



Proceedings of the 17th annual meeting of the

**Northern European Network for
Wood Science and Engineering
(WSE2021)**

14 – 15 October 2021

Edited by
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Title

Proceedings of the 17th annual meeting of the Northern European Network for Wood Science and Engineering (WSE2021)

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Preface

The Northern European Network for Wood Science and Engineering (WSE) had its first annual meeting in 2005. This year, for the 17th time meeting of the Northern European Network for Wood Science and Engineering will take place on 14-15 October 2021. A one-day PhD course will be arranged for the PhD students and early stage researchers before the conference, 13th October. Young researchers are particularly encouraged attend meetings and present their work.

This year the main focus of the conference – ”**Wood in the future products**”. Wood is a renewable resource that has wide material applications in many industries. During the conference, we will discuss wood innovations that make significant enhancements towards products and processes that reduce fossil fuel use, increase clean environments. Other topics such as wood physics and mechanics, wood modification and durability, wood composites, etc. will be also covered.

We would like to thank Nordic Forest Research (SNS) for its financial support to WSE2021 and JSC “Freda”, who sponsored this year’s awards for best student oral presentation and best student poster presentation.

Faculty of Mechanical Engineering and Design at Kaunas University of Technology is pleased to host the 17th Annual Meeting of the Northern European Network for Wood Science and Engineering.

Kaunas University of Technology is part of a very ambitious European University initiative – together with 11 partners across Europe, it creates the joint ECIU University. The core of this University is the challenge-based approach – where students, learners and researchers cooperate with cities and businesses to solve real-life challenges.

Welcome to Kaunas, Lithuania!

List of previous WSE meetings:

2005 Honne, Norway	2013 Hannover, Germany
2006 Stockholm, Sweden	2014 Edinburgh, United Kingdom
2007 Helsinki, Finland	2015 Poznan, Poland
2008 Riga, Latvia	2016 Riga, Latvia
2009 Copenhagen, Denmark	2017 Copenhagen, Denmark
2010 Tallinn, Estonia	2018 Tallinn, Estonia
2011 Oslo, Norway	2019 Lund, Sweden
2012 Kaunas, Lithuania	2020 Helsinki, Finland

Kaunas, October 2021

Kristina Ukvalbergienė and Vaida Jonaitienė

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Wood Modification with Phenol-Formaldehyde-Resin and its Influence on the Dimensional Stability of Homegrown and Imported Hardwoods

Carlo Kupfernagel¹, Morwenna Spear, Andy Pitman, Graham Ormondroyd

Background

The modification of wood with thermosetting resin is widely considered to be a passive modification, which means that there is no chemical reaction between wood and resin (He & Yan, 2005; Hill, 2006). The monomer solution diffuses into the cell wall, where it forms a cross-linked network when cured (Deka and Saikia, 2000; Furuno et al., 2004). Commercial modification with PF-resin uses three process steps: impregnation, diffusion/drying and heat curing. Sufficient treatability during impregnation is prerequisite for successful modification. Radiata pine (*Pinus radiata*) is currently the main species modified in commercial processes requiring impregnation, partly because of its excellent treatability (Jones et al., 2019). From an economic and ecological perspective, it is desirable to source raw material more locally. The aim of this study is to evaluate alternative wood species for use in the commercial process. The treatability of these alternative species has not been addressed in this study where wood samples were very small giving excellent uptake.

Keywords: PF-resin, wood modification, anti-swelling efficiency (ASE).

Experimental

Sample dimensions were 20 (r) x 20 (t) x 5 (l) mm. Each test group consisted of 10 samples with good growth ring orientation. Low molecular weight PUF-resin was kindly provided by *Prefere GmbH, Germany*. The resin was adjusted to a solids content of 30% before use. Resin pH varied between 9.0 and 9.2.

Resin Impregnation

A vacuum was drawn for 20 mins prior to impregnation. Subsequently, the resin was introduced through a dropping funnel until all samples were fully submerged. Still under vacuum, the samples were soaked for 20 min. The fluid was then drained off and the samples were dried at 50°C (16h) and cured at 150°C for 8h. The liquid resin uptake describes the mass change between the oven dry and the freshly impregnated state. The WPG (Weight percentage gain) describes the dry weight gain achieved after cure. The bulking coefficient *B* describes the dry volume gain after cure. They are calculated as follows:

$$\text{Liquid uptake} = \frac{m_{Imp} - m_{OD 0}}{m_{OD 0}} * 100\% \quad \text{WPG} = \frac{m_{OD 1} - m_{OD 0}}{m_{OD 0}} * 100\%$$

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$$B = \frac{(r * t)_{OD1} - (r * t)_{OD0}}{(r * t)_{OD0}} * 100\%$$

Cyclic swelling

Oven dry mass and dimensions of all samples were determined after drying at 105°C. One set per species was resin impregnated another set served as control. Water soaking was performed in the same manner as the resin impregnation for the anti-swelling efficiency (ASE) test.

The ASE illustrates the effectiveness of the modification by comparing the average swelling coefficient (S) of control and test group. They are calculated as follows:

$$S_{control} = \frac{(r * t)_{WS1} - (r * t)_{OD0}}{(r * t)_{OD0}} * 100\% \quad S_{mod} = \frac{(r * t)_{WS1} - (r * t)_{OD1}}{(r * t)_{OD1}} * 100\%$$

$$ASE = \frac{mean(S_{control}) - mean(S_{mod})}{mean(S_{control})} * 100\%$$

Results and Discussion

Table 1 shows that WPG and Bulking coefficient are correlated to the oven dry density of the modified wood species. In case of WPG this relation is inverse, which suggests that the resin uptake in most species is governed by the available void volume. The Bulking indicates the proportion of resin in the cell wall. Comparison of Figure 1 and Table 1 shows that bulking is correlated with the

Table 1 OD density before modification, Weight percentage gain and bulking in each observed wood species

Species	Density OD	WPG in %	Bulking in %
Beech	0.73 (0.010)	24.82 (1.242)	17.55 (1.085)
Birch	0.64 (0.029)	24.00 (2.670)	13.93 (2.501)
Sycamore	0.60 (0.017)	24.27 (2.147)	9.36 (0.891)
Lime	0.55 (0.013)	33.72 (1.412)	15.00 (0.442)
Tulip	0.44 (0.007)	48.15 (2.082)	10.30 (0.483)
Poplar	0.44 (0.023)	36.63 (10.120)	8.64 (1.273)
Willow	0.36 (0.019)	51.37 (3.587)	6.52 (0.929)

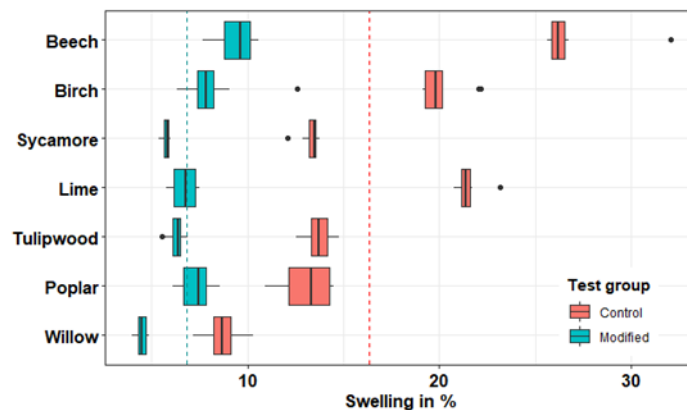


Figure 1 Swelling of modified and unmodified control groups. Swelling in modified groups refers to the OD volume of the 1st cycle (after cure) and swelling of control groups refers to the OD unmodified volume.

relative reduction of swelling (ASE), but not with the swelling coefficient itself.

Figure 1 shows the swelling of modified and unmodified test groups in more detail; note that the wood species on the y-axis are arranged in order of decreasing density. The mean S values of modified groups ranges from 4.46 to 10.41% whereas unmodified groups vary between 9.99 and 29.02%. The horizontal distance between boxplots in Figure 1 illustrates the effectiveness that the

same treatment had in different timbers. For example, the swelling in Beech is reduced more than in Willow. On the other hand, low density species like Willow are relatively dimensionally stable when unmodified. The modification adds very little benefit to that. The dotted lines represent the mean values of all species for the modified and control populations. The change in distance between the boxplot and the mean value indicates a highly effective treatment in Lime and a less effective treatment in Poplar.

Conclusions

It was shown that wood anatomy has a strong influence on WPG, Bulking and Swelling in resin modified wood. The effectiveness of the modification can be expressed by ASE, but the absolute swelling of the modified wood must be considered, too.

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Vacuum, low-temperature, microwave-assisted pyrolysis of various technical lignins

Johannes Karthäuser¹, Vladimirs Biziks², Holm Frauendorf¹ and Holger Militz¹

Background

Lignin is obtained as a side-product in pulping processes, and is mainly used to regain chemicals and energy (Rinaldi *et al.*, 2016). Many attempts have been made to find higher-value applications for these lignins, however, the recalcitrant, heterogeneous and complicated structure of lignin is a major challenge. A prominent approach to solve these issues is cleaving the lignin to obtain organic monomers, more specifically phenolic compounds (De Wild, Huijgen and Gosselink, 2014). These could for example be used to substitute phenol, which is mainly won from non-renewable resources, in resins (Solt *et al.*, 2018). A possible technology to cleave lignin is microwave pyrolysis. However, publications on it are scarce and more results are needed to investigate its potential. In this paper, the products of pine kraft lignin (PKL), beech organosolv lignin (BOSL), spruce organosolv lignin (SOSL) and softwood calcium lignosulfonates (LS) cleaved with vacuum, low-temperature, microwave-assisted pyrolysis are described.

Keywords: lignin, pyrolysis, bio-oil.

Experimental

Examined lignins were PKL (“Lineo™”, Stora Enso Oyj, Helsinki, Finland), BOSL and SOSL (Fraunhofer Center for Chemical-Biotechnological Processes CBP, Leuna, Germany), and LS (Borregaard AS, Sarpsborg, Norway).

The pyrolysis was performed in a vacuum, microwave-assisted reactor (Microwave Systems (MWS), Leutkirch, Germany). A glass reactor filled with lignin was connected to the microwave system. Applying vacuum, the lignin was heated with a heat rate of 3.5 °C/min until 110 °C and 5 °C/min to 280 °C, followed by a constant temperature of 280 °C for two minutes. The condensates were separated into an organic and an aqueous fraction by liquid-liquid fractionation using trichloromethane. Extraction of the pyrolysis char using acetone produced a tar-like heavy organic fraction.

Qualitative and quantitative analysis of the chemical composition were performed using GC-MS (Thermo Electron Corporation Waltham, Massachusetts, USA) and GC-FID (Agilent Technologies, Santa Clara, California, USA) with iodobenzene as an internal standard.

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Results and Discussion

The pyrolysis products were separated into five fractions: coke, a heavy organic fraction (tar), a light organic fraction (phenolics), an aqueous fraction, and non-condensable gases (NCG) (table 1). The LS pyrolysis produces 76% coke, much more than that of the other lignins, which only produce about 45-50% coke. Almost no tar could be extracted from the coke of the lignosulfonates. PKL produced most phenolics yield with 16.5%. The yield of SOSL was in a similar range (14.8%), while the yields for the other lignins was significantly lower (BOSL: 6.0%, LS: 1.8%).

Table 1 Mass balance of the coke, tar, phenolic, aqueous and non-condensable gas (NCG) fractions of PKL, SOSL, BOSL, and LS

Pyrolyzed Lignin	NCG %	Aqueous %	Phenolics %	Tar %	Coke %
PKL	5.2	5.4	16.5	28.3	44.6
SOSL	11.8	10.9	14.8	13.5	49.0
BOSL	10.4	0.7	6.0	46.1	36.8
LS	5.3	13.2	1.8	3.3	76.4

The low condensate and tar yields of the LS could be caused by high molecular sizes of LS. The often lower molecular size of organosolv lignins explains the high condensable and NCG yield of the SOSL. (Kai *et al.*, 2016). However, the low condensate yield for BOSL shows, that there have to be other factors influencing the products, like the chemical structures of the lignin.

Main components of the phenolic phase were, with few exceptions, guaiacol, 4-methylguaiacol, *p*-ethylguaiacol, 4-propylguaiacol, and 4-(1-prophenyl)-guaiacol. The concentration of components in the phenolic fraction varies depending on the lignin (Table 2). For lignins with lower phenolics yields, the concentration of the main products in the phenolic fraction is lower.

Table 2 Yield of the main components in the phenolic phase of PKL, SOSL, BOSL, and LS analysed with GC-FID

Pyrolyzed Lignin	Guaiacol %	4-Methyl- guaiacol %	4-Ethyl- guaiacol %	4-Propyl- guaiacol %	4-(1-prophen- yl)-guaiacol %
PKL	19.2	29.5	12.8	3.1	4.2
SOSL	11.6	19.6	4.8	1.2	2.2
BOSL	6.4	5.1	2.2	5.7	3.9
LS	5.7	5.1	3.3	0.8	2.2

The results could be explained by a similar matrix of the phenolic fraction for all lignins, in which different amounts of aromatic monomers are present. The matrix could contain either small or large molecules which are not detected by GC-MS or GC-FID in the given temperature range.

Con-clusions

The source of lignin has a significant influence on the products of vacuum low-temperature microwave-assisted pyrolysis. Most promising for applications that require high phenolic fraction yields are PKL and SOSL. The chemical composition of the light organic fraction varies depending on the lignin, however, the main components are similar.

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Initial Quality Control Trials of Sorbitol and Citric Acid (SorCA) Modified Wood

Katarzyna Kurkowiak¹, Aaron Kilian Mayer, Lukas Emmerich and Holger Militz

Background

Wood modification via esterification of polycarboxylic acids in combination with polyols, e.g. sugar alcohols, has been extensively investigated within the last years (Kurkowiak et al., 2021). In particular, a significantly improved dimensional stability and biological durability was measured on wood blocks after treatment with sorbitol and citric acid (SorCA) (Larnøy et al., 2018; Mubarok et al., 2020). To evaluate the quality of SorCA modification of wood, as for any other wood treatment process, a rapid and repetitive quality control (QC) method is required to assess, if chemicals have been deposited uniformly within the wood structure. Until now, the QC of esterified wood has been focused on the mid-infrared spectroscopy, with an emphasis on FTIR techniques (Berube et al., 2018; Vukusic et al., 2010). Since wet-chemistry methods, traditionally used to estimate the amount of ester bonds, are very laborious and difficult to perform on solid material, they have not yet been used on SorCA-modified wood. Therefore, spectroscopic methods (near-IR, mid-IR and X-ray density profiling) were evaluated to analyse SorCA distributions in modified wood.

Keywords: citric acid, esterified wood, quality control, sorbitol

Experimental: Wood modification and spectroscopic measurements

Scots pine sapwood (*Pinus sylvestris* L.) blocks of 50 x 50 x 50 mm³ were treated with aqueous solutions of SorCA at a molar ratio of 1:3 and solid contents in the impregnation solution increasing in 2.5% steps from 2.5 to 50%. Impregnated specimens were dried for 264 h at step-wise increasing temperature values, before curing at 140°C for 24 h. Changes in dry mass and dimensions were measured after curing to calculate weight percent gain (WPG) and cell wall bulking (CWB). ATR-FTIR spectra were recorded with Alpha spectrometer (Bruker, Germany), in a range of 4000–400 cm⁻¹ at a spectral resolution of 4 cm⁻¹ and 64 scans per sample.

NIR spectra were registered using PSS 1720 spectrometer (Polytec GmbH, Waldbronn, Germany), with 10 scans collected at a spectral resolution of 8 cm⁻¹ in a diffuse reflection mode. The scans were averaged and saved as the absorbance log(1/R). Python's scikit-learn library (Pedregosa et al. 2011) was used to pre-process spectra and build the partial least-square regression (PLS-R) models.

The density profiles of 50 x 50 x 50 mm³ specimens were measured by DAX 6000 X-ray densitometer (GreCon GmbH, Alfeld, Germany) in a radial direction prior and after modification. The density was recorded at a resolution of 0.05 mm and using a voltage of 33 kV.

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Results and Discussion

The esterification reaction in wood was confirmed by ATR-FTIR spectroscopy (Fig. 1 (a)). The correlation between the WPG and the band area ratio of peaks (BAR) between 1774–1689 cm^{-1} (C=O stretching in esters, Coates, 2000) to 1139–914 cm^{-1} (C–O stretching in cellulose, Popescu et al., 2007) has been used to develop a prediction model based on a linear regression. The model resulted in a high correlation of 0.92 between BAR and WPG, as shown on Fig. 1 (b).

Based on NIR measurements, prediction models for WPG were developed using PLS-R. In general, developing a model based on the entire tested wavelength range (844–1656 nm), independently of the tested grain direction or pre-processing method used, resulted in the highest predictive power. The best model was developed based on the second derivative with a correlation of 0.81 (Fig. 1 (c)).

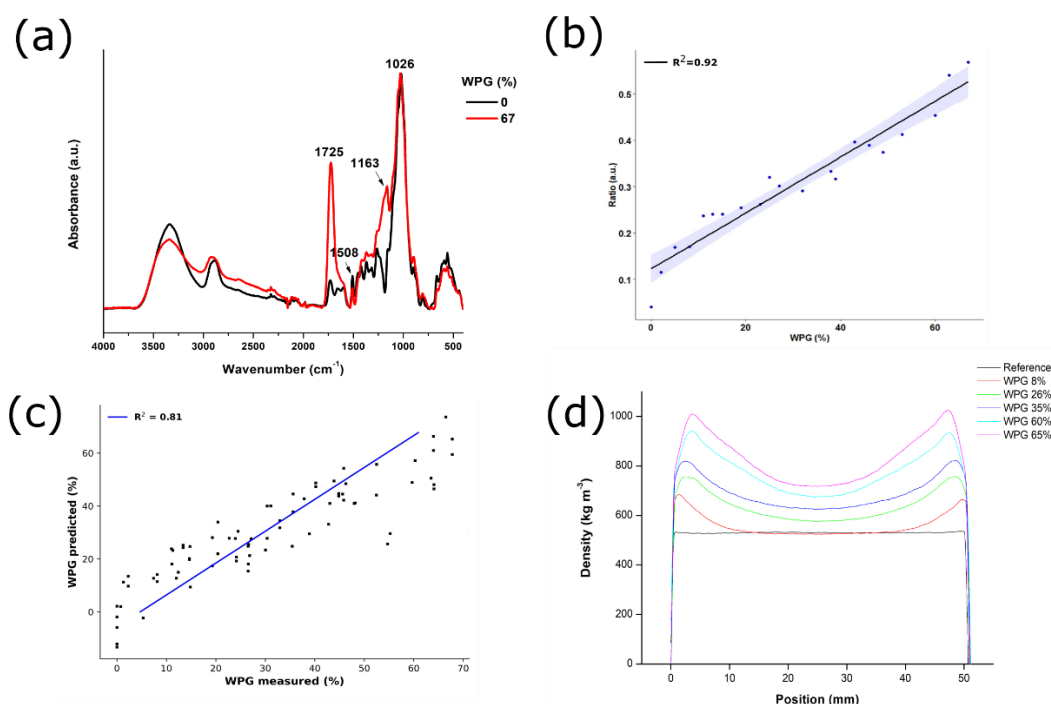


Figure 1 FTIR-ATR spectra of untreated (black line) and SorCA-treated (red line) wood (a), correlation between the WPG and the band area ratio (BAR) 1774–1689 cm^{-1} / 1139–914 cm^{-1} , calculated from ATR-FTIR spectra of SorCA-treated wood (b), WPG of SorCA-treated wood based on the PLS-R model prediction (second derivative S-G) and calculated in a laboratory - test set (c) and density profiles of 90° turned specimens from various treatments measured by X-ray density profiling (d).

Surprisingly, despite the small specimen's dimensions (50 x 50 x 50 mm^3), an uneven distribution of the impregnation solution has been detected upon densitometric measurement, due to a higher density in the outer regions of the sample (Fig. 1 (d)). The highest discrepancy between the core of the specimen and the edges was 31% and observed in specimens which were treated with the highest chemical concentration. Presumably, an uneven distribution has been caused by the outward movement of non-fixed chemicals upon dry curing (Smith and Cockcroft, 1961).

Conclusions

Overall, spectroscopic techniques can be suggested as screening methods for distribution of impregnation chemicals of esterified wood. The results show that using spectroscopic methods such as ATR-FTIR, NIR and X-ray density profiling for a WPG prediction have a potential to develop robust models for the QC of SorCA-modified wood. Future research should focus on investigating wet chemistry methods to acquire more precise reference values.

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Weathering Influence on Fire-retardant Resin Treated Thermally Modified Scots Pine Wood

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Background

Fire-retardant modified wood for exterior purposes requires protection against weathering, e.g. UV light and moisture uptake, as the long-term performance might be reduced over time (Östman and Tsantaridis, 2017). A previous study revealed that the water-resistance of the conventional fire-retardant modified wood could be improved by a microencapsulation technique using melamine formaldehyde (MF) resin (Lin et al., 2021). However, the weathering resistance of such material remained unclear as the effect of UV light was not considered in the study. As the UV light might degrade the MF resin, the microencapsulated fire-retardant additives could, as a consequence, be lost. Additionally, the wood components, mainly lignin, will also absorb UV light and might be degraded, resulting in loosening of fibres (Kropat et al., 2020). The loosened fibres might be washed away by rain along with the fire-retardant additives. Therefore, the aim of this study was to evaluate the necessity of introducing a UV absorber for increasing the stability of the exterior fire-retardant resin modified wood.

Keywords: fixation, outdoor, resin-modified wood.

Experimental

Scots pine (*Pinus sylvestris* L.) timber was thermally modified according to the ThermoWood® Thermo-D process, and specimens with a of dimension of 110 × 18 × 330 mm (Tangential × Radial × Longitudinal) were cut, end-sealed and conditioned at 20°C and 65% relative humidity (RH) to reach an equilibrium moisture content of 9%. Two formulations were prepared for sample impregnation. The first formulation contained of 5 wt% of guanyl-urea phosphate (GUP)/boric acid (BA) (mass ratio 7:3), and 30 wt% of MF resin powder obtained from Dynea AS, hereafter denoted as 5-30MF. The second formulation had the similar solid contents as the first solution before adding the addition of the UV absorber/hindered amine light stabilizer (HALS), specifically 2.5 wt % of UV absorber Tinuvin 477-DW and 1.5 wt% of HALS Tinuvin 123-DW (where the percentage of UV absorber was based on the solid content of the MF resin). The modified specimens were denoted as 5-30MF-UV. The impregnation was performed for 30 min. at 20 mbar prior to 1 hour at 10 bar. The specimens were heated in an oven at 75°C for 2 days. The prepared specimens were subjected to an accelerated weathering tester for 1 month, following the standard EN927-6 (CEN, 2018). The weathered specimens were denoted with the suffix W.

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Results and Discussion

The colour measurement shown in Fig. 1a revealed that the introduction of the UV absorber to the treatment could alleviate the difference in colour change of the modified wood specimens treated with fire retardant. The specimen treated with UV absorber remained at a relatively constant ΔE after about 300 exposure hours and consequently had the lowest ΔE along with all groups. The fire-retardant resin modified wood without UV absorber (5-30MF) showed higher ΔE than the specimens that had not been treated with fire retardant. This was probably due to the visible white residue observed on the surface of 5-30MF after UV-treatment.

The thermal behaviour analysed by TGA indicated that the fire-retardant resin modified specimen (5-30MF) had a higher carbon-rich residue at elevated temperature, as shown in Fig. 1b. This is because GUP/BA promoted the char formation as well as creating glassy protective layers (cf. Wang et al., 2004). The corresponding weathered specimen, 5-30MF-W, also showed a high mass residue by analysis with TGA. The high mass residue was most likely attributed to the remaining GUP/BA, as the pure MF resin modified wood would be mostly decomposed at elevated temperature (Lin et al., 2021). The specimen modified with additional UV absorber, 5-30MF-UV, showed a similar trend with a higher mass loss rate after the main decomposition temperature. This might be because of the added organic UV absorbers not contributing to the char formation.

The FTIR spectra in Fig. 1c. showed that the weathered thermally modified specimen decreased the content of wood component hemicellulose and lignin. The band at 1708 cm^{-1} corresponding to the C=O stretching in O-acetyl groups in hemicellulose was decreased (Özgenç et al., 2017). The bands at 1604 cm^{-1} and 1509 cm^{-1} attributed to the C=C stretching of the aromatic ring in lignin were reduced (Faix, 1992). The fire-retardant resin modified wood had a different spectrum as the resin changed the chemical functionalities of the wood. For instance, the bands at 1548 cm^{-1} , 1509 cm^{-1} and 1458 cm^{-1} were attributed to triazine ring and methylene bridge bending vibrations in the hardened MF-resin (Merline et al., 2013). The weathered specimen had the same bands attributed from the MF resin with a new band at 1694 cm^{-1} . The new band might result from the oxidation of GUP during the weathering corresponding to the introduction of a C=O band (Wang et al., 2006). It was also noticed that the band at 1509 cm^{-1} , corresponding to the methylene bridge in MF resin, became less distinguished (Merline et al., 2013). On the other hand, the specimen modified with the additional UV absorber (5-30MF-UV) had a new band at 1728 cm^{-1} . The new band was consistent with the band position of the UV absorber and became more visible after the weathering. It was also noticed that the peak at 1509 cm^{-1} corresponding to the methylene bridge in MF resin remained distinguishable after the weathering.

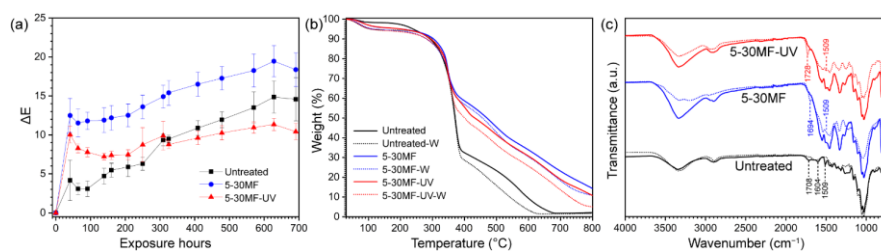


Figure 1 (a) Colour change difference ΔE over exposure hours, (b) TGA curves, and (c) FTIR spectra of the untreated Thermo-D, 5-30MF and 5-30MF-UV specimens. The solid curves in FTIR spectra represented pre-weathering, while the dot curve represented post-weathering according to the standard EN927-6.

Conclusions

The study revealed that introduction of the UV absorber to the fire-retardant resin modified wood enhanced the colour stabilisation because the brownish colour contribution from the lignin was partially stabilized during the weathering. Inevitably, the additional organic UV absorber would also reduce the carbon-rich mass residue when heated at elevated temperature. Further investigation

to conclude whether the organic UV absorber could be used for obtaining an exterior fire-retardant resin modified wood will be undertaken.

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Impact of Thermal Treatment Processes on Wood-water Interactions

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Background

Wood protection used to focus mainly on naturally durable wood species, often from tropical regions, or treating non-durable wood species with fungicidal wood preservatives. General awareness of the negative impact of biocidal products on the environment initiated a new way of thinking about wood protection. Modern methods to protect wood from degradation aims at increasing the service life of the material by removing or reducing a prerequisite for fungal degradation: water within the material. This can be done by wood modification, such as acetylation or heat treatment. However, there is a lack of understanding of what happens within the wood, which hampers optimization and development of modification techniques and processes.

As part of the MODUWOOD project, two types of thermal treatments are investigated. In the high-acidic process, both heating and cooling occur at high pressure in a closed process. The low-acidic process is similar, but the cooling phase occurs at atmospheric pressure, hereby evaporating volatile chemicals formed during the thermal treatment. For both treatments, we investigate how changes in material chemistry affect wood-water interactions and the resistance to fungal degradation in Scots pine.

Keywords: thermal modification, wood-water interactions, LFNMR.

Experimental

Specimens of Scots pine (*Pinus sylvestris* L.) were exposed to three types of treatments: no treatment (control), low-acidic thermal treatment and high-acidic thermal treatment. For each treatment, 15 specimens (size 5 x 5 x 10 mm³) were selected. Of those 15 specimens, 5 specimens were extracted with Soxhlet-extraction (9:1 acetone-water and 1:2 ethanol-toluene mixture, based on Holbolm (1999) and Sluiter et al. (2008)), 5 specimens were water-extracted according to EN84 (CEN EN 84 standard, 1997) and 5 specimens were not extracted, to determine the effect of water-soluble compounds on LFNMR analysis. All specimens were water-saturated under vacuum pressure and the wood-water relations were assessed with LFNMR, according to Fredriksson and Thygesen (2017).

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Results and Discussion

Untreated Scots pine and Scots pine exposed to the low-acidic thermal treatment process were selected as a subset to illustrate our work. The spin-spin (T_2) relaxation time of water molecules depends on their physical (e.g. pore size) and chemical environment (Fredriksson and Thygesen, 2017). For untreated softwood, usually three peaks are observed: the first peak related to cell wall water (Fredriksson and Thygesen, 2017; Beck et al., 2018), the second peak related to free water located in pits and the third peak related to water in cell lumina (Figure 1). During thermal modification, several water-soluble degradation products are created (Hill *et al.*, 2021), which can affect the T_2 during LFNMR measurements. Peak 2 and 3 of the non-extracted specimens (Non) had indeed a higher T_2 for the thermally modified pine (LA TT), in comparison to the untreated pine (ctrl), while this was not the case for the Soxhlet-extracted specimens (Sox). This higher T_2 is therefore likely linked to the presence of soluble degradation products, and not to increases in lumen diameter due to deformation and cracking during thermal treatment. For cell-wall water (peak 1), the T_2 was always lower in the thermally treated specimens (LA TT) than in the untreated specimens (ctrl), irrespective of the extraction method. This decrease in the T_2 of peak 1 has also been found in Radiata pine (*Pinus radiata* D. Don) by Guo *et al.* (2018). Since the third peak was not affected by the chemical changes in the lumen surface, it is hypothesized that the first peak was also not affected by them, assuming that the chemical changes inside the cell wall are similar to those at the wall/lumen interface. Presumably, the decrease in T_2 for peak 1 is linked to a decrease in pore size in water-saturated state, due to increased crosslinking within the cell wall polymers, changes in the mobility of the polymer network and bulking of thermally degraded components that have remained in the cell wall (Hill *et al.*, 2021).

As the water extraction procedure is less intense than Soxhlet-extraction, water-soluble degradation products likely still remained in the water-extracted specimens, as the T_2 of peak 2 and 3 of the thermally treated wood were also higher than those of the untreated wood.

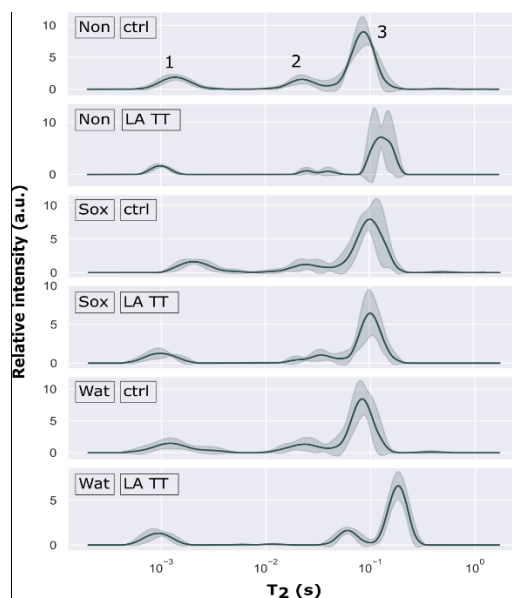


Figure 1 Continuous T_2 distributions (with peak numbers 1, 2 and 3) of untreated and thermally treated Scots pine. ctrl = control (no thermal treatment), LA TT = low-acidic thermal treatment, Non = no extraction, Sox = Soxhlet extraction, Wat = water extraction.

Conclusions

Longer T_2 for void water in non-extracted thermally modified specimens were likely related to soluble degradation products, as the T_2 for void water of Soxhlet-extracted specimens was similar to that of non-modified specimens. The shorter T_2 for cell wall water in thermally modified specimens was likely linked to a decrease in pore size in water-saturated state.

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Continuous Densification of Solid Wood – the Belt-press Approach

Alexander Scharf¹, Benedikt Neyses and Dick Sandberg

Background

In the past, many efforts have been made to improve the mechanical properties of low-density wood species through densification, i.e., the transverse compression of wood. Although densified wood products have been commercially available for many decades (Navi and Sandberg 2012), they remain as niche products with low annual production volumes, and to this date, successful mass-production has not been achieved (Neyses 2019, Jones et al. 2019). One of the main reasons for this has been the reliance on batch-type processes, which limit the achievable process speed and integration into the largely continuous wood-processing chain. As a solution to this obstacle, we propose the use of a belt press, which allows the continuous densification of – in theory – infinitely long wood boards. Such a press has been installed in the Wood Science and Engineering at Luleå University of Technology, functioning as a research and process development platform.

Keywords: compression, Scots pine, wood modification

Design of the Belt Press

The belt press (Figure 1) is designed for the densification of wood components of up to 250 mm in width and 100 mm in thickness, at a processing speed of up to 60 m min⁻¹, and with control of the infeed belt temperature. It is equipped with sensors to measure the pressing forces and moments, and its design allows for digital image correlation analysis of the densification process.

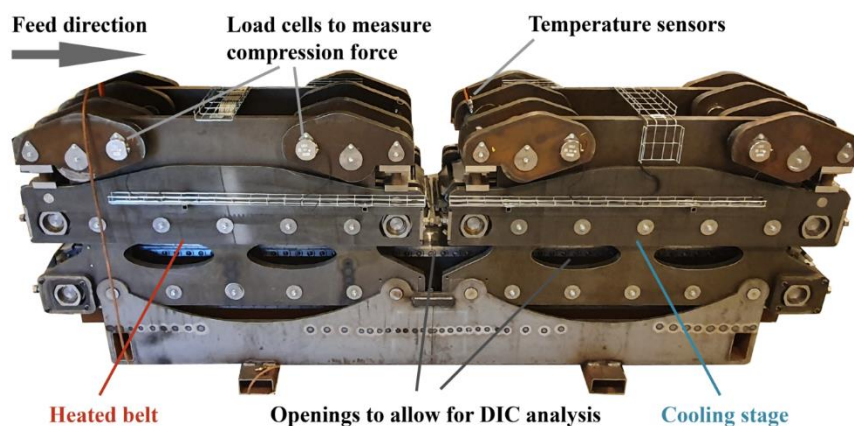


Figure 1 Continuous belt press for the densification of large wood specimens. The press is 5 m long, 1 m wide and 1.85 m high. The total weight is 18 tons.

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Working Principle and Results

The principle of continuous surface densification of wood in the belt press is shown in Figure 2. Contact between the sawn timber and the heated belt increases the temperature of the surface region and thus softens the hemicellulose-lignin matrix. Moving further through the press, the plasticised wood is compressed without crushing the cell walls. In the cooling stage, the wood is cooled, preferable to ca. 80°C, while still being under pressure, returning to a non-plasticised state, which avoids the recovery of the compression set when the wood leaves the press.

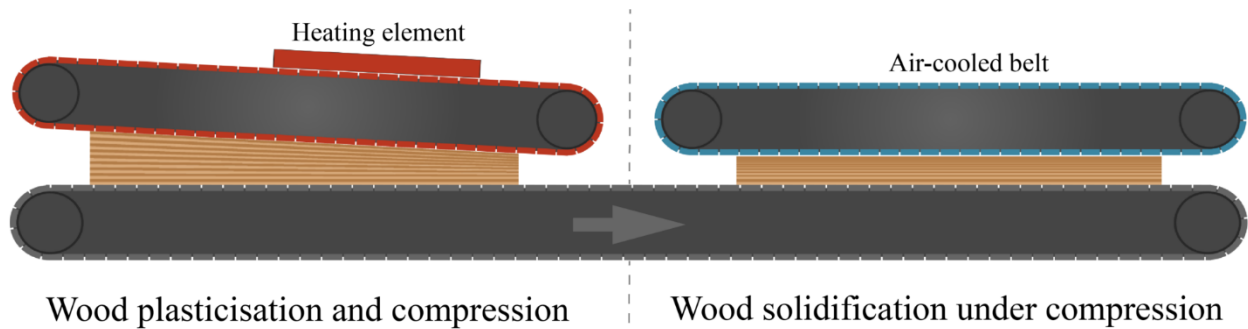


Figure 2 Belt-press concept for continuous wood densification. The heating and cooling of the sawn timber take place by contact heat transfer between the timber and the belts.

Scots pine boards with dimensions of 38 (T) x 120 (W) x 1600 (L) mm were successfully surface-densified at 125°C and a process speed of 1 m min⁻¹ to a thickness of 27 mm, achieving a two-fold increase in peak density, as measured by X-ray densitometry (Figure 3). The density profile and thus the densification remained constant over the whole length of the timber. Brinell hardness measured on the densified surface was similar to an equivalent specimen surface-densified in a laboratory hot press (Rautkari et al. 2010).

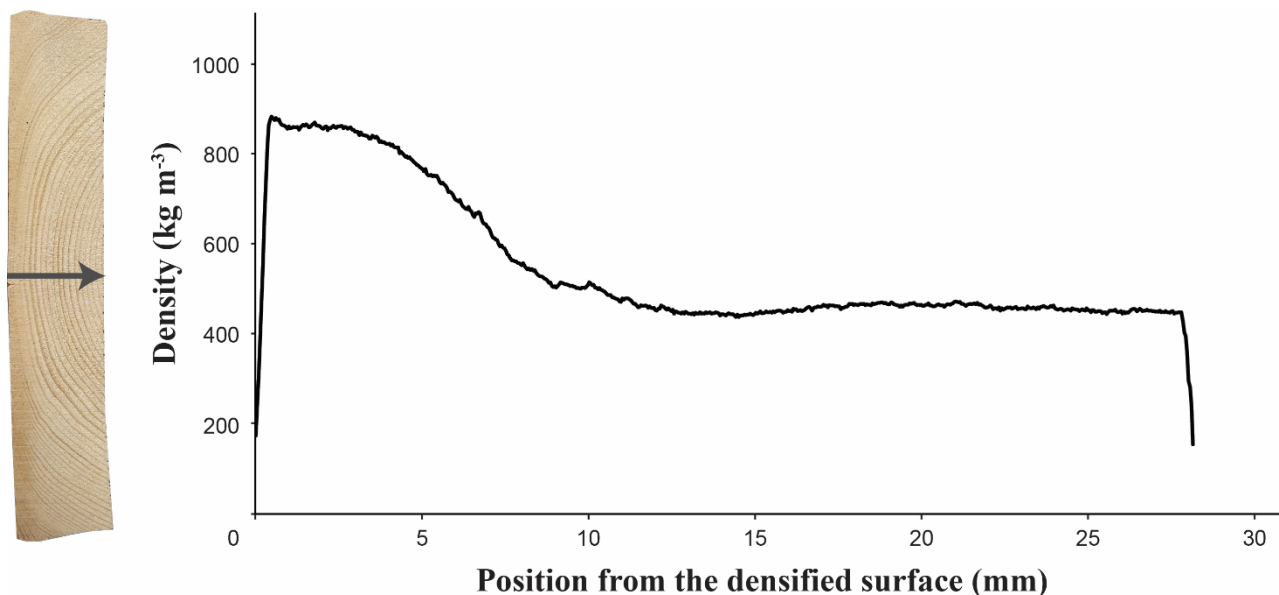


Figure 3 Density profile in the compression direction (arrow) measured by X-ray densitometry.

Conclusions

The belt-press process is a promising concept for industrialised surface densification of timber in large scale. Work continues with larger-scale experiments, aimed at understanding the capabilities of the belt-press approach, in particular with respect to the potential large-scale industrial production of densified wood products. New collaborations with other research groups have already been initiated and will ideally expand further in the future.

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Raman Microspectroscopy of Native and Acetylated Wood at Different Relative Humidities Using a Tailored Moisture Chamber

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Background

Understanding wood-water interaction is crucial to predict and possibly manipulate dimensional changes and degradation of structural wood (Sandberg 2017; Thybring 2021; Thybring 2018). Raman Spectroscopy (RS) has been used with success to image wood cell chemistry at the micro-scale, but always with the specimens either in the wet or dry state (Gierlinger 2018; Gierlinger 2007). In this work, we introduce a novel moisture chamber (Figure 1d) for RS to map the chemistry of wood specimens under controlled relative humidity (RH) and a statistical method to analyse Raman absorbance bands for moisture conditioned samples. The moisture system, used in combination with D₂O and scanning RS and a bespoke statistical analysis, provides a promising tool for reliable and non-invasive chemical imaging of moisture within thin wood specimens in a range of hygroscopic states.

Keywords: wood-water interactions, heavy water, Raman micro-spectroscopy, moisture, chamber, acetylated wood, modified wood, hygroscopic range

Material and Methods

We employed one native and three modified Norway spruce (*Picea abies* (L.) Karst.) specimens with dimensions 10 (longitudinal) x 5 x 5 mm³ (Digaitis 2021). Modified samples comprised one interface acetylated (24h in acetic anhydride, 75°C), one uniformly acetylated (3h in 1:4 acetic anhydride: pyridine, 80°C) and one pyridine control (3h in pyridine, 80°C). The latter one, as well as the native batch, were used as reference (Digaitis 2021). 36 Raman images were acquired, from four batches of Norway spruce: two references and two types of acetylated wood. Three tracheids per batch were each scanned three times at three different humidities (5, 50, respectively 95 % RH), using heavy water (D₂O). A confocal Raman microscope (alpha300R, WITec, Germany) equipped with a 532nm laser and an oil immersion objective (100x, NA=1.4). Laser power prior to the objective was 10 mW and the integration time was 0.1 s (Bock 2019; Prats-Mateu 2018). Data treatment consisted of three steps: (1) pre-processing (to correct fluorescence contribution) and normalization (Piqueras 2020), (2) cluster analysis by k-means to assign spectra to one of three different families (lignin-rich, glucose-rich, and empty spectra), and (3) pixel-wise hypothesis test of O-D and C=O stretching peak presence to localize and quantify the statistically significant pixels regarding moisture and acetylation in the different settings (e.g. RH, wood modification). All Raman images were analysed in MATLAB®.

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Results and Discussion

Each spectral image was divided into three clusters, namely the S2, CCML and LUMEN. The clusters resembled closely the area they were named after, the secondary cell wall, the cell corner-middle lamella and the macro-voids (e.g. lumen). The combination of S2 and CCML was used to analyse the non-empty part of the tracheid, the cell wall. Mean values of the OD stretching peak areas ($2300\text{-}2685\text{ cm}^{-1}$) in the cell wall and in the individual clusters were computed and compared for the four different batches at the three humidity levels. Because the OD signal at 5 % RH represents a value that is very close to the dry state, i.e. almost the hydroxyl accessibility, it was subtracted from the OD signals of the other two levels to obtain and quantify the signal related to the moisture uptake only (Figure 1a). In the cell wall, the pyridine treated specimens had the highest moisture uptake at both 50% and 95% RH, closely followed by native Norway spruce and then by

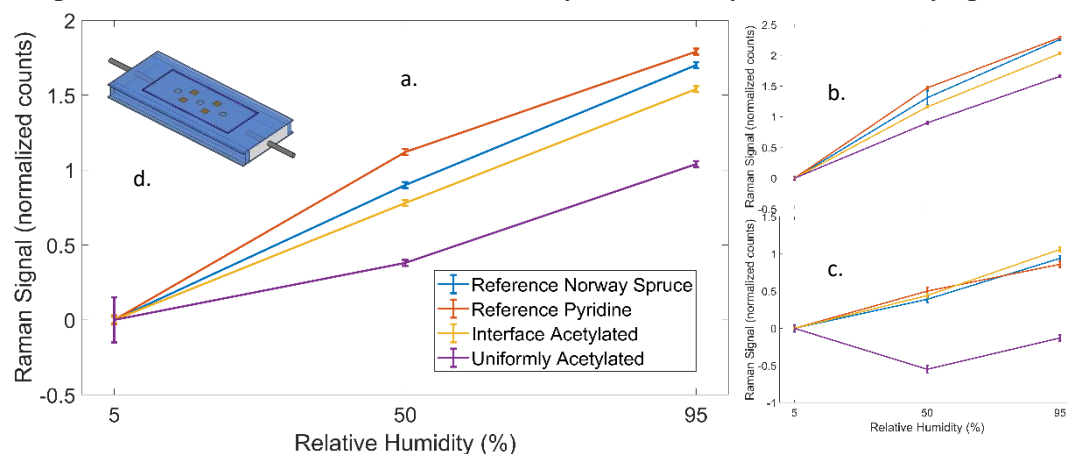


Figure 1 Line plots of moisture content as expressed by excess OD Raman peak mean area compared to the OD signal at 5 % RH. The four different batches are shown, colours are given in the legend. a) mean of the whole Cell Wall Cluster b) S2 cluster, i.e. hemicellulose-cellulose dominant spectra c) CCML cluster, lignin rich spectra d) Three-dimensional representation of the moisture chamber (sketchup.com, Trimble inc. USA)

interface and uniformly acetylated specimens. Looking at the clusters, all the specimens have a higher moisture uptake in the S2 than in the CCML (Figure 1b, 1c). Also, the C=O peak ($1710\text{-}1780\text{ cm}^{-1}$) was present in more pixels for acetylated samples (Figure 2), but unlike the OD, with no changes at different equilibrium moisture contents (not shown).

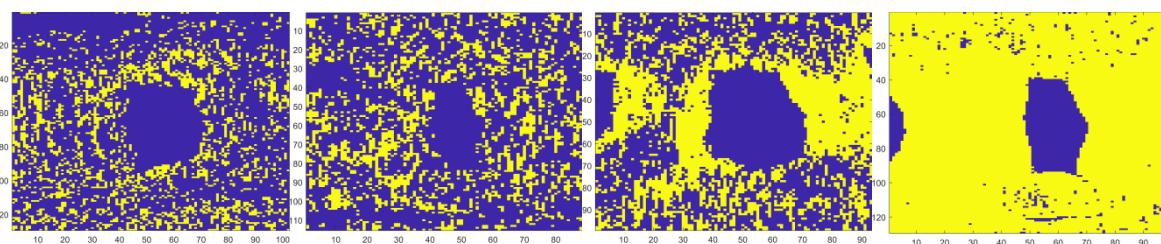


Figure 2 Example of binary colour maps showing the localisation of statistically significant C=O peaks (yellow) within the tracheid cell wall. Raman images were obtained at 50 % RH. From left to right: reference Norway spruce, reference pyridine, interface acetylated and uniformly acetylated wood. Pixel size: $333\text{*}333\text{ nm}$

More interestingly, information on the localisations of the C=O and the D-O molecular groups could be compared to study the influence of acetylation on moisture distribution within the cell wall.

Conclusions

The moisturizing system can be used in combination with Raman micro-spectroscopy to image thin biological specimens at different relative humidity levels in the hygroscopic range. Our analysis showed higher moisture uptake in the S2 cluster of the cell wall than in the CCML. The overall moisture uptake was lower for the acetylated specimens, confirming the hydrophobic/bulking effect of acetyl esters. Further, the acetylated samples had significant C=O peaks present in more locations than the two references.

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A Comparison Between the Ultrasonic, Wedge Cut and Microscopic Method for the Measurement of the Dry-Film Thickness of Wood Coatings

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Background

Measuring the dry film thickness of wood coatings is of great importance in quality control. The dry film thickness is negatively correlated with the formation of coating defects like cracking and, thus, has a major influence on the service life of a wood coating (e.g. Grull *et al.* 2014). In case of flame retardant (FR) paints and lacquers, the film thickness has a special significance as it is positively correlated with the reaction-to-fire performance (e.g. Mariappan 2017). CE marking implicates the control of the film thickness because FR-treated wooden construction products belong to AVCP system 1; this entails factory production control by a notified body according to EN 14915:2013+A1:2017+A2:2020. CE marking, however, does not cover the control of FR paints and lacquers applied by hand on construction sites. Therefore, portable instruments for measuring the film thickness accurately, fast and easy are of great value as they allow on-site inspections associated with internal or external quality control routines or liability cases. Of all film thickness measurement methods specified in EN ISO 2808:2019, the acoustic and the wedge cut method appear to be most appropriate. The present study compares the measurement accuracy and applicability between a portable ultrasonic and a wedge cut instrument with each other, considering the factors coating type, microfoam, the type of substrate and surface roughness.

Keywords: film thickness measurement, microfoam, quality control, wood coatings.

Experimental

The study comprised a total of 9 specimens (150 x 74 mm² / l x w) of different substrates with with different surface roughness and different film forming and non-film forming coatings (Table 1). In addition, the sample set included a paint with microfoam to study the influence of air inclusions that may especially occur at spraying on the thickness measurements. On each specimen, 10 points were marked for measuring the dry film thickness with an ultrasonic thickness gauge (PosiTektor 200, DeFelsko Corporation, Ogdensburg, NY USA) and then a wedge edge gauge (Paint Borer 518 USB, Erichsen GmbH & Co. KG, Hemer, Germany). On each of the 10 points, 5 consecutive measurements were carried out. In case of the wedge cut gauge, 5 replicates means that the concentric circle was set 5 times on the conical hole at each measurement point. As reference method served light microscopy (BX 60, Olympus Corporation, Tokio, Japan).

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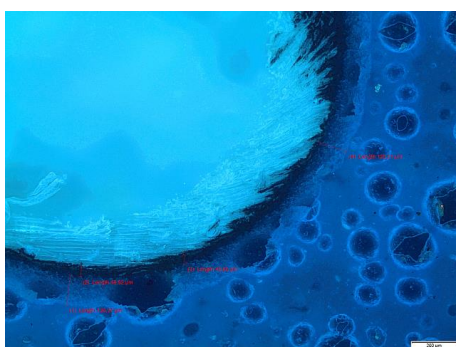
The cross sections analyzed by microscopy were removed directly next to the wedge cut holes. Two microscopic pictures were taken, one picture on each side of the hole; the film thickness was measured 5 times on each picture.

Results and Discussion

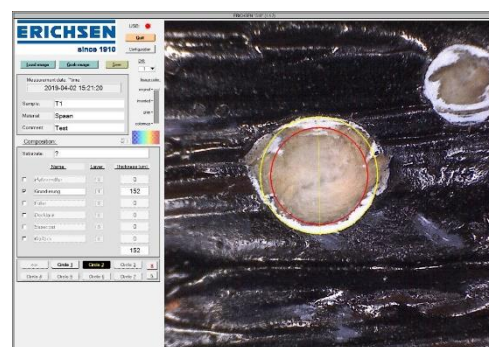
The ultrasonic gauge measured a mean film thickness of 41 μm on the uncoated oak reference (Table 1). The false values can be ascribed to the density variations that the instrument misinterprets as coating film (EN ISO 2808:2019). On all film forming coatings, the ultrasonic gauge provided accurate measurements independent from the substrate. The inclusion of microfoam (Figure 1a) however resulted in an underestimation of the film thickness by 71%. In comparison, the wedge cut gauge was not affected by microfoam and proved to be a reliable instrument on all film forming coatings, given that the substrate surface was smooth. On the fine-sawn surface, the strongly varying film thickness of the paint was especially difficult to measure with the wet cut gauge as its accuracy depends on setting the concentric measurement circle precisely (Figure 1b).

Table 1 Film thicknesses and the percentual deviations of the wedge cut measurements (WC) and ultrasound measurements (US) from the microscopic measurements (MIC). The fine-sawn surface was prepared with a paint cutter tool

Coating	Film-forming	Substrate	Surface	Overall film thickness (standard error) [μm]			Deviation from microscopy [%]	
				Micro	WC	US	WC	US
/	/	Oak	Sanded	0	0	41 (23)	/	/
Stain	No	Oak	Sanded	0	0	55 (1)	/	/
Stain	Yes	Oak	Sanded	42 (2)	45 (2)	36 (2)	8	-14
Stain	Yes	Spruce	Sanded	56 (5)	48 (5)	63 (3)	-14	14
Lacquer	Yes	Oak	Sanded	127 (3)	137 (3)	130 (2)	8	2
Paint	Yes	Spruce	Sanded	146 (3)	151 (3)	144 (3)	3	-2
Paint with microfoam	Yes	Spruce	Sanded	200 (4)	204 (4)	58 (2)	2	-71
Paint	Yes	Spruce	Fine-sawn	106 (6)	171 (6)	87 (2)	62	-17
Paint	Yes	Aluminium	Sanded	96 (1)	90 (1)	108 (2)	12	-7



a



b

Figure 1 Microfoam (a) and measurement circles using the wedge cut method on a sawn surface

Conclusions

The ultrasonic gauge provides accurate measurements on all film forming coatings except of those including microfoam. As microfoam is only visible in clear coatings, the applicability of the ultrasonic gauge excludes pigmented coatings. The wedge cut gauge is accurate on all film forming coatings; it also bears the advantage that microfoam is detectable. It is therefore the methods of choice for on-site inspections of exterior coatings on planed and sanded surfaces. On sawn surfaces, reliable results are difficult to obtain with portable instruments, and the microscopic method is advised.

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Phosphorylated Microfibrillated Cellulose Based Eco-friendly Fire-Retardant Coatings for Wood

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Background

Wood needs fire retardant treatments or coatings due to its inherently flammable nature. Typically, the fire retardants are based on halogens, phosphorus, nitrogen, metal ions, or nanofillers. There are environmental and toxicity issues with some of these fire-retardant chemicals. For example, the halogen-based compounds can leach from the coating into the environment and can bioaccumulate. In addition, during combustion they release toxic gases. Phosphorus-containing flame retardants are more suitable than halogen-based compounds as they favour the formation of char instead of combustible volatile species. A bio-based resource with high potential as a fire retardant is functionalized microfibrillated cellulose (MFC). Phosphorylation and amination of MFC have also been explored previously to prepare fire retardant MFC (Ghanadpour et al. 2018).

The production and functionalization of MFC has been explored only at low solids content so far. The excess amount of water in the formulations leads to coating application and drying challenges. The high consistency enzymatic fibrillation of cellulose (HefCel) technology in which MFC is produced at high consistency with the aid of enzymes (Hiltunen et al. 2015) can potentially resolve this challenge. This technology has also proven to be cost-effective compared to many state-of-the-art technologies for MFC production (Lehmonen et al. 2017). Furthermore, this technology allows functionalization of MFC at high solids making the functionalized MFC a competitive candidate in development of low-cost, environmentally friendly alternatives to synthetic components in wood coatings.

In this work performed under the FireCellCoat project, a phosphorylated MFC was produced using a novel concept at high solids content (25 wt.%) with low energy consumption (0.6 MWh/t). The fire-retardant coating formulations based on phosphorylated MFC were prepared and applied to a wood substrate using spray coating process. The formulations were also optimized for their rheological performance using carboxymethyl cellulose (CMC) as a rheology modifier. The fire-retardant properties of phosphorylated MFC coated wood were improved compared to those of uncoated wood. The coated wood showed self-extinguishing behaviour during flammability tests and did not ignite quickly when subjected to the cone calorimeter heat flux.

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Experimental

MFC preparation

MFC and phosphorylated MFC (denoted as P-MFC) used in the experiments was produced using high consistency enzymatic fibrillation (HefCel) process, as described in detail elsewhere (Jaiswal *et al.* 2021). Briefly, never-dried bleached softwood kraft pulp suspension at 25% consistency was mixed at 70°C and pH 5 at a mixing speed of 30 rpm with an enzyme cocktail comprising of commercial cellulases in 0.1M sodium acetate buffer in a reactor equipped with a temperature controller and a two-shaft sigma-type mixer (Jaygo Incorporated, Randolph, NJ, USA). The enzyme dosage was 4.5 mg/g of dry fiber weight and the total batch size was 500 g (% od). After 5 h, the enzyme was inactivated by increasing the temperature in the mixer to 90 °C for 30 min while keeping the same mixing speed and (NH₄)₂HPO₄ and urea were added at two AGU/(NH₄)₂HPO₄ molar ratios (low and high). (NH₄)₂HPO₄ and urea impregnated microfibrillated cellulose was then dried in an oven at 105 °C followed by curing at 150 °C for 1 h. The phosphorylated fibrils were then washed with boiling deionized water to remove unreacted chemicals as well as any remaining enzyme. MFC was produced following the same enzymatic treatment process with an exception that no phosphorylating chemicals were added during the enzyme inactivation step. P-MFC grades were named P-MFC_L and P-MFC_H to indicate the low and high AGU/(NH₄)₂HPO₄ molar ratios.

Coating application on wood

The MFC and P-MFC grades were fluidized prior to coating application to ensure good adhesion. The coating formulations were prepared at 5% solids content, and CMC (Finnfix 4000G) was used as a rheology modifier. The coating was applied directly on the wood surface by a spraying process (1 mm circular CS nozzle, $\Delta P \sim 2$ bar), as shown in Figure 2. The coating was dried in oven at 80°C. Multiple layers were applied as wet on dry. The samples were stored in a conditioned environment (23°C and 50% RH) pre- and post-coating.

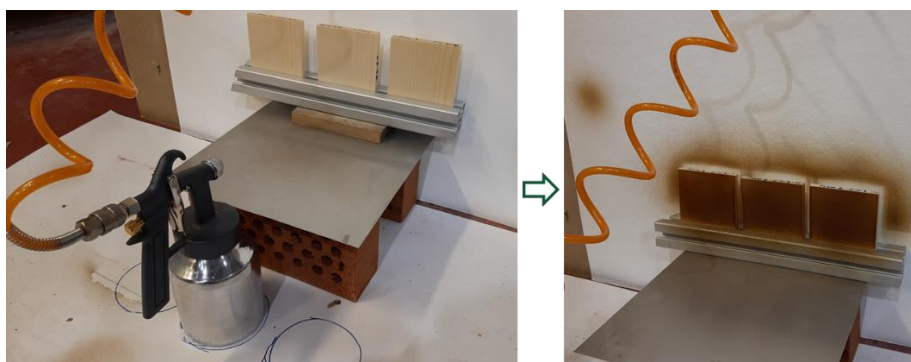


Figure 2 Coating application setup and the resulting P-MFC coating on wood

Fire retardancy tests

Cone calorimetry was performed for the coated wood samples according to ISO Standard (ISO 5660-1). A heat flux of 50 kW/m² was used. Since the coated area was not covering the whole wood surface, the testing area was limited by a tinfoil, as shown in Figure 3, to not influence the results.

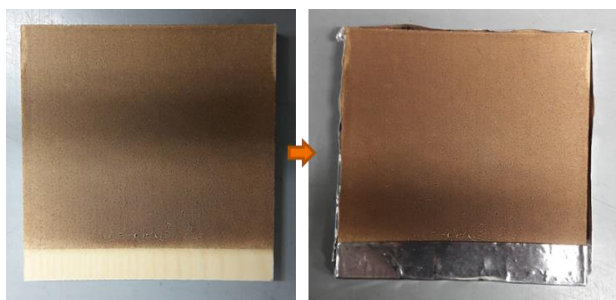


Figure 3 Coating coverage area and test area

Results and Discussion

The coating application was uniform, especially for single layer application. However, some adhesion challenges were observed during multilayer application of P-MFC, as seen from Figure 4. This was probably caused by lower availability hydroxyl groups in P-MFC compared to MFC which improve binding in the multilayer structure. Fluidizing of P-MFC was found to improve the inter-layer adhesion, as shown in Figure 4. Fluidizing seems to have exposed new hydroxyl groups which became available for hydrogen bonding.

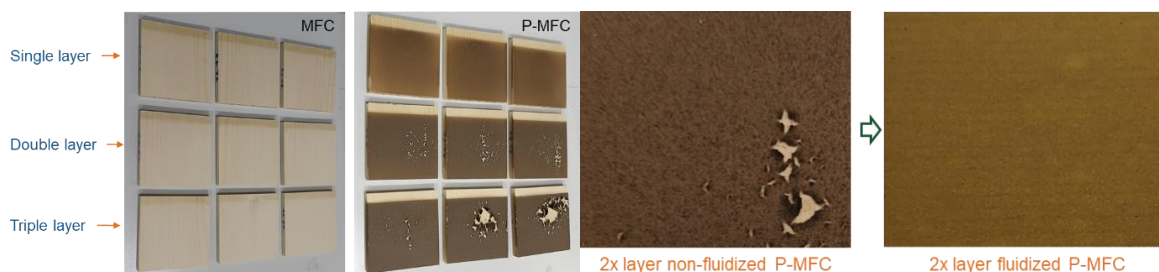


Figure 4 Single layer vs. multilayer application of MFC- and P-MFC coatings and impact of fluidization

The fire-retardant properties of MFC and P-MFC coated wood were improved compared to those of uncoated wood. The coated wood showed self-extinguishing behaviour during flammability tests and did not ignite as quickly when subjected to the cone calorimeter heat flux, as shown in Figure 5. The coatings were also found to delay the heat release. However, some improvements are still needed to reach the industry standard.

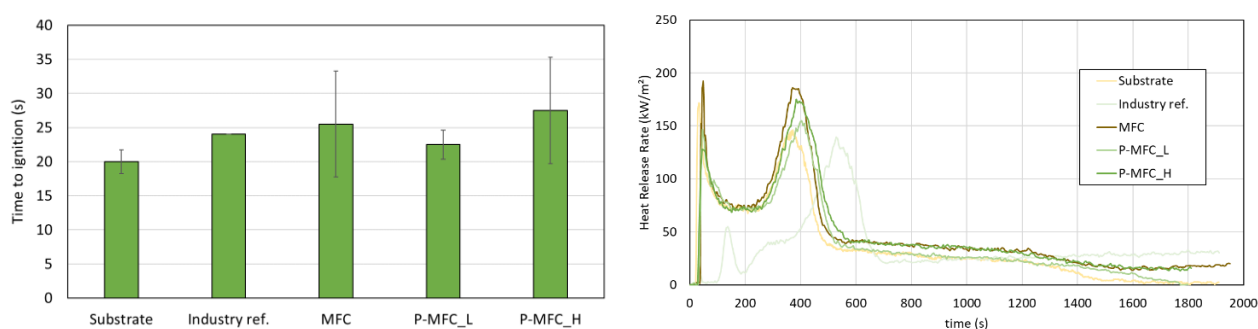


Figure 5 Time to ignition and heat release rates of the different MFC coatings and an industry reference

Conclusions

In the FireCellCoat project the target was to improve the fire resistance of wood with MFC-based coatings. The findings here are of great importance and clearly indicate that phosphorylated MFC is an efficient, eco-friendly, and sustainable flame-retardant material which could potentially replace the environmentally harmful halogen-based alternatives.

Acknowledgements

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Targeted Acetylation of Wood: a Tool for Tuning Wood-water Interactions

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Background

Wood susceptibility to fungal degradation may be reduced by a range of non-toxic wood modification methods. Some modification methods alter wood-water interactions, which could be the reason for its improved durability. In this study, we refined a well-known chemical modification with acetic anhydride and showed how the spatial distribution of the modification could be controlled in Norway spruce. The aim of the refined modification was to alter the wood-water interactions differently in different parts of the wood structure. By controlling the acetylation reaction conditions, it was possible to acetylate only the cell wall-lumen interface, or uniformly modify the whole cell wall to different degrees. The spatial distribution of the acetylation was visualized by confocal Raman micro-spectroscopy. The developed method is beneficial for studies of how the moisture distribution within the wood affects its susceptibility towards fungal decomposition and is useful when designing novel wood modification systems and wood products.

Keywords: Wood modification, moisture, Raman micro-spectroscopy

Experimental

Norway spruce (*Picea abies* (L.) Karst.) specimens with dimensions 10 (longitudinal) x 5 x 5 mm³ were vacuum dried at 60 °C for 24 h prior to acetylation. The specimens were then vacuum saturated with reagent solutions; 10 g of solution (either pure acetic anhydride or 1:4 mixtures of acetic anhydride and pyridine) was used for each g of wood. The acetylation reaction was carried out at elevated temperatures (75-80 °C) for a defined period of time at atmospheric pressure. The specimens were then washed sequentially in acetone, acetone:water and water in several washing cycles. All specimens were then vacuum-saturated with deionized water.

A Bruker mq20-Minispec NMR instrument equipped with a 0.47-Tesla permanent magnet was used to identify location and state of water in vacuum saturated specimens.

A WITec alpha300R Confocal Raman Microscope equipped with a 532 nm laser and an oil immersion objective (100x, NA=1.4) was used to identify the extent and location of the acetylation in wood.

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Results and Discussion

By varying the conditions of the acetylation process, it was possible to acetylate the cell wall-lumen interface only, control the depth of interface acetylation as well as to uniformly acetylate the whole cell wall to different degrees. Raman micro-spectroscopy showed that acetylation successfully excluded moisture where acetyl groups were found in the cell wall and LFNMR data revealed that by this targeted acetylation procedure it was possible to independently alter the wood-water interactions both in and outside of cell walls (Figure 1). The acetylation induced swelling led to a reduced lumen volume and thus a slight reduction in the amount of capillary water. The hydroxyl accessibility decreased with increasing modification intensity for all modifications. However, for untreated as well as modified specimens, the hydroxyl accessibility was higher in latewood than in earlywood (Digaitis et al., 2021).

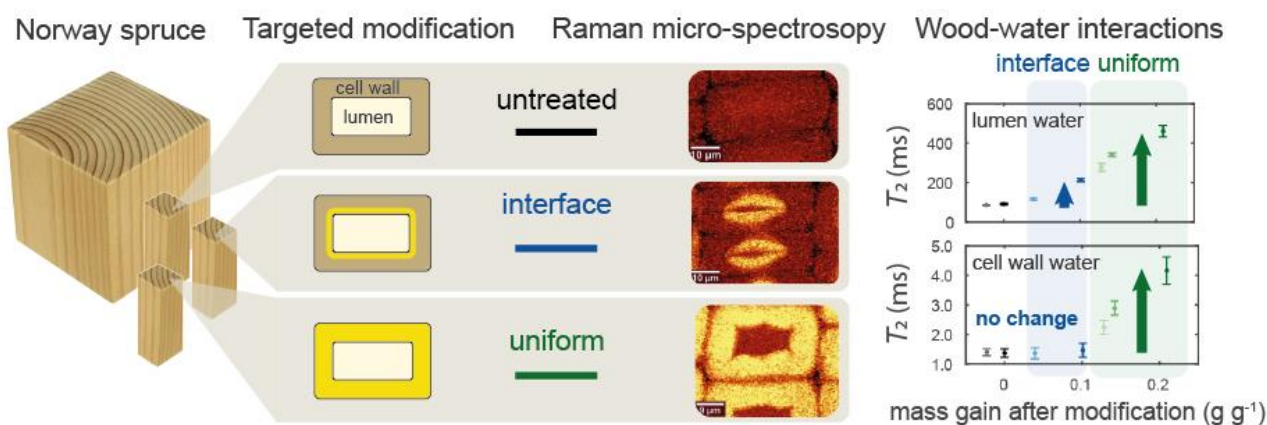


Figure 1. Raman images depicting targeted acetylation of Norway spruce and T_2 relaxation times (LFNMR data) showing that the cell wall-lumen interface modification altered the interaction between the wood and the water in cell lumina without affecting the interaction with water in cell walls, while the uniform acetylation affected both (Digaitis et al., 2021).

Conclusions

By controlling the acetylation reaction conditions it was possible to distinctively acetylate the cell wall-lumen interface only, to control the depth of the interface acetylation as well as to uniformly acetylate the whole cell wall to different degrees. The LFNMR analysis demonstrated that targeted acetylation can be used to modify wood water interactions differently in different parts of the wood structure. This opens up new possibilities to design innovative wood modification systems and wood products as well as for studying wood-water interactions in detail.

Acknowledgements

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Deterioration and Decay of Wooden Cultural Heritage in Arctic and Alpine Environments – a New Project

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Background

Wooden cultural heritage in the Arctic Svalbard and the Alpine regions of mainland Norway is situated in vulnerable ecosystems with high impact from the ongoing climate changes in addition to threats from increased human influence and land use changes. The Arctic will be strongly affected by climate change over the coming decades with increasing temperature and precipitation, more extreme weather and significant thawing of the permafrost (Øseth 2010). Alpine regions in Norway are projected to have a similar change (Hanssen-Bauer 2017) with increasing temperature and precipitation. Microorganisms are temperature and moisture dependent, and the impact of climate changes on microclimatical conditions will extend their period of activity both in Alpine and Arctic ecosystems (Ernakovich et al. 2014). There are hardly any no comprehensive approaches or strategies on how to execute managerial responses and priorities based on the knowledge on projected effects of climate change and increased utilisation of the vulnerable Arctic-Alpine cultural heritage environments (Flyen et al. 2020, Hagen et al. 2012). Biological deterioration and wear and tear from tourists and users are hypothesised to reinforce each other and must be addressed to ensure resilience in wooden cultural heritage for the future. The aim of this paper is to present the new project *ArcticAlpineDecay* that will target these challenges.

Keywords: arctic, alpine, decay, human influence, wood cultural heritage.

The project *ArcticAlpineDecay*

The project *ArcticAlpineDecay* will start the fall of 2021 after receiving funding from the Research Council of Norway. This is a 4-year project with cross-disciplinary cooperation and research between stakeholders, governmental institutions, tourist trade, commerce and science. The partners in the project are: Norwegian Institute of Bioeconomy Research (NIBIO), Norwegian Institute for Cultural Research (NIKU), Royal Danish Academy - Architecture, Design, Conservation, Mycoteam, Directorate for Cultural Heritage - Norway, Vestland County Council, Kings Bay AS, Store Norske and Norwegian Trekking Association.

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The primary hypothesis is that climate change and increased human impact (mainly tourism) will accelerate the deterioration rate of wooden cultural heritage in Arctic and Alpine regions. To mitigate this *ArcticAlpineDecay* will address the following research questions:

- What are the main wood deterioration types, species and decay rates in different wooden typologies and what are their frequency, distribution and effect on wood properties?
- What awareness level do tourists, guides and local users have regarding fragile wooden cultural heritage?
- What is the perception of tourists, guides and local users towards wooden cultural heritage objects influenced by different stages of decay?
- How will projected climatic and human impact affect the wooden cultural heritage?
- How to facilitate the most resilient and sustainable managerial responses on current knowledge and projected risk assessment analysis?
- How to adapt difficult-to-access research-based knowledge for different target groups?

Organisation and experimental

The project is organised in 4 scientific work packages, each with a specific objective:

WP1 The current condition of wooden cultural heritage. Objective: establish an open access database characterising the current condition, including the main deteriorating factors, of wooden structures in Arctic-Alpine regions in Norway. A three-step approach will be used to characterise the current state and study the deterioration dynamics in different exposure situations (typologies) by collecting data on direct and indirect wood deterioration factors.

WP 2 Understanding of and adaptation to wooden cultural heritage. Objective: analyse tourist', guides' and users' understanding of their impact on wooden cultural heritage, and on what conditions they could constructively adapt their practices. The relation between tourism and deterioration will be probed from a social science perspective. Attention will be given to the potential changed travel and tourist situation due to COVID-19 and its implication for wooden cultural heritage.

WP 3 Scenarios and Risk Assessment. Objective: develop and perform risk assessment analysis for typologies of wood cultural heritage given alternative future deterioration scenarios. Scenarios for future deterioration will be calculated based on the knowledge of the current situation for selected wood cultural heritage objects and their historic development of deterioration caused by fungal decay and direct human induced influence.

WP 4 Resilience of wooden cultural heritage for the future. Objective: facilitate management strategies to increase the resilience of wooden cultural heritage for the future. Building upon results from WP 1-3, the future consequences for the wooden cultural heritage will be identified and future fitting managerial responses will be facilitated.

Expected impact of the project

Current knowledge on Norwegian wooden cultural heritage in Arctic and Alpine regions is scattered and contains significant knowledge gaps. *ArcticAlpineDecay* will therefore make a significant impact on short term by: 1) understanding type, degree and rate of degradation in relation to microclimate and wood typology in Arctic and Alpine environments to obtain suitable measures in conservation management, 2) identifying how tourists, users and guides understand their impact on cultural heritage and how they can adapt their practices. In a long term *ArcticAlpineDecay* will enable knowledge-based decisions in future management and conservation plans.

The projects' main impact regarding societal challenges is to acquire knowledge about how fast we can expect the existing wooden cultural heritage structures will degrade if no preservation and management are performed. The provided platform for future knowledge-based decisions regarding preservation and conservation will enable future generations to experience the wooden cultural heritage in Arctic-Alpine regions. We hypothesise that future tourist activity will need to be modified significantly based on the findings of this project.

It is important to preserve our cultural heritage for future generations, not least because it reflects and shapes the values, beliefs and aspirations that make up a national identity. The social and economic value of this transmission of knowledge keeps our integrity as a people. Digital storage, digital tools and web-based solutions have played, and will continue to play, a large role in the preservation of cultural heritage. This project will put the advantages of digital tools to use in a major contribution to our ability to safeguard the physical proofs of our heritage.

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Evaluation of Splash Water Contact Scenarios on Wooden Cladding and its Influence on the Moisture-Induced Risk of Decay

Philip Bester van Niekerk¹, Christian Brischke, Joshua Jannik Rabke, Christian Simmering and Jan Miguel Tausendfreund

Background

Wood durability researchers have long emphasised the need to identify regions with increased decay risk in the built environment. Direct soil contact and moisture trapping design have received the most attention to date (Niklewski and Fredriksson, 2019; Marais et al., 2020), while timber components affected by splash water from precipitation are mostly anecdotally presumed to have an increased risk of decay. Splash water is of particular concern when timber components do not have suitable durability requirements, resulting from the assumption that these components are sheltered from direct precipitation. Some research on splash water could be found in other fields such as agriculture (Fitt et al., 1989; Walklate et al., 1989; Huber et al., 1997 & 1998); however, little research has focused on timber design and construction (Brischke, 2013). In the present study, experiments were conducted to analyse the splash water behaviour with different undergrounds and investigate the effect of splash water on the wood moisture content of timber claddings.

Keywords: Splash water, decay, wood.

Experimental

A rain chamber was used to simulate precipitation events. The chamber also had a removable base tray, which allowed different kinds of underground substrates to be investigated. The splashing behaviour of four different substrates (concrete, wood, coarse gravel, grass) regarding the splash water distribution and the splash water amount at different height intervals was investigated. Moisture-sensitive paper was used to assess the splash water distribution visually. Furthermore, water capturing tubes and cups were used to determine the amount of splash water at different height intervals. In the second part of the study, the influence of splash water on the wood moisture content was investigated. For this purpose, wooden façades were inserted into the rain chamber made of Norway spruce (*Picea abies* Karst.), and Scots pine sapwood (*Pinus sylvestris* L.) with electrical resistance sensors installed in-situ. Only one type of substrate (concrete) was used in this test. A two-hour rain event was simulated, followed by a monitoring period of the drying behaviour over several days. The wood moisture content of the façades was determined at different heights above the ground by measuring the electrical resistance at the surface and at 1 cm depth.

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Results and Discussion

The results of our tests showed that splash water behaviour differs between the four types of substrate. The splash water height and the splash water amount were much higher for the concrete and wooden substrates. Moreover, the influence of splash water on the wood moisture content decreases with increasing distance from the ground. The surface properties (water film, roughness, angle of inclination) and mechanical properties (flexibility) of the subsurface are thus important. Other experiments have shown that wet subsurfaces produce greater amounts of spray water than dry ones (Huber et al., 1997; Walklate et al., 1989). Moreover, Yang and Madden (1993) found that the amount of spray water decreases with increasing surface roughness.

The moisture monitoring experiments found that the wood moisture content of 25 %, which is considered critical for fungal growth, was not reached in any of the façade elements at the measurement depth of 1 cm. However, as seen in Figure 1, the surface measuring points showed moisture values above the critical value up to a height 37.5 cm. As expected, the façade elements made of Scots pine sapwood absorbed noticeably more water and showed a significantly longer drying time than Norway spruce. In conclusion, the wood degradation conditions were most beneficial for the fungus near the ground, where suitable decay conditions were sustained at the lowest surface measuring point for more than seven days after the simulated precipitation event.

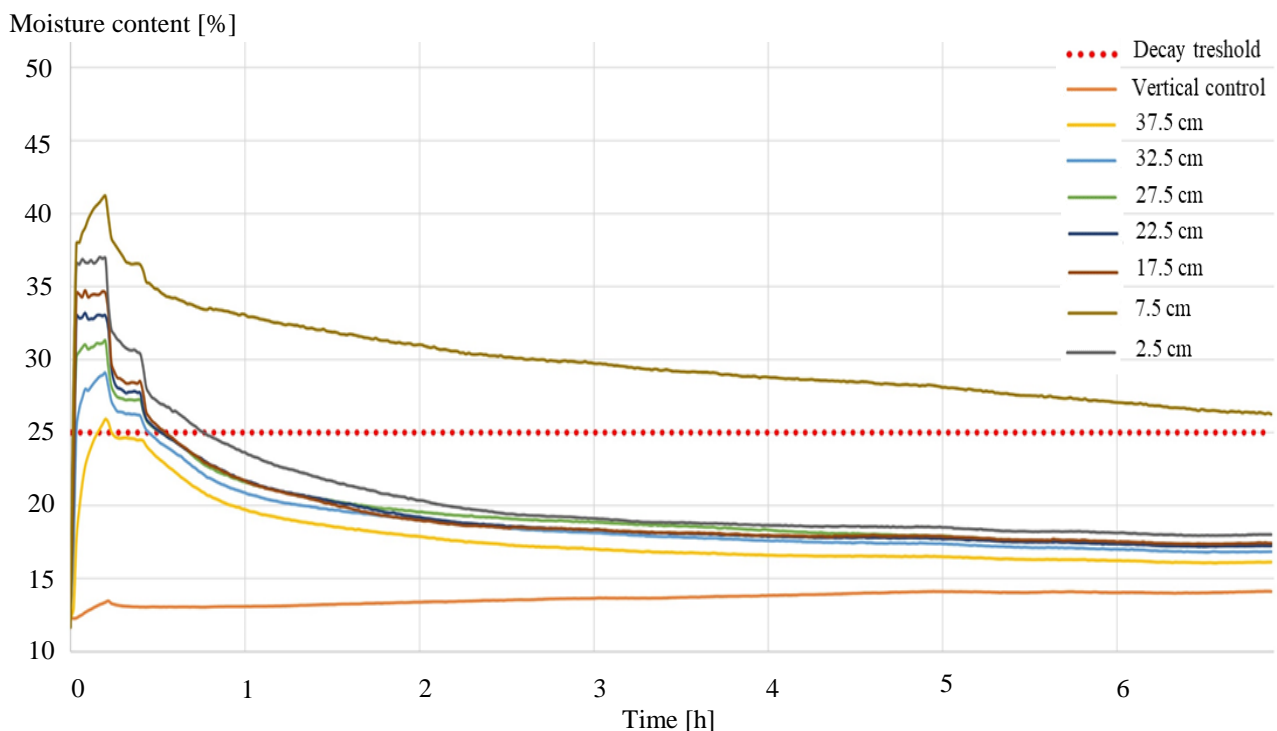


Figure 1 Resistance-based moisture content behaviour of Norway spruce (*Picea abies* Karst.) cladding at different height intervals following artificial wetting. The Monitoring period consisted of a 2-hour spray cycle followed by seven days of drying

Conclusions

Wooden claddings in the precipitation splash zone have an increased risk of decay development. Moreover, the splash water zone varies significantly between different undergrounds/subsurfaces regarding surface roughness, hardness, angle of inclination, and the absence or presence of a water film. The most susceptible region for decay development is at the bottom surface of the cladding, where prolonged suitable moisture conditions were observed. These conditions are assumed to stem from the accumulation of moisture moving downwards in the cladding, while closer proximity to the ground further reduces ventilation. For service life planning purposes, the effect of splashwater

can be captured in a factor method approach. Higher durability timber should thus be considered for cladding that is subject to splash water.

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Reality Check on Sorption Isotherm Models: do they Really Describe the Wood-Water Equilibrium State?

Emil E. Thybring¹, Charles R. Boardman², Samuel L. Zelinka² and Samuel V. Glass²

Background

Water vapor sorption is fundamental to the behavior of wood and affects nearly all its properties. The relation between equilibrium moisture content of the wood and relative humidity at a given temperature is described by the water vapor sorption isotherm. For a century this has been a central part of wood science, and for nearly as long, the scientific discussion has focused on the fundamental mechanisms governing the wood-water equilibrium state and the sorption process towards this state. Sorption isotherm models are often used to understand the interactions of water with wood. While based on idealized physical systems, these models are used to predict actual physical properties of wood. Given the complexity of the wood-water equilibrium state, we hypothesize that the most common sorption isotherm models are unable to describe water in wood, despite their popularity and widespread use to do exactly that.

Keywords: Sorption isotherm, model, Hailwood-Horrobin, GAB, Dent, BET

Experimental

We review twelve models with a parabolic form, i.e. where the ratio of relative humidity (water activity, a_w), to the equilibrium moisture content, is a second-order polynomial function of a_w . These include the parabolic models of Anderson (1946), Anderson and Hall (1948), Brunauer et al. (1938), Cassie (1945), de Boer (1953), Dent (1977), Gascoyne and Pethig (1977), Guggenheim (1966), Hailwood and Horrobin (1946), and Langmuir (1918). By fitting these models to high quality sorption isotherm data at multiple temperatures from Weichert (1963), physical properties are calculated from the model parameters. Variability arising from uncertainties in the experimental data is propagated using a novel Monte Carlo method. For more details please refer to (Thybring et al. 2021).

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Results and Discussion

Several of the most popular models used in wood science, namely the Guggenheim-Anderson-de Boer, Hailwood-Horrobin, and Dent sorption isotherm models, can be rearranged into the same mathematical form using algebraic transformations. While mathematically equivalent, these models predict (1) different monolayer capacities (2) different relative amounts of primary and secondary absorbed water, and (3) different values for the differential enthalpy of sorption. It logically follows that at most one of these models can be physically valid. However, we compared the model predictions against independently measured values of (a) hydroxyl accessibility determined gravimetrically by deuterium exchange, (b) experimental data of two distinct populations of cell wall water from 2D-low field NMR and Quasi-Elastic Neutron Scattering (QENS) as a function of relative humidity, and (c) differential sorption enthalpy obtained by sorption calorimetry as well as from direct derivation by the Clausius-Clapeyron equation applied to the Weichert sorption data. In all cases the model predictions were far from measured values as exemplified in Figure 1 for the monolayer capacity compared with the hydroxyl accessibility. Furthermore, we used a Monte Carlo method to propagate the uncertainties in the sorption isotherm data (error bars in Figure 1), yet still found that the range of model predictions were outside of the range of measured data.

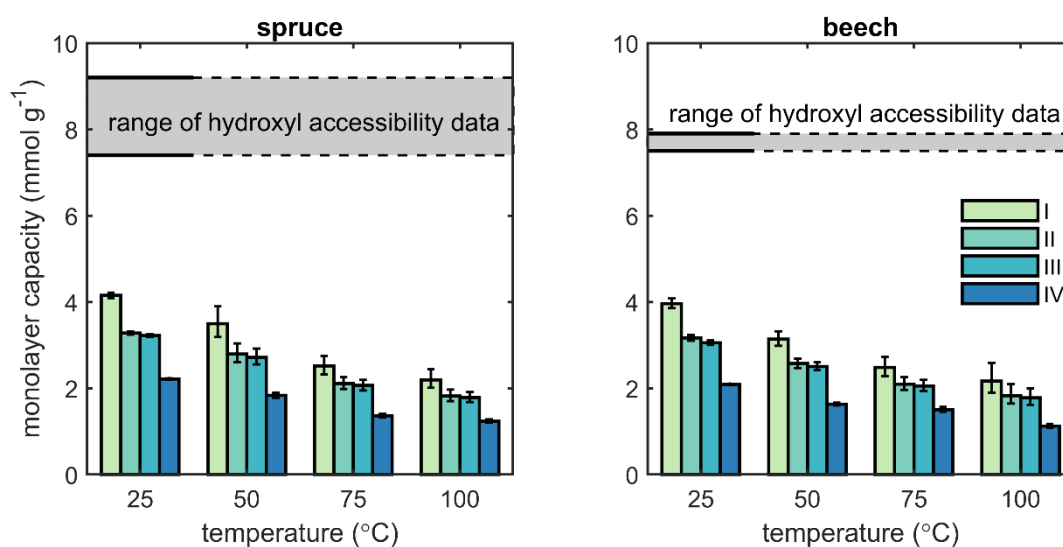


Figure 1 Predicted monolayer capacity based on fitting models to sorption data for spruce and beech as a function of temperature compared to experimental hydroxyl accessibility data. The four model designations (Roman numerals) refer to four different predictions of the monolayer capacity based on the exact same parabolic fit to data. Error bars were calculated from Monte Carlo simulations accounting for sorption measurement uncertainty. For more details please refer to (Thybring et al. 2021).

Conclusions

The data and analysis presented in this work thoroughly show that physical quantities predicted by parabolic sorption isotherm models are not valid for water in wood cell walls.

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Discolouration of Wood Due to Artificial Lighting

Dace Cirule¹, Edgars Kuka and Melita Hivriča

Background

The colour of wood is an essential element of its value for objects of aesthetic importance. Discolouration due to irradiation is an inherent wood property. The pattern and extent of the colour change depend mostly on the wood species, the spectral composition of the incident light, the radiation intensity, and exposure time (Tolvaj and Mitsui 2005, Kataoka et al. 2007, Oltean et al. 2008, Timar et al. 2016.). Most studies of wood discolouration have focused on the effect of UV radiation. Although it has been found that the shorter wavelengths of visible light also induce colour changes in wood (Kataoka et.al. 2007, Živković et al. 2014, Cirule et al. 2016), there is a lack of knowledge regarding the potential influence of artificial lighting on wood discolouration. The present study is a part of the research aimed at evaluating colour changes and providing discolouration models of different wood species depending on the type of the artificial lighting.

Keywords: wood, discolouration, artificial lighting.

Experimental

Specimens measuring 70 × 70 mm of 7 wood species (2 softwoods and 5 hardwoods) were used in the experiments: A – alder (*Alnus glutinosa*), F – ash (*Fraxinus excelsior*), T – aspen (*Populus tremula*), B – birch (*Betula pendula*), Q – oak (*Quercus robur*), P – pine (*Pinus sylvestris*), and S – spruce (*Picea abies*). For ash and pine, sapwood (s) and heartwood (h) specimens were separated. The exposure of specimens was carried out in chambers specially designed for this study and equipped with 4 artificial light sources of different spectral composition: incandescent lamps (Inc), fluorescent lamps (Fl), and LED lamps of two colour temperatures, namely 3000 K and 6500 K. A portable spectrophotometer Konica Minolta CM-26dG (standard illuminant D65, d/8° measuring geometry, 10° standard observer, measuring area Ø 8 mm) was used for measuring colour parameters of the CIELAB colour model: L*, a*, b*. The total colour changes ΔEab were calculated from the colour parameter differences between the initial and resulting values ΔL*, Δa*, Δb* according to the formula:

$$\Delta E_{ab} = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \quad (1)$$

Spectrophotometric measurements were performed before and at definite exposure doses always at the same five points on the surface of each specimen.

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Results and Discussion

To compare discolouration of wood caused by different artificial light sources, the colour changes corresponding to equal irradiation doses are analysed. In Figure 1, discolouration of specimens exposed to the total dose of 4.6 Mlx h is shown.

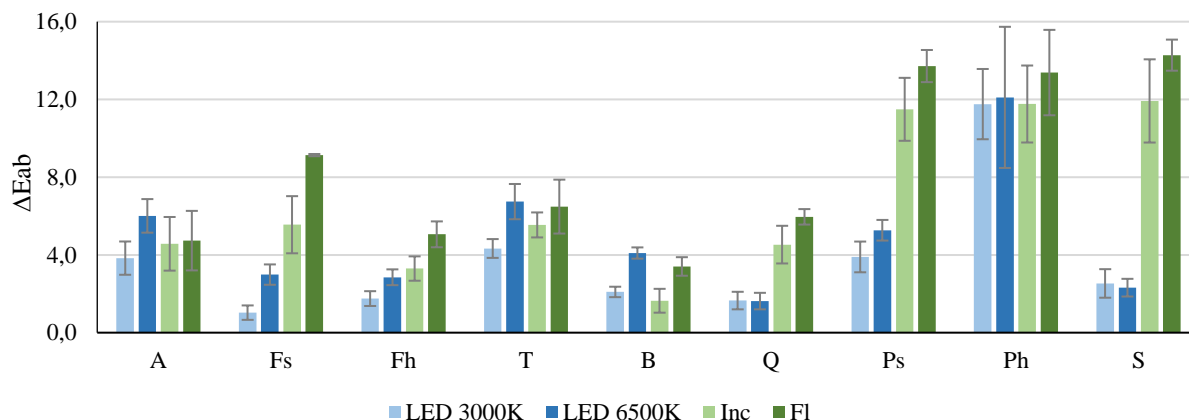


Figure 1 Discolouration of wood exposed to total irradiation dose of 4.6 Mlx h: A – alder, Fs – ash sapwood, Fh – ash heartwood, T – aspen, B – birch, Q – oak, Ps – pine sapwood, Ph – pine heartwood, S – spruce; Inc – incandescent lamp, Fl – fluorescent lamp.

The highest discolouration, which exceeded 10 ΔE_{ab} units, was detected for all softwoods (S, Ps, Ph) exposed to incandescent (Inc) and fluorescent (Fl) lamps as well as for pine heartwood (Ph) exposed to LED lamps. A characteristic feature of the Inc and Fl lamps are the relatively high emittance of UV radiation with UV making up 0.6 % and 1.4% of the total radiation for Inc and Fl lamps, respectively. These two types of lamps caused more discolouration than LED lamps also for ash sapwood (Fs) and heartwood (Fh) and oak (Q) indicating that UV radiation is the main cause of discolouration of these wood species similarly as for spruce (S) and pine sapwood (Ps). LED lamps emit hardly any UV radiation but have quite substantial emittance in the shorter wavelength region of visible light, which has been identified to possess enough energy to trigger wood photo-degradation resulting in wood discolouration (Kataoka et al. 2007, Živković et al. 2014, Cirule et al. 2016). The much higher discolouration of pine heartwood than sapwood caused by LED lamps points out that the extractives formed during the formation of the heartwood are involved in the colour change caused by exposure to visible light. LED 6500K lamps contain higher ratio of shorter wavelength of visible light than LED 3000K lamps. Comparing two types of LED lamps, similar or higher colour changes were observed for specimens exposed to LED 6500K lamps suggesting that the ratio of radiation of the shorter wavelength of visible light can essentially influence discolouration of wood. Discolouration of aspen (P), birch (B), and alder (A) caused by LED 6500K lamps was even higher than that caused by the lamps emitting UV radiation implying the importance of visible light in discolouration of these wood species.

Conclusions

Artificial lighting can cause significant changes in the wood colour. Discolouration of wood due to exposure to artificial light depends on both the wood species and type (sapwood or heartwood) as well as on the spectral composition of the light source.

Acknowledgment

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Natural Weathering of Surface Charred Spruce – Comparison of Two Techniques

Maija Kymäläinen

Background

In search for more natural, non-toxic construction materials, interest towards surface charred wood has increased. Charred boards can be used in several applications, especially as exterior claddings or fences. The weatherability of surface charred boards depends on several factors, of which the charring method has a high impact. A gas flame will create a severely degraded structure that is rather inert in use, but the has poor resistance to mechanical abrasion. Contact charring at a lower temperature creates a hard, smooth surface, but the wood components may still be chemically and biologically reactive. To evaluate the outside performance of surface charred spruce, a natural weathering test was implemented. The goal was to assess the changes in surface properties and appearance, as well as compare two different techniques: a hot plate/contact charring combining a moderate temperature with a long modification time, and flame charring that produces a heavily charred surface within a short time.

Keywords: Surface charring, Weathering, Wood.

Experimental

Planed spruce (*Picea abies* L.) boards were charred with a flame or hot plate. Flame charring was implemented with a butane gas torch until a consistent crack pattern emerged. A hot plate at 320 °C for 30 minutes was used for the contact heating. Half of the flame charred boards were brushed to remove the friable char layer. Black acrylate paint references as well as doubles coated with linseed oil (to evaluate the effect of adding a simple organic coating) were prepared. Four samples per treatment were prepared as described in SFS-EN 927-3:2019. The samples were exposed at a 45° angle towards south. After one year, the overall appearance, cracking, flaking, molding and colour changes were recorded.

Results and Discussion

After exposure, the changes were first assessed visually. Molding of the surface was recorded on a scale of 0-5 (quantity of defects) as in SFS-EN 927-3:2019. The number of cracks was evaluated on the same scale. The painted references were practically unaltered, bar a few minor cracks. No mold was detected on the flame charred samples, while the unmodified references were heavily molded. This also affected the colour change, with ΔE^* close to 30 and the surface dark gray (Figure 1). The contact charred samples showed similar values ($\Delta E \sim 25$), with the brown-black colour turned to gray-brown. Linseed oil is a natural, organic wood preservative commonly used in traditional oil paints. It may, however, increase moulding. This was easily detected in the unmodified references as well as contact charred samples, where the colour change of oiled specimens was higher. In flame charred, as well as flame charred and brushed samples, the oiling had little effect. In terms of cracks, the oiling even seemed to be beneficial for flame charred wood samples, but did not improve/decrease the surface quality of contact charred, nor flame charred and brushed samples.

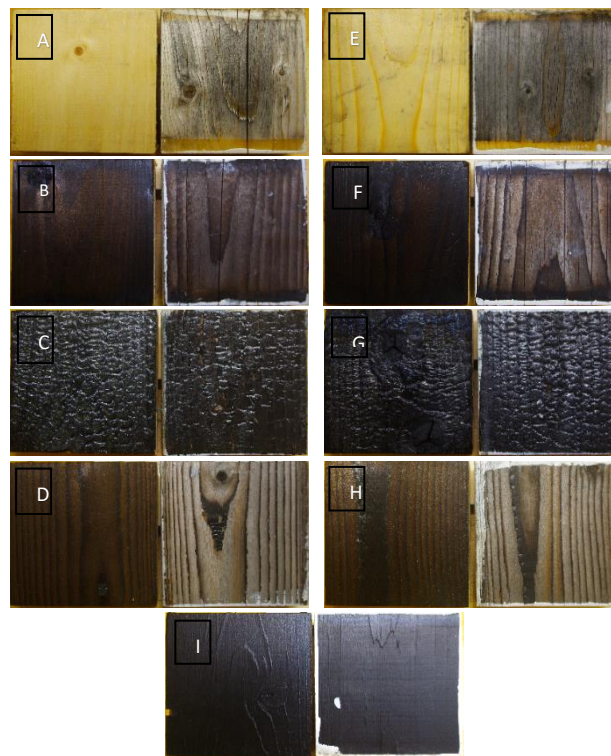


Figure 1 Comparison of indoor stored (left) references and weathered (right) samples. A,E = unmodified; B,F = contact charred at 320 °C; C,G = flame charred; D,H = flame charred and brushed. Samples A-D are uncoated, E-H oiled twice with linseed oil. Sample I = acrylate painted reference.

Conclusions

Hot plate charring did not produce a weathering-resistant surface, as the color was faded and the samples heavily cracked. In contrast, the flame charred samples withstood weathering well, with only slight flaking and minor cracking. Brushed flame charred samples showed extensive fading but little cracking, indicating less internal stresses from the processing. For Norway spruce in Finnish conditions, gas flame charring may be a viable surface modification alternative for exterior cladding boards. Brushing may not be recommended at least for south-facing applications.

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Mapping the Present and Future Fungal Decay Hazard of Aboveground Wood in Europe

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Holger Militz

Background

The Intergovernmental Panel on Climate Change (IPCC, 2014) has released four Representative Concentration Pathways (RCP 2.6, 4.5, 6.0, and 8.5) (Taylor et al., 2012) to capture trends in future emissions scenarios. The RCPs make predictions about how future anthropogenic greenhouse gas concentrations in the atmosphere will change. The RCPs consider emissions from sectors such as energy generation and transportation to the use of new emissions capture technologies. Intensified future climatic conditions will place wooden structures under more pressure to deliver suitable periods of service-life. Intensified temperature and moisture conditions will favour fungal decay processes, in-turn reducing service-life. This paper serves to visualise the fungal decay risk of wood exposed aboveground, Europe-wide, while considering two future RCP scenarios and their effect on fungal decay potential.

Keywords: dose-response, fungal decay, IPCC, RCP 2.6, RCP 8.5.

Materials and Methods

The Meteororm meteorological software tool (Meteotest, 2021) was used to extract climate information of the European continent and other regions bordering the Mediterranean Sea. Predefined weather station locations were selected (551 in total), with data representing three climate scenarios extracted for each location. Precipitation, relative humidity and temperature data at an hourly scale for a contemporary and two future scenarios (RCP 2.6 and 8.5) for the year 2050 was extracted. Following the physiological requirements of wood decaying fungi, days of suitable aboveground wood decay conditions (i.e. dose), for the three climate scenarios were calculated using a dose-response model for Norway spruce sapwood (*Picea abies* (L.) Karst.) (Isaksson et al., 2013; Niklewski and Fredriksson, 2021). Fungal decay hazard maps were then developed using the natural neighbour interpolation method available in the system for automated geoscientific analyses (SAGA) module (Conrad et al., 2015), within the free and open source geographic information system QGIS 3.20.1 Odense (QGIS Development Team, 2021). Country borders and land area extents were taken from Eurostat (European Commission, 2021). The maps were prepared in the coordinate reference system of the European Petroleum Survey Group (EPSG) 4326, on the World Geodetic System's 1984 (WGS 84) ellipsoid.

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Results and Discussion

The contemporary risk map (Figure 6) shows higher fungal decay risk at coastal regions with high rainfall, while mountainous regions and arid environments present a lower fungal decay risk. Parts of Ireland present the highest single risk region, while the United Kingdom, on average, shows the highest decay risk, followed by regions bordering the North Sea. Both future scenarios show an increase in total dose (Figure 7 and Figure 8), therefore intensified wood decay hazard. However, some regions show reduced dose, therefore weakened future wood decay hazard resulting from decreased humidity due to increased temperature and dryness.

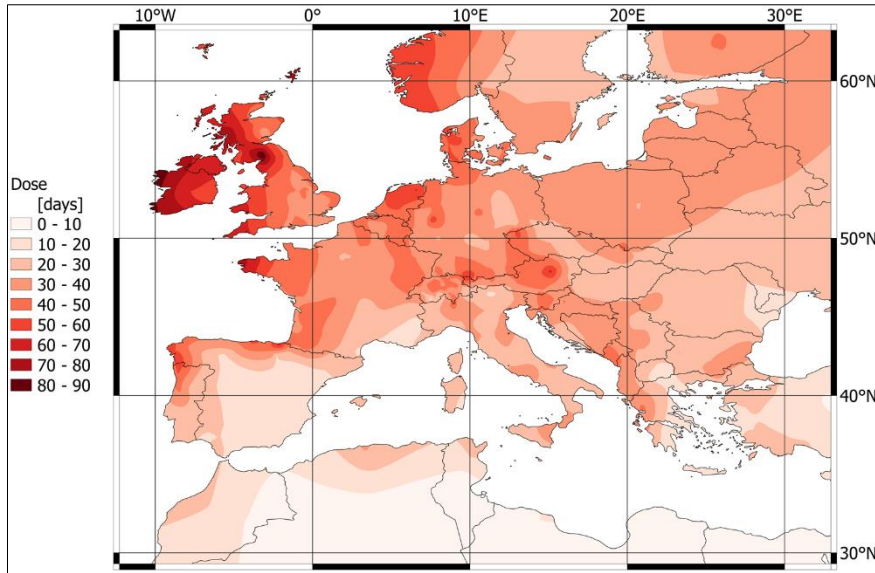


Figure 6 Fungal decay risk map of Europe based on contemporary climate data

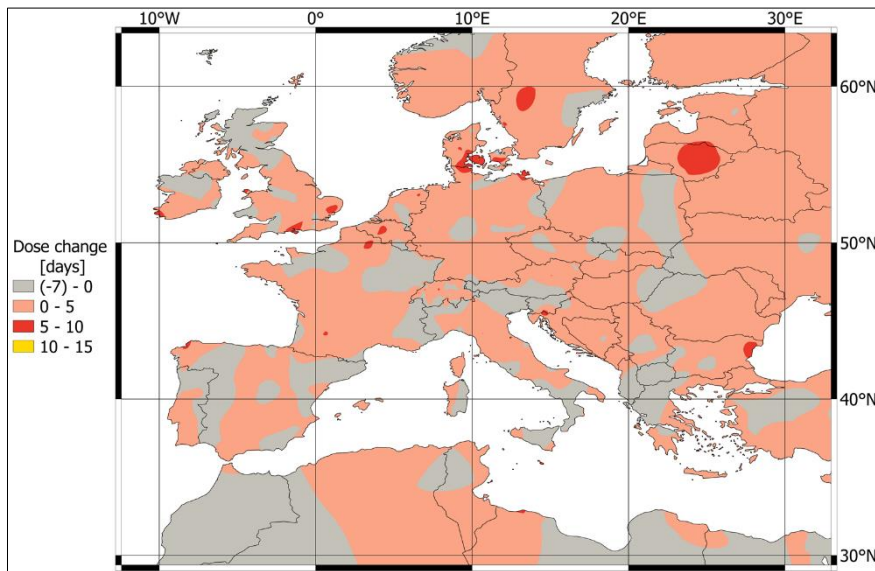


Figure 7 Fungal decay risk map of Europe based on climate data representing RCP future scenario 2.6 for the year 2050

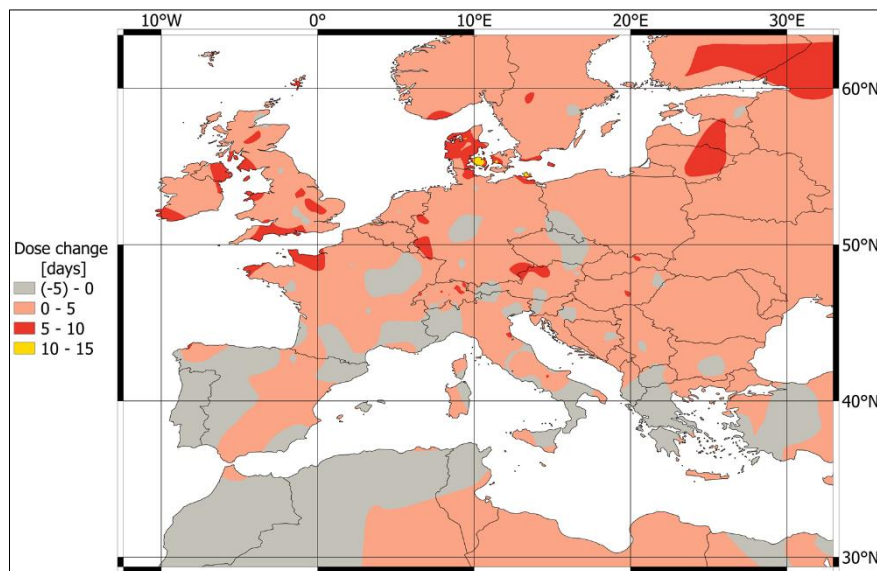


Figure 8 Fungal decay risk map of Europe based on climate data representing RCP future scenario 8.5 for the year 2050

Conclusions

The presented hazard maps show that wood decaying fungi are expected to increase activity in Europe as a result of climate change. The intensity of increased future wood decay hazard is expected to be proportional to the intensity of the RCP future emissions scenario. Hazard maps and their constituent models are essential tools for service-life planning. They have the potential to reduce the number of prematurely failing wooden structures and thus improve the competitiveness of wood as a building material against others.

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Wood-water Interactions of Thermally Modified, Acetylated and MF Resin Modified Beech Wood

Petr Čermák¹, Jakub Dömény, Petr Pařil, Radim Rousek, Dominik Hess and Jan Baar

Background

Wood has very good properties as a building material, such as high stiffness to weight ratio and good insulation properties, and it is also biodegradable at the end of the life cycle. However, wood–water interactions has always been one of the main issues when using wood in the built environment. Nowadays, wood modification allows considerable reduction or even elimination of natural disadvantages of wood in order to obtain better performance over the service life. Chemical, thermal and mechanical treatments are commonly applied to wood resulting in permanent or temporary changes in wood properties.

Despite the extensive literature on the wood modification and its water-related characteristics, comprehensive experimental data of wood-water interactions for various wood modifications are limited. Therefore, the present study aims to study wood-water related characteristics, i.e., water vapour and liquid water, for thermally modified, acetylated and MF resin modified beech wood (*Fagus sylvatica* L.).

Keywords: wood modification, sorption isotherm, wood-water interaction

Experimental

Beech wood specimens were thermally modified (TM) at 180, 200 and 220°C in a laboratory chamber using superheated steam environment for 3 hours. Furthermore, specimens were vacuum-impregnated using acetic anhydride (Acet) at 5kPa for 0.5 h and left in solution at ambient pressure for 0.5 h and finalized at sealed vessels at 120°C for 24 h. Moreover, specimens were vacuum-impregnated at 10kPa for 1 h with an aqueous solution of low molecular weight MF (Mel) resin (solid content of 25%) and left in the solution at ambient pressure for 1 h and at lab conditions for two weeks. Afterwards, the water vapour characteristics, i.e., water vapour sorption isotherms, equilibrium moisture content (EMC), dimensional stability of specimens conditioned at 30, 65 and 90 % RH and liquid water characteristics, i.e., water absorption, maximum moisture content, leachability and swelling kinetics, were determined and the results compared with reference (Ref) specimens.

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Results and Discussion

From the results, it is evident that the scale of wood-water interactions was highly dependent on the thermal modification temperature and type of chemical modification. The water vapour isotherms of thermally modified wood decreased, whereas more severe treatment exhibited more distinct reduction (Figure 1). The EMC values of the Mel and TM_1 specimens decreased only at high RH, whereas the most significant decrease, within the whole range of observation, was found in the Acet group. This large decrease of the reduced EMC can be attributed to the presence of the covalently bonded acetyl groups in the nanopores in the cell wall matrix.

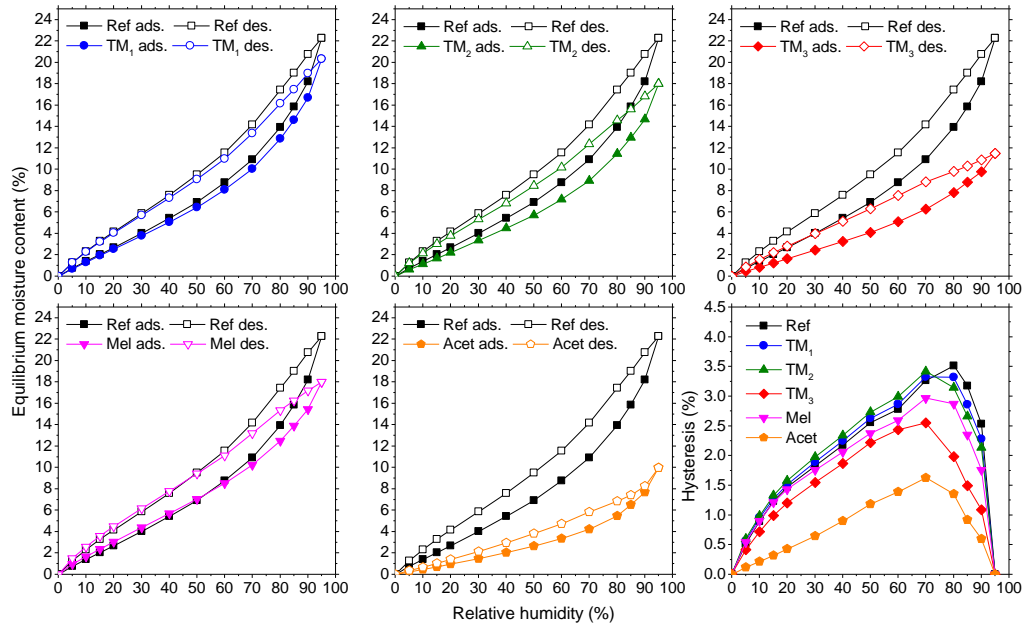


Figure 1 Sorption isotherm and hysteresis plotted as a function of relative humidity for all modified groups

The maximum moisture content reduction was achieved by acetylation. As a consequence of swelling reduction, dimensional stability expressed as anti-swelling efficiency was considerably improved. A relatively high initial linear-phase swelling rate was found for the Ref specimens, whereas modified wood exhibited comparatively slow and gradual swelling (Figure 2).

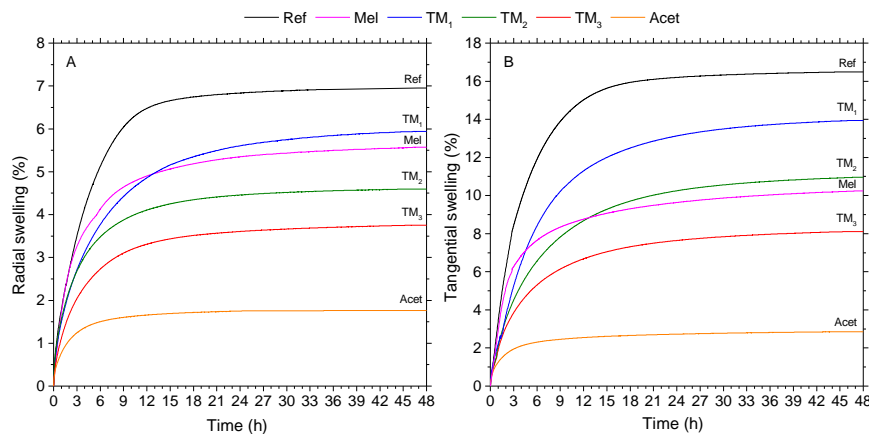


Figure 2 the radial (A) and tangential swelling kinetics of reference and modified beech wood

Conclusions

The water vapour and liquid water related characteristics of beech wood treated by thermal modification, acetylation and MF resin were significantly improved. All studied wood modifications provided a high efficiency against interactions between wood and water whereas more detailed analysis of melamine formaldehyde resin modified wood needs more attention, as heat-curing conditions may have a significant effect on the water-related properties.

Investigation of the Influence of Two Different Thermal Treatment Processes on the Change of Various Material Properties of Spruce Resonance Wood (*Picea abies* (L.) KARST.)

Christoph Munk¹, Hauke Wohler¹ and Alexander Pfriem¹

Background

Due to various property changes such as low moisture sorption, reduced reaction to climatic variability or improved elastic properties different thermal treatment processes also offer its application in the field of instrument making for the treatment of tonewood. In recent years, the process has become more important in the search for tropical wood alternatives, but is also recommended for use in restoration for artificial wood aging (Pfriem *et al.*, 2008, Krüger *et al.*, 2020). In previous studies investigations on property changes due to thermal treatment were presented, in which only changes in temperature or time were made but always using a single process. Therefore, in this study, the influence of two different processes but at the same treatment temperature, a thermo-vacuum process and a process that takes place in a reduced-oxygen atmosphere on various property changes of spruce resonance wood was investigated.

Keywords: thermal modification, resonance wood, CIELab, acoustic properties.

Experimental

The subject of the present study was spruce resonance wood (*Picea abies* (L.) KARST.) from the Swiss canton of Graubünden provided by the tonewood retailer Florinett. Guitar soundboards (L 600 x R 230 x T 6 mm³), cut out of the same region from a single tree trunk, were thermally modified at a temperature of 160 °C. One part in a proprietary thermo-vacuum process at Florinett (THV) and the second part in a low-oxygen process in a pilot plant at Eberswalde University (LOX). A third part remained untreated as reference. In total 137 test specimens for measurements in longitudinal (L) and 77 for radial (R) direction with the dimensions 190 x 28 x 4,5 mm³ (L, R x R, L x T) were cut and conditioned at 20 °C and 65% relative humidity (RH) until mass constancy. Resonance frequency and quality factor were determined by means of experimental modal analysis with free-free boundary conditions. The Young's modulus was calculated using the Euler-Bernoulli beam theory based on the frequency of the first bending mode. Furthermore, equilibrium moisture content, density and acoustic radiation were calculated and CIELab brightness values were measured with a spectrophotometer.

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Results and Discussion

The test results (Table 1) show that both treatment processes achieved similar property improvements of Young's modulus, acoustic radiation and quality factor in the longitudinal direction, whereas only the LOX process improved these properties in the radial direction. The density and especially the brightness values were significantly reduced due to the LOX process. Both processes lead to a reduction in the equilibrium moisture content, which is, however, reduced more strongly by the LOX process.

Table 1 mean test results (percentual standard deviation) of thermal treated (LOX, THV process) and untreated (reference) spruce test specimens (20 °C, 65% RH): Young's modulus (E), acoustic radiation (R) and quality factor (Q^{-1}) each in longitudinal (L) and radial (R) direction, density (ρ), equilibrium moisture content (EMC) and brightness value (L^*)

properties	reference	low oxygen process (LOX)	thermal – vacuum process (THV)
E_L (GPa)	11,1 (14)	11,8 (14)	12,0 (9)
E_R (GPa)	1,10 (18)	1,12 (18)	1,03 (13)
R_L ($m^4kg^{-1}s^{-1}$)	13,1 (6)	13,6 (7)	13,2 (10)
R_R ($m^4kg^{-1}s^{-1}$)	3,9 (3)	4,3 (4)	3,9 (5)
Q^{-1}_L (%)	0,31 (10)	0,27 (7)	0,28 (7)
Q^{-1}_R (%)	1,02 (6)	0,78 (5)	0,92 (9)
ρ (kgm^{-3})	408 (8)	397 (8)	409 (5)
EMC (%)	11,0 (5)	8,2 (5)	10,2 (5)
L^* (-)	82 (1)	63 (4)	79 (2)

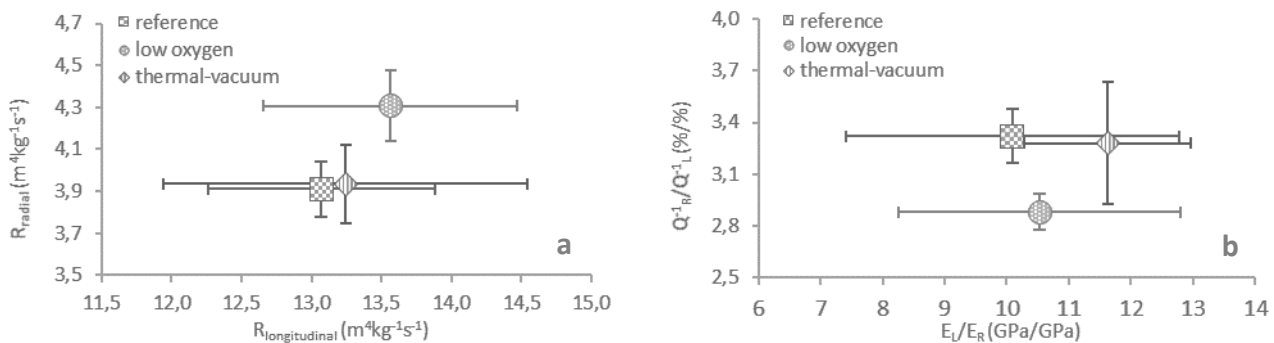


Figure 1 comparison of the acoustic radiation (R) in longitudinal and radial direction (a) and comparison of the ratio of the Young's modulus (E) longitudinal to radial to the ratio of the quality factors (Q^{-1}) radial to longitudinal (b).

The acoustic radiation values in the longitudinal and radial directions shown in Figure 1a can be described as a measure of the average amplitude or loudness of the radiation (Brémaud, 2012). The highest changes in acoustic radiation were obtained due to the LOX process, whereas slight changes were determined for the THV process. Figure 1b shows the ratios $E_{L/R}$ to $Q^{-1}_{R/L}$ which provides information on the anisotropy of these characteristic values. The LOX process achieved a reduction in the anisotropy of the quality factor by about 13%, mainly due to the reduced value in radial direction. Both processes lead to an increase in the anisotropy of the Young's modulus, with the THV method having a greater influence.

Conclusion

Due to the reduced density and moisture content as well as the significant reduction of the brightness value, it can be assumed that the LOX process represents a more intensive treatment variant compared to the THV process. Both processes achieved improvements in the elastic

properties in longitudinal direction, however, the LOX process achieved better improvements in radial direction.

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Wood Densification by Sodium Hypophosphite Impregnation and Mechanical Compression

Alexander Scharf¹, Injeong Kim, Benedikt Neyses and Dick Sandberg

Background

The mechanical properties of wood are closely related to its density (Kollmann 1936). Increasing the density of low-density wood species is thus an attractive method to increase the value of such species (Navi and Sandberg 2012). Higher densities than achievable with traditional densification and an almost complete elimination of the set-recovery are possible using certain chemicals (Neyses et al. 2017). Studying the effects of different chemicals on wood densification is hence of interest (Sandberg et al. 2021). In a screening experiment it was observed that aspen (*Populus tremula* Michx.) impregnated with sodium hypophosphite (SHP) exhibited a large degree of shrinkage after leaching out the chemical, reaching a density above 1000 kg m⁻³. This study aims to further investigate the observed phenomenon and to combine the process in question with mechanical compression.

Keywords: aspen, wood compression, wood modification

Experimental

Specimens with dimensions of 50x25x21 mm³ of aspen (*Populus tremula* Michx.) and Scots pine (*Pinus sylvestris* L.) sapwood were pressure impregnated in a full-cell process with an aqueous solution of sodium hypophosphite (1 Mol/L or 2 Mol/L). The impregnated specimens were surface-densified at 170°C in a hot press to 15 mm thickness, followed by heat treatment. Afterwards, the specimens were exposed to water leaching for 5 days, exchanging the water every 24 h. Modification procedure is shown in Table 1.

Table 1 Treatment groups for each species. SHP – sodium hypophosphite. Specimens per g

Group-ID	SHP-concentration (Mol/L)	Surface-densification	Heat-treatment	Water leaching
U	—	—	170°C for 6h	yes
D	—	yes	170°C for 6h	yes
SHP1	1	—	170°C for 6h	yes
SHP2	2	—	170°C for 6h	yes
SHP1-D	1	yes	170°C for 6h	yes
SHP2-D	2	yes	170°C for 6h	yes

The specimen dimension, mass and the vertical density profile were measured by X-ray densitometry at oven-dried state prior to the treatment, after the heat treatment and after water leaching. The specimen were dried at 70°C.

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Results and Discussion

The resulting specimen properties are presented in Table 2. An increase in density by SHP-treatment was only observed in aspen. The heat treatment led to a permanent fixation of parts of the mechanical compression (Inoue et al. 2007) in densified pine (Pine-D), but not in aspen (Aspen-D). The combined treatment of SHP and mechanical densification, however, resulted in the highest increase in density (Aspen-SHP1-D), indicating a set-recovery-reducing effect of SHP in aspen. Figure 2 shows the density profiles of one specimen of the Aspen-SHP1-D group. Even though the SHP can be expected to be leached out due to the low mass change, the density profile before leaching and after leaching are similar. The reduction in thickness can be attributed to the loss of the SHP.

Table 2 Specimen group properties. Oven-dry density – density prior to the treatment; WPG – weight percentage gain after heat-treatment; Mass change – mass after leaching relative to the mass prior to the treatment; Final density – density after leaching; Density change – density after leaching relative to the oven-dry density prior to the treatment. Specimens per group = 5

Group	Oven-dry density (kg m ⁻³)	WPG (%)	Mass change (%)	Final density (kg m ⁻³)	Density change (%)
Aspen-C	490.4	-0.1	-0.6	485.6	-1.0
Aspen-D	486.6	-0.1	-1.0	494.6	1.6
Aspen-SHP1	487.2	11.0	2.7	536.0	10.0
Aspen-SHP2	491.0	22.8	4.0	566.2	15.4
Aspen-SHP1-D	490.2	11.2	1.9	602.8	23.0
Aspen-SHP2-D	490.6	21.5	-1.0	577.0	17.6
Pine-C	513.6	-0.2	-1.0	495.2	-3.6
Pine-D	494.6	-0.5	-1.3	542.6	9.7
Pine-SHP1	480.2	9.5	1.0	478.4	-0.4
Pine-SHP2	472.0	20.1	2.1	474.2	0.5
Pine-SHP1-D	477.8	9.4	-0.8	527.8	10.5
Pine-SHP2-D	485.0	18.7	-1.2	503.2	3.7

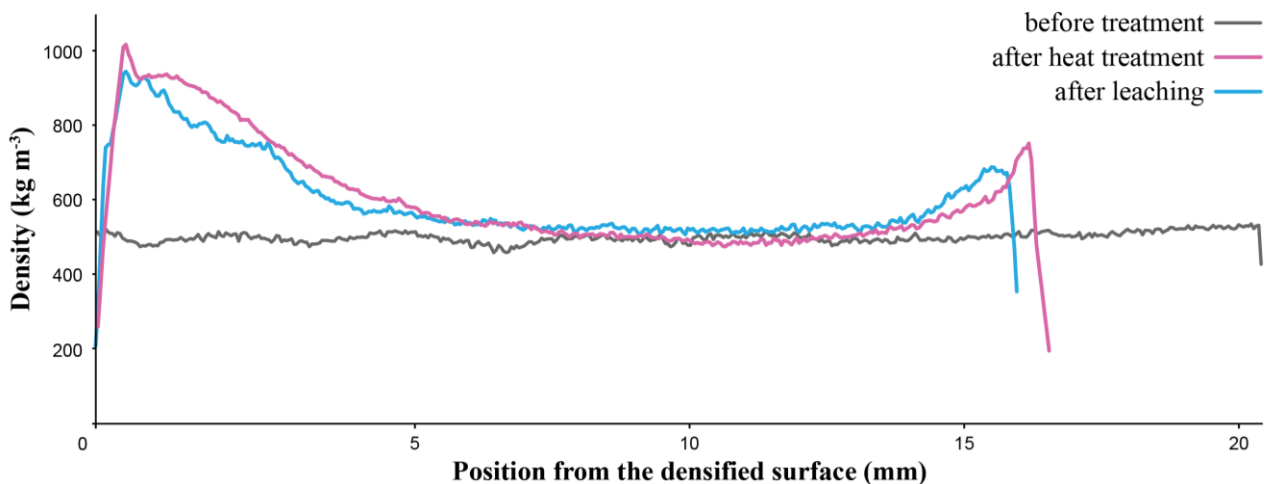


Figure 1 Density profiles at different experimental stages of a representative specimen of the group Aspen-SHP1-D.

Conclusions

Aspen impregnated with sodium hypophosphite followed by heat treatment at 170°C exhibited an increase wood density after leaching out the chemical. The phenomenon requires further research by an extended experiment design and chemical analysis.

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Influence of Growth Conditions on Some Stem and Branch Parameters on Norway Spruce Plantations

Lina Beniušienė¹ and Marius Aleinikovas¹

Background

In the practice of forest management, it is essential to focus not only on stand productivity but, even more importantly, on the improvement of stem wood quality as well. Most recently, because of increased attention to high carbon concentration in wood products, there is a surge in demand for high quality sawn wood that can be used in long-lasting constructions. The quality of the wood is largely defined by tree characteristics such as the straightness of the stem and the lack of defects in branches [1-4] as well as stem diameter and wood density. The majority of internal (tree genetics) and external (natural factors, forest management) elements influence the growth and the development of quality stem wood [4-6].

Norway spruce (*Picea abies* (L.) H. Karst) stands cover 21.0% of forested area in Lithuania [7]. It means that evaluating the stem quality of Norwegian spruces is important – this species offers significant economic value and is a profitable resource to the forestry industry. So far, there have been several experiments conducted that aimed to assess the stem quality of the Norway spruce [8-11]; however, further research would provide additional knowledge to both academic and practical forestry. The goal of this study was to determine the impact of stand density to Norway spruce stem and branch parameters.

Keywords: Norway spruce, stem wood quality, branch diameter, stand characteristics

Materials and methods

Four sites of 36-43-year-old Norway spruce were selected from a long-term experimental area established in 1990–1992. These study sites come from a variety of regions across Lithuania. Each site was characterised by different stand density (from 500-600 to approx. 4000-5000 trees ha⁻¹) and thinning intensity (no thinning, and 1-4 times per 40 years period). Parameters that were measured include tree height (H), diameter at breast height (DBH, cm), height of the lowest live branch (Hlb), height of the lowest dead branch (Hdb), and the diameters of each branch (cm) along a butt log (hereafter, 0–6-m log). The measurements were performed according to the standard methods used in forest science and practical forestry. Calculations of all stem branch parameters were made for the whole 0–6-meters long log as well as separately for each of its different sections (0–3-meters log and 3–6-meters log), measured from ground level.

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Results and conclusions

The results of this study provided new information on stem quality of relatively young spruce trees, grown under different conditions in relation to stand density and thinning regime. The results revealed that branch diameters along the stem log of 6 meters decreased significantly with increasing stand density (Figure 1).

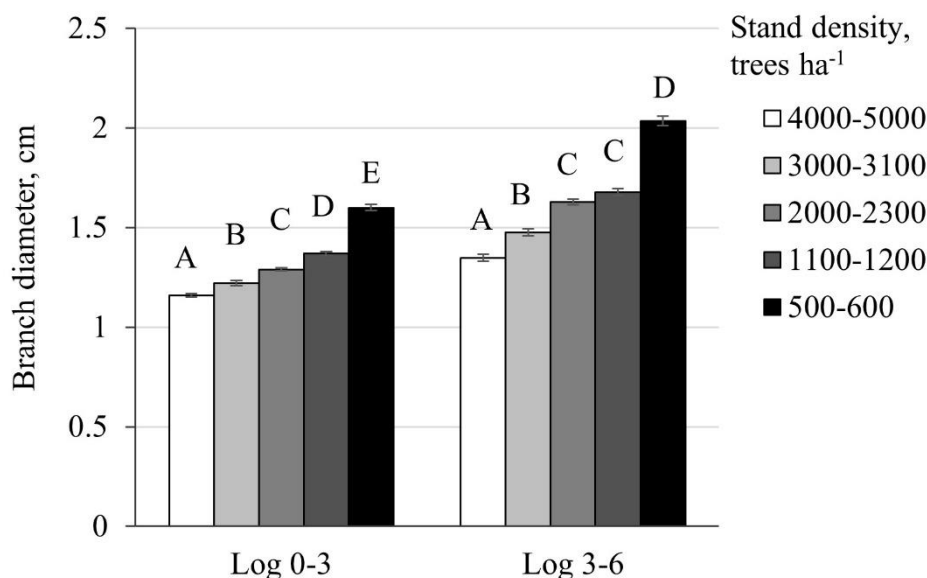


Figure 1 Mean values of branch diameter in 0-3-meter log and 3-6-meter log. Bars show Std Error of the mean. Different capital letter show statistically significant differences between the sites at $p < 0.05$

The branch parameters from the 3-6-meters log had strong correlation with those from the 0-3-meters log. It showed that, in order to have a relatively reliable result that enables full-stem evaluation, only the lower stem section and its branch parameters should be taken into account. The best-fitted models, developed including stand density, tree diameter at breast height, and branch diameter or diameter of the thickest branch in 0-3-m log from root collar, might be used for managing of stem wood quality.

Tree diameter, branch diameter, and branch count in 0-6-meters log decrease with increasing SD (stand density). In a 0-6-meters log, the average branch diameter and the diameter of the thickest branch were identified as primary parameters indicating stem quality.

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The Influence of Temperature in Compression Molding on the Mechanical Characteristics of Cellulose Diacetate

Catherine Kilumets¹, Heikko Kallakas, Jaan Kers and Andres Krumme

Background

Cellulose is the most abundant biopolymer, however, its full potential has yet to be reached since 3% is only utilized (Onwukamike *et al.*, 2018). The long-term goal is to replace current materials with bio-derived resources because of overriding environmental contamination and diminishing fossil reserves worldwide (Willberg-Keyriläinen, Orelma and Ropponen, 2018). Cellulose diacetate is one of the most common derivatives which is employed in the industry but the use is limited due to the narrow melt processing window (Lee *et al.*, 2006; Willberg-Keyriläinen, Orelma and Ropponen, 2018). Higher temperatures than 250°C are not recommended, since cellulose diacetate will release gases like CO, CO₂, and acetic acid (Gaan *et al.*, 2011; Kumar Vangala *et al.*, 2017). Given that the material is known to be sensitive to higher temperatures, determining its degree of impact on material mechanical properties is appealing. There have been studies on the effects of UV light on aging. However, there is a lack of data on compression molding with cellulose derivatives. This paper outlines a methodology for compression molding and its lab-scale testing. Mechanical qualities will be studied at various temperatures, as well as which pressing material is ideal for a smooth appearance.

Keywords: cellulose diacetate, compression molding, tensile, surface roughness, modulus of elasticity, tensile strength, elongation, heat degradation.

Experimental

This study used cellulose diacetate to produce 1 mm boards by compression molding in compliance with ISO 293. The 65x55 mm dimension was achieved using a flash mold. Heat (220-250°C), pressure (5, 8.5, 10 MPa), and various pressing plate cover materials are all used (aluminum, silicone, Teflon, steel). The pressing time remained constant at 3 minutes, as well as 1 minute of prepressing with contact pressure. Visual inspection and mechanical tests were used to assess heat degradation. The elastic modulus, tensile strength, and elongation were measured using specimen 5B in a tensile test according to ISO 527. Surface roughness was measured in accordance with ISO 4288.

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Results and Discussion

As shown in Figure 1, the different pressing plates produce variable results. Pressing plates with higher thermal conductivity values result in more heat being transferred to the board, resulting in darker samples. Amorphous regions, which are darker than crystalline parts, are more visible at higher temperatures. Lower temperatures produced the best outcomes, especially with Teflon sheets.

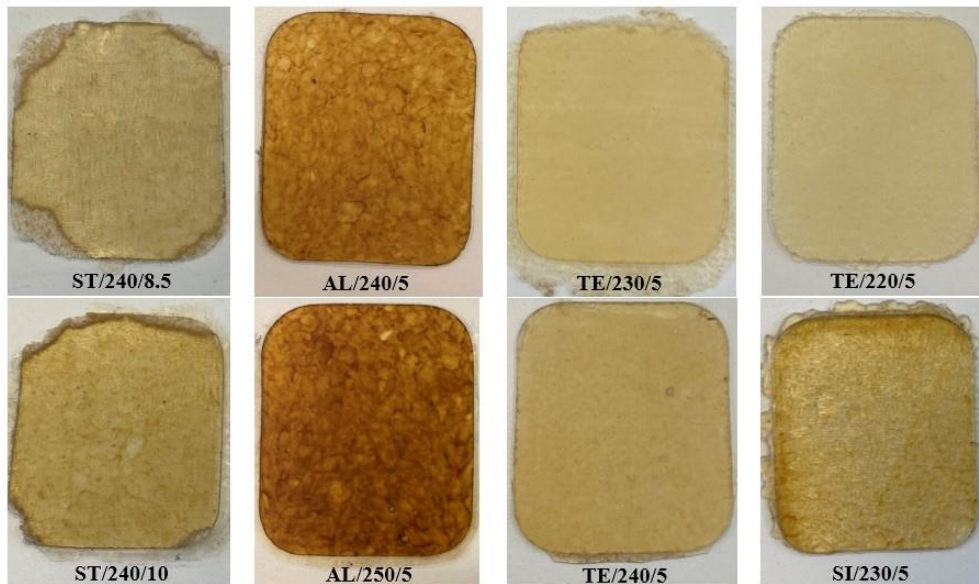


Figure 9 Cellulose diacetate boards (pressing plate cover material/temperature, °C/pressure, MPa), ST- steel, AL- aluminum, SI- silicone, TE- Teflon.

With higher temperatures, the tensile strength and elongation increase while the elastic modulus decreases. According to the strength-to-surface-roughness relationship (see Figure 2), a more textured surface causes the material to fail faster, making it more brittle. Aluminum pressing plates with a relatively smooth surface (1.54 μm) produced the highest strength (73 MPa) when heated to 240°C. Teflon gave also high strength (66 MPa) and smoother surface (0.92 μm).

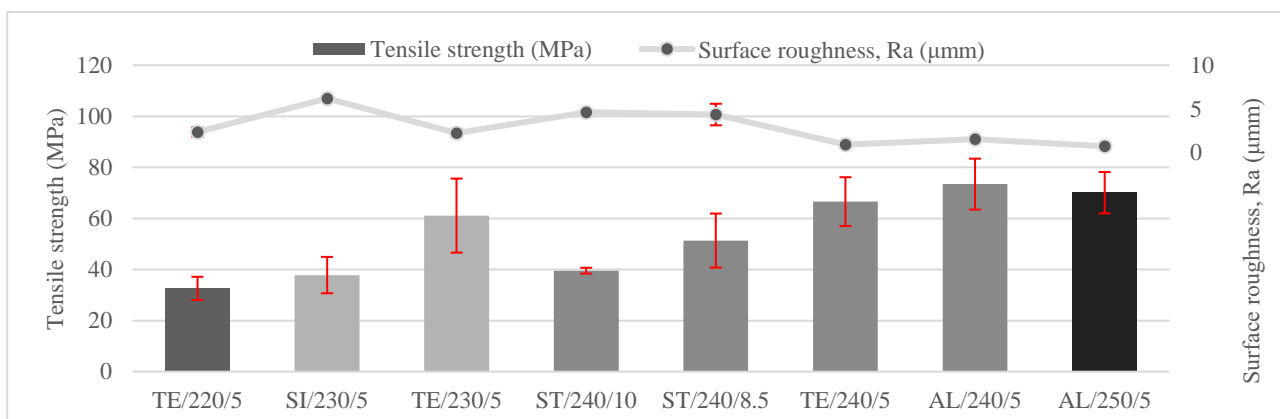


Figure 10 Tensile strength and surface roughness of the boards

Conclusions

The material possesses brittle properties in general. It acquires a higher elongation when the temperature is raised above the maximum processing temperature, increasing the ductility. It's wise to note that the variation in pressing plate cover materials impacts how much heat gets into the

pressed matter. The best for this instance is Teflon by giving the material a smooth surface and homogeneous structure. The mechanical resistance of a smoother surface will be higher.

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Relationship Between Phenological Phases and Wood Anatomic Parameters of Silver Birch

Austra Zuševica¹, Didzis Elferts, Iluta Dauškane, Roberts Matisons, Gunta Kalvāne and Dagnija Lazdiņa

Abstract

Across Europe, including Latvia, earlier tree leaf unfolding in spring are observed. Time of leaf unfolding has a significant impact on the gross primary productivity of the ecosystem and on the further physiological processes of the tree. The aim of research was to find out whether the leaf unfolding date of silver birch had an impact on the wood anatomical parameters of the current year and how the interaction between these two factors was influenced by climate data. The results obtained show that both climate change and changes in leaf folding date have a significant impact on both wood trachea and fibre parameters. The shift of leaf unfolding date has also changed the time of earlywood development to a significantly warmer and drier period. This leads to the formation of cells with smaller lumen area but increased cell wall thickness.

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Evaluating use of the Secondary Timber in Cross Laminated Timber Production (CLT)

Roja Modaresi¹, Andreas Stenstad and Stine Lønbro Bertelsen

Abstract

The use of CLT in the construction sector has been growing significantly. In addition, the lumber price soars in many regions. Therefore, circular economy strategy is emerging. The main goal of this research is to show the possibility to adopt the strategy and to optimise the utilisation of low-grade wood in CLT. Secondary wood collected from recycling plants has been mixed with high quality timber to produce prototypes of CLT panels. This secondary wood was further processed with planing and removal of nails and has gone through mechanical tests for bending strength and modulus of elasticity, Brookhuis Timber Grader MTG and visual grading tests. The mechanical tests in this study show that the wood is above the acceptable strength limit and can technically be used in the production line. 9 CLT prototypes were produced for mechanical testing to investigate the quality of the elements according to standards, focusing on stiffness, rolling shear and delamination tests.

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Dynamic Moe of Small-Leaved Lime (*Tilia Cordata* Mill.) in Urban Area

Benas Šilinskas¹, Marius Aleinikovas¹, Mindaugas Škėma¹ and Lina Beniušienė¹

Background

In Lithuania, the small-leaved lime, as dominant tree species in forest stands, occupies about 0.5 percent of total forest cover (Ministry of Environment, State Forest Service, 2019). This tree species is the most common species in the urban green areas of the country and comprise about 45 percent of all urban trees (Zeimavicius and Budriunas, 2001; Semaškienė, 2006).

The environmental conditions in the urban areas, specifically described by enhanced air, soil and water pollution, and other disturbances, alter wood structure of trees, reduce tree growth and vitality or cause higher tree mortality (Oven and Levanic, 2001). Up to now, too little attention has been paid to wood formation and quality of the urban trees (Marion et al., 2007). Only few studies have investigated growth and phenology of small-leaved lime under urban environment (Buhler et al., 2006). However, due to its wide ecological tolerance, this species could become more important in future forestry under the changing climate conditions (De Jaegere et al., 2016).

Keywords: Dynamic modulus of elasticity, urban trees, small-leaved lime.

Materials and methods

The modulus of elasticity was further taken as the most important parameter for assessing wood quality. The acoustic tool ARBOTOM 3D (Rinntech), specifically designed for the standing trees, was used for this study.

The dynamic modulus of elasticity ($MOEdyn$) was estimated from the velocity of acoustic waves passing through the wood, according to the formula (1):

$$MOEdyn = \rho V^2 \quad (1)$$

here, $MOEdyn$ is dynamic modulus of elasticity; ρ is wood density; and V is velocity of acoustic waves.

To ensure non-destructive testing, wood density of 1000 kg m⁻³ was taken as a fixed parameter (Moore et al. 2009). The dynamic modulus of elasticity was calculated for two logs per each standing tree, totally for 584 logs. The health of selected urban trees was assessed visually according to the requirements approved by Order of the Minister of Environment of the Republic of Lithuania in 2008 (Ministry of Environment of the Republic of Lithuania (2008, updated in 2020).

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Results

The mean values of the top-end diameter ($D_{\text{top-end}}$, cm) and the dynamic modulus of elasticity (MOEdyn, N mm^{-2}) of the small-leaved lime trees at each site are summarized in Table 1.

Table 1 Mean top-end diameter ($D_{\text{top-end}}$, cm) and the dynamic modulus of elasticity (MOEdyn, N mm^{-2}) of the small-leaved lime trees in different sites. The std. error of the mean is given next to the mean. Different letters indicate statistically significant differences between the sites at 0.05 level

Sites	n^*	Tree age (years)	$D_{\text{top-end}}$ (cm)	MOEdyn (N mm^{-2})
Neries Street	82	120	39.9±0.7 c	2636.6±77.4 b
Vilties Street	74	120	37.0±0.8 d	2867.8±96.6 b
Sportininku Street	82	90	33.7±0.7 e	2776.9±66.2 b
Tilzes Street	144	90	34.6±0.5 e	2654.6±46.7 b
Donelaicio Park	120	120	57.2±0.8 a	1972.3±56.6 c
Forest Site 1	40	120	42.9±1.6 b	1838.0± 63.2 c
Forest Site 2	42	90	33.4±0.9 e	4604.7±138.3 a

* n shows the number of observations made for two logs of each selected standing tree

For the urban small-leaved lime trees, the $D_{\text{top-end}}$ varied in a range from 33.7 ± 0.7 cm to 57.2 ± 0.8 cm, for the forest trees it was 33.4–42.9 cm. The parameter $D_{\text{top-end}}$ was by 1.2-1.3 times higher for the 120-years old trees, grown in the street-sites and forest-sites, than for younger trees. The highest mean values of $D_{\text{top-end}}$ were obtained for the trees in the urban park, i.e. here, the $D_{\text{top-end}}$ was by 1.5 times higher than the values for the trees in the street-sites and forest. The parameter MOEdyn was evaluated for all urban trees, regardless of tree age and the site, assigned to different health classes (Figure 1). The values of MOEdyn of the small-leaved lime trees were similar for the trees assigned to 1–3 health classes, representing healthy, slightly, and moderately damaged trees. However, significantly lower values of MOEdyn were obtained for the trees of 4th health class, representing the severely damaged trees.

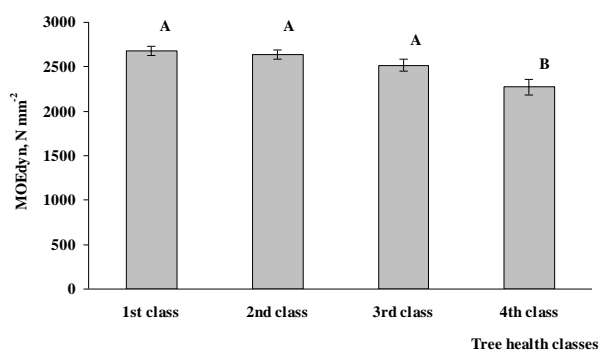


Figure 1 Mean values of the dynamic modulus of elasticity (MOEdyn, N mm^{-2}) of the urban small-leaved lime trees correspondingly to different health classes. Bars show the std. error of the mean. Different capital letters at the top of the columns show statistically significant differences between the different health classes at $p < 0.05$.

Conclusions

The results of this study showed that 90-120-years old small-leaved lime trees growing in the urban area still have a potential to be used for timber industry. The data analysis revealed lower dynamic modulus of elasticity (MOEdyn, N mm^{-2}) of the small-leaved lime trees in the urban area than forest sites.

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Durability of the Printed Surface in the Sauna Environment

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Background

The use of digital printing creates added value for wood-based products, especially in terms of marketing. It allows them to be distinguished amongst the competitors and offer the customer the desired result. Thanks to larger digital printing equipment, it is also possible to print on larger surfaces. As a result, entrepreneurs have become more interested in digital printing and experimenting with new ways of using it, including extreme conditions, such as the sauna environment. The stability of digital printing was set in two different sauna environments – Finnish and Russian, according to the standard. The methodology measured and evaluated three variables on test specimens: colour, gloss, and acrylic ink adhesion through a cross-cut test. The test results have a practical value that can be used as a basis for future projects related to the use of digital printing in hot and humid conditions.

Keywords: digital printing, thermal modification, aspen, acrylic ink.

Material and methods

Thermally modified (TM) aspen (*Populus tremuloides*) was autoclaved from industrial scale at 160 degrees for 12 hours in TM wood producer. Test specimens in Figure 1 were cut to size 136×136×27 mm and then printed colour gamma, using printer Pixart Plot 16. The testing specimens was performed in the climate cabinet according to standard ÖNORM M 6219-1:2016-11. In the experiments were used two treatments: 1. 40 days, 100 °C, 5% moisture; 2. days 80 °C, 40% moisture content. The cycle lasted to measure the colour 40 days control measurements were taken every 10 days.



Figure 1 Test pieces: above - without treatment; below – 100 °C, 5% moisture

The changes in the colour spectrum of the test pieces were measured using Lovibond RT530 spectrophotometer in light D65 at 10° according to ISO/CIE 11664-4:2019. To evaluate the results of printed surface gloss meter tests and cross cut test were according EVS-EN 13722:2004 and DIN EN ISO 2409.

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Results and Discussion

Due to two different sauna environments, the changes in surface print were studied by three different methods. First, changes in colouring in the CIELab system (a^*) in Figure 2 were studied, second, changes in gloss of test specimens were measured, and third, cross-sectional tests were performed.

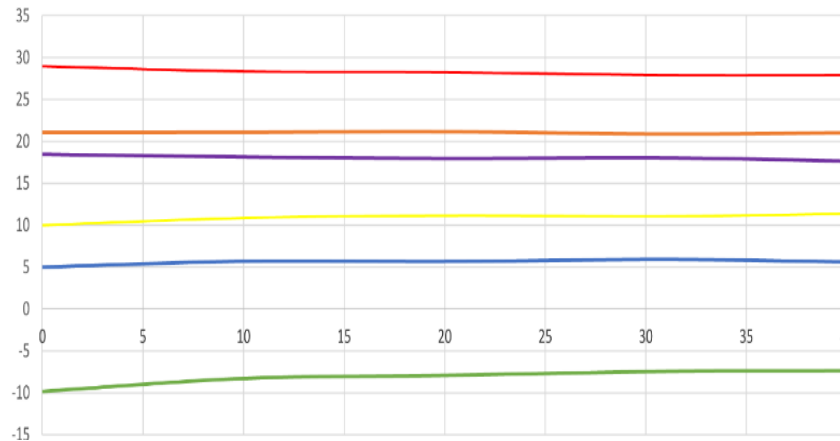


Figure 2 Coordinate a^* change over time

On visual assessment there is no change on the printed surface. Colour measurement results show that the biggest change was in the surface print after the tenth day compared to all subsequent days. The a^* coordinate of the green colour change was the largest of the other colours. The change was 0,156 nits daily for ten days within. Based on the CIELab system, the colours green, blue and purple changed to red. Changes in colouring were in the first 10 days higher than during the rest of the test. Due to moisture the ink adhesion was weaker from the environment than in the Finnish sauna environment.

Table 1 Coordinate a^* regression formula over time

SCE L*	a1	0-10	10-20	20-30	30-40
Yellow		0,088	0,029	-0,007	0,033
Purple		-0,031	-0,016	0,004	-0,039
Orange		0,003	0,007	-0,024	0,016
Red		-0,060	-0,010	-0,030	-0,001
Green		0,156	0,037	0,043	0,007
Blue		0,070	-0,002	0,021	-0,032

Conclusions

The measurement results showed that the surface print changed after 40 days. There was an increase in gloss in the Finnish sauna within 40 days, but in the Russian sauna, there was a decrease in gloss. Finnish sauna had better results in terms of ink adhesion than in a Russian. The test results have a practical value as they form the basis and support for project that concerning surface print research in a sauna environment.

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Foil Storage for Conservation of Beetle-infested Spruce Logs – a Feasibility Study

Christian Brischke¹, Susanne Bollmus, Marco Braun and Lukas Emmerich

Background

On January 18, 2018, winter storm Friederike hit Central Europe and caused billions in damage. Solely in Germany, 9.1 million bank meter - mainly Norway spruce (*Picea abies*) - were felled within a few hours (Pöschel 2018). Subsequently, the price for roundwood dropped, and after the two dry summers 2018 and 2019 with a bark-breeding beetle disease, the market for Norway spruce roundwood in Germany and its neighboring countries collapsed. In total, 171 million bank meter calamity timber accumulated on a total area of 277.000 hectares, and large amounts have not been harvested yet (BMEL 2021). Free areas for storage at the saw mills become increasingly unavailable and wet storage through permanent spraying is limited due to dryness and water scarcity. Foil storage which had been used in the 1990s for the conservation of storm-felled trees (Mahler 1992, Bues und Weber 1998, Schüler und Wurster 2000) was brought back on the agenda. Its mode of protective action is simple: Freshly felled timber is stored in an air-tight foil tent. The living parenchyma cells reduce the oxygen content inside the tent and thus inhibit fungal growth and decay. The main concern about this technique is its applicability for beetle-infested and partly dead and dry timber. This study aimed at examining the potential of foil storage for conservation of Norway spruce wood, which had been infested and damaged by bark-breeding beetles to varying extent.

Keywords: bark-breeding beetles, fungal decay, storm-felled trees

Experimental: Vitality and decay tests

Three assortments of Norway spruce were submitted to conditions representing foil storage, i.e. sections of 35 cm length were cut each from three trees (DBH = 17-20 cm) which were (1) uninfested, (MC = 120 ± 83%), (2) slightly infested by bark-breeding beetles, but still green (MC = 62 ± 41%), or (3) severely infested and already dead (MC = 24 ± 4%). Sections were stored in plastic boxes, which were either airtight (Baden-Württemberg procedure) or open at the bottom allowing direct access of moisture from the ground (Swiss procedure). Oxygen and CO₂ content were monitored during a period of 8 weeks. In addition, the brown rot fungi *Coniophora puteana* and *Gloeophyllum trabeum* and the white rot fungus *Trametes versicolor* were grown in Petri dishes and the mycelial growth was measured.

In addition, mini-block test specimens (5 x 10 x 30 mm³) were cut from Norway spruce and European beech (*Fagus sylvatica*) and incubated with *T. versicolor* in Petri dishes, which were stored for 66 days in airtight boxes and either filled with freshly felled or severely infested spruce wood.

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Results and Discussion

The ‚Swiss procedure‘ did neither lead to a significant reduction of the oxygen content nor to an increase in CO₂ compared to atmospheric conditions (Fig. 1). As expected, agar plates were overgrown during two (*C. puteana* and *T. versicolor*) and five weeks (*G. trabeum*). Thus, independent from the type of stored wood no protective action was observed. In contrast, the entire exclusion of air oxygen according to the ‚Baden-Württemberg procedure‘ reduced O₂ and increased CO₂ in the storage boxes (Fig. 1). Within a few hours O₂ dropped below 5 % when fresh and non-infested or slightly infested wood was stored; after one day it was below 1 % and fungal growth was significantly inhibited. Severely infested wood also led to a decrease in O₂, but the effect was only temporary.

The brown rot fungi *C. puteana* and *G. trabeum* stopped growing almost immediately when incubated with fresh or slightly infested wood. Agar plates were fully grown with mycelium when they were incubated with severely infested wood. In contrast to the brown rot fungi, the growth of the white rot fungus *T. versicolor* was slightly inhibited, but it was able to fully grow the agar plates even when it was incubated with freshly felled wood. Different authors reported on the high tolerance of white rot fungi against lacking oxygen (Metzler et al. 1993, Rabe 2008).

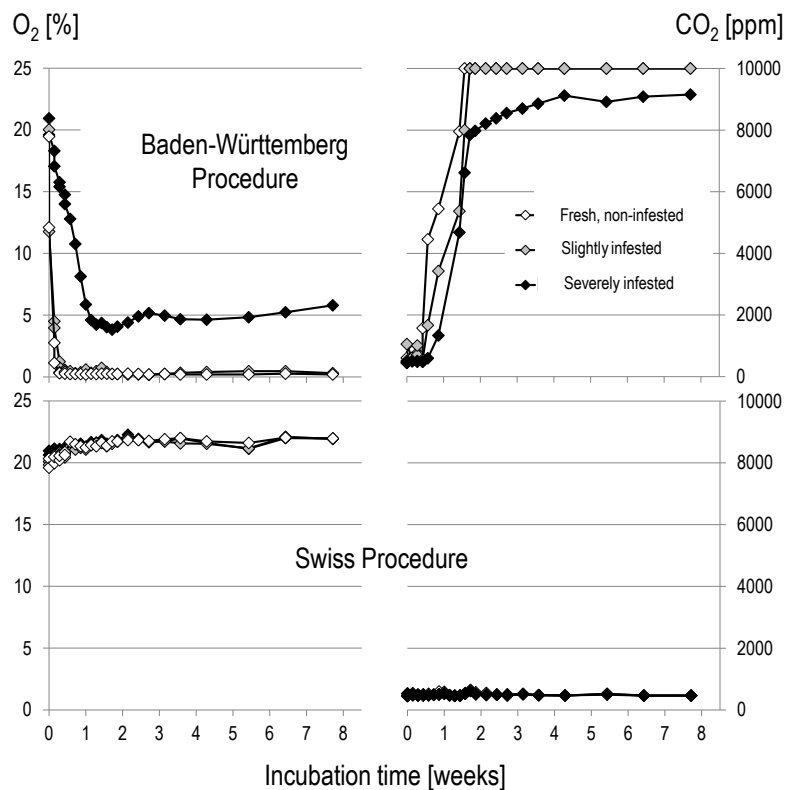


Figure 1 Oxygen and CO₂ content during 8 weeks of ‚foil storage‘ of Norway spruce wood differently infested by bark-breeding beetles. Note: the upper limit of CO₂ measurements was 10.000 ppm.

The decay tests revealed that solely storage of freshly felled wood led to conditions inhibiting wood degradation. Beech wood specimens incubated with *T. versicolor* and severely infested Norway spruce wood showed significant decay and an average mass loss of 10 %.

Conclusions

Independent of economic considerations, foil storage can be used for temporary conservation of calamity timber. The lack of living parenchyma cells in severely infested ‚beetle wood‘ is

significantly reducing the protective effectiveness. It became evident that only an airtight foil wrapping leads to an effective reduction of the oxygen content.

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Advances in CIOL-protected Wood - the Road Towards Commercialization

Erik Larnøy¹, Johan Biørnstad² and Andreas Treu²

Background

Most commercial wood from the northern European region are of low natural durability. Products from these wood species for outside applications need therefore protection to increase service life. This protection should be free of biocides, come from renewable resource, have great performance and hold a low consumer price. A mixture of water, sorbitol and citric acid has the potential to do just this and are now studied extensively by NIBIO and others. This extended abstract describes the road towards commercialization at NIBIO and ARD Innovation and shows the obtained material properties. Our research has now come far enough to start the actual commercialization of products under the name CIOL[®].

Keywords: CIOL, citric acid, commercialization, sorbitol, wood protection.

Experimental

NIBIO discovered the potential to use sorbitol and citric acid as a wood protection system in 2016 and after some internal verifications and funding applications, NIBIO received two research projects in 2019/2020, namely PolySorb and ValorWood.

The PolySorb project has a highly commercialized focus with the main purpose of getting CIOL[®] to the marked. To get a product to the marked, there are several aspects to discuss. Intellectual Property (IP) strategy is essential in a commercialization project to ensure Intellectual Property Rights and to make sure the project is not infringing on existing technologies and patents. Preparations before initialising the project was therefor done and included patentability and freedom-to-operate (FTO) searches using professional companies. Patentability search was done to investigate if any parts of our technology could be patent-protected, and current state-of-the-art, while freedom-to-operate search was done to ensure that the project did not infringe on any current/active patents currently on the world marked. Searches showed that the basic technology of polyesterification with sorbitol and citric acid was a known technology, published and presented by persons within the field and that we had full freedom-to-operate within the project. This is a very important strategy to have, control and continuously monitor before, during and after the project.

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In addition to the PolySorb project, NIBIO is leading the Valorwood project, which is a basic research project dedicated to understand the mechanisms and performance of CIOL®. The ValorWood project investigates the use of different wood species, examines the treatment and process and evaluates various material properties, which are relevant for the use in outside applications. In addition, gluing and lamination will be investigated as well as the environmental impact and the economic feasibility. In addition to the project results from the PolySorb project, the CIOL® commercialization benefits as well from the outcomes of the ongoing ValorWood project.

Results and Discussion

When working on industrial projects, an important question is: when is it time to move towards commercialization. One can always do more research, but if the good ideas achieved in the laboratories should ever see the light of day, steps toward commercialization need to be taken.

In the road towards commercialization of CIOL® there are two main reasons why we were able to move forward: A good cooperation with the TTO (Technology transfer office) and a great contact with the industry, who should use the innovation at a later stage. The industry comes with great feedbacks on what to do and not to do.

When a test is verified in the lab, it will be sent out to a third-party institute for validation. For CIOL®, these results will be available in the spring of 2022. From the labtests we have tested at NIBIO, the results we have achieved are described in Table 1.

Table 1 Evaluation of product properties relevant to the commercial success

Tests at NIBIO	Results
Fungal degradation	The treatment shows good protection 
Soil contact	Good preliminary results 
Staining fungi	Good protection 
Dimension stability	Treated samples shows good dimension stability 
Termite protection	Good protection 
Leaching	Very low leaching 
Marine environment	Good results after two years 
Heartwood/spruce impregnation	Varying results 
Fire resistance	Good for class D, more work needed for class B 
<u>Paintability</u>	Good results after pretrials 
<u>Glueability</u>	Good results after pretrials 
Large scale testing	Good results after pretrials 

Conclusions

The protection of wood by the CIOL® treatment shows good results, and is now on the way to commercialisation, hopefully having the first industrial run in 2022.

Finding the Optimal One-Component Adhesive for Curved and Impregnated Glued Wood Products for Outdoor Use

Edgars Kuka¹, Dace Cirule, Ingeborga Andersone and Bruno Andersons

Background

Curved shape products are more preferable over products with sharp transitions due to less threatening notion (Bar and Neta, 2006). Also in the case of wood, the interest of curved objects is relatively high. Interior elements, furniture as well different outdoor structures frequently have integrated curvature in their shapes. For some of these purposes, glued wood materials made of thin lamellas are excellent allowing in relatively simple process create curved shape objects without any pre-treatment (steam treatment etc.) (Rowell, 1999). Different wood adhesives can be used for gluing, however for outdoor use the most important and easy to work on are one-component polyurethane (1C-PUR) and polyvinyl acetate (PVAc) D4, which both corresponds to the highest durability class D4 according to EN 204:2016. For curved outdoor products the adhesive should withstand not only the internal stresses caused by curved shape, but also moisture fluctuations including impregnation, which is important for ensuring suitable fungal resistance (Pitzner, Rambol and Lind, 2004). The objective was to investigate which of the one-component adhesives is the most appropriate for ensuring the highest quality of curved and impregnated glued-wood products intended for outdoor use.

Keywords: glued wood, polyurethane, polyvinyl acetate.

Experimental

Three different one-component adhesives were compared, to determine the most suitable adhesive for production of curved and impregnated glued wood products. Two of the adhesives were 1C-PUR with different open times: 8 min (1C-PUR A) and 25 min (1C-PUR B). The third adhesive was PVAc D4. The performance of each adhesive was tested by analysing the glued wood specimens made with each of the adhesive. The applied adhesive amount as well as the press time and pressure complied with the specific adhesive technical specification. Pine (*Pinus sylvestris* L.) was the wood species used in the present study. For the glued wood specimens shear tests (EN 205:2016) and delamination tests (EN 302-2:2017) were carried out. During the shear test, such influencing factors as fibre orientation, wood density, wood moisture content before gluing, time until load application after gluing as well as the effects of impregnation were analysed and evaluated for each of the adhesive. As the impregnation solution, wood preservative based on copper (Cu) azole was chosen. The impregnation was carried out in a 50 L autoclave equipped with vacuum pump and compressor. The impregnation process included vacuum for 15 min and pressure (10 bar) for 60 min.

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Results and Discussion

The results regarding the fibre orientation showed no significant differences between radial and angular direction. Similarly also wood density had only minor effect resulting in low correlation between wood density and bond quality in the density range between 0.35 g/cm^3 and 0.50 g/cm^3 . Moreover, the situation was similar regardless of the adhesive. Minor effect of wood density on the tensile shear strength has also previously been reported (Iždinský et al. 2021). In contrary, wood moisture content before adhesive application, did have an effect on the shear strength (see Fig. 1a), however only in the case of PVAc D4. For this adhesive, the shear strength significantly decreased in the case of wood moisture content of 16 %. This indicate that for the PVAc D4 it is important to work with a relatively dry wood. The adhesives were tested also immediately after gluing without allowing them to be completely cured to determine which of the adhesive would be less problematic for curved products. The shear strength as well as the visual evaluation of the fracture surface of the shear test specimens suggested that the highest probability that the curved glued wood product might delaminate after the removal of the pressure was in the case of PVAc D4. For the rest of the adhesives the bond quality during this test was less affected.

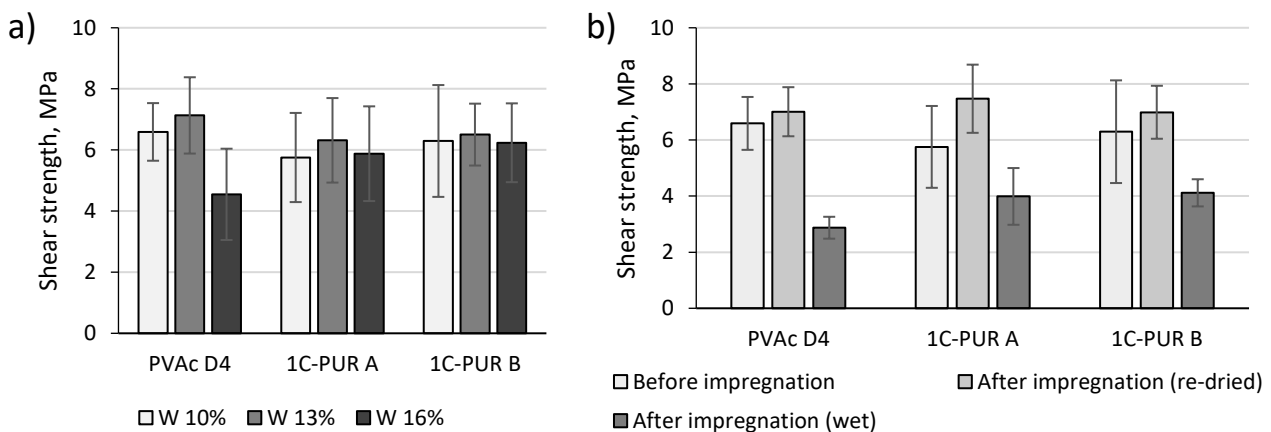


Figure 1 The effect of wood moisture content before adhesive application (a) and impregnation (b) on shear strength of glued wood products made with PVAc D4, 1C-PUR A and 1C-PUR B

The effect of impregnation on the shear strength was tested on the glued wood specimens both at wet and re-dried state. The results show (see Fig. 1b) that after impregnation for all of the adhesives the shear strength significantly decrease. Besides the decrease in the case of PVAc D4 is more significant. Smaller water resistance for the PVAc D4 comparing to PUR adhesives is also reported in other tests (Bomba et al. 2014). Nevertheless, all of the adhesives managed to regain their initial strength after re-drying. The delamination test was carried out only for 1C-PUR adhesives as the most promising choices. The results showed no delamination in the case of 1C-PUR B. Less promising were the results for 1C-PUR A where the delamination was around 5 %. This most likely was the result of the relatively short open time because the delamination occurred only in the bottom bondline.

Conclusions

The results indicate that the most preferable adhesive for the curved and impregnated glued wood products is 1C-PUR B, which showed sufficient result in all of the tests. The least reliable choice for the specific glued wood product would be PVAc D4.

Acknowledgment

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Effect of Log Soaking on Colour of Estonian Hardwoods

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Background

Colour is an important property of veneer in furniture industry. Often the furniture companies struggle with the problem that the colour of veneer from the same species ordered from different producers vary remarkably. Elevated wood treatment temperatures have generally been shown to affect wood chemistry, e.g. colour (Srinivas et al. 2012). Commonly these treatment processes are high temperature drying, thermal treatment etc. In veneer production, logs are primarily pre-heated before peeling process in order to soften the wood material. Soaking temperatures are usually in a range between 20 – 40 °C, but sometimes also higher temperatures up to 80 °C are used. Soaking temperature has been shown to affect birch veneer surface quality, e.g. colour (Rohumaa et al. 2016). However, no systematic study has been done on Estonian hardwoods colour and on their colour response to soaking temperature. In this study the effect of the soaking temperature on colour of birch, aspen, black alder and grey alder veneers were studied.

Keywords: veneer colour, birch, aspen, alder

Experimental

In this study, four different wood species were used: birch (*Betula pendula* Roth), grey alder (*Alnus incana* L), black alder (*Alnus glutinosa* L.) and aspen (*Populus tremula* L.). Prior peeling, the logs were cut to bolts and then completely immersed into the water tank at 20, 40, or 70 °C for 48h. After soaking at selected temperatures, the bolts were rotary-cut on an industrial scale lathe (Model 3HV66; Raute Oyj, Lahti, Finland) into continuous veneer mats with nominal thickness of 1.5 mm. After peeling, the veneer was cut into sheets (950 x 450 mm) and these sheets were immediately dried to target moisture content of 5% in a laboratory scale veneer dryer (Raute Oyj, Lahti, Finland) at temperature of 170 °C.

The colour measurements of veneers were performed using CIELab colour space according to EN ISO/CIE 11664-4:2019. For the colour measurement, 3nh Colour Quality Controller System CQCS3 was used. The colour specimens were visually inspected to be free from obvious defects. In each group, at least 60 colour measurements were conducted and in total 700 colour measurements were collected.

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Results and Discussion

The results of the study show, that the lightness of aspen was remarkably higher than the other wood species had (Fig 1a). Similarly, the colour coordinates of aspen showed different trends compared with other wood species (Fig 1b and Fig 1c). Figure 1 clearly demonstrates that the soaking temperature did not have effect on aspen colour, which was similar after soaking at different temperatures. Differently the colour of other wood species were getting less reddish (Fig 1b) and less yellow (Fig 1c), if the wood material had been soaked at higher soaking temperature prior the peeling process.

The most significant differences after the soaking can be seen in colour coordinate b^* values, where the material soaked at 70 °C was less yellow compared to 20 and 40 °C soaked material. At the same time wood materials soaked at 20 and 40 °C did not show statistically different colour.

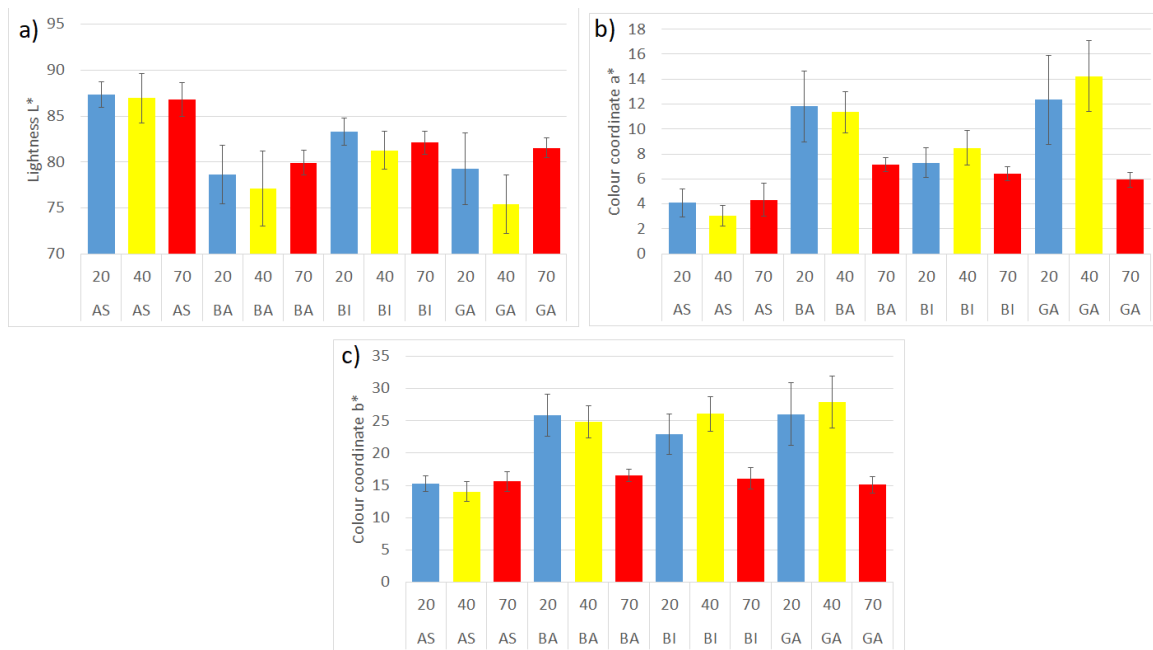


Figure 1 Lightness and colour coordinate a^* and b^* values of aspen, birch, grey alder and black alder veneers, which materials were soaked at 20, 40 or 70 °C prior to peeling process. AS – aspen, BA – black alder, BI – birch and GA – grey alder.

Conclusions

The results of the study show that the soaking of the bolts had remarkable effect on most of these wood species, except for aspen. Generally the increased soaking temperature affected veneer colour mostly by decreasing the colour coordinate b^* (yellow) of the dried veneer, which seems to be the primary cause of alteration in colour.

Acknowledgements

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EN ISO/CIE 11664-4 (2019) Colorimetry - Part 4: CIE 1976 L*a*b* colour space.

Effect of Log Soaking Temperature on Veneer Strength and Veneer Lathe Checks Development

Heikko Kallakas¹, Anti Rohumaa, Onyekachi Fortune Nwokocha and Jaan Kers

Background

In the manufacturing industries, it is a standard procedure to heat the logs to soften them before the peeling process, generally achieved by immersing the whole logs in a hot water bath or by steaming them in vats, using water as the medium to transfer heat to the log (Denaud *et al.*, 2007), a procedure that results in both the production of veneer sheets that are smoother with lesser lathe checks (Dupleix *et al.*, 2012) and a production process that is less energy-dependent (Marchal *et al.*, 2004). Researchers have carried out studies on the formation of veneer lathe checks during the log peeling process and indicated that the depth of lathe checks reduces at a higher temperature (Tomppo, Tiitta and Lappalainen, 2008; Pałubicki *et al.*, 2009; Dupleix *et al.*, 2012; Antikainen, 2015; Denaud *et al.*, 2019). However, higher temperature makes the logs softer during the peeling and leads to irreparable changes that affect plywood bond strength (Rohumaa *et al.*, 2017). The log heating times and temperatures can affect hardwood species differently. The aim of this research is to study the effect of the log soaking duration and temperature on lathe check development and veneer crosswise tensile strength of different hardwoods.

Keywords: lathe check, crosswise tensile strength, pith, bark, veneer, log soaking.

Experimental

This study investigates the effect log soaking temperature has on the crosswise tensile strength of veneer and the development of veneer lathe checks. Hardwood species used in this study were Aspen (*Populus Tremuloides*), Birch (*Betula pendula* Roth), Black alder (*Alnus glutinosa*), and Grey alder (*Alnus Incana*). The logs were soaked for 20 °C, 40 °C, and 70 °C in water for a time of 24 h and 48 h. Veneers with nominal thickness of 1.5 mm were peeled with an industrial lathe (Raute Oyj). A crosswise tensile test was performed on the freshly peeled veneers, and the lathe check depth of veneer sheets close to the bark and pith of the logs was measured from images captured with the aid of a microscope. The cutting plan for the lathe check depth samples was such that it would be exactly from the same region as the samples for the crosswise tensile strength.

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Results and Discussion

The tensile strength results obtained (see Figure 1) show that the samples soaked at 70 °C had the highest crosswise tensile strength for both the 24 and 48 h soak duration. For the samples soaked for 24 h duration, the birch at 70 °C had the highest mean value of 2.04 N/mm². However, for the 48 h soak duration, the black alder sample soaked at 70 °C had the highest mean value of 2.37 N/mm², with the aspen species having the lowest at 70 °C, 1.83 N/mm². For all the wood species considered, an increase in the log soaking temperature resulted in the production of veneers with significantly improved crosswise tensile strength.

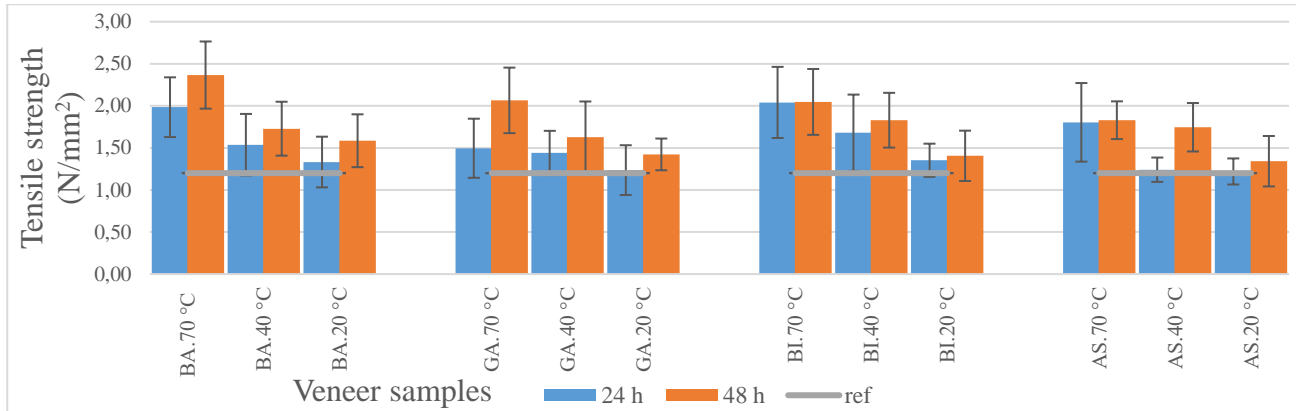


Figure 1 24 and 48 h veneer samples crosswise tensile strength, ref = minimum strength acceptable

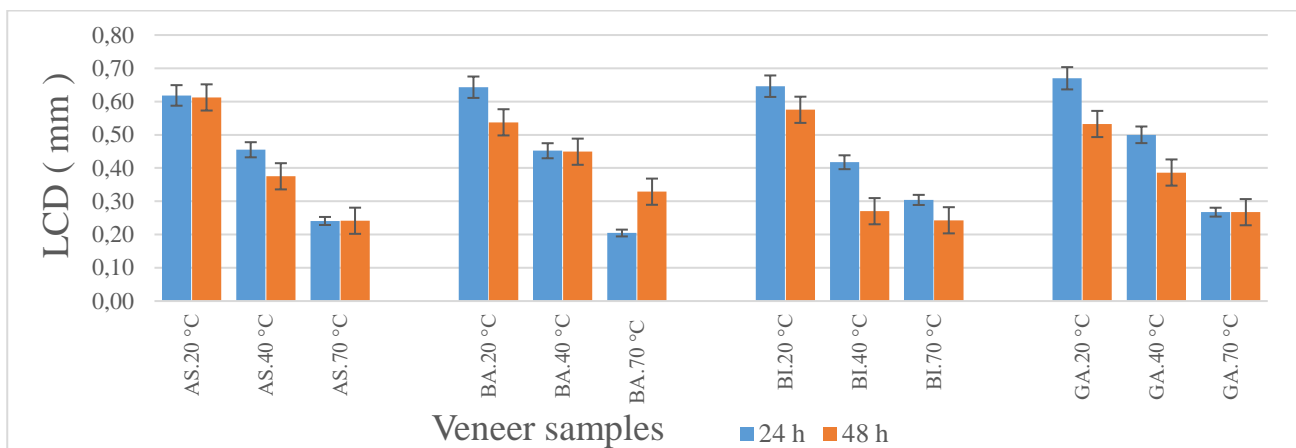


Figure 2 Effect of soaking temperature on lathe check depth (LCD)

The lathe check depth of the samples soaked at 70 °C had a minor mean lathe check depth for a given species, and this increased as the soak temperature decreased to 20 °C. This was the same for both the 24 and 48 h soak duration. From the results, it could be observed that variations from bark to pith were not consistent. For instance, at 20 °C, 24 h, for both birch and aspen species, the bark had a higher average LCD when compared to the pith. However, the reverse was the case for the black alder and grey alder species under the same conditions. A more critical observation suggests that there is more instance of the bark having a higher LCD than the pith. A clear example would be the birch species with bark having higher LCD in 80% of the sample.

Conclusions

It is very clear from the result that veneer lathe check depth and crosswise tensile strength is affected by the soaking temperature and soak duration. The lathe check depth is at the minimum level at a soaking temperature of 70 °C and increases from 40 °C to 20 °C. The results suggest no significant difference in LCD between the bark and pith within the species in this study.

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Cellulosic Ester Based on the Ionic Liquid-assisted Transesterification: Substitution and Mechanical Analysis

Umair Qasim¹, Heikko Kallakas and Jaan Kers

Abstract

Cellulose, a sustainable material, exhibits excellent properties and can be converted into functional products. Here, the dissolution and transesterification (vinyl laurate) of cellulose has been successfully done in a novel protonic ionic liquid [mTBNH][OAc]. Vinyl laurate, in the presence of IL, was added to the cellulose solution in various molar ratios (Anhydrous Glucose Unit:Vinly Laurate =1:1, 1:3 and 1:5), different time (2, 3, 4, and 5 hours) and temperature (25 °C, 60 °C, 80 °C, and 100 °C) conditions. Co-solvent, dimethyl sulfoxide, has also been added to decrease the overall viscosity of the solution. Fourier Transform Infrared Spectroscopy proved the successful substitution of cellulose hydroxyl groups with acyl groups with a maximum degree of substitution of 2 obtained after 4 hours long reaction. This cellulose laurate has been inspected for its tensile properties and found to be a good replacement for conventional cellulose acetate material.

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Demonstrating the Suitability of Laser Incision for Timber Treatment Technologies

Morwenna Spear¹, Paul Mason², Geraint Williams², Chris Miles¹, Elen Williams¹, Andy Pitman³, Roger Bailey³, Tom Theobald³, Subhasisa Nath⁴, David Waugh⁴ and Graham Ormondroyd¹

Background

In any form of wood treatment – preservatives, fire retardants or wood modification – the uptake of treatment agents is a limiting factor for performance of the finished product. Mechanical incision is widely used to treat products for demanding applications such as railway sleepers, and has been increasingly used for fencing applications in the UK in recent years. Laser incision offers a similar increase in fluid uptake and distribution within the wood, and reduces tool wear, and down-time for knife-sharpening or blade replacement (Morris et al. 1994, Wang et al. 2013). The use of lasers reduces splitting and crushing in the vicinity of the holes, but may lead to localised darkening or formation of heat affected zone at the hole margin. Another significant benefit is the ability to drill small holes rather than form long slits in the timber, and offers the opportunity to control of the depth of these holes (Nath et al. 2020a). While a few studies have reported increased fluid uptake in laser incised timbers (Islam et al. 2009, Wang et al. 2013) further information is required to better address the wide range of available commercially important species and differences in their wood anatomy (Spear et al. 2018, Nath et al. 2020b). This paper reports investigations into uptake and distribution of fluids in laser-incised wood samples of different dimensions.

Keywords: laser incision, timber treatment, permeability.

Experimental

We report a series of experiments moving from small laboratory specimens to full planks incised with a laser incision rig designed and built within the LaserWood project. Timbers of various species (beech, tulipwood, Scots pine, Southern yellow pine, Sitka spruce) were sourced through local timber merchants. Laboratory specimens (20 x 20 x150mm; T x R x L) were sealed on all surfaces with a clear lacquer prior to incision, so that uptake through only the incised hole could be studied. Plank sections were end-sealed with a rubber coating to permit study of fluid entering the plank through lateral faces and the incisions only. Impregnation tests were conducted both in the laboratory and at a commercial treatment plant (Lignia Wood Company). The treatment vessel used in laboratory tests had maximum length 38cm. Pressure treatment, with vacuum before and after, used a non-toxic water-based blue ink to permit study of the fluid distribution.

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In the development of a laser incision rig for commercial incision of timbers, key steps were: evaluation of the flow patterns of the fluid around individual incision holes in different timber species; development of suitable incision patterns for individual species; observation of improved fluid uptake in end-sealed short planks; and study of full length planks (2.1m) in an industrial process.

Results and Discussion

Incision into sealed specimens with single and multiple holes

Sealed specimens of many species were incised into either the radial or the tangential face using a frequency tripled pulsed Nd:YAG laser working at wavelength 355nm. The blue ink uptake was clearly associated with the incision hole, extending longitudinally for between 4mm (spruce) and over 50mm (beech) (Spear et al. 2018). Differences were observed between the earlywood (short distances) and latewood (longer distances) in conifers. In Southern yellow pine the uptake was highest (102% w/w) and distribution through both the latewood and the resin canals led to an enhanced distribution in the radial direction, compared to other species.

Similar samples were prepared using a CO₂ laser (wavelength 10.6 μm) with multiple holes at a range of spacings longitudinally and laterally in the face. The fluid uptake and ink distribution was studied, permitting patterns with good performance to be identified. The effect of multiple incision holes on drying rate was also studied (Spear et al. 2019).

Incisions into short and full length plank sections

Planks of Southern yellow pine, Scots pine, spruce and tulipwood of 38cm length were incised with various patterns of laser holes using a flat bed CO₂ laser. The number of holes per square metre varied from 8,333 to 12,500 in softwoods and 9,091 to 15,625 in the tested hardwoods. The planks were cut to expose the ink distribution 3mm below the surface, and scanned for digital image analysis using a Python script. Analysis of weight uptake on a mass basis and available volume basis was coupled with % area coverage of ink.

A laser rig was developed to deliver rapid incision of full length planks with fine control of incision patterns and depths. It was used to create bespoke hole patterns in full length planks for industrial treatment. A significant increase in fluid uptake was seen, compared with unincised control planks. Image analysis was conducted on dissected samples cut from the planks, confirming the improved uptake of fluid and enhanced distribution within the plank.



Figure 1 (a) Blue ink distribution in samples of redwood incised into tangential and radial faces, (b) enhanced uptake in heartwood of tulipwood, (c) Southern Yellow Pine plank segment cut to reveal distribution 3mm below the surface

Conclusions

Laser incision significantly increased the uptake of fluids by the timbers. It enhanced uptake in species with resistant heartwood, and in refractory species. Laser incision patterns were developed for different species of timber and flow characteristics. The technique offers great flexibility in the

number and location of holes to optimise fluid distribution with low visual impact on the product. A high-throughput laser incision system was developed and demonstrated at commercial scale.

Acknowledgement

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Investigation of the Influence of Fabric Inforcement in Bamboo T-Connectors

Moritz Sanne¹, Caroline Sperling and Alexander Pfriem

Background

Worldwide, there are few companies, who manufacture bamboo frames for bicycles in serious numbers (Iosifidis 2017). Most of the bamboo bicycles on the market are made constructed with wrapped nodes soaked in epoxy resin. Worldwide, there are few companies, who manufacture bamboo frames for bicycles in serious numbers (Iosifidis 2017). All frames are made by hand and know-how is based on unpublished experience. For Fitting Welding welding cannot be applied. Therefore, the bamboo tubes are connected butt-jointed and reinforced with fabrics. To simplify the type of connectors to a still realistic design in a bamboo bike, a T-connector was chosen within this experiment.

The aim of the preliminary research was to find the optimal application of fabric for bamboo connectors. Thus, the number of fabric layers and the length of their contact area were altered. These connectors were tested in a bending construction. Despite the small amount of samples, an optimum was found which was recommended to bamboo companies.

Keywords: bamboo bicycle frames, butt-joint bamboo-T-connectors, bending strength of bamboo

Experimental

Method

The bending test on the 90 ° T-Connectors required a vertical metal pipe to transfer the force to the construction joint. Therefore the bamboo tube was horizontally butt jointed to that with the epoxy-impregnated fabric. Since the strength of the fabric-epoxy part had to be stronger than the bamboo tube, the number of cloth laminates was increased until the horizontal bamboo tube broke.

Material

Bamboo: *Phyllostachys nigra* (LOOD. EX LINDL.) MUNRO

Epoxy: Epoxy 300 and hardener 3018 by Bootsservice Behnke, Germany (with Microsphere Filler) cold hardening.

Fabric: Flaxdry BL 300, Ecotechnillin (Grammage: 318 g/m²)

Steel pipe D = 40 mm, Wall thickness: 2 mm

The number of laminated fabrics (1 - 4) as well as the length of contact area ($1/3 \cdot D$ (Diameter of Bamboo tube) – $4/3 \cdot D$) was altered (fig. 1 left).

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Results and Discussion

As long as the strength of the wrapped fabric does not exceed the bending strength of the bamboo tube, the epoxy filler at the tensile side cracked and the flax fabric delaminated (fig.1 right). In some cases the delamination of fabrics was visible at the contact area.

The fractures appeared very spontaneous and thus corresponded to the experience of the users where at a failure the damage is sudden.



Figure 1 (Left) not yet epoxy impregnated layers of flax fabric around the vertical steel pipe and the bamboo tube of the T-connection. (Right) fractured specimen on the holder after the bending test

The maximum bending strength of about 140 N/mm² with three layers of flax fabric and a contact area of 1*D in this setup. The more layers and contact area of the fabric were introduced the stronger the T-connection became. This observation was linear until the maximum strength of the bamboo was exceeded and further applications of flax fabrics result only in fractured bamboo tubes.

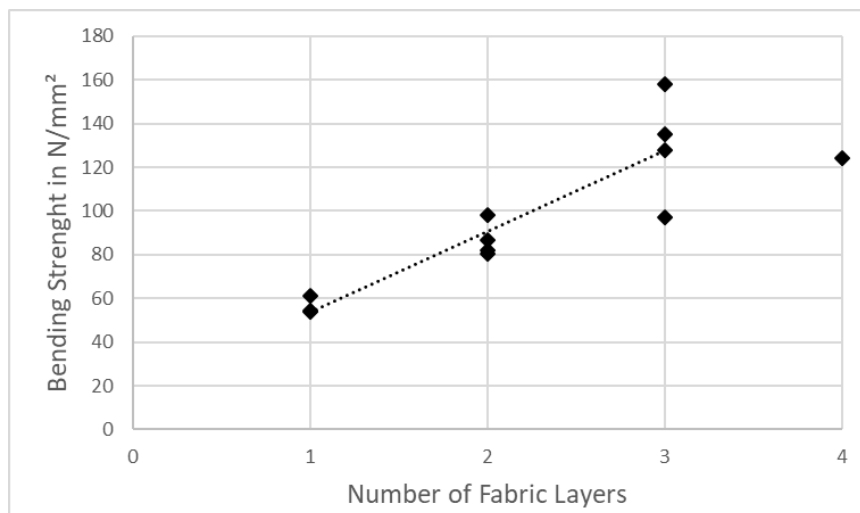


Figure 2 Linear correlation of bending strength and number of fabric layers

Conclusions

Whether a bamboo frame can be certified according to the CE standards for bicycle, cannot be determined. But the results show an optimum of 3 layers and 1*D of covered area on the bamboo. Further investigations with finite element analysis could reveal more bicycle frame specific results.

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X-ray Microtomography Applications in the Wood Composite Research

Olli Paajanen¹, Anti Rohumaa^{1,2} and Eetu Paasonen³

Background

X-ray tomography is a non-destructive 3d imaging technique that has many applications in wood science and industry. Tomography is used e.g., in log scanning, while microtomography is utilized in many applications, for example in the study of the wood microstructure, adhesive (Jakes et al., 2018) or chemical penetration (Van den Bulcke et al., 2013), the structure of composites or other wood products. Recently, there has been development both in x-ray scanning technology, as well as 3d analysis software, which can potentially provide more accurate 3d models and methods to study them. The aim of this presentation is to discuss the current technology level in high resolution desktop X-ray microscopy and present some examples of its use in wood composite research.

Keywords: X-ray microtomography, ABES, adhesive.

Experimental

In this study, 1 mm thick birch (*Betula pendula* Roth) veneer was used. Bonded veneer specimens were prepared with ABES (Automated Bonding Evaluation System, Adhesive Evaluation Systems, Corvallis, OR, USA) and bonded with commercially available phenol-formaldehyde (PF) resin (Prefere 14J021, Prefere Resins Finland Oy, Hamina, Finland). For comparison, specimens were cut also from commercial birch plywood. Different specimen sizes were experimented with, the width of the ABES specimen varied from 3...20 mm.

The specimens were scanned using Neoscan N80, a desktop micro-CT-scanner, manufacturer NeoScan BVBA, Mechelen, Belgium. The scan settings were 50 kV and 80 μ A, exposure time was in most cases 202 ms. The camera is a 16 Mp CCD unit. The pixel size depended on the specimen size and magnification. The imaging, 3d model reconstruction and initial visualization was done using Neoscan software package. The further analysis and visualisation were done using Dragonfly software, manufacturer Object Research Systems inc, Montreal, Canada.

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Results and Discussion

The plywood and ABES-samples were scanned using the Neoscan micro CT-scanner and some results can be seen in the image 1. On the left is a complete plywood specimen, showing single adhesive line in the middle of the image. The right part shows a detail from a ABES specimen. For comparison purposes, the plywood specimen was cut from a plywood board, which had some parallel bonded veneers. The plywood with smaller pixel size shows the finer details more accurately, although the cell structures are not perfectly reconstructed. Still, various details can be noted also from the ABES specimen with a larger pixel size, for instance: adhesive line between the specimens, vessels and rays.

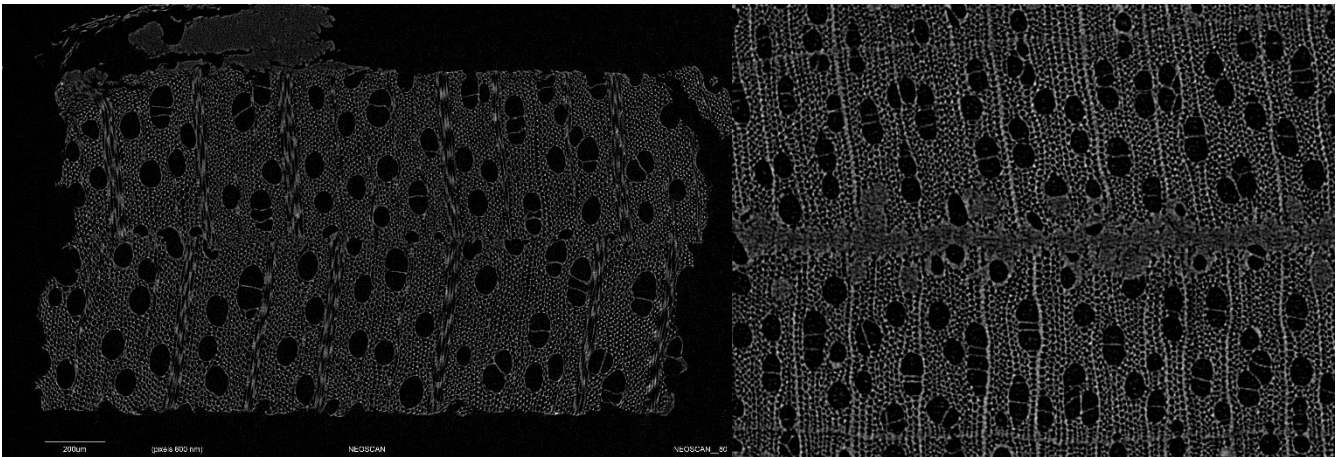


Figure 1 Examples of bondline scans; on the left plywood specimen (pixel size 600 nm); on the right a detail from a ABES specimen (pixel size 2000 nm)

Conclusions

A new desktop micro-CT system was tested using ABES and plywood specimens. It can be concluded that the resolution achieved with the desktop system is sufficient for the analysis of the wood structure as well as general analysis of the bondline. Depending on the focus of the study and the needed accuracy, the specimen size must be small enough, so that the specific details can be located from the image. While not the focus of this abstract, advanced image analysis software facilitates a rapid image segmentation process and subsequent quantitative analysis of the data. Still, a sufficient specimen and image quality is the first step in the analysis of micro-CT data.

Acknowledgements

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More Than the Sum of Their Parts - How UK Timber Houses Can Be Deconstructed and Reused

Marlene Cramer¹ and Ylva Sandin

Background

Buildings in the UK are often being demolished because they are in the wrong place at the wrong time, and intact materials become waste in the process (Cramer and Ridley-Ellis, 2020a). About one quarter of the UK's wood waste results from building demolition and is mostly chipped and incinerated for energy production (Cramer and Ridley-Ellis, 2020b). Deconstruction instead of demolition would allow the reuse of timber and wooden building elements, so that they could replace virgin materials and avoid becoming waste, while also having a smaller environmental impact than new materials (Bertino *et al.*, 2021; Niu *et al.*, 2021). The InFutUReWood project (infuturewood.info) focuses on the reuse of structural timber and is working on improving the design of buildings to facilitate deconstruction and reuse, amongst other things. For this purpose, we conducted six case studies in four of the partner countries, which analyse the design of contemporary houses and seek to improve them to facilitate deconstruction and reuse. The case study presented here focuses on a Scottish light timber frame house, which is partly manufactured offsite and is a typical example of UK timber-frame construction, as described by Lancashire and Taylor, 2012.

Keywords: Circular economy, offsite construction, timber frame, demolition

Case Study Method

The case study was conducted in collaboration with Robertson Timber Engineering and Offsite Solutions Scotland. The companies selected a typical Scottish light timber frame house with offsite manufactured elements. Nobody in the companies had ever attempted to deconstruct one of their buildings, so we discussed how a possible deconstruction could be attempted and which complications could occur. To narrow the scope of the discussion, we focused on a scenario in which the house has to be moved after 50 years of service life but is rebuilt in a short distance under the same wind- and snow loads. In this scenario the building elements can stay assembled to a high degree and do not need retrofit. We analysed the deconstruction steps, tools needed, complications that might occur and damage to the parts we could foresee and focused on the load-bearing timber structure only. Mike Turner, Managing Director of Robertson Timber Engineering and Nicola Jackson, Technical Manager of Robertson Timber Engineering, provided valuable insights in the building's construction and possible deconstruction and reuse.

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The results of the discussion revealed which factors in the building design facilitate deconstruction and which factors complicate deconstruction and therefore compromise the reuse potential of timber elements. We addressed some of these factors with design changes that facilitate deconstruction and reuse.

Results and Discussion

Robertson’s “Everett Grand”, a 5-bedroom detached house, represents typical Scottish construction methods and materials. The timber frame structure is partly manufactured offsite and includes a trussed rafter roof, 2D-wall panels with solid wood studs and OSB sheathing, and floor cassettes with I-joists and OSB cover.

The case study building presents with several advantages for deconstruction, and generally Robertson’s team was very optimistic regarding the reuse potential of building elements. It is estimated that 95% of the structure could be recovered and reused. Advantages include:

- Industrially produced, large elements can be deconstructed in a reversed construction process, resulting in even more finished/ larger elements. Fast and rational deconstruction is possible.
- Knowledge and logistics are already in place for the prefabricated system with its efficient transport and assembly methods. Deconstruction and reuse, as well as quality control and possible repair works, can be worked into the business model if there are incentives to do so.
- Lifting of wall and floor elements is planned. They have existing positions for lifting devices and can be lifted in the same way as during the original construction.
- Few, common tools are needed, such as drill, saw and electric screwdriver. As the elements are large, a crane will be needed for lifting, which is already part of the construction process.
- Services and membranes are accessible after the (relatively easy) removal of the plasterboard. Services and membranes as well as insulation can then be replaced, repaired or altered.

We also identified factors that complicate deconstruction and reuse, and in the following table propose solutions for the most important ones:

Table 2 Factors that complicate deconstruction and reuse and proposed solutions

Factors that complicate deconstruction	Proposed solutions
Nailed connections are irreversible and it could be difficult to remove nails without damaging the wood. The process could be labour intensive.	Nails could be replaced with screws in all on-site works.
75 different types of wall panel are present. Highly specific wall panels have limited reuse potential, should they not be reused in exactly the same building. In addition, room layouts are often not adaptable for different use scenarios.	Wall panels could be standardised to come in fewer different configurations, e.g. the panel height could be made the same on all floors and walls could have lengths that are multiples of 600 mm. Room layouts should be adaptable for different uses.
Not prescribed connectors might be used by the assembly team, which would complicate deconstruction and pose a health and safety risk.	A deconstruction plan should specify the position of all fasteners. During construction, a protocol should enforce workers to record additional fasteners.
Verification of assembled elements according to building regulations would be needed before mass-reuse is possible. The reuse of elements needs to be negotiated with insurance providers.	Initially recovered elements should be tested. From these results a protocol should be developed for visual and factory assessment of recovered parts.

Conclusions

Deconstruction and reuse of building elements from modern UK timber frame houses might already be feasible with conventional designs. Up to 95% of the timber structure can be recovered and reused, and small adaptations of the design would facilitate recovery and open more reuse possibilities. If companies had the intention to reuse houses when they are planning and building them, most obstacles that complicate deconstruction and reuse would fall into place effortlessly.

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Results on One-shot Process for Wood-Based Composites

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Abstract

Recently the development and use of bio based materials is targeted in a lot of industries addressing the private and public sector. When thinking about combining wood and plastic usually the wood component is used as a filling material or as a decorative surface. The goal of this research is to use wood veneer as a load bearing part in a composite as it is a natural fibre reinforced material with anisotropic characteristics. To reach this goal a combined manufacturing process (one-shot) including forming, cutting and injection moulding sequences is targeted to be developed. The single process parameter correlations between forming and cutting as well as the combination with and adhesion of plastic on veneers is presented.

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Synthesis of Wood – GdPO₄·H₂O:Eu Composites

Monika Baublytė¹, Edita Garškaitė², Denis Sokol¹ and Ramūnas Skaudžius¹

Background

Due to high sustainability, thermal and electrical insulating properties, and aesthetics, wood is the most abundant building material used in residential and non-residential buildings, furniture constructions, and decoration. Thus, high weathering, biological and pyrolytic resistance of wood is essential (Fabiya, 2010).

Mechanical, biological, thermal, and accelerated weathering behaviors of wood can be increased using various materials. Usually, organic compounds (phosphorus-based, phosphorus-nitrogen, phosphorus-halogen compounds) are used to impregnate the wood. Also, high resistance can be reached preparing wood-polymer composites (WPC) (Nikolaeva, 2011). Besides, inorganic compounds may achieve high-performance levels at wood preservation and improvement of its characteristics (Chen, 2020). Therefore, this work proposes inorganic GdPO₄·H₂O:Eu compound produced by in situ hydrothermal syntheses as a new alternative method to increase wood chemical resistance and confer new optical properties.

Keywords: wood, ceramics, composites.

Experimental

The starting materials were NH₄H₂PO₄ (9.99% trace metals basis, Sigma-Aldrich), Gd(NO₃)₃ (ACS reagent, ≥99.0%, Sigma-Aldrich), Eu(NO₃)₃ (ACS reagent, ≥99.0%, Sigma-Aldrich), distilled water and ethanol (CH₃CH₂OH, 96%, Vilniaus degtinė). Samples were prepared by in situ hydrothermal GdPO₄:Eu synthesis in the wood matrix using sample pre-vacuumation. First, a wood sample was placed in a low vacuum for desorption of air contents. After 24 hours, NH₄H₂PO₄ solution was added to the reaction chamber for additional 24-hour immersion. At the last stage, the vacuum was released. Swollen specimen (with precursor solution) was placed in Teflon vessel containing gadolinium and europium nitrate solution. The hydrothermal reaction was carried out at 110 °C for 18 hours. Evaluation of wood properties was carried out for unaltered and modified specimens. In order to evaluate if GdPO₄·H₂O:Eu has any impact on wood properties, scanning electron microscopy (SEM)/energy-dispersive X-ray (EDX), UV/VIS spectroscopy, X-ray micro-CT, and thermal analyses were performed.

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Results and Discussion

After in situ hydrothermal syntheses, wood samples were measured to investigate the dependence of luminescence properties on the synthesis conditions. $\text{GdPO}_4:\text{Eu}^{3+}$ formation in woods matrix can be observed by characteristic transitions of ${}^5\text{D}_0 \rightarrow {}^7\text{F}_{1,2,3,4}$ of Eu^{3+} , with ${}^5\text{D}_0 \rightarrow {}^7\text{F}_1$ transition as the most prominent group. Sample surface and its uneven morphology must be taken into consideration, assessing fluorescence results.

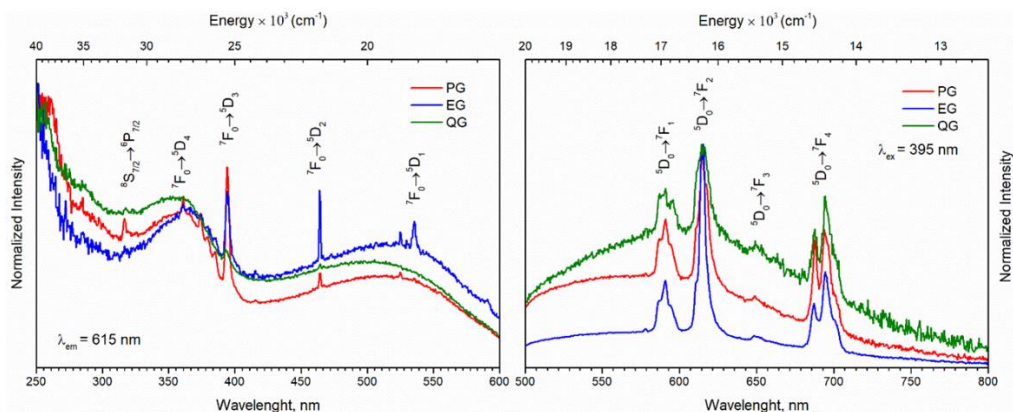


Figure 1 Excitation and emission spectra of woods matrix after in situ $\text{GdPO}_4:\text{Eu}$ hydrothermal synthesis: PG – plain grain, EG – end grain, QG – quarter grain

Due to wood's difference in grain type, even distribution of $\text{GdPO}_4:\text{Eu}^{3+}$ is improbable. Luminescence results show noticeable growth of $\text{GdPO}_4:\text{Eu}^{3+}$ distribution from well packed quarter grain (QG) structure to porous end grain (EG) matrix. Results presenting luminescence dependence from grain structure are shown in Figure 1.

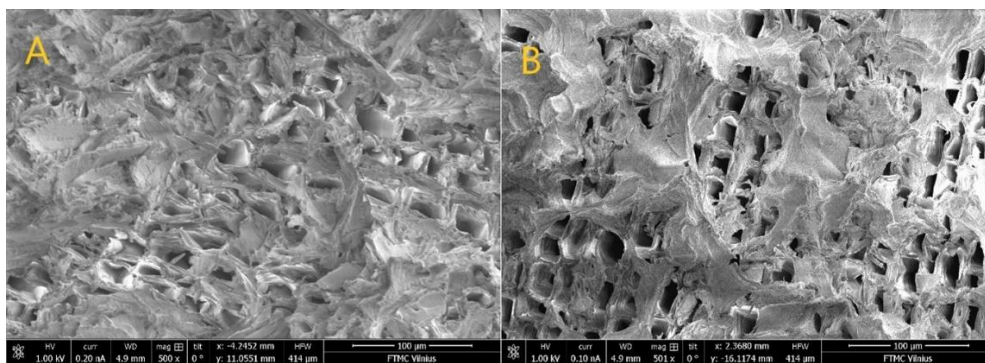


Figure 2 SEM images of the wood surface after in situ hydrothermal $\text{GdPO}_4:\text{Eu}$ synthesis in wood's matrix

SEM images of wood samples provided in Figure 2 show wood surface areas with uneven coatings of $\text{GdPO}_4 \cdot \text{H}_2\text{O}:\text{Eu}$. Analyzed samples possess part coverage of $\text{GdPO}_4 \cdot \text{H}_2\text{O}:\text{Eu}$ sediment. All the cases reveal visible clogging of the pores – cell walls exhibit a thin layer of gadolinium phosphate.

Conclusions

$\text{GdPO}_4:\text{Eu}^{3+}$ formation in wood's matrix can be observed by characteristic transitions of ${}^5\text{D}_0 \rightarrow {}^7\text{F}_{1,2,3,4}$ of Eu^{3+} . Moreover, the growth of $\text{GdPO}_4 \cdot \text{H}_2\text{O}$ particles is observed using SEM. Coatings are exhibited to be uneven, nevertheless, thin layer of particles are observed on cell walls. The studies performed suggest that the synthesis of wood-ceramic composites was successfully performed at 110 °C temperature by in situ hydrothermal synthesis. Further studies revealed that altogether wood-ceramic composites excel significantly improved properties.

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The Use of an Internal Airtight Membrane in CLT External Wall in Terms of Hygrothermal Performance

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Background

CLT envelope works hygrothermally safe if the panel is not covered by material layers that cause moisture accumulation on the CLT surface, which in turn increases the risk of moisture damage. The most critical period is the start of the service life immediately after construction when the CLT moisture content equilibrates and the excess moisture dries out. In addition to the drying capacity, the airtightness of the building envelope must also be ensured, for which in many cases an internal airtight membrane is used. General recommendations are usually given for the use of the membrane. Mainly to use "low" water vapor resistance products. The objective of this research was to analyze the effect of the internal airtight membrane on the dry-out performance of the vapor-permeable CLT external wall and to find the parameters of water vapor resistance at which the sufficient dry-out is not prevented.

Keywords: keyword, keyword, keyword.

Experimental

Weather conditions (RH_e , t_e), indoor environment (RH_i , t_i), temperature, and relative humidity between materials layers (t & RH_{L1-L4}) in the test walls were measured during the test, see Figure 1. Laboratory measurements of the test walls started on the 16th of June 2018 and finished on June 30 in 2019. This paper focuses on the vapor-permeable external wall, which was insulated with 300 mm glass wool insulation and CLT used as a load-bearing element with a thickness of 100 mm was exposed to an indoor environment. The external wall was designed with a ventilated wooden cladding façade and a glass wool insulation board was used as a wind barrier. Based on the laboratory measurements the simulation model was created and validated. The properties assigned to the material layers of the wall were taken from the Delphin database. The hygrothermal performance of the wall was analyzed by a stochastic approach. Thermal conductivity (W/m·K), vapor diffusion resistance, and moisture content (m^3/m^3) was used as continuous random variables. The presence of an internal airtight membrane between the insulation and CLT was used as discrete random variables. Two main scenarios based on discrete random variables were used: the CLT wall without (scenario 1) and with (scenario 2) the internal airtight membrane (with the water vapor resistance of $S_d = 244$ m). Hygrothermal performance of the wall was evaluated by the risk of mold growth on the material surface via a mold growth index (a numerical scale from M=1 to 6, the risk of mold occurs when index 1 is exceeded) (Viitanen *et al.*, 2011).

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Results and Discussion

In the first scenario, it can be seen that if the remaining wall layers do not prevent the dry-out of CLT, the RH on the CLT surface quickly equilibrates even with high variability in moisture content (13- 25%), see Figure 2, a and there is no risk of mold, see Figure 2, c. Figure 2, a, also shows that the results of all 100 different calculations converge and differ little from each other after the first 6 months. Figure 2, b, shows clearly that in the second scenario the added air barrier with high water vapor resistance has created an environment with high RH on the CLT surface and drying is slow in all sub-scenarios. This is reflected also in the mold index results where about 85% of the results of sub-scenarios exceeded the mold growth index 1, varying between 1 and 5, see Figure 2, d. Simulating with different vapor resistance values (S_d) of additional internal airtight layer, it was found that in the CLT initial MC range of 13-20% there is no risk of mold on the CLT surface if the vapor resistance value is no greater than 3 m, see Figure 2, f. In the MC range of 13-25%, there is no risk of mold on the CLT surface if the vapor resistance of the additional airtight layer does not exceed 1.5 m, see Figure 2, e. The results showed that even if the CLT panel is open to the indoor environment, it must be ensured that the surface of the CLT panel towards insulation is not covered with a high vapor resistance layer and external drying is also allowed.

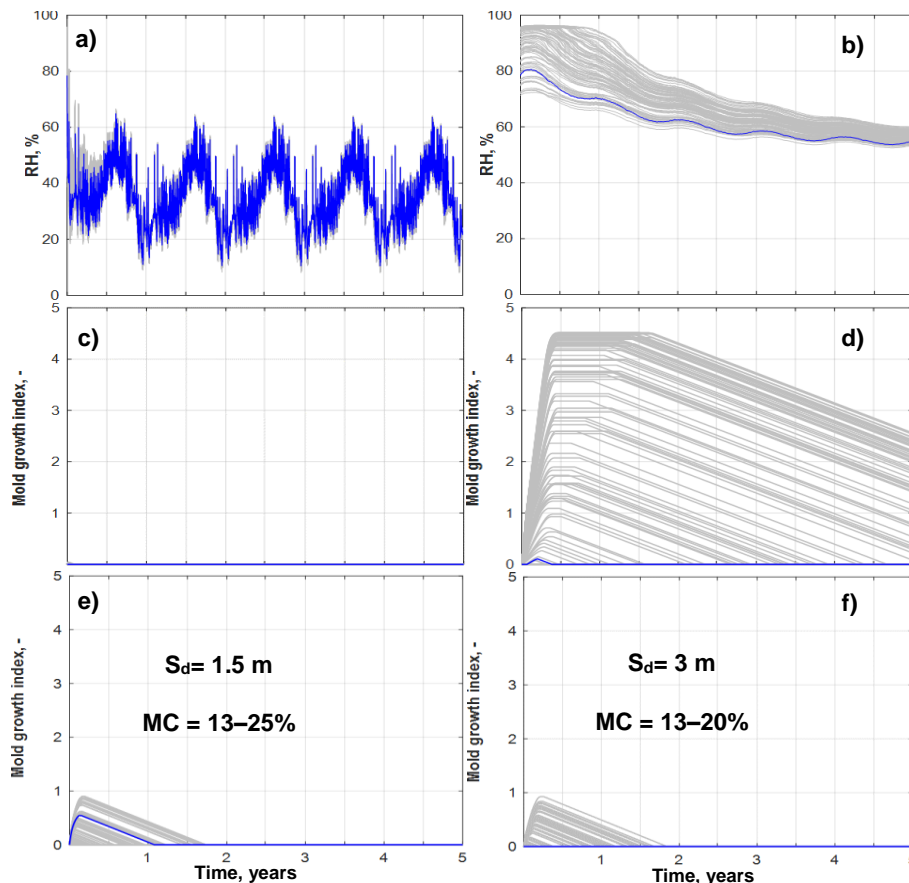


Figure 1 Dry-out performance (RH) of CLT in the external wall, analysed between the CLT and insulation, of scenarios 1 (a) and 2 (b), mold growth risk of scenarios 1 (c) and 2 (d), and when using an internal membrane at CLT MC up to 25% (e) and up to 20 % (f).

Conclusions

The results of this showed that the CLT dries out quickly and safely in a wall with high water vapor permeable material layers, even with the large range of initial CLT MC (13-25%). When an additional airtight layer with high vapor diffusion resistance (S_d of 244 m) is added between the insulation and the CLT, the dry-out capacity of the CLT decreases significantly and there is a high probability of mold growth on the CLT surface. The risk of mold growth can be prevented when the vapor resistance (S_d) of an airtight layer is reduced to 1.5 m in the case where initial CLT MC is up

to 25% and in the case where initial MC is up to 20%, the vapor resistance of an airtight layer must be reduced to 3 m.

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Selected Mechanical Parameters of Pine Wood (*Pinus sylvestris* L.) from a Copper Mine Area

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Background

Phytoremediation is a proven technology for many organic and inorganic pollutants (Pilon-Smits, 2005). Although previously trees were perceived as less effective than hyperaccumulative herbaceous plants, they appear to be very effective in field trials. This is due to their large biomass, rapid growth, powerful root systems, and an innate ability to tolerate and remediate a wide range of pollutants from soil (Gómez et al., 2019). Research on trees in this context is still a developing field called ‘dendroremediation’. Many tree species are tested and compared for their ability to accumulate pollutants (Al-Ibrahim and Mohammad, 2017; Mleczek et al., 2017). However, very little or no research has been carried out on mechanical properties of wood which could be potentially obtained from such biomass and its utility in the wood industry, peculiarly for structural work (Muthusaravanan et al., 2020). Therefore, this study compared some of the mechanical properties of wood samples from industrially polluted area that can be possibly treated by phytoremediation.

Keywords: Scots pine, dendroremediation, tensile strength, mechanical properties

Experimental

The study examined trees covering area of closed reservoir of tailings from copper ore flotation processes located in south-west Poland. Wood samples of 25 years old Scots pines were compared with reference samples from trees of similar age growing in unpolluted area. For both sites, four annual rings were selected, from which microtomic wood samples were obtained: each of them 300 µm thick, 9 cm long and 1 cm wide. This approach made it possible to compare analogous increments and to test separately early- and latewood. The ends of the samples were clad with pieces of HDF board on both sides for their safe assembly in the testing machine (ZWICK Z050TH), so that the effective length of the samples was 6.5 cm.

The mechanical parameters analyzed in the tensile strength test parallel to the grain included: Young's modulus, stress and strain at the proportional limit, ultimate tensile strength, ultimate tensile strain. Wood density was also determined.

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Results and Discussion

Although all the parameters were measured along the rays, Figure 1. below shows a plot for the wood density exclusively. The results of the proportionality limit, Young's modulus and ultimate tensile strength of wood were qualitatively similar to the density of the wood. Analogous increments show very little differences among tested parameters.

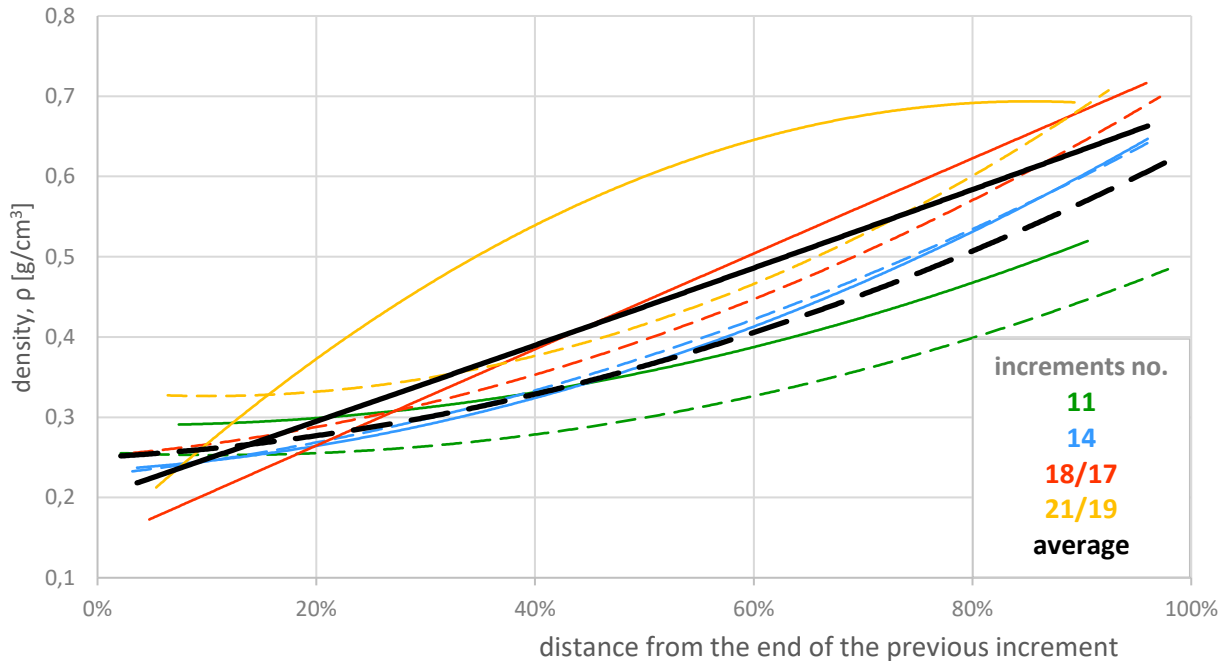


Figure 1 Wood density along the rays in selected annual increments. Samples from the polluted site are marked with a solid line, wood from the control area is marked with a dashed line.

Unfortunately, it was extremely hard to obtain analogous control samples for 18th and 21st increments of wood originated from polluted area. For the increment 21st compared with 19th, larger differences were observed in wood density (yellow lines). However, for each pair compared, the result of statistical analyses shows no significant differences (Table 1). Some significant differences in strain at proportional limit were observed. All t-test p-values are shown in Table 1.

Table 1 The results of the analysis of the significance of differences for the examined increments ($p < 0.05$ means a statistically significant difference)

increment number	11	14	18	21
density, ρ	0.065	0.830	0.458	0.337
Young's modulus, E	0.595	0.052	0.818	0.286
ultimate tensile strength, R_{\max}	0.732	0.339	0.850	0.405
ultimate tensile strain, ϵ_R	0.530	0.032	0.181	0.551
proportionality limit σ_Y	0.223	0.000	0.447	0.994
strain at proportional limit ϵ_Y	0.012	0.000	0.388	0.280

Though trees growing on the reservoir of flotation tailings were relatively young, sooner or later they will be potentially ready for logging and use in the wood industry. Quite possible that in the future, as a consequence of the development of dendroremediation, there will be more such stands.

Conclusions

In most cases, the mechanical parameters of wood growing on flotation tailings did not differ significantly from the control material. It seems that it can be successfully used in construction. Nonetheless, more extended research is required.

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Effect of Different Hardwood Species and Veneer Thickness on Bending and Density Properties of Plywood

Tolgay Akkurt¹, Jaan Kers¹, Heikko Kallakas¹, Anti Rohumaa¹ and Percy Festus Alao¹

Background

Plywood is one of the most widely used wood-based product in the world and mainly produced from silver birch (*Betula pendula* Roth) tree. It is constructed by combining layers of veneers with using glue as a binder. For sustainability and to improve properties like bending strength, weight, density and glue consumption amounts, finding alternatives to this wood specie and reducing glue consumption is of vital importance for plywood industry and considering also the environmental impact of product. Currently information about alternative species and effect of veneer thickness on plywood properties are not investigated enough. In plywood production the mostly common species like birch, spruce, poplar and pine are used because of their abundancy. In this research, the performance of plywood produced from aspen and black alder veneers and plywood from different veneer thicknesses were compared to plywood from birch.

Keywords: veneer, plywood, aspen, birch, black alder, bending strength, modulus of elasticity, modulus of rupture, veneer thickness, combination, glue consumption, lay-up

Experimental

Birch, aspen and black alder veneers with thicknesses of 1.5 mm and aspen veneers with thickness of 2.6 mm used for plywood production. Five plywood thicknesses (6.5 mm, 9 mm, 12 mm, 15mm and 18 mm) were investigated. In addition, combination plywood types which have face veneers from birch and middle veneers from either aspen or black alder were tested. Four different samples were used for every thickness and plywood type and total of 120 plywood samples were prepared for experiment. Data for soaking, moisture content, log dimensions peeling, cutting, drying, gluing, conditioning, laying up, cold and hot pressing and sampling parameters were noted. A total of 1440 specimen were examined for bending properties based on EN325, EN315, EN326-1, EN310 and the plywood density was evaluated from 720 specimen in accordance with EN 323.

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Results and Discussion

The glue consumption results showed that aspen plywood absorbed the highest amount of glue (177g/m²) while plywood from birch recorded the lowest outcome (152 g/m²) per ply. However, the 2.6 mm veneer plywood from aspen consumed the least total amount of glue for the same plywood thickness (less plies). In density calculations, lowest density was with 2.6 mm pure aspen plywood and the highest was with birch plywood. As shown in Figure 11 the plywood delivered different strength properties when compared based on the wood species, grain direction or type of veneer combination. Overall, birch plywood reported the highest bending strength (MOR) values for grain (120 MPa to 99 MPa) and across the grain (54 MPa to 72 MPa) directions changing with thickness. Black alder plywood reported the lowest MOR values for grain direction (98 MPa to 65 MPa) while aspen plywood with 2.6 mm veneers had the lowest MOR across the grain direction (21 MPa to 46 MPa). There does not appear to be any meaningful impact on MOR with veneer thickness in grain direction however, there is significant strength reduction across the grain (50% to 30%) for aspen plywood. The combination plywood of black alder showed significant increase in grain (around 20% on the average) and no significant change in across the grain comparing to black alder plywood. On the other hand, combination plywood of aspen didn't show significant change in results in both directions. In addition, as the plywood thickness increased, the discrepancy between the birch plywood and combination plywood increased more significantly as plywood thickness increases. For instance, for the 15 mm and 18 mm thick plywood, the best outcome for combination plywood was by C-alder (85 MPa) and C-Aspen (82 MPa), respectively, representing a 22 % and 25 % reduction in grain direction, while it was 30% to 24% across the grain compared to the birch plywood.

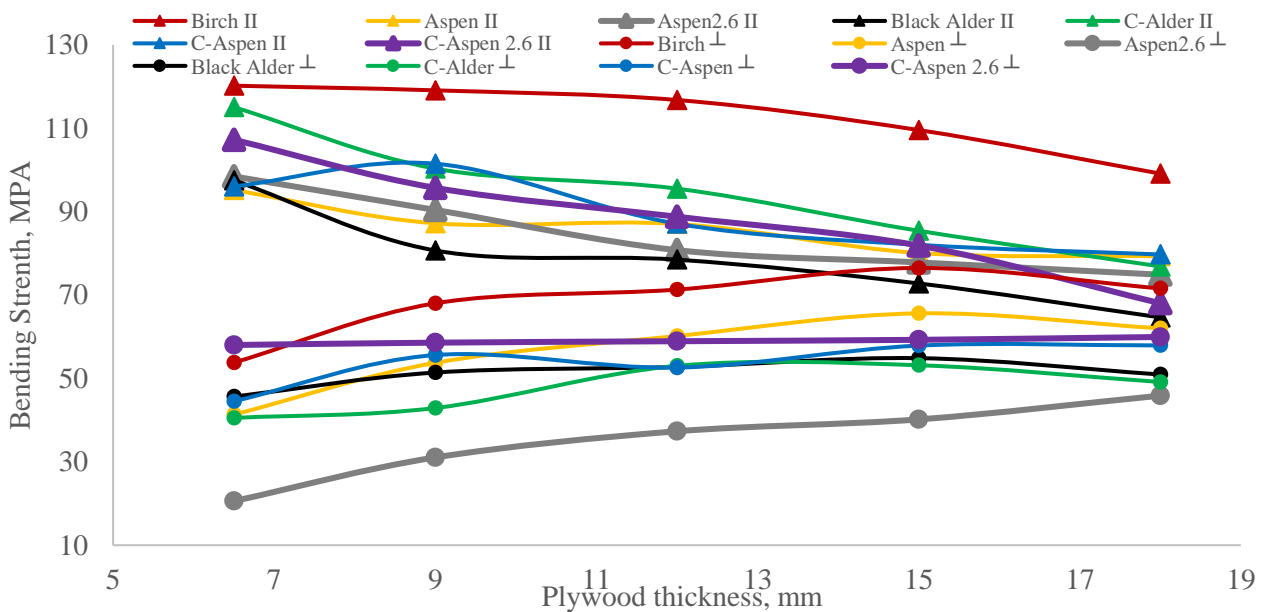


Figure 11 Different plywood types and plywood thickness; change of bending strength vs thickness in grain II and perpendicular direction ⊥ (Note: C stands for combination, also for aspen plywood types with 2.6 mm veneer some MOR results were interpolated since some plywood thicknesses couldn't be reached.)

Conclusions

In plywood production, it is good to keep in mind all of the aspects like end use, costs and proximity of log yard etc. Aspen plywood, use more glue (Kallakas, et al., 2020)but is lighter and cheaper but their strength is lower. Plywood which has 2.6 mm veneers has less glue consumption in total but less strong across the grain direction. Also, by using curtain or extrusion coaters for gluing aspen plywood glue consumption can be lowered to the values of birch without losing

strength. So, depending on end use these hardwoods can be utilized in plywood production instead of birch plywood.

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Investigation into the Heating of Wood Veneers by Infrared Radiation and Damage Analysis in Tensile Tests

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Abstract

Sustainable materials are also becoming increasingly important in structural components, especially in combining them with other materials. In combination with plastics, wood veneers can have a load-bearing and plastics a stiffening effect. In addition, the bond strength at the interface between wood and plastic is of major significance for the mechanical performance of the component. To increase the bond strength, it is possible to heat the wood surface in the area for the plastic application. An infrared heater can be used for this purpose. In the context of this work, the irradiation of wood veneers by means of infrared radiation is to be investigated. For this purpose, the emitter power and irradiation time will be varied. The resulting temperature on the veneer is measured. Following the irradiation, potential damage to the wood veneer is identified by means of a tensile test.

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The Potential of Cellulosic Substances Modification via Silanization for the Packaging Applications

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Background

Nowadays, cellulosic substrates and paper products have been most attention, as the main component of various packaging usage, due to their unique properties like distinctive mechanical features, abundance, accessibility, biodegradability, reusability, and environmentally friendly. Alongside all of these great characteristics, the major challenge of using cellulose biopolymer arises from its high wettability faced with humidity [1–5]. It is noticeable that finding effective methods has become introduced, improving its resistance against water and moisture contents. For this purpose, numerous kinds of materials such as starch, cellulose derivatives, waxes, silicon compounds, etc., have been employed as barrier agents either individually or as components of hybrids [1–8]. Various modifying procedures can be applied to protect the cellulose against water, gas, high humidity air, and other factors. The modifying processes can be divided into primary and secondary modification. This classification is totally correlated to the fibres as a primary and final product as a secondary treatment [6-8]. Most researchers investigated green, bio-based, and organic materials, as water repellents, to make hydrophobic cellulose-based substrates [8–15]. Li *et al* [4] have declared that starch and its derivatives have desirable potential to use as sizing agents, binder for coating of paper and paper-based industry. Ganicz *et al* [7] have employed the mixture of the silicon compound and starch through secondary modification to reach a hydrophobicity paper. They declared that the abovementioned combination not only can be improved the paper hydrophobicity (more than 90° water contact angle) without any colour changing of the paper surface but also keep the constant level of tensile and tear properties. Yang *et al* [8] has acknowledged that the promising composition of cationic starch and carboxymethyl cellulose exhibited great performance in terms of wettability and strength properties compared with using them separately. The aim of this study was concentrated on applying starch and carboxymethyl cellulose as two bio-based polymers which have been modified with various types of silane to make hydrophobic properties to paper sheets. For this purpose, the modified material was applied to our produced paper sheet via primary (before sheet produce) and secondary treatments (as a coating on the surface of the sheet).

Keywords: Paper, Water repellent characteristics, Starch, Carboxymethyl cellulose, Silane-based substrates.

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Experimental

All chemicals were applied as received and as follows:

Bleached softwood Kraft fibers (Södra black R), starch (wheat Commercial, C*Flex 20002, CAS no, Minneapolis, MN, USA), carboxymethyl cellulose (CMC), (carboxymethylcellulose sodium salt, low viscosity, CAS no, 9004-32-4, POL-AURA, Poland).

Methyltrimethoxysilane (MTMOS) (Sigma Aldrich, CAS no, 1185-55-3, S. Louis, MO, USA), Triethoxymethylsilane (TEOS) (Sigma Aldrich, CAS no, 78-10-4, S. Louis, MO, USA), N-octyltriethoxysilane (NOTES) (Sigma Aldrich, CAS no, 1760-24-3, S. Louis, MO, USA), Aminoethyl-aminopropyltrimethoxysilane (AATMOS) (Sigma Aldrich, CAS no, S. Louis, MO, USA) and commercial product Protectosil SC CONCENTRATE[®] (EVONIK GMBH < Germany). Sodium Hydroxide (CAS no 1310-73-2, CHemPur, Poland), 98% purity, was employed as accelerating for the gelation process.

Preparation of samples:

Paper sheets were produced from bleached softwood Kraft pulp using Rapid-Köthen sheet former (Labomex, Poland) to achieving of the 0.5 mm thickness. For the primary modification, the water repellent materials were added to the fibers to give the hydrophobization to the final papers during the papermaking process. As a secondary modification, Meyer's rod (No. 5 rods) was used which has allowed for an even application of the coating layer on the surface of the sample.

Evaluation of water repellency:

- Water contact angle was determined using a PG-3 goniometer.
- Water uptake evaluation

The mass of each sample was measured after soaking in deionized water for 5 minutes.

- Water absorption from wet air

The hygroscopic properties have been measured using the solution containing mono ammonium phosphate salt (Ammonium dihydrogen phosphate, 30% w/w) which displays the constant level even exposed to high moisture more than 90% and room temperature (20-30°C). Mass of samples was measured after 1, 2, 4, and 8 h. Abbreviations description of the samples is presented in Table 1.

Table 1 Description of treatments abbreviation

Abbreviations	Abbreviation description
PM	Primary modification of cellulose
SM	Secondary modification (i.e. coating on a final product)
WR	Commercial water repellent (Protectosil SC Concentrate [®])
M	Methyltrimethoxysilane
T	Triethoxymethylsilane
N	N-octyltriethoxysilane
A	Aminoethyl-aminopropyltrimethoxysilane
LC15%	Carboxymethylcellulose, low viscosity, 15% w/w
LC30%	Carboxymethylcellulose, low viscosity, 30% w/w

Results and Discussion

Water contact angle evaluation

As shown in Fig. 1, the samples coated with starch and silane-modified carboxymethylcellulose showed better resistance to water droplets compared to the hydrophilic control. It is worth noting, however, that the hydrophobic properties (water contact angle of 100° or even more) can be attributed to the treatments modified with Protectosil SC concentrate and a mixture of starch and methyltrimethoxysilane in both primary and secondary impregnation, respectively. The hydrophobic properties showed a downward trend when the type of alkali groups in the silane structure changed sequentially from M to T, N, and A. This probably means that more hydroxyl groups in the cellulose structure are blocked by methyltrimethoxysilane in order to obtain a hydrophobic effect [12–15].

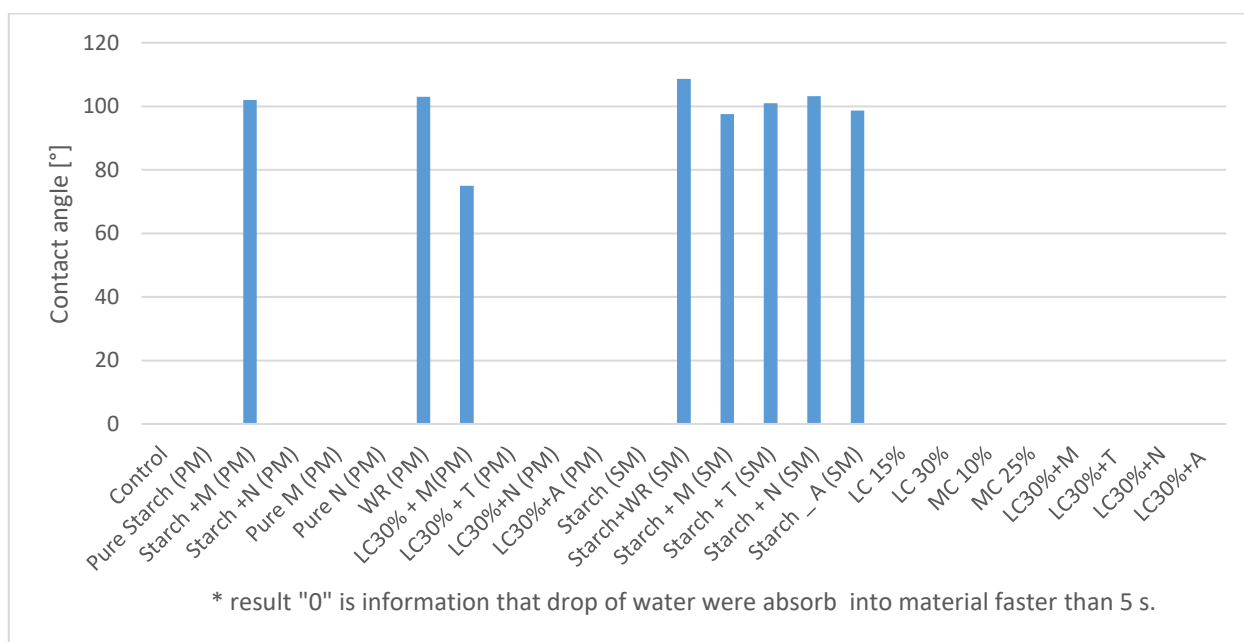


Figure 1 Contact angle results of paper modified via primary and secondary modification

Water uptake measurement

Based on the water uptake test, as seen in Fig. 2 and 3, parallel achievements were obtained that comprehensively explained above mentioned. Water absorption in samples modified with carboxymethyl cellulose along with silane groups was significantly greater than starch-modified treatments supported by silanes [1–3, 7, 8].

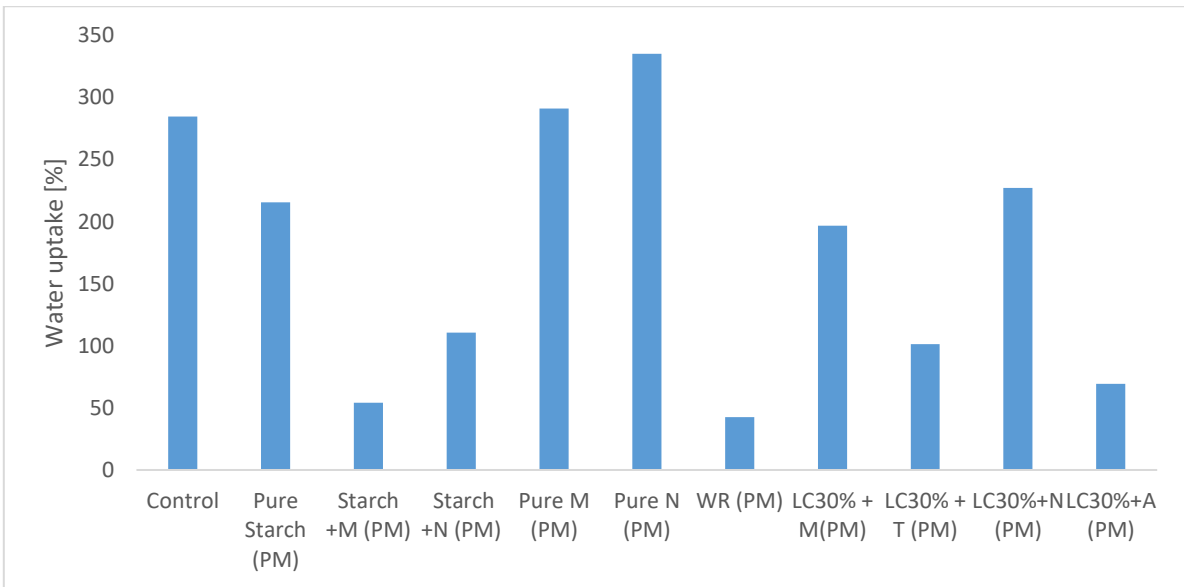


Figure 2 Water uptake of modified paper (primary modification)

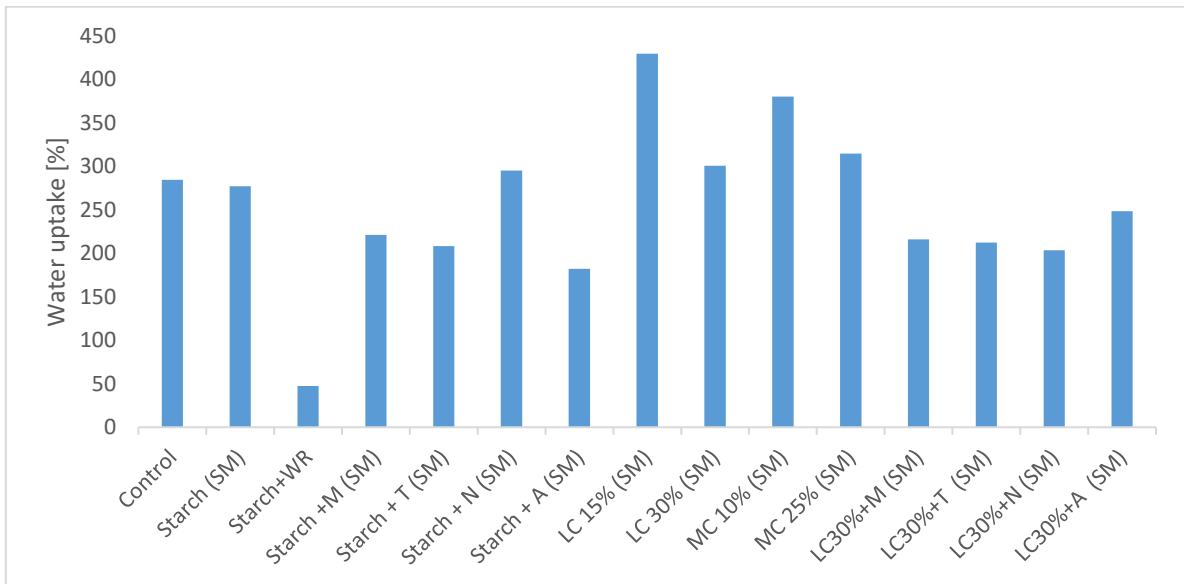


Figure 3 Water uptake of coated samples (secondary modification)

Hygroscopicity properties

As obviously shown in Fig. 4 and 5, water absorption from wet air of treated papers remarkably decreased than untreated samples. This declining trend could be seen in both primary impregnation and secondary ones. So that, in the light of using Methyltrimethoxysilane in treated samples, the reduction tendency reached 20% compared with untreated ones [7, 12-15].

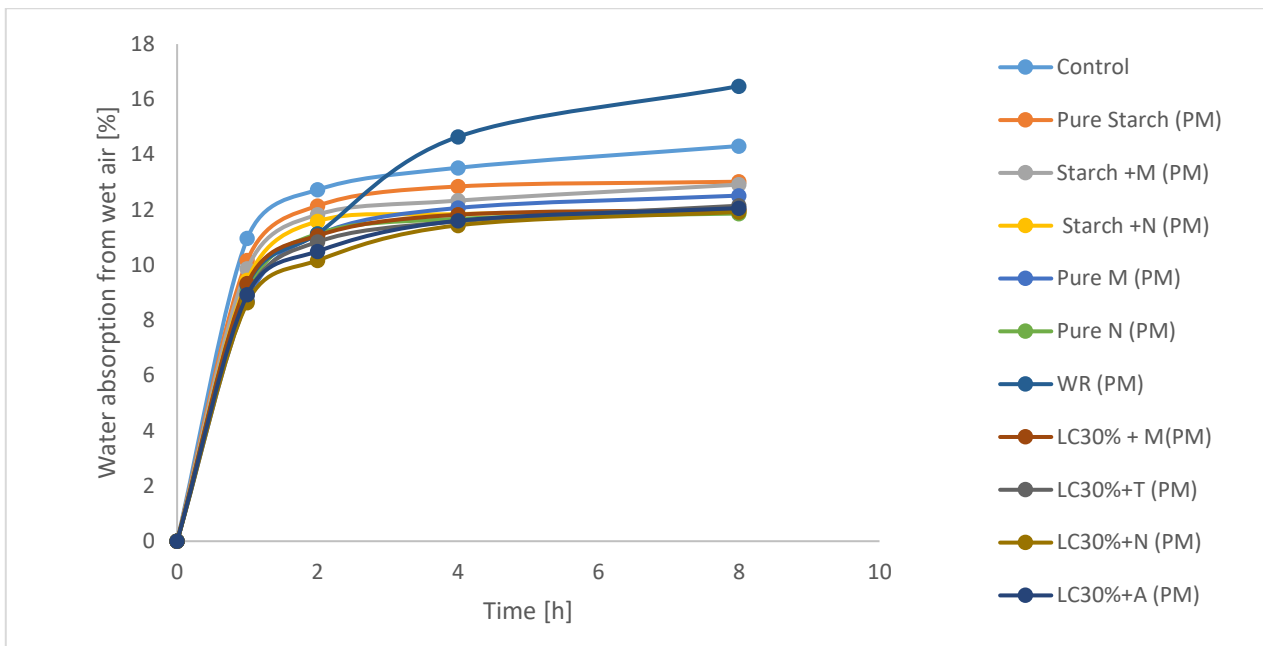


Figure 4 Hygroscopicity (Primary modification)

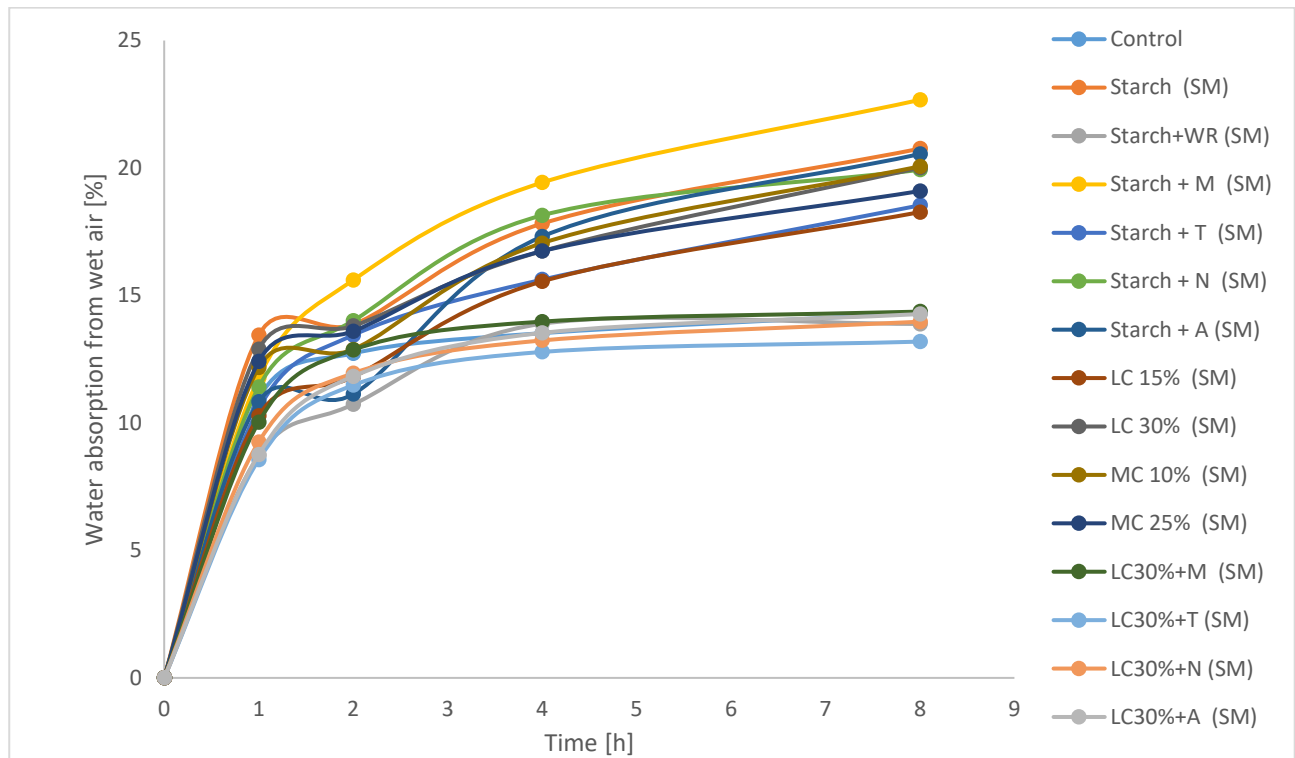


Figure 5 Hygroscopicity (Secondary modification)

Conclusions

Cellulose fibres have great potential for use in the production of packaging materials. However, its structure, due to its hydrophilic nature, is easily damaged by moisture. As a result of the performed experiments, a hydrophobic effect was obtained thanks to the use of two biopolymers, i.e. starch and carboxymethylcellulose. The hydrophobic effect was obtained thanks to their primary or secondary modification with the use of silanes. The best effect was obtained with the use of the starch-silane system in which the hydroxyl groups were blocked with methyltrimethoxysilane. This system is a potential solution for high-quality hydrophobic cellulose packaging materials.

Moreover, additional improvement of the hydrophobic properties can be provided by the use of a fluorosilane, e.g. Protectosil SC.

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Multiple Shear Plane Timber Connections with Birch Plywood and Dowel-Type Fasteners

Tianxiang Wang¹, Yue Wang, Roberto Crocetti and Magnus Wälinder

Background

Timber connections with slotted-in steel plates are commonly used in large-scale structures. One alternative could be timber connections with birch plywood plates (Crocetti et al., 2021; Furuheim et al., 2021). Birch plywood not only exhibits high strength-to-weight ratio, but it is also cost-efficient, it has less environmental impact, it is not very sensitive to tolerances and it has good workability. However, the load-bearing capacity of this type of connection needs to be investigated for its applicability in the structural field. In this study, lumber and plywood were assembled by one or three dowel-type fasteners and then loaded in uniaxial tension. The geometry of the timber components and the fasteners are designed in a way that a ductile behavior of the global connection system and the formation of several plastic hinges in the fastener are expected. The structural performance was analyzed and further compared with the values obtained through analytical models.

Keywords: birch plywood, timber connections, multiple shear planes, dowel-type fasteners.

Experimental

The outer birch plywood (15 mm (thickness)), the inner structural lumber (C24 (45 mm) and planed pine (15mm)) and the inner two birch plywood plates (30 mm) were assembled by means of one or three S235 dowels (diameter: 8 mm) or VGZ screws (outer diameter: 9 mm) (Rothoblaas, 2021), creating four shear planes for each fastener. Four test series were conducted with one dowel (labelled as 1D), one screw (1S), three dowels (3D) and three screws (3S); each test series has 2 replicates, with the constant loading rate of 1 mm/min. The density and the moisture content of each timber component were measured (BSI, 1993), which are 715 kg/m³, 474 kg/m³, 681 kg/m³, 10.9%, 13.1%, 11.8% for birch plywood, C24 and planed pine, respectively. The location of the fasteners was designed according to the minimum requirement of the spacing, edge and end distances for dowels and screws in Eurocode 5 (BSI, 2004).

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Results and Discussion

The piston load-piston displacement curves of all the tested timber connections are displayed in Figure 1 (a). All the connections exhibited a ductile behavior with the formation of plastic hinges in the fasteners (see Figure 1 (b)), as predicted by means of Johansen's theory (Johansen, 1949).

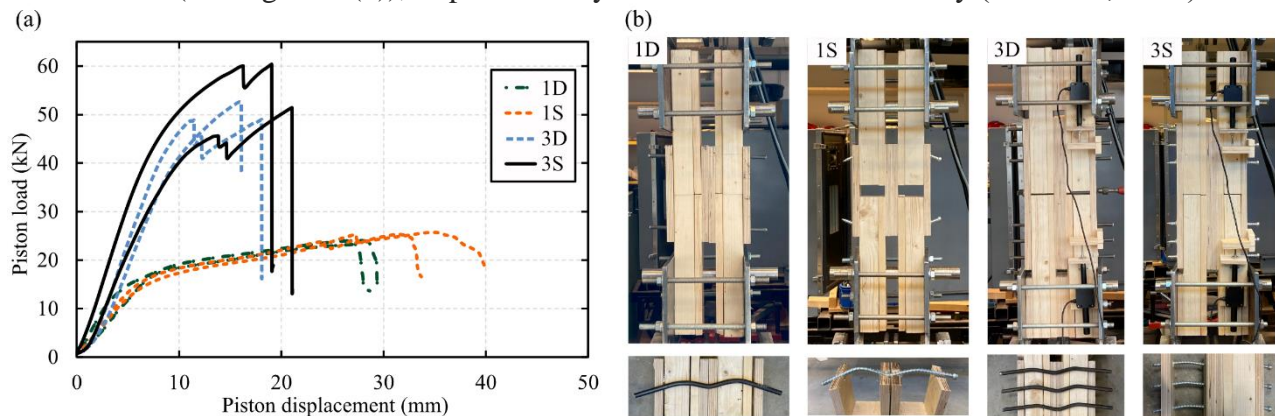


Figure 1 (a) Piston load-piston displacement curves and (b) test setup with corresponding deformed fasteners after the test.

The experimental load-bearing capacities are defined as the maximum forces during the test. From Table 1, it is evident that the capacities of the screw connections predicted by the analytical models based on Johansen's theory and Eurocode 5 (Johansen, 1949; BSI, 2004), are larger than the dowel connections, which are validated by the experimental results. For all the test series, the experimental capacities are approximately 20% larger than the analytical predictions. This discrepancy might be due to different reasons:

1. possible discrepancy between the yield strength of the dowel declared by the producer ($f_y=235$ MPa) and the real yield strength of the dowel (typically, in steel the declared strength is always less than the real strength),
2. the rope effect was not considered in the analytical model for dowel connections, as suggested by Eurocode 5 (BSI, 2004); however, in connections with more than two shear planes, when the dowels yield with the existence of the plastic deformation, the frictions between the dowels and the timber components would enhance the capacities to some extent.

Finally, the effective number of the fasteners, i.e. the ratio of the capacities between the connection systems with three and one fastener, evaluated from the analytical modes, is in good agreement with the experimental ones.

Table 1 Load-bearing capacity and effective number of the fasteners obtained from the experiments and the analytical models for all the test series

Test series	Capacity_exp (kN)	Capacity_ana (kN)	Effective number of the fasteners_exp	Effective number of the fasteners_ana
One dowel (1D)	23.5	18.3	-	-
One screw (1S)	25.3	21.9	-	-
Three dowels (3D)	50.7	38.6	2.16	2.11
Three screws (3S)	55.8	46.3	2.21	2.11

Conclusions

The load-bearing behavior of the timber connection with birch plywood and the dowel-type fasteners were investigated. A ductile behavior in the global connection system and the formation of plastic hinges in the fasteners were observed during the tests. This type of connection is promising in timber structural applications. Nevertheless, further analysis should be performed for the

connections with the utilization of birch plywood as gusset plates when subjected to complex stress states.

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Bending Strength in Softwood Branches

Marie Hartwig¹, Kristofer E. Gamstedt and Malin Wohlert

Background

Compression wood in softwood is often considered as an inconvenience for structural applications, saw and paper milling, since it affects the end product negatively. However, it serves a mechanical function in green state, e.g. in supporting tree branches. These features found in softwood branches can be an example for improving bending strength in engineered composite materials. The maximum bending moment of a branch can be increased significantly solely through the presence of compression wood. This is noteworthy, since chemical components of the compression wood do just differ slightly from the normal wood. The tissue gradients in the branch resulting from variation in density, microfibrillar angle and cell geometry contribute to the strength improvements. In this work, we have investigated the mechanical implications of structural and chemical changes in softwood branches through a model based on Euler-Bernoulli beam bending.

Keywords: compression wood, Euler-Bernoulli beam bending, composite beam

Materials and methods

The branch was modelled as a composite beam with an elliptical cross-section divided into two sections with different material properties. The upper part corresponds to opposite wood and the lower part to compression wood. The different material properties are presented in Table 1. The area ratio was varied for the two materials between the extreme cases of 0 and 100 % compression wood.

The bending moment was calculated based on Euler-Bernoulli beam theory, ignoring shear stresses in the beam due to its relatively small values compared to the induced normal stresses.

Table 1 Material properties of compression and opposite wood

Material	Material property	Value (MPa)	Literature
Opposite wood	Young's modulus	3250	(Dinwoodie, 2000)
	Compressive strength	20	(Timell, 1986)
	Tensile strength	40	(Dinwoodie, 2000)
Compression wood	Young's modulus	1000	(Burgert & Jungnikl, 2004)
	Compressive strength	25	(Timell, 1986)
	Tensile strength	24	(Li et al., 2021)

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Results and Discussion

The results from the model in Figure 1 show that an increasing proportion of compression wood leads to a higher maximum moment carried by the tree branch with an optimum between 35 and 75 %. The moment can increase by 35 % compared to the maximum moment carried by a branch only consisting of opposite wood. On the other hand, a branch consisting of around 90 % compression wood leads to a similar or even lower acceptable bending moment.

Furthermore, four different failure modes were determined, since the stress distribution over the height of the composite beam varies, as shown in Figure 2, depending on the area ratio of compression wood and opposite wood. Compressive failure in opposite wood occurs for proportions of compression wood lower than 35 %, while tensile failure in opposite wood occurs for values above 35 %. The branch/beam fails in compression when it consists of one material no matter if it is pure compression wood or opposite wood.

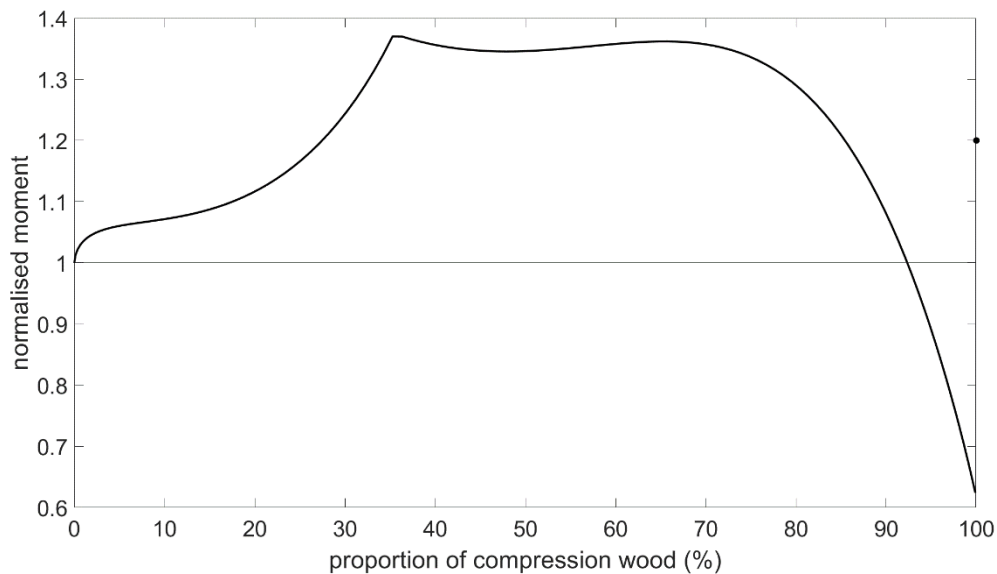


Figure 1 Maximum moment which can be applied before failure normalised to the maximum moment when composite beam only consists of opposite wood.

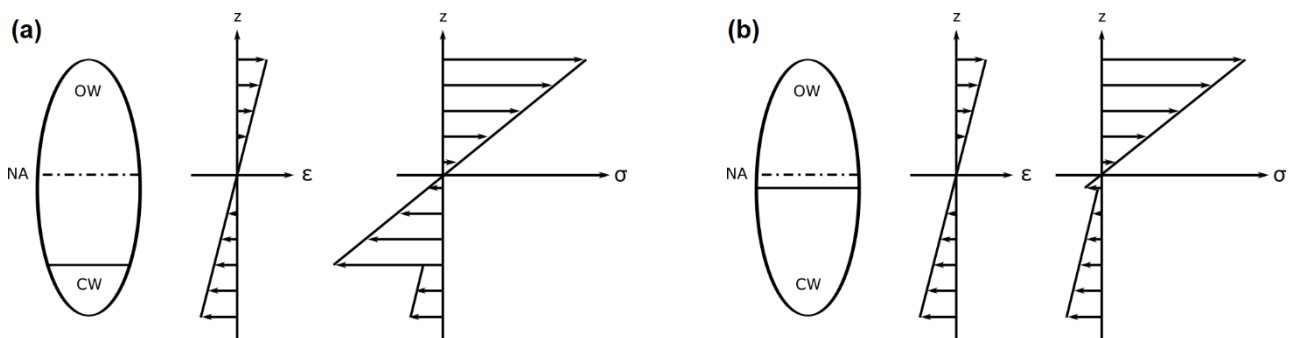


Figure 2 Examples of stress diagrams for (a) less than 35 % of compression wood, and for (b) more than 35 % compression wood.

Conclusions

By the use of an idealized composite beam model and Euler Bernoulli beam theory this study shows the mechanical significance of the presence of compression wood in softwood branches. The optimal composition of a branch cross section was found to be between 35 and 75 % of compression wood. The model is a simple way to elucidate the mechanical function of compression wood as an enhancer of bending moment strength in branches in a living tree.

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Production and Utilization of Briquettes and Improved Cooking Stoves as Alternatives to Sustainable Biomass

Odunayo James Rotowa¹ and Zaccheaus Tunde Egbewole²

Background

The globe these days is confronted with series interrelated demanding situations with reference to climate change, energy, financial sustainability and poverty. Energy-poverty, marked via loss of sustainable electricity and access to modern cooking fuels, creates limitations to accomplishing the Millennium Development Goals (MDGs). About 2.5 billion people persons across the globe depend upon the traditional use of biomass, by and large firewood, for cooking this therefore implies strain is placed on the forest and it resources.

Keywords: Sustainable energy, Briquette, Cooking fuels, Charcoal and Cooking stove

Introduction

Half of the world population, and as much as 95 percent in low income countries, depend on solid fuels, which includes biomass and coal, to satisfy their energy need (Gordon et al., 2014). The World Health Organization lists “indoor air pollution (IAP) from primitive families cooking fires as the main environmental motive of death in the world” mentioning that “it contributes to almost 2 million deaths yearly,” about as many deaths as malaria and tuberculosis put together (Martin et al., 2011). Moreover, cooking with biomass fuels is a key source of climate change through its releases of carbon dioxide (CO₂) and black carbon (Kandlikar et al., 2009). In response, improved cooking stoves are increasingly visible as a tool to enhance respiration fitness and fight climate change. Their use with briquette has and will likewise enhance the sustainability of biomass production for energy functions, have an impact on the policy of partners accountable for investment in renewable energy and will broaden capability and information in developing nations in regards to renewable resources. This paper therefore analyses these factors and their implications as well as policy options for the Production and Utilization of Briquettes and Improved Cooking Stoves. The aim is to address so many identified problems associated with sustainable energy and to provide drivers for biomass use in Nigeria.

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Analysis of trends and pattern of energy consumption in Nigeria

Over the years, research has diagnosed exclusive resources of household energy in developing countries. According to Adegbulugbe and Akinbami (1995), the major use of energy in families is for cooking, accompanied by heating and lighting. Households usually use a mixture of energy sources for cooking. These sources can be categorized as conventional (dung, agricultural residues and gas-wooden), intermediate (charcoal and kerosene) or cutting-edge (LPG, biogas, ethanol gel, plant oils, dimethyl ether and electrical energy). Electricity is specifically used for lighting fixtures and small appliances, in preference to cooking, and represents a small proportion of overall household intake in terms of energy. In sub-Saharan Africa large share of the population depended on biomass because it is the main source in their families' strength. In many parts of this region, more than 90% of the rural population is based on gas-wooden and charcoal (World Bank, 2006). Many households use three-stone fires to cook dinner, without ventilation and the firewood used is harvested in an unsustainable amount (UNDP, 2002). In Nigeria, more than half of the urban households rely on wood, charcoal or wooden waste to meet their cooking needs. More than a third of urban dwellers in some Asian nations also rely upon these fuels (Adegbulugbe and Akinbami, 1995).

Identifying missing links and adopting strategies for way forward

The predominance of biomass in energy consumption mix can be attributed to some factors, consisting of monetary elements inclusive of poverty, unreachability and excessive price of current gasoline in addition to socio-cultural elements, way of life of individuals and the population length and many of these potentials are yet to be identified. Notwithstanding these demanding situations, biomass and biofuels have a few exceptional potentials for the Nigerian economic system. Presumably, if the fuels are sustainably and efficaciously used, then it has wonderful potentials as a supply of easy energy for family use, energy era, transportation and small-scale industries (Rotowa and Donald-Amaechi, 2017). Biomass production as a revenue of rural empowerment through employment and earnings for the agricultural population and to a point, as a complement to hydrocarbons in exports and forex earnings are incontestable. Another important challenge is that of policy failure and lack of political wiliness to promote these technologies nor pursued policies and programs to promote domestic use of biofuels which has the potentials to attract foreign direct investments from where these technologies has successfully been effective including countries in Europe, America and Pacific. As a matter of urgency, it is therefore imperial to adopt technology of maximum utilisation of wood waste that has been successfully proven to be healthy, environmentally friendly and as well sustainable.

Conclusion

This current work, as well as existing literature, implies that the evidence on improved cooking stoves is significant. It is conventional wisdom that it is possible to reduce exposure to indoor air pollution, improve health outcomes, and decrease greenhouse gas emissions in the rural areas of developing countries through the adoption of improved cooking stoves.

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A New Wood Facade Element System - Evaluation of the Montage and Service Performance in Two Multi-Storey Timber Buildings

Karin Sandberg¹, Alexander Scharf² and Göran Berggren¹

Background

A wooden facade system of pine has been developed, adapted for buildings up to eight stories in an urban environment in terms of requirements for fire safety, aesthetic design and service life. The façade system consisting of individual elements mounted on a frame that provides added economical value but also in terms of environmental aspects. Therefore, the design has considered the possibility of recuse and circularity avoiding metal and adhesives but also the choice of raw material. Verification of the facade system's functions has been done through lab tests and by montage of the facade system on two timber buildings in Luleå, Sweden from April 2020 (Berggren et al., 2020). Reported in this article is the performance of the system during montage and operation phase by interviews, photos, measuring moisture content (MC) and deformation of the wooden façade-systems by terrestrial laser scanning.

Keywords: Façade system, pine, design, circularity, moisture, 3-D scanning.

Experimental.

The façade system was mounted on two 4-storey timber buildings to ensure that montage and technical solutions worked. The mounting was documented on-site on several occasions with photos and interviews with the construction workers. Eleven wireless sensors with moisture meters were installed on the backside of the elements. The continuously collected data; electric resistance (EN 13183-2:2002), relative humidity (RH) and temperature (T) were transferred to a database and moisture content (MC) calculated. The deformation of the façade elements was measured by terrestrial laser scanning with a FARO Focus 3D S120 laser scanner and further processed in CloudCompare software. The deformation was determined for each row of elements by the distance of the measurement points to a best-fit 2D plane. The method is described in (Scharf, 2019).

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Results and Discussion

Experience from the montage and interviews on-site

Two workers can easily handle the elements. The façade system can be mounted faster than the current system especially on the surfaces without windows and doors. Around the windows the montage time was about the same as traditional mounting. The environmental conditions were improved by the absence of sound from the nail gun and less lifting several individual pieces of boards.

Moisture measurements

Figure 1 show MC measured with eleven sensors. The average MC was about 20% during winter (low T, high RH) and about 11% during summer. This is in line with the typical response of traditional wooden facades to the annual variation in climate in Sweden.

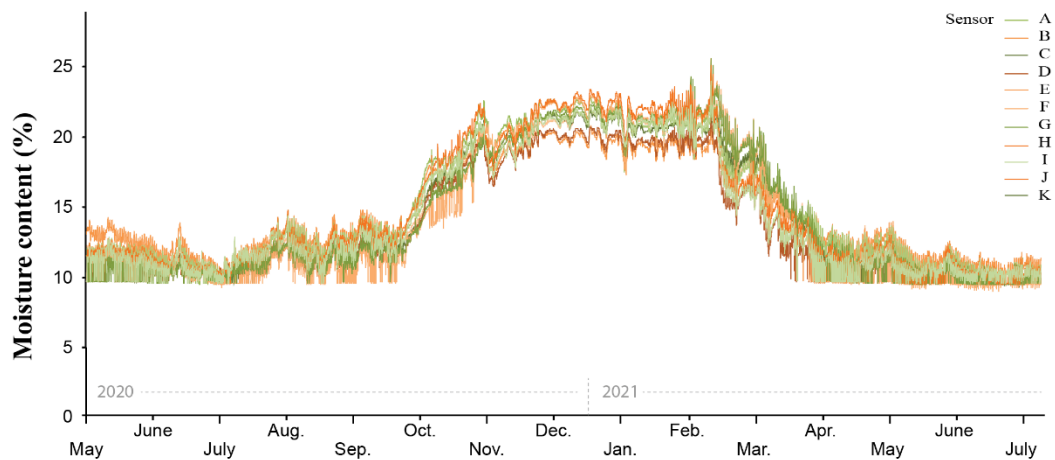


Figure 1 Moisture content (MC) behind the façade elements during measurements for 15 months

Deformation measurements

In Figure 2, the measurements of the façade on-site (A) did deviate by ± 1 cm from a perfect plane, which is at the used scanning distance close to the inherent noise of the scanner. As a reference, elements of different construction type (B) are shown, highlighting the promising performance of the façade elements mounted to the building.

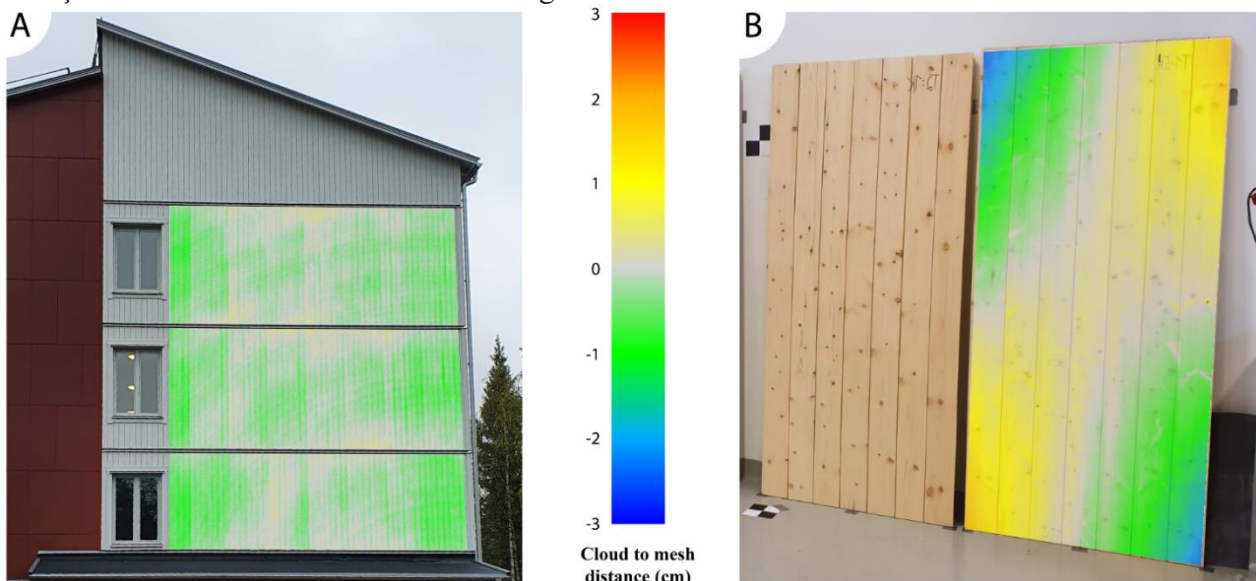


Figure 2 (A) Deformation of façade elements after 15 months on-site, and (B) a laboratory test of free-standing elements after exposure to a high-humidity climate raising the MC of the elements to 20%.

Conclusions

The system can be mounted by construction workers faster or at the same time as traditional wooden facades. The moisture content behind the façade elements was within agreeable limits during more than one year's measuring. The deformation measured with laser scanning gave little deviation from a perfect plane, indicating a better dimensional stability than traditional mounted facades.

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Structural Analysis of Structural Cross-laminated Bamboo Panels Using Timber Design Methods

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Abstract

Densified lamellas of bamboo *Guadua angustifolia* Kunth (*Guadua*) were arranged orthogonally and glued together to form three- and five-layer cross laminated (XLam) panels with symmetrical compositions, which are referred as G-XLam3 & G-XLam5, respectively. This XLam composition is typical of plywood and cross-laminated timber (CLT) panels, hence analytical design methods developed for these systems have been applied to analyse the structural performance of G-XLam panels. For structural analysis G-XLam panels were considered as multi-layered systems composed of contiguous lamellas with orthotropic axes orientated at 0° and 90°. Timber engineering methods normalised by international standards were used in this study for the prediction of the mechanical properties of G-XLam panels. Bending stiffness properties of these panels were predicted using the transformed cross section method to find the modulus of elasticity of beams from the moduli of elasticity of the individual layers.

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Analysis of Cross-Laminated Timber (CLT) Panels upon Exposure to Standard Time Temperature Curve Testing Conditions

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Background

Cross-laminated timber (CLT) is an engineered timber product that has been widely accepted and used in Europe and North America due to its many applications including its lightweight, installation speed and structural capabilities. Despite many applications, there is always a concern about the fire performance of any combustible material including CLT. Initially, it was proposed that the fire performance of CLT would be similar to that of solid timber. Some approximations are being used for engineered timber products acting like solid timber to measure the char depth and strength reduction (White 1995). However, the above assumption was discounted following fire testing of CLT (Klippel et al. 2014). It was observed that the behaviour of CLT is different than solid timber due to the delamination of charred layers which causes an increase in char rate. In delamination, the exposed layer of the CLT is detached from the panel due to fire exposure causing the loss of protection to the underlying timber (Johansson et al. 2018). However, if there was no delamination or layer fall-off occurrence in a CLT fire test, then the charring rate and behaviour of CLT would be similar to that of a solid timber test sample (Klippel et al. 2017). As CLT is a relatively new engineered product, only limited literature appears to be readily available on the manufacturing process of CLT panels. This paper discusses the testing of CLT panels which are manufactured in different ways from two different manufacturing facilities.

The important parameter that was considered in this research was the quality control of the CLT panels during production. Although significant research has been performed in recent years to analyse the fire performance of CLT panels manufactured from Scandinavian and North American timber, it is still uncertain whether the same research can be applied to the Irish grown timber. Therefore, this paper analyses the fire performance of CLT floor panels made from Irish Spruce which are produced using different procedures and tested under similar conditions.

Keywords: Cross-laminated timber (CLT), Charring rate, fire performance.

Experimental Work

In this research, three-layer CLT floor panels were tested in a fire-testing kiln under standard time/temperature curve heating conditions (ISO-834 1999). For this purpose, two different CLT floor panels were studied and compared i.e. National University of Ireland Galway (NUIG) and Munster Technological University (MTU) panels. The mean moisture content of the CLT panels ranged from 12-13%.

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All CLT panels were simply supported and a constant concentrated load of 0.8 kN was applied at the mid-span throughout the fire testing. Type K thermocouples were inserted at different depths, to record internal temperature distribution during firetests. All the specimens were 970 mm long-spanning between supports and 500 mm wide. The specimens are categorized as Series-A and Series-B based on whether it was protected or not and is shown in Table 1. The MTU and NUIG specimens were manufactured under different conditions however both types of panels were bonded using a one-component polyurethane (1C PUR) adhesive. All MTU specimens were manufactured by applying adhesive only on the surfaces using a paintbrush. The panels were then pressed by a load of 140 kg on the top surface of the panels for 48 hours. However, the NUIG specimens were manufactured by applying adhesive with a spreading rate of 160 g/m², and a pressure of 0.6 N/mm². The pressure was maintained for 120 min to allow the adhesive to cure. Thus, the NUIG specimens were manufactured in a more controlled environment using high loading and a uniform spreading of adhesive that resulted in a better bond compared to MTU specimens.

Table 1 Test specimens

Category	Designation	Grade	Dry Density (kg/m ³)	Layers layout (mm)	Orientation*	Protection on exposed side
Series-A	MTU-1	C24	420	40-40-40	p/c/p	No
	MTU-2	C24	420	40-40-40	p/c/p	No
	MTU-3	C24	420	40-40-40	p/c/p	No
	NUIG-1	C16	370	40-30-40	p/c/p	No
Series-B	MTU-12.5FP	C24	420	40-40-40	p/c/p	12.5 mm FireLine gypsum plasterboard
	MTU-15FP	C24	420	40-40-40	p/c/p	15 mm FireLine gypsum plasterboard
	NUIG-12.5FP	C16	370	40-30-40	p/c/p	12.5 mm FireLine gypsum plasterboard
	NUIG-15FP	C16	370	40-30-40	p/c/p	15 mm FireLine gypsum plasterboard

* P stands for parallel orientation and c stands for crosswise orientation of layers.

Results and Discussion

The charring depth versus time of Series-A and Series-B test specimens are shown in Figure 1. The charring rate of all MTU specimens of Series-A was higher than the one-dimensional charring rate of 0.65 mm/min as defined in Eurocode (EN 1995-1-2 2004). The charring rate at various depths are recorded using K thermocouples and are shown in Table 2. The overall charring rate of the MTU specimens was also higher than that recorded in the NUIG specimens. The higher charring rate of MTU specimen was due to layers-fall off which exposed the fresh layer of CLT directly to heat. The application of gypsum Fireline plasterboard on the exposed surface of the CLT panels not only delayed the charring of the specimens but also reduced the charring rate.

Table 2 Test results of all specimens

Category	Designation	Delay in charring of CLT due to protection (min)	Charring rate (mm/min)			
			Depth from the exposed surface of CLT			
			20 mm	40 mm	60 mm	80 mm
Series-A	MTU-1	Not applicable	-	1.18	-	1.27
	MTU-2	Not applicable	1.08	1.4	1.32	1.48
	MTU-3	Not applicable	1.05	1.11	1.2	1.24
	NUIG-1	Not applicable	0.5	0.57	0.72	0.72
Series-B	MTU-12.5FP	19	0.48	0.75	0.88	1.15
	MTU-15FP	39.5	0.49	0.99	0.94	-
	NUIG-12.5FP	24	0.69	0.78	0.90	0.98
	NUIG-15FP	40.5	1.74	1.6	1.19	1.18

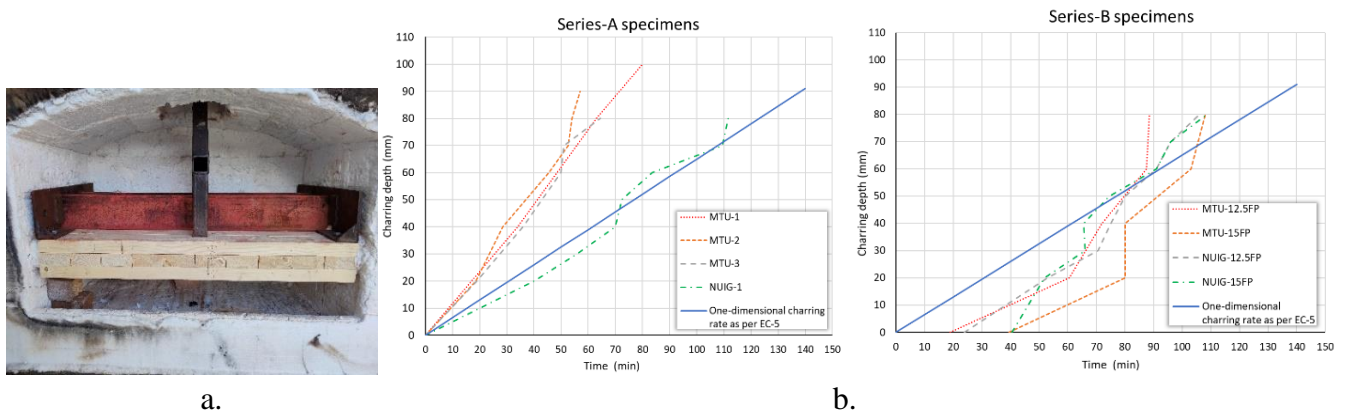


Figure 1 a) Test setup b) Charring depth-time curves of test specimens

Conclusions

The average charring rate calculated for Irish Spruce CLT panels made at MTU was 1.36 mm/min, which is almost twice that of a one-dimensional charring rate of 0.65 mm/min (EN 1995-1-2 2004). The main reason for the higher char rate was the delamination of layers in the MTU panels. However, for the unprotected NUIG panels made with Irish Spruce, the charring rate was found to be 0.72 mm/min. Thus, proper bonding and pressing of the CLT panels during production can minimize the effect of delamination and hence can increase the effectiveness of CLT panels in fire. Fire protection using 12.5 mm and 15 mm gypsum Fireline plasterboard delayed the charring of CLT panels up to 24 min and 40.5 min respectively. This also reduced the charred depth to less than 30 mm for the first 60 mins of the fire test for all specimens protected with gypsum FireLine plasterboard.

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Potential Resources for Future Wood Products

Bahareh Nasiri¹ and Mark Hughes

Abstract

The use of wood in construction is being promoted due to the renewability, and carbon storage potential of wood and instability in the supply of fossil resources. However, if wood resources were used irresponsibly, the increasing use of wood could hamper its supply from the forest to market. One way to tackle this issue, is to use wood in an efficient and sustainable manner. Recovering wood from buildings could contribute to this, by prioritizing the reuse and recycling of wood over energy recovery. Reuse and recycling also contribute to climate change mitigation by storing carbon in wood elements for long periods of time. However, reuse and recycling of wood is not a common waste management practice now. One of the reasons hinders reuse and recycling of wood is that there is not a good understanding of wood that can be reused and recycled from buildings. Currently, wood from construction and demolition projects are sorted into clean and hazardous wood wastes skips by weight. Moreover, every wood skip might contain other materials such as metals and insulation materials as material impurities. So, information on actual wood that can be reuse and recycled is clearly missing. To facilitate this, information about the quantity, type, characteristics, quality and when wood will become available is required to plan for its potential second use. Thus, the aim of this study is to describe three typical Finnish detached houses built in the 1950s, and to assess the volumes, dimension, and characteristics of timber within them, and their potential as a resource for future wood products. The aforementioned building typologies were chosen as they have been predominantly built with timber. Also, detached houses built in the 1950s accounted for 22% of demolished detached houses between 2000-2012 and around 20% of existing Finnish building stock.

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Reuse of Solid Timber - Case Study: IsoTimber Frame System

Carmen Cristescu¹, Karin Sandberg¹ and Urban Haggström¹

Background

IsoTimber is unique type of structural system based on large size wooden boards. A board contains a frame and a core made from timber studs. Air ducts are first milled in the core-studs, which are placed next to each other (Figure 1a), providing good insulation properties (IsoTimber 2021). During the project InFuTReWood (2021) the idea of using reclaimed timber as material for the core-studs was inspired by the research on CLT (Cross Laminated Timber) boards made out of reclaimed wood (Rose et al., 2018, Arbelaez 2019). At the moment the entire building industry chain lacks knowledge on the performance of building products made partially or entirely out of reclaimed timber (timber that had already been used in structures). The aim of this study is to compare the compression strength of IsoTimber boards made from new strength-graded timber with IsoTimber boards containing core-studs made from reclaimed timber.

Keywords: reuse, compression strength test, reclaimed wood.

Experimental

Six standard boards (called S), industrially manufactured according to Isotimber (2021) had the frame and the core from fresh strength graded timber C14 with cross-section 45 mm x 88 mm of pine - *Pinus Sylvestris L.* For the board with reused timber (called R) the frame was made from strength-graded timber and the core-studs (Figure 1a) were made from reused timber of spruce - *Picea Abies L.*, acquired from three demolition sites around Östersund, Sweden. The R-board with reclaimed core-studs was manufactured manually, as described by Henriksson (2021). The size of each tested board was 2400mm length, 1200mm width and 100mm thickness. The compression test was performed at RISE Skellefteå. Boards were placed horizontally, on the test beam. A uniform load was applied longitudinally, using a hydraulic cylinder and steel beams, with movable fastening on the pressure side and rigid fastening on the support side. Load speed: 4 mm/min.

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Results and Discussion

The six standard boards (S1-S6, Figure 2) were tested up to 400kN. The plywood boards cracked at the ends at support under a compression force of ranging from 150 – 220kN. No breaking was noticed in the rest of the block. The R-board containing reclaimed timber as core-studs was tested twice. The first time, when the testing was interrupted at 200kN, no visible damage was visible. The second time the block was tested up to 400kN. The plywood boards were cracked at the ends at a compression force of 220kN. No breaking was noticed in the rest of the block.) The test stopped when the applied load reached 400kN because of limitation in test setup.

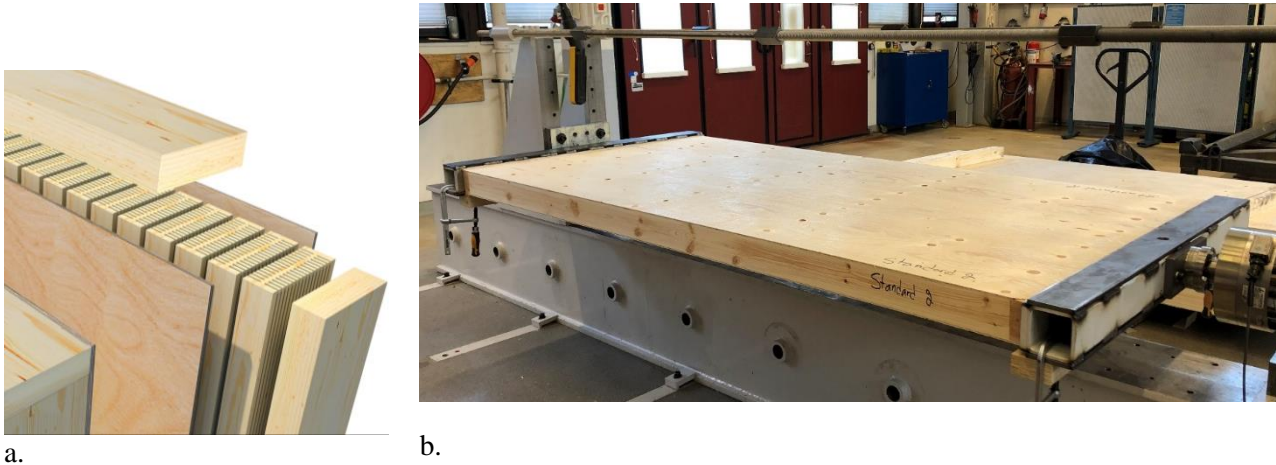


Figure 12 a: IsoTimber composition: core-studs with air ducts placed next to each other, (IsoTimber 2021); b: Test setup : an IsoTimber board under longitudinal compression (photo by Urban Haggström, RISE)

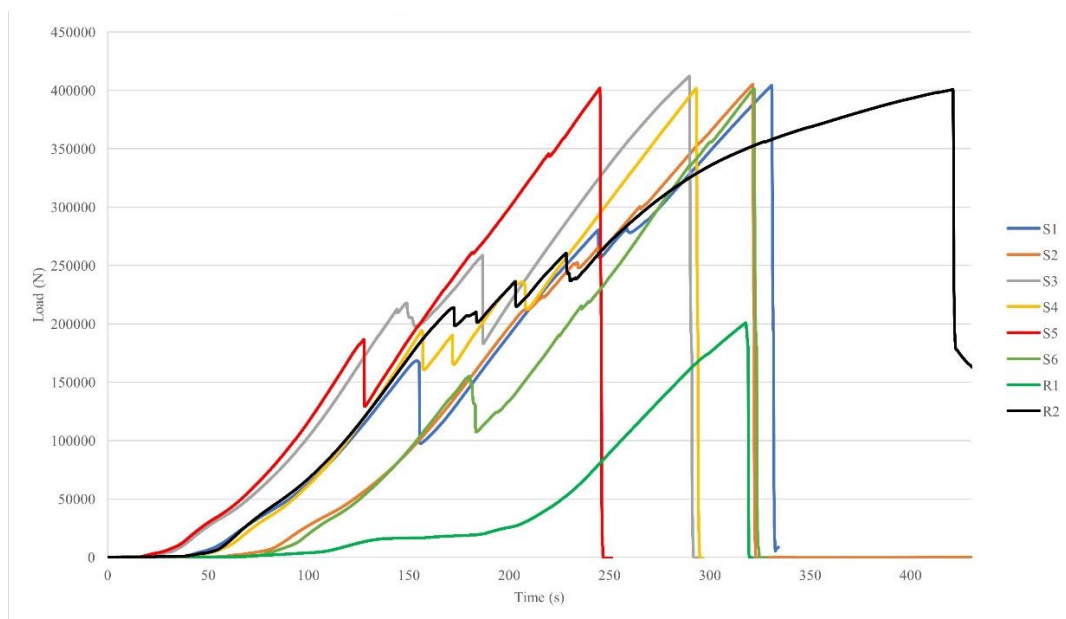


Figure 2 Compression test results. S stands for standard boards (6 samples), R stands for reclaimed timber in the core. R1 and R2 refer to the same samples. R1 shows a pretest of the reclaimed board under a load up to 200 KN and R2 shows the evolution of the same board up to the interruption of the loading at 400 KN.

Conclusions

The board with reclaimed timber as material for core-studs manufacturing had a slightly higher compression strength than the "Standard" boards containing only new C14 grade timber. The reason might be a more careful manual manufacturing process as well as a higher quality of the reclaimed

timber. For future comparison studies it is important to choose the same species, and, for both new and reclaimed wooden products, to measure their mechanical properties with non-destructive testing.

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Experimental Study on an Innovative Timber-Steel Hybrid System

Yue Wang¹, Tianxiang Wang, Roberto Crocetti and Magnus Wälinder

Background

An innovative timber-steel hybrid system, composed of glulam beams reinforced by means of steel rods with shear keys as connectors, was proposed to improve glulam's structural performance in terms of strength, stiffness, and ductility. This hybrid system can be used for both reinforcing prefabricated timber members and retrofitting existing timber members. The aim of this paper is to experimentally study the structural performance of the aforementioned hybrid beams and compare the results with the prediction models given by EC 5 and the numerical models.

Keywords: Timber-steel hybrid structure, mechanical connection, shear key

Experimental

Two glulam beams with the width, height, and length of 90 mm×180 mm×4200 mm were laboratory tested. Each beam had four notches symmetrically placed with respect to the beam mid-span. Four shear keys, which act as shear connectors, were installed on the glulam beam with eight full-threaded screws for each shear key. Six screws were inserted through the shear key plinth and the other two were placed on the glulam bottom as local reinforcement against compression perpendicular to the grain. When the shear keys were installed, the steel rod, could thereafter be anchored through the plinths of the shear key by nuts and washers.

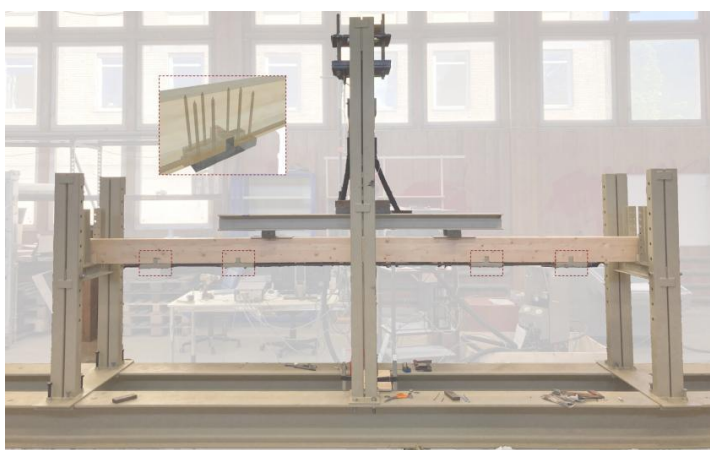


Figure 1 Set-up of the four point bending test and illustration of the shear key assembly.

The hybrid beams were tested under four-point bending, the mid-span deflection of the beam was measured by wire displacement sensors, as shown in Figure 1.

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Results and Discussion

During the test, the four meter-spanned hybrid beam showed a linear elastic behavior during moderate load, after that, the system entered the nonlinear stage. Thereafter, several local cracks were initiated in the glulam beam by the shear key heads (Figure 2a), which resulted in minor drops of force as shown in Figure 3. The final structural failure was detected as a tensile failure at the bottom of the glulam beam at mid-span, as shown in Figure 2b. The capacity is 40.0 kN and the mid-span deflection at failure is 114.8 mm.

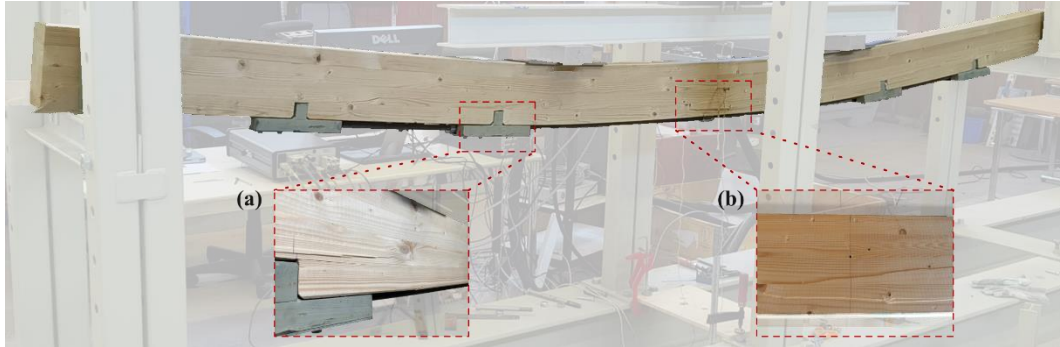


Figure 2 (a) Cracks at the shear key notches. (b) Tensile failure in the glulam beam bottom at mid-span.

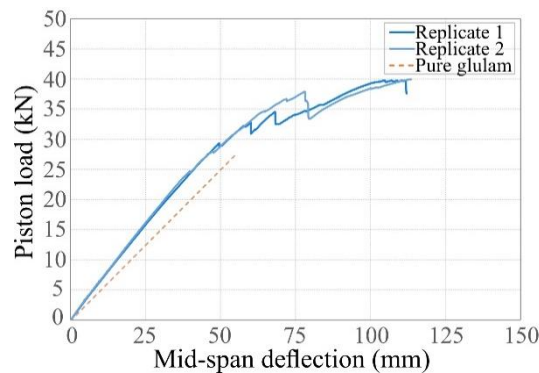


Figure 3 Load-displacement curves of the tested hybrid beams and the pure glulam beam (estimated).

The bending stiffness, capacity (total load from piston), and the mid-span deflection under 20 kN load is illustrated in Table 1. The pure glulam beam is estimated based on Wang et al. (2020). The gamma method given by Eurocode 5 and the numerical method is described in Wang et al. (2021). The presented test results have already subtracted shear deformation and local deformation at support.

Table 1 Bending stiffness (analytical, numerical and experimental), the capacity of glulam and hybrid beams

	Bending stiffness ($N \cdot m^2$)	Deflection under 20 kN piston load (mm)	Capacity (kN)
Pure glulam beam	5.69×10^5	41.4	27.8
Hybrid beam (Test results)	7.98×10^5	28.5	40.0
Hybrid beam (Gamma method)	9.03×10^5	25.1	-
Hybrid beam (Numerical)	8.47×10^5	26.8	-

Conclusions

In this paper, an innovative system composed of steel shear-key connections and steel rods to create timber-steel hybrid (composite) members was experimentally studied. The test results proved a considerably improved strength, stiffness, and ductility of this innovative timber-steel hybrid system. In addition, both the analytical method given by Eurocode 5, and the numerical analysis give satisfactory predictions in terms of the bending stiffness.

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Investigation of Binder-less Medium Density Particleboards Produced from Steam-Exploded Hemp Shives and Wheat Straw

Ramunas Tupciauskas¹, Janis Rizhikovs¹ and Martins Andzs¹

Background

In the last decade, the sector of wood-based composites has a serious challenge for raw materials due to increasing demand of industrial roundwood in all wood consumption sectors (UNECE/FAO, 2019) and petroleum-based adhesives due to its hazardous emissions. Wood-based panels conventionally are made of processed wood bonded by formaldehyde-containing resins or by PMDI resins, both are designated as carcinogenic (Sitz *et al.*, 2017). Approximately 7.8 Mm³ of air are contaminated by formaldehyde emissions per m² of particleboard produced making the greatest impact on human toxicity (Dos Santos *et al.*, 2014). The development of lignocellulosic-based binder-less boards aims to solve these problems looking for suitable agricultural industrial crops to at least partially substitute wood making new composites without hazardous synthetic adhesives (Tajuddin *et al.*, 2016). The study aims a development of medium density binder-less board from steam-exploded hemp (Uso31) shives and wheat straw; these crops are not still enough considered for binder-less board production.

Keywords: hemp shives, wheat straw, steam explosion pre-treatment, binder-less board, properties.

Experimental

Wheat straw and hemp (Uso31) shives were crushed and steam-exploded at previously found (Tupciauskas *et al.*, 2021a) optimal conditions (220°C/2 min). The pre-treated crops were dried to moisture content (MC) of 2±1 wt% and crushed to pass 4 mm sieve eliminating fine fractions of ≤ 0.05 mm and 0.125 mm to prepare different board types. One board type was prepared from 3 layers with particle fraction of 1...4 mm in core layer and ≤ 1 mm in the face layers. Particleboards were hot-pressed without external adhesives with dimensions of 12×310×310 mm and set density of 800 kg/m³ varying temperature (210...220 °C) and time (12...25 min) based on previous study (Tupciauskas *et al.*, 2021b). The obtained boards were evaluated by the thickness swelling (TS) and water absorption (WA) after immersion in water for 24 h (EN 317, 1993), the modulus of elasticity (MOE) and the modulus of rupture (MOR) in bending test (EN 310, 1993), and internal bonding (IB) (EN 319, 1993) according to the relevant EN standard procedures.

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Results and Discussion

The results of the obtained boards properties are outlined in Table 1. The density of the obtained boards varies from 730 to 862 kg/m³ depending on particle MC and pressing time. The higher density was achieved at higher MC (3.5%) and pressing time (20...25 min) during production of first 3 runs from both crops (Table 1). In the next runs of the board production a lower mass of the particles was prepared resulting to lower density. WA of the boards varies from 48 to 64% strictly depending on density: the higher the density, the lower WA. TS of the boards varies from 5.1 to 10.3% depending on pressing temperature and time: the higher the parameters, the lower TS values achieved. The boards bending properties seems to be depend generally on density: the higher the density, the higher the bending values. Taking into account that the obtained boards were produced only from pre-treated crops without external adhesives the achieved water resistance and bending properties are quite good especially for those with a density of above 800 kg/m³. IB values of the boards vary from 0.07 to 0.4 N/mm² characterising too low adhesion of the particles. The low IB values probably were impacted by the inner gaps formation in the core layer detected after the production of the boards. The gaps formation further was prevented by changes in the pressing cycle; however, this didn't improve the IB values (runs 6 and 7 from hemp shives). For further investigation of the boards the addition of sucrose and glucose could be helpful for improvement of IB values (Lamaming *et al.*, 2013).

Table 1 Properties of obtained binder-less boards depending on crop and fabrication variables

Particle fraction mm	^a T _{pr} °C	^b τ _{pr} min	Density kg/m ³	WA %	TS %	MOR N/mm ²	MOE N/mm ²	IB N/mm ²
Hemp shives								
> 0.05-4	210	15	835	51	8.1	14.1	3349	0.11
> 0.05-4	210	20	862	47	7.8	14.5	3270	0.08
> 0.05-4	210	25	860	48	6.6	11.5	2846	0.4
> 0.125-4	220	25	742	60	6.3	8.2	2105	0.26
> 0.125-4	220	30	737	61	5.5	8.9	2003	0.21
4	220	12	739	64	9.0	7.1	2148	0.25
^c 1-4-1	220	12	743	64	10.3	7.0	2017	0.21
Wheat straw								
> 0.05-4	210	15	804	52	6.5	14.8	3492	0.07
> 0.05-4	210	20	802	53	5.4	14.1	2805	0.12
> 0.05-4	210	25	822	51	5.3	15.3	3013	0.09
> 0.125-4	220	25	735	59	5.1	^d nd	nd	0.04
> 0.125-4	220	30	730	61	5.8	7.8	1894	0.02

^aT_{pr} – pressing temperature; ^bτ_{pr} – pressing time; ^c1-4-1 – three layers board with different particle fractions; ^dnd – not detected.

Conclusions

The study showed that there is possible to obtain binder-less boards from steam-exploded hemp shives and wheat straw. There is not necessary to eliminate a fine fraction of the steam-exploded particles as it didn't show an impact on the board properties. An excellent water resistance of the boards was achieved thanks to steam explosion pre-treatment. Bending properties of the boards are quite good however only at the density level of above 800 kg/m³. Further study is necessary of binder-less medium density board to investigate the production parameters improving the IB values at retaining levels of achieved water resistance and bending properties.

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The Innovawood Module Bank: Harnessing the Potential of an International E-Learning Platform in Wood Science and Technology

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Background

The InnovaWood Module Bank (IMB) is an e-Learning platform for standalone wood science and technology modules on MSc level. This contribution describes its main features and benefits for higher education institutions in Wood Science and Technology that might want to join and contribute to the IMB.

Keywords: e-learning, shared learning platform, e-didactics, training in wood science and technology, distance learning, online education.

Objective

The IMB is a cost-effective solution for higher education organisations to expand their study programmes on a high-quality level. Moreover, it provides a broader choice and options for more individualized competency acquisition to the students. Today, we see a plethora of unique and highly relevant wood science and technology modules across Europe. Access to these modules is in most cases limited to the students that are enrolled in a study program and vice versa, these students are also limited to the modules of their curriculum. However, especially considering the new e-Learning boom triggered by the pandemic, these limitations appear somewhat absurd when considering the technical possibilities that are not only available, but actually being widely used on a day-to-day basis in distance learning and collaboration.

Hence, there is a huge potential for increasing value for money for both the lecturers developing the digital content for modules and the students benefiting from them, if training modules were shared online in an international community. Therefore, the main objective of the IMB is to harness this untapped potential for their member organisations. InnovaWood's network includes more than 60 leading research and technology institutes (RTOs), universities and vocational education and training (VET) centres in 28 countries all along the value chain from forestry and wood processing to construction, furniture and biobased products.

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Description

The IMB was launched by several member organisations in 2017. Each organisation must commit to develop and contribute at least one full module in order to obtain access to the series of modules that are offered collectively. The Module Bank is set up on a Moodle platform and managed by InnovaWood ensuring flexible sharing of modules among the organisations while regulating the specific access rights. A module consists of one MSc-level course equivalent to 3 ECTS credits (60 to 90h of work). To ensure complementarity and usability, each module must be a stand-alone course in English. Other languages might be included as subtitles. The online material is ready to be offered as a full (elective) course within a study programme at a partner organisation. Accordingly, tutoring and assessment are the responsibility of the implementers, not of the original module authors.

The collaborative creation of modules comes with further benefits for the engaged organisations. Scientists and teachers who are developing a module can obtain coaching from the InnovaWood e-learning expert group about the didactic concept and quality of content through peer review. Finally, the partner organisations develop a continuous collaboration and widen the possibility for their students to experience foreign higher education organisations without going abroad.

Conclusions

The IMB has the potential to grow into a significant platform for more exchange and collaboration in wood science, research and training in Europe. Interested parties who wish to learn more about how to join the Module Bank initiative are invited to directly contact InnovaWood.

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