XVIIIth, XIXth and XXth C because of the Antique Vogue and the trend for commodity search. Such objects, as stands, tables, trays, tea-tables, etc., are considered. In the process of this research, the role of this ancient archetype is revealed for the creation of modern products with a folding tripod structure, e.g., portable stools, tables, stands, etc.

Key words: style, furniture, tripods, tables, archetype, classicism.

MODERN ENGINEERING TECHNIQUES FOR THE PRODUCTION OF MODIFIED POLYSACHARIDES WITH BIOLOGICAL ACTIVITY

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ABSTRACT

Esters are used in the industry. The rapid increase in demand for esters in the food, cosmetics and pharmaceutical industries makes it mandatory to find alternative ways of synthesis instead of low-yield, expensive, energy-intensive and prolonged reactions.

The production process for the synthesis of esters is based on chemical esterification of fatty acids with alcohol in the presence of inorganic catalysts at high temperatures. However, these chemical processes are non-selective and consume a large amount of energy. In this regard, the current situation of environmental degradation requires the development of efficient and environmentally friendly methods in terms of energy consumption and waste reduction. The synthesis of esters by sonication is also an economical and effective method of performing esterification with broad practical application.

The article presents a review of research and modern engineering solutions based on "green technologies" for the synthesis of esters. Significant advantages of the method of transesterification of methyl caprate with sucrose, leading to esters with potential biological activity such as antifungal and antimicrobial agents, are highlighted.

The intensifying effect of ultrasonic effect in the transesterification of methylcaprate with sucrose catalyst sodium methylate at room temperature has been demonstrated, in which sucrose caprate is obtained with a significant minimization of reaction time.

As a result, the reaction time is reduced and the reaction temperature is reduced. Under the conditions of ultrasonic synthesis, the composition of the resulting esters is the same as those obtained by the conventional method.

Similarly to undecylene, inulin and fructooligosaccharide esters, it is expected that sucrose caprates synthesized according to the method described in the article should also possess an antimicrobial and antifungal agent and may be used to develop a new plant protection formula and ecological fungicide. The promising ability to foam and emulsify offers an adequate solution to treatment and adhesion problems on root or leaf surfaces. These functional properties in combination with antimicrobial activity can also be successfully used for the administration of sucrose caprates in pharmaceutical preparations and for food preservation.

Key words: polysaccharides, esterification, ester, ultrasonic, sonochemistry, capric acid.

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CHANGE IN THE DURATION OF AUTOCLAVE STEAMING REGIMES OF NON-FROZEN PRISMS AT DISPATCHING INTERVENTIONS IN THE PRODUCTION OF VENEER

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ABSTRACT

An approach for computing and research of the duration of regimes for autoclave steaming of non-frozen wooden prisms at limited heat power of the steam generator in cases of dispatching interventions into the regimes in order to obtain a duration that is suitable for the subsequent cutting of the veneer from the heated plasticized wood has been suggested. Using own 2D unsteady model of the wood steaming process, which is implemented in the approach, calculations of the change of the duration of regimes for plasticizing of beech prisms in an autoclave have been carried out. The variables used during the computer simulation were, as follows: initial wood temperature of 0°C, wood moisture content of 0.6 $kg \cdot kg^{-1}$, and cross-section dimensions of the prisms 0.4 × 0.4 m; steaming autoclave with a diameter of 2. 4 m, length of 9.0 m, and loading level of 50% for the cases of lowering by the dispatcher the maximal temperature of the basic steaming regime from 130°C to 120, 110, and 100°C in the 3rd, 5th, and 7th hour of this regime.

Key words: wooden prisms, autoclave steaming, duration of regimes, dispatching intervention, veneer production.

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COMPUTING THE AVERAGE MOISTURE CONTENT OF WOOD MATERIALS SUBJECTED TO STEAMING IN AN AUTOCLAVE

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ABSTRACT

An approach for computing the average moisture content of the whole quantity of wood materials in given batch subjected to steaming in an autoclave has been suggested. This value of the wood moisture content is needed for calculation and automatic realization of optimal energy saving regime for autoclave steaming of the materials. The approach is based on two own 2D mathematical models: one of the temperature distribution in non-frozen prismatic wood materials during their steaming and other – of the heat balance of the autoclave. The calculated by the models increase in the steaming medium temperature in the beginning of basic regime is compared with the real increase of that temperature, which is measured with a sensor in the automatic control system. After proper processing of the obtained differences between measured and calculated temperatures with the software package Table Curve, an equation for calculating the average moisture content of the wood materials batch loaded in the autoclave is derived. The application of the suggested approach for the cases of autoclave steaming of beech prisms in the production of veneer is presented.

Key words: wooden prisms, average moisture content, autoclave steaming, mathematical models, veneer production.

EFFECT OF THE HYDROLYSIS REGIME ON THE PROPERTIES OF RECYCLED FIBRES

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ABSTRACT

The production of fibreboard panels is one of the sustainable wood processing industries. The total increase in the production volume of this type of material for the last five years is approximately 10%. In 2021 worldwide, Medium Density Fibreboard (MDF) production amounted to 105 million m3. MDF completes its life cycle for about ten years. Because of that, the possibility of recycling this type of material is of considerable relevance. It should be emphasized that, unlike the recycling of particleboards, the recycling of MDF is not a widespread industrial practice. Recycling is possible with and without the extraction of the binders used. Applying recycling methods without removing the resins significantly reduces the slenderness of the fibres and increases the formaldehyde emissions of the panels manufactured with such fibres.

The extraction of binders, mostly urea-formaldehyde (U.F.) resins, is carried out mainly by hydrolysis. Hydrolysis can be done with or without chemical reagents. Applying thermal hydrolysis without using chemical reagents increases the processing time but reduces its cost due to the absence of expensive chemicals and reduced contamination of the residual solution.

This report presents a study on the effect of the hydrolysis regime, process time and temperature on the properties of recycled, from MDF, wood fibres. The hydrolysis temperature varied at two levels - 121°C (0.2 MPa) and 134°C (0.3 MPa), and for each temperature were applied three durations - 30, 45 and 60 minutes. After hydrolysis, the material was refined by a hammer mill. The fractional composition of the obtained fibres and the elemental composition of the recycled fibres were determined. The hemicellulose content after each hydrolysis regime was also studied. The chemical oxygen demand (COD) of the wastewater was determined as an indicator of contamination of waste waters and an indirect indicator of the quantitative yield of the process.

It was found that there were no significant changes in the elemental composition of the recycled fibres, and no decrease in the content of pentosans was observed in the selected hydrolysis regimes. Recycled fibres have a similar fractional composition, being shorter than natural fibres. With increasing temperature and time of hydrolysis, a significant increase in COD was observed. On this basis, the optimal regime of hydrolysis can be pointed to the one with a temperature of 121°C and a time of 30 min.

Key words: Medium Density Fibreboards, recycling, hydrolysis, nitrogen content, hemicelluloses.

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SUNFLOWER STALKS AND LIGNOSULFONATE – ALTERNATIVE RAW MATERIALS FOR THE PRODUCTION OF ECO-FRIENDLY MEDIUM DENSITY FIBREBOARDS

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ABSTRACT

The main advantages of the technology for producing Medium Density Fibreboards (MDF) are the reduced requirements for wood raw material, the possibility of fabricating that type of product from sawmill residues and the potential of including other non-wood lignocellulosic raw materials in the composition of the panels.

Such lignocellulose raw materials are residues from agriculture. In our country and worldwide, there are many successful studies for at least partial replacement of wood raw material with agricultural residues. Sunflower plantations are the second largest in our country, which is why they would be a significant source of non-wood lignocellulosic raw material.

Another significant problem in MDF production is the presence of formaldehyde emissions from the panels. One of the main directions for solving this problem is replacing the traditional binders with alternative ones without formaldehyde emissions. These alternative binders should not significantly increase the cost of board production, maintain their performance, and, most importantly, not be hazardous to human health. This binder includes the so-called bio-based binders, of which lignin-based products are the most promising. A typical representative of such an alternative bio-based binder is lignosulfonate (methylated lignin).

That leads to the relevance of a study on the possibility of partially replacing wood raw material with sunflower stalks and reducing the number of synthetic binders used in MDF by adding lignosulfonate in the adhesive system.

As a result of the research on the influence of urea-formaldehyde resin content, lignosulfonate content, and pulp from sunflower stalks on the properties of thin MDF, the main conclusions were deduced, and recommendations were made on the practical use of these alternative raw materials.

Key words: eco-friendly MDF, sunflower stalks, lignosulfonate, urea-formaldehyde resin.

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INVESTIGATION OF THE INFLUENCE OF SOME FACTORS ON THE STRENGTH AND STIFFNESS OF JOINTS WITH STAPLES AND GUSSET PLATES

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ABSTRACT

Joints made with staples and gusset plates are widely used in the wood frame construction of various types of furniture, due to the quick and easy production and the availability of simple technology. In this regard, their good knowledge of bending loads would help furniture designers in the design process. The investigation aims to summarize the data from the specialized literature on the values of parameters characterizing the behavior of joints with staples and gusset plates of details in wood frame, as well as to establish the influence of some key factors such as the detailed thickness, the angle between wood details of the joints, thickness and type of material of the gusset plates on their strength and stiffness under bending load.

Key words: joints with staples and gusset plates, strength and stiffness, wood frames, bending load.

TECHNOLOGICAL RESEARCH OF PNEUMOSEPARATOR FOR FOREST SEED EXTRACTION

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ABSTRACT

A technological study on the operation of a pneumatic separator on a BCC Cleaner&Seed Sizer (mini) machine for extraction of Scots pine (Pinus sylvestris L.) seeds has been carried out. It is part of the new technological equipment for greenhouse production of container seedlings in the Lokorsko forest nursery. Compared to the traditional production of saplings in Bulgaria for afforestation, the new production requires the extracted seeds to have higher quality indicators. In order to establish the optimal operating modes of the pneumoseparator for high quality seed production, with minimal seed losses in the waste in the aspiration system, a multifactor active experiment and optimization in the treatment of Scots pine seeds was conducted. The obtained results were used to establishment of a regression models to predict the technological parameters and the quality of the obtained seeds depending on the operating modes of the machine. The optimal parameters for setting the pneumatic separator have been established and functional modes for Scots pine seeds extraction have been determined.

Key words: pneumoseparator, scots pine seeds, quality, models, optimization.

EXPLOITATION RESEARCHES ON FORESTRY MILLING MACHINES FOR SOIL PREPARATION AT THE TERRITORY OF SHUMEN NORTH-EAST STATE FORESTRY

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ABSTRACT

Forestry milling machines for soil preparation of afforestation are featured by higher technological and ecological properties, but also with higher energy costs, compared to the traditional machines used in our country. This paper presents the results of the conducted experimental studies to establish the main operational properties of forestry milling machines for complete soil preparation for afforestation in the lower forest vegetation zone in Bulgaria. The study were carried out with FAE SSH/HP 250 forest tiller in experimental sites located in open forest areas, forest fellings and field protection forest belts on the territory of the Shumen Forest North-East State Enterprise. The fuel consumption and productivity for complete soil preparation of open forest areas and clearings with stumps of hardwood species, with an average stumps diameter from 10 cm to 38 cm and stumps density from 220 pcs/ha to 1310 pcs/ha, at tilling depth up to 40 cm, at different rotation speed of the tiller were determined. Based on the obtained results, regression models were developed to determine the main operational indicators of the forest cutters and the optimal operating modes of the machines under certain working conditions were established.

Key words: forestry tillers, soil preparation, fuel consumption, operating productivity.

EXPLOITATION RESEARCH OF A CABLE SKIDDER TAF 690 PE FOR TIMBER SKIDDING IN THE WESTERN STARA PLANINA

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ABSTRACT

This paper presents the results of a study that was conducted to establish the basic performance characteristics of a specialized forestry tractor for skidding of a whole tree stems and long timber sections in mountainous conditions. The tractor travel speed at different gradients as well as the hourly productivity for a tree-length harvesting system in the Western Balkan Mountains region were determined. The regression analysis method was used to conduct the study and to determine the influence of various factors on the hourly productivity of the tractor, at a constant trip load volume. For this purpose, a planned two-factor experiment with three levels of variation of input factors was conducted. The time for tractor's moving in different gradients was determined by timing. Running speeds were found at range from 3,23 to 4,82 km/h, hourly productivity from 5,36 to 10,98 m^3/h with trip loads ranging from 6,9 to 8,5 m^3. Regression equations were derived and by their use could be determined the productivity for different gradients and different lengths of skidding distances.

Key words: cable skidder, skidding wood, speed of skidding, hourly productivity.

SUCCESSFUL COLLABORATION BETWEEN DISCIPLINES THROUGH THE APPLICATION OF DESIGN THINKING IN THE CONTEXT OF TEACHING IN A VIRTUAL ENVIRONMENT

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ABSTRACT

The curriculum in the "Engineering Design (Interior and Furniture Design)" bachelor program has been frequently changed over the years, both in terms of how and what kind of disciplines are taught. In the past 2020-2021 academic year, the teaching staff was presented with another novelty – transition to full-time virtual training in practical design and purely artistic disciplines.

In the context of the introduction of a new, virtual education modality the new teachers in the department decided to leverage the moment and test innovative ways of working that are widely applicable in their individual practices and were formerly introduced in their design training in foreign universities. Their approach was based on integrating design thinking with the traditional approach used in the program, to bridge two separate disciplines from the curriculum – "Graphic Design" and "Furniture Design for Public Spaces". In the process the assistant-proffesors introduced a few new tools, principles, and perspectives, all with the idea to raise the level of engagement and practical field work experience among students, taking advantage of the positive aspects of working in a virtual environment.

Key words: design thinking, virtual ways of working in the design process, motivation, collaboration between disciplines, interdisciplinary training.

DATA ENVELOPMENT ANALYSIS OF FACTORS FOR FOREST INDUSTRY WAGES AND SALARIES LEVELS IN NUTS 2 REGIONS OF BULGARIA

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ABSTRACT

Determining the economic efficiency of entire enterprises or of certain processes in the use of resources is a topic of constant relevance. Bulgaria's forest industry is a specific sector that provides employment to the population in all regions of the country. So far, many studies have been done on the economic efficiency of the forestry sector in the country. Human resources in the sector, as well as labor costs, were also investigated. In the present study, a methodology is applied that determines the economic efficiency of employment compared to the salaries paid. In this way, the study determines the optimality in the ratio of employment / wages and answers the question to what extent in each of the regions of the country companies have managed to provide productive jobs with good pay.

Key words: economic efficiency, employment, factors, wages, regions.

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AUTOMATED ELECTRO-PNEUMATIC MECHATRONIC COMPLEX FOR TREATMENT OF SMALL ROTARY DETAILS OF SOLID WOOD

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ABSTRACT

The report presents an automated electropneumatic mechatronic complex using a programmable controller to implement the logical control of actuators for processing small rotating parts of solid beech wood. The elements from which the production complex is built are described, a functional layout scheme is presented, the control program is shown, the electrical scheme of the complex is realized.

Key words: automated complex, rotary details, logical control.

INFLUENCE OF INITIAL LARCH HEARTWOOD OUTDOOR LEACHING ON DURABILITY OF SELECTED OIL-BASED COATING DURING ACCELERATED WEATHERING

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ABSTRACT

Arabinogalactans and other extractives contained in larch wood (Larix decidua, Mill.) Reduce the overall life of exterior coating systems, especially transparent and semi-transparent. The aim of the work was to find out whether the initial leaching of natural wood extracts in the exterior will positively affect the selected characteristics and the overall life of the semi-transparent oil-based coating. Samples exposed to leaching for 10 and 20 weeks, respectively, and reference samples without leaching were subsequently treated with a low pigment oil based coating system. Testing was performed by the method of artificial accelerated aging with spraying in the UV-chamber (AW) according to EN 927-6 and thermal cycling for 6 weeks. The evaluated properties were changes in color, gloss, contact wetting angle, microscopic surface changes and visual evaluation of paint damage. Only a sufficiently long, 20-week initial washout had a positive effect not only on a significant increase in color fastness during AW, but also on a slight increase in the overall life of the tested semi-transparent larch wood coating system, which was assessed visually.

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MECHANICAL RESPONSES OF THIN-WALLED HONEYCOMB PANELS WITH DISCREETLY PLACED REINFORCING ELEMENTS

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ABSTRACT

Strength and stiffness of honeycomb furniture plates with hexagonal shape cells core were studied during static bending test. The influence of discreet arrangement of reinforcing elements on the relative energy absorption has been determined. The effect of edge bending on the stress distribution in facings was explained. Experimental and numerical test were used. The possibility of using new panels for designing tables and cabinet furniture were discussed.

Key words: sandwitch panels, hexagonal cells, bending, energy absorbtion, test, FEM.

DETERMINATION OF THE ANNUAL CAPACITY OF A MANUFACTURING COMPANY FOR SOLID WOOD MATERIALS

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ABSTRACT

The annual capacity of the woodworking factory for solid wood materials (SWM) is their main characteristic and has important technological, technical and economic significance. It is used in the design of new production lines and reconstruction of existing ones, in the operational management of production, in planning the supply of raw materials, tools, energy and more. According to him, the number of staff, the type and number of machines are determined, the balance of wood raw material is made. At the same time, there are no clear rules and principles for the motivated determination of the annual capacity. The production of solid wood materials has specific characteristics. The application of the general rules and principles described in the theory of operational management cannot be applied to determine their annual capacity.

The aim of the present work is to consider the possibilities and to propose a reasonable methodology for determining the annual capacity, resulting from the specific features of production.

Key words: annual capacity, woodworking factory, materials from massive wood, Break-even point.

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DEFECTS OF WOOD AND QUALITY ZONES IN DOUGLAS FIR (PSEUDOTSUGA MENZIENSII) STEMS

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ABSTRACT

Douglas fir is a coniferous fast-growing tree species, and its wood has very good physical and mechanical characteristics. According to these indicators, it surpasses all traditional for Bulgaria coniferous tree species. It is widely used in the production of interior furnishing products. The very good ratio between density and strength indicators, combined with the high resistance to biological pests and atmospheric influences makes it a desirable raw material for the production of engineered wood for use in building structures.

Douglas fir is an introduced tree species for the Republic of Bulgaria. It is well adapted to our geographical conditions. Its is very good qualities and its fast growth make it a promising raw material for our raw material balance.

The aim of this paper is to present the results of experimental studies on the size and quality characteristics of Douglas fir stems. They are an important prerequisite for their optimal processing as a raw material for SWM.

Key words: solid wood materials, Douglas fir, stems, defects, quality zones

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ASSESSMENT OF NATURAL DISTURBANCES IN FOREST AREAS BY REMOTE METHODS

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ABSTRACT

An assessment of the degree of damage to the stands in the Experimental forest range "Petrohan" from the snowfall in January 2021 using a remotely determined normalized difference vegetation index (NDVI). The results show that the most affected are the stands between 750 and 1000 m above sea level with excess at 900 m above sea level. Among them, the most damaged are the forests on slight slope terrain. The most affected tree species in the damage zone are the stands with a predominance of spruce, followed by those with common birch and beech. Hornbeam stands are the least affected.

Key words: NDVI, snowfall, remote sensing, natural disturbances.

RESTORATION OF BEECH FORESTS AFTER NATURAL DISTURBANCES

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ABSTRACT

The main chemical elements (carbon, nitrogen and phosphorus) were analyzed in leaves of beech saplings from four stands with disturbed canopy located at Western Balkan in the range 700–1450 m a.s.l. For comparison, leaves of beech saplings from neighbouring undisturbed stands were also analysed. For all study stands, it was found that the content of nitrogen and phosphorus was higher in leaves of saplings in the disturbed stands than under the canopy. This difference was considerable at 850 m above sea level. The differences in the carbon content were negligible without a clear trend.

Key words: chemical elements, beech forests, natural disturbances.

CERTIFICATION SCHEMES FOR LEAN SIX SIGMA PROFESSIONALS IN THE EUROPE

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ABSTRACT

In recent years, certified Lean Six Sigma (LSS) professionals have become highly sought after in the European market. At a time when the difference between the selling price and the cost price of the product is becoming smaller, eliminating all types of waste from the production process is a necessity of business. In addition, it is necessary to eliminate all types of deviations from the desired performance that occur in the production process. These are precisely the issues and tasks that LSS certified professionals deal with in their scope of work. According to the general division, LSS professionals are divided into 5 categories, namely: LSS Yellow Belt, LSS Green Belt, LSS Black Belt, Lean Practitioner and Lean Leader. The certification procedure for all these levels is based on three international standards dealing with the LSS theme, namely ISO 13053-1: 2011, ISO 13053-2: 2011 and ISO 18404: 2020.

Key words: certification schemes, Lean Six Sigma, professionals, ISO standards, DMAIC methodology.

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INVESTIGATIONS OF THE VISCOSITY OF LACQUER PRODUCTS FOR PRINTING UV TECHNOLOGIES

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ABSTRACT

Apparent and conventional viscosity of the lacquer products used for finishing have been estimated. Changes of both viscosities in function of temperature were determined. A Ford cup and a Brookfield rheoviscometer were used for the viscosity measurements. Based on the results of the investigations the tested lacquer products were classified as rheologically unstable liquids.

Key words: apparent viscosity, conventional viscosity, temperature, UV lacquer, printing technology.

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ADHESION OF LACQUER COATINGS TO HDF SUBSTRATE IN UV ANALOQUE PRINTING SYSTEMS

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ABSTRACT

Adhesion of lacquer coating system to the HDF substrate in UV analoque printing system has been estimated. Samples for experiments in versions „birch“, „oak“, „ash“, „mat white” and „high gloss white” in industrial on-line conditions were prepared. Contact angle acc. to the PN-EN 828 standard was determined. Surface free energy with dispersion and polar shares for each coatings was calculated. The adherence acc. to the pull-off method (PN-EN 4624) was carried out. It was stated that all tested coatings showed good adhesion to the substrate.

Key words: UV hardening, analoque printing technology, contact angle, surface free energy, adherence.

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INVESTIGATION OF ATMOSPHERE SUSTAINABILITY OF PROTECTIVE-DECORATIVE COATINGS – PART I

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ABSTRACT

The strength of bonding between protective-decorative coatings and the surface of wood materials, plays a major role for the durability of the wooden products, exposed to atmospheric conditions in the open area. This article analizes the effects, that has the protective-decorative coatings, like durability of the natural oils and synthetic laquer products used for protective layer of wood and the surface condition, after stay under the environmental impacts. For aciving this aim it is manufactured an experimental stand by standart BDS EN 350/1:2002 and mounted in the territory of Yundola Training and Experimental Forest Range. By the determined under review time period it is followed the change of surface of different types natural oils and synthetic laquer products used for protection of wood exposed to open area. The change in color is reflected, the damage of the surface of the used protective-decorative coatings, the mold formation and moisture resistance of the protective coatings. The results are analized and graphically presented.

Key words: atmosphere sustainability, wood, protective-decorative coatings, oils, laquers.

INFLUENCE OF HYDROTHERMAL TREATMENT OF BEECH WOOD ON THE PROPORTION OF DUST PARTICLES FROM THE MILLING PROCESS

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ABSTRACT

In the process of hydrothermal treatment of wood, there are changes in its chemical composition. The result of this change is a material with properties different from the original material. On the one hand, the change of the given properties is targeted, for example, a change in the colour of the wood, but there are also associated changes, such as a change in the particle size distribution from the machining process of the given material. The aim of this article is to define how the temperature of thermal modification will affect the particle size distribution of the chip, especially the proportion of dust particles.

The experiment published in the article evaluates the effect of three levels of steaming temperature of beech blanks 105/125/135°C within a standard 9-hour steaming cycle. The process of machining - chip formation took place on a 5-axis CNC machining center, during counter-rotating cylindrical milling with a three-edged spiral end mill. The granulometric composition of the chip is monitored within the range of the usual values of the sliding speed 2–6 $m.min^{-1}$ and the removal of 1-5 mm during the standard machining of the material of the given type.

As the statistical analysis of the obtained data showed, thermal treatment statistically significantly affects the redistribution of the chip within the individual granulometric stages. Thermal modification negatively affects the proportion of dust particles; as the steaming temperature increases, their proportion increases. On the other hand, as far as critical dust fractions below 32 μm are concerned, they have not been demonstrated by the standard particle size determination methodology. Based on the interpretation of the obtained data, thermal treatment does not represent a significant technological complication in the subsequent processing of such treated material from the point of view of chip formation.

Key words: hydrothermal treatment, steaming of wood, steaming temperature, hydrothermally treated wood, particle size distribution, dust particles.

EDGE WITHDRAWAL CAPACITY OF SCREWS AND CONFIRMAT INTO DIFFERENT WOOD-BASED PANELS

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ABSTRACT

The edge withdrawal capacity of screws and Confirmat is of interest to furniture designers and hardware manufacturers because it is a critical factor for the strength and durability of structures. For the study, laminated particleboard, three types of plywood, MDF – laminated and non-laminated and OSB were selected. The edge withdrawal capacity methodology is under European and Bulgarian standards. The analysis of the obtained results provides several essential conclusions. First, the type of wood materials significantly influences the edge withdrawal capacity. Second, the screws ∅4x40 have a higher edge withdrawal capacity compared to Confirmat. Third, the best indicators are received in beech plywood and the lowest in laminated particle board.

Key words: edge withdrawal capacity of screw, wood-based panels, screw for wood, Confirmat.

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