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WOOD SCIENCES IN THE CARBON ECONOMY- RETURN TO THE BIRTHPLACE OF U.S. FORESTRY



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Ultra-Lightweight Foamed Insulation Panels Made of Oil Palm Trunk Fibres. Lukmanul Hakim Zaini, University of Natural Resources and Life Sciences, Vienna, Austria.

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BIOMASS/BIOENERGY- MEETING THE NEED WHILE PROTECTING THE ENVIRONMENT

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End-rain Flooring from Underutilized Raw Materials: Solution to Extend and Enhance the Hardwood Resource. Dan Meyer, North Carolina State University, United States

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Individual Tree Analysis via Person-Carried Laser Scanning (PLS) in Forest Stands. Andreas Tockner, University of Natural Resources and Life Sciences, Vienna, Austria.

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Workforce Diversity in the US Forest Sector: What Can Data Tell Us? Jaana Korhonen, Oak Ridge Institute for Science and Education (ORISE), United States.

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MASS TIMBER – NEW MATERIALS, ENGINEERING PROPERTIES, AND CONNECTIONS

Evaluating Operational LCA of Mass Timber Buildings: A Case Study of Adohi Hall

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Prof. Tahar Messadi - University of Arkansas
Ms. Mahboobeh Hemmati - University of Arkansas
Dr. Hongmei Gu - USDA Forest Service, Forest Products Laboratory

Abstract

The issue of climate change has gained increased global attention, and buildings play a significant role in contributing to carbon emissions. Specifically, heating, cooling, lighting, and other building operations are responsible for 28% of the world's carbon emissions. It is crucial, therefore, to evaluate the environmental impact of different buildings and implement sustainable strategies to mitigate their carbon footprint.

While numerous studies have been conducted to determine the carbon footprint of conventional building operation phases, there is a lack of available data on the operational carbon emissions of mass timber buildings. This study, therefore, aims to quantify the carbon footprint of a mass timber building, using Adohi Hall as a case study. Adohi Hall is the largest residential mass timber building in the United States, situated in Fayetteville, Arkansas.

The research team obtained data on the building's energy consumption and input usage (such as water, electricity, chilled water, and natural gas) from 2020 to 2023, spanning three years. The data collected from the University of Arkansas Facilities Management (FAMA) includes the yearly, monthly, daily, and hourly consumption of energy and water usage and cost, as well as the identification of the fuel mix used. For this building, the chilled water system is used for cooling and the natural gas for heating energy.

The study relies on Life Cycle Assessment (LCA) as its primary tool. The research team utilized SimaPro 9 software, Ecoinvent v3.7 database, and the USLCI database to accurately model Adohi Hall's LCA during the operational phase. The study's findings result in a thorough analysis of the global warming potential of the targeted mass timber building during the operation phase, allowing for comparison with similar buildings in future studies.

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From Seedling to Product: The Louisiana Forest Products Innovation Center at Louisiana Tech University

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Abstract

The Louisiana Forest Products Innovation Center at Louisiana Tech University will serve as a hub for connecting disciplines from growing trees to developing products as well as enhancing private-public partnerships for innovative manufactured forest products. We will innovate, test, commercialize, and showcase engineered wood, wood fiber, and woody residuals-based products generated from forests of the U.S. Gulf South region. We hope to develop a knowledgeable, research-trained, and diverse workforce to serve the forestry and wood products industry, and to promote sustainable utilization of biomaterials to accelerate the transition to a low carbon future. Research areas within the center will include development and testing of forest products. We will investigate how forest management and field performance affects new material development and applications, such as Cross-laminated timber (CLT) and residue properties, utilizations, inspections, and commercialization in the region.

Keywords: CLT, workforce development, forest products, biomaterials, residue, biomass, conversion processes

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Study on Load-carrying Capacity and Failure Modes of Tensile-bolted Joints in Timber Structures

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Abstract

Tensile-bolted joints, commonly utilized in timber structures, are beam-column and column-base joints characterized by their semi-rigidity, high load-carrying capacity, and ease of assembly. This study focuses on tensile-bolted joints that connect a timber column and steel base. When a bending moment acts on the tensile-bolted joint, internal bolts counteract a tensile force, causing a washer to compress the timber beneath. Tensile yielding of a bolt is recognized as the safest failure mode among those observed in tensile-bolted joints. To guide the failure mode toward the tensile yielding of a bolt, a thorough understanding of other failure modes of timber is required: compressive yielding of the timber under the washer; bending of the column; and splitting of the timber under the washer. Moreover, regarding the rotational stiffness, the Japanese standard formula for embedment stiffness is assumed that dowels compress the timber and is thus not valid for the timber compressed by square-type plates in tensile-bolted joints. Therefore, this study aims to investigate the failure modes and embedment stiffness of the timber through bending tests and proposes formulas predicting their load-carrying capacity. The tests were performed as static cyclic tests simulating seismic forces. From experimental results, the compressive yielding had the highest ductility, and its load-carrying capacity could be predicted by a current calculation method. The bending failure occurred at a load lower than the design load by the Japanese standard. This may be due to stress concentration around the specimen's notches and decreasing bending strength by cyclic loading. Moreover, because no model exists for the splitting failure, a new model for assessing the load-carrying capacity based on fracture mechanics was proposed. The model indicated good agreement with the experimental results, which was 1.03 times that of the calculated results. In addition, this model was applied to a uniaxial tensile test of tensile-bolted joints that resulted in splitting failure and showed good approximation with the experimental results. In the bending tests, the rotational stiffness was twice that of the calculated values. A possible explanation for this is that the experimental values for embedment stiffness were higher than the calculated values. This study showed that the calculation method for dowels underestimates the embedment stiffnesses of the timber compressed by square-type plates and a column's butt end in tensile-bolted joints.

Keywords: tensile-bolted joints, column-base joints, load-carrying capacity, timber, splitting, rotational stiffness

Introduction

In recent years, high-rise timber structures have been increasing for environmental requirements across the world. Tensile-bolted joint, which use high-performance tensile bolts to provide a moment-resisting connection, are commonly utilized in Japan. They are used as column-beam joints or column-base joints in high-rise timber structures (Sakata et al. 2022) due to their semi-rigidity, high load-carrying capacity, and ease of assembly (Fig. 1). When a moment acts on the tensile-bolted joint, the bolt counteracts tensile loads, causing the washer to compress the timber (Fig. 2). Previous research (Inayama 2013, Araki et al. 2018) pointed out four predicted failure modes of column-base tensile-bolted joints: tensile yielding of a bolt; shearing failure from the washer to the column's butt end (Fig. 3); compressive yielding of the timber due to compression in a fiber direction (Fig. 4); and bending failure of the column with a defect in the cross-section (Fig. 5). It is assumed that there are only four failure modes of column-base joints, and the splitting of the timber under the washer (Fig. 6) occurs after the compressive yielding. However, Tao et al. (2018) observed that this splitting occurred before the compressive yielding.

Figure 1. Tensile-bolted joints in building

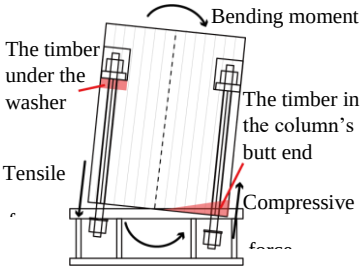


Figure 2. Geometry of a column-base joint

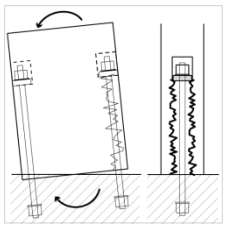


Figure 3. Shearing failure

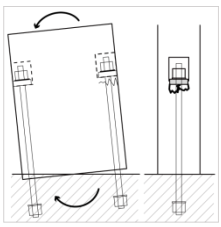


Figure 4. Compressive yielding

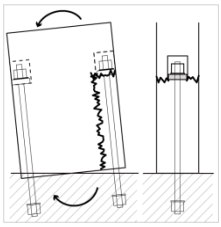


Figure 5. Bending failure

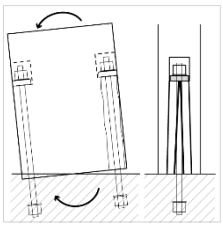


Figure 6. Splitting failure

It is generally accepted that the tensile yielding of a bolt is safer than the failure modes of timber. Therefore, to guide the failure mode toward the tensile yielding, a thorough understanding of the other failure modes of timber is required. This study aims to investigate the failure of timber through bending tests and proposes formulas for predicting their load-carrying capacity. Regarding the tensile yielding of a bolt, good agreements between calculated values and experimental values were shown through bending tests on tensile-bolted joints by Araki et al. (2018) and Akiyama et al. (2022). For the shearing failure, a method that can predict the failure load on tensile-bolted joints was proposed by Hayasaki (2017). For the compressive yielding, Totsuka et al. (2021) reported that the spreading parallel to the grain was very small through partial compression tests. Regarding the bending failure, Yamazaki et al. (2022) pointed out that the bending strength subjected to cyclic load is smaller than that of subjected to a monotonic load on tensile-bolted joints. For the building capacity, it is important to consider not only the failure load but the stiffness of joints. The rotational stiffness of tensile-bolted joints is affected by the embedment stiffness of the timber under the washer and the timber in the column's butt end (Fig. 2). These embedment stiffnesses are determined by the formula proposed by Hirai (1982). However, this formula focused on dowels, and there has been limited research on the embedment stiffness of the timber under a square-type washer and the timber in the column's butt end. In the present study, cyclic loading tests on column-base tensile-bolted joints are conducted to examine the following three issues that are highlighted in the literature above. Firstly, the Japanese standard does not account for cyclic load that simulate seismic force in predicting bending failure. Secondly, in the present assumption, the splitting failure is evaluated as the compressive yielding of the timber even though there are examples of the splitting failure occurring prior to the compression yielding. Thirdly, the current calculation method for

embedment stiffness is based on the assumption that dowels compress the timber and is thus not valid for the timber compressed by square-type plates and the timber in the column's butt end in tensile-bolted joints.

Specimen and Test Setup

Bending tests on column-base joints were conducted with glulam columns consisting of Japanese cedar, *Cryptomeria japonica*, with an average density of 378 kg/m^3 and moisture content of 12 %. The experimental parameters were a cross-sectional dimension (450×180, or 450×120 mm^2) and a bolt length (400 or 600 mm). In Figure 7, a total of six specimens, two for each series, were used. PC steel bars with high tensile strength were used as the bolts (φ23 mm) to prevent the occurrence of the tensile yielding of a bolt. The tests were performed as static cyclic tests simulating seismic forces, which was defined as the story drift angle (α), and each loading sequence was repeated three times as shown in Figure 8. α is calculated by dividing the average horizontal displacement of the point of application by the distance from the column base to the point of application l, 1500 mm. The α value was varied from 1/450, 1/300, 1/200, 1/150, 1/100, 1/75, 1/50, and 1/30 (rad). After α =1/30 rad, testing was continued with a monotonic load to the point of failure. In Figure 9, the test setup of the specimens, the load was measured by 100-kN capacity load cells L1, L2, and L3. The displacement was measured by displacement sensors at D1, D2 (horizontal) and D3, D4, D5, D6 (vertical). The absolute values of measurements are expressed in italics for example $L_1, D_{1\ldots}$.

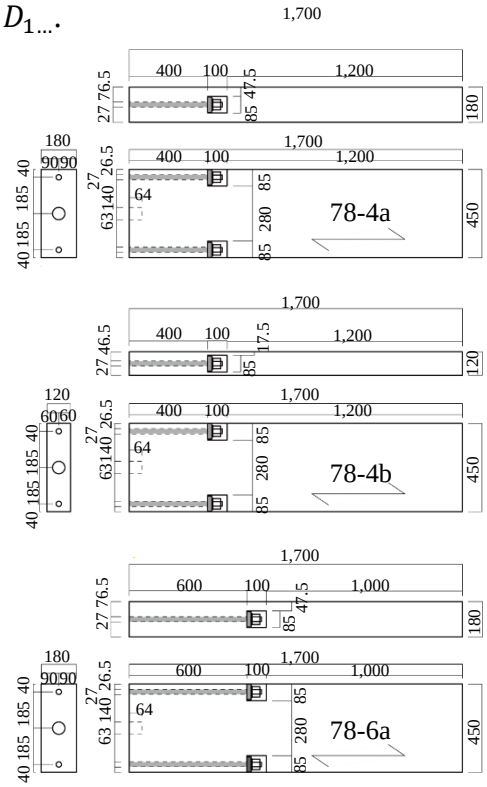


Figure 7. Specification of each specimen [mm]

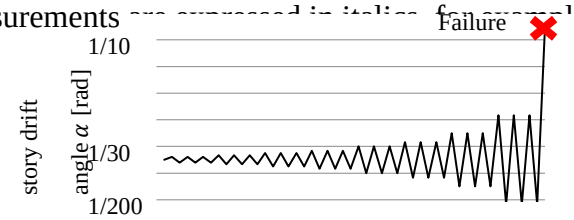


Figure 8. Loading protocol

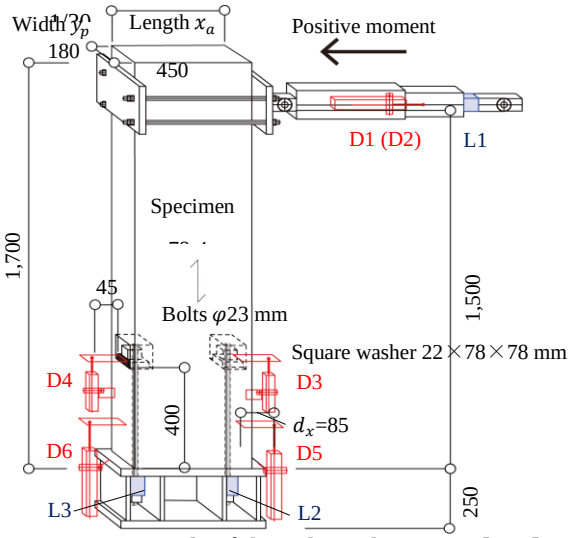


Figure 9. Details of the column-base joint [mm]

Calculation Method for Stiffness and Ultimate Moment of Column-Base Joints

We introduce the calculation method for stiffness and ultimate moment by Inayama (2013) in the elastic range of tensile-bolted column-base joints. Figure 10 shows the tensile bolt and the column's butt end subjected to tensile (T) and compressive (ΣN) force, respectively, when a moment is applied to the joint. On the tensile side, the tensile force T is calculated as:

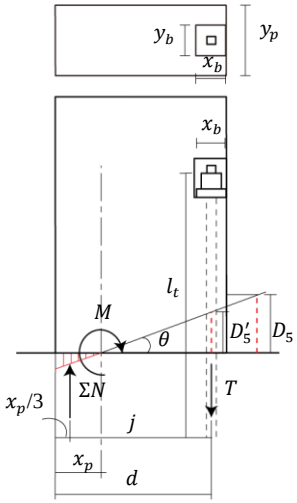


Figure 10. Schematics of the force at the column-base ioint

$$(d - x_{p,cal})\theta = T\big((1/K_2) + (1/K_{3,cal})\big), \qquad K_2 = E_t A_t / l_t \,, \tag{1}$$

$$K_{3,cal} = x_b \cdot y_b \cdot k_{0b,cal}, \quad k_{0b,cal} = E_{c0}/(31.6 + 10.9 \cdot x_b), \tag{2}$$

where d is a distance from the edge of a specimen to a bolt shaft center (mm); $x_{p,cal}$ is a distance from the neutral axis to the edge of a specimen (mm); θ is the rotational angle (rad); K_2 and $K_{3,cal}$ are the stiffness of a bolt and the embedment stiffness of the timber parallel to the grain, respectively (N/mm); E_t is the Young's modulus of a bolt (N/mm^2); A_t is an effective cross-sectional area of a bolt (mm^2); l_t is an effective length of a bolt (mm); $x_b \cdot y_b$ is a cross-sectional area of a washer (mm^2); $k_{0b,cal}$ is the embedment stiffness of the timber under the washer (N/mm^3), presented by Hirai (1982); and E_{c0} is the Young's modulus of the timber (N/mm^2). On the compressive side, the compression force ΣN is calculated as:

$$\Sigma N = 1/2 \cdot x_{p,cal}^2 \cdot y_p \cdot \theta \cdot k_{0c,cal} \,, \qquad k_{0c,cal} = E_{c0}/\big(31.6 + 10.9 \cdot x_{p,cal}/2\big) \,, \tag{3}$$

where y_p is the width of a column (mm) and $k_{0c,cal}$ is the embedment stiffness of the timber in the column's butt end (N/mm^3). When there is no axial force on the column, an equilibrium condition $T = \Sigma N$ is satisfied and leads to an equation (4) by using equations (1), (2) and (3).

$$\frac{1}{2} x_{p,cal}^2 \cdot y_p \cdot \theta \cdot \frac{E_{c0}}{31.6 + 10.9 \cdot (x_{p,cal}/2)} = \frac{(d - x_{p,cal})\theta}{(1/K_2) + (1/K_{3,cal})} \tag{4}$$

Thus, $x_{p,cal}$ and the rotational stiffness K_θ (kNm/rad) of column-base joints are calculated as:

$$x_{p,cal} = \frac{b \pm \sqrt{b^2 + ac}}{a}, \quad a = y_p \cdot E_{c0} \cdot \left(\frac{1}{K_2} + \frac{1}{K_{3,cal}}\right) + 10.9, \; b = 5.45d - 31.6 \,, \; c = 63.2d \,, \tag{5}$$

$$M = T \cdot j = \frac{(d - x_{p,cal})\theta}{(1/K_2) + (1/K_{3,cal})} \cdot j \quad \therefore K_\theta = \frac{(d - x_{p,cal})j}{(1/K_2) + (1/K_{3,cal})} \,, j = d - \frac{1}{3} x_{p,cal} \,, \tag{6}$$

where j is a distance between the stress centers (mm) and M is a moment on the total (kNm). The ultimate moments are presented as:

$$M_{ut} = A_t \cdot F_{ty} \cdot j, \quad M_{yb} = x_b \cdot y_b \cdot F_e \cdot j, \quad M_{us} = (2x_b + y_b) \cdot l_s \cdot F_s \cdot j, \quad M_{cu} = Z_c \cdot F_{bc} \,, \tag{7}$$

where M_{ut} is an ultimate moment decided by the tensile yielding of a bolt (Nmm); F_{ty} is a tensile design strength of a bolt (N/mm^2); M_{yb} is a compressive yielding moment in the timber under the square washer (Nmm); F_e is a compressive strength of the timber (N/mm^2); M_{us} is a shear failure moment (Nmm); l_s is a shearing length (mm); F_s is a design shear

strength of a column (N/mm^2); M_{cu} is a bending failure moment of a column (Nmm); Z_c is a cross-sectional coefficient of a column (mm^3); and F_{bc} is a design bending strength of a column (N/mm^2).

Experimental Results and Discussion

Failure Modes of Experimental Results

All the failure modes observed in the tests are shown in Figure 11. The compressive yielding occurred in three specimens (78-4a2, 78-6a1, 78-6a2). Moreover, splitting was observed in the 78-4a1 specimen, despite having the same dimensions as 78-4a2. The bending failure was observed in specimens with the narrower column widths (78-4b1, 78-4b2). Figure 12 shows the $M-\theta$ relationships of the three failure modes, which are calculated as:

$$M = L_1 \cdot l, \quad \theta = (D_5 + D_6)/(x_a + 2d_x), \tag{8}$$

where x_a is the length of the column and d_x is a distance from D5 or D6 to the specimen (Fig. 9). Specimens of the compressive yielding showed a steady state after reaching the maximum moment. On the other hand, the specimens of the splitting and bending failure showed a rapid strength degradation after reaching the maximum moment (Fig. 12). A comparison of the ultimate moment with experimental and calculated values for the same failure modes indicated that the experimental values were smaller than the calculated values in the case of the bending failure. Regarding the ultimate moment of the compressive yielding, experimental values were on average 1.7 times larger than the calculated values. Substituting $F_{e2} = L_{2,max}/(x_b \cdot y_b)$ into F_e (Eq. 7), experimental values were in good agreement with the calculation, which shows the validity of the calculation of the compressive yielding moment M_{yb} (Fig. 12 (c) cal. 2). For the bending failure, overestimation of the moment could be due to both stress concentration around the specimen's notches and the effect of cyclic load. The effect is that when the negative moment is applied to the joint, the compressive yielding of the timber around the notches reduced the bending strength. After that, the positive moment subjected to the joint made the timber around the notches resist the tensile force. Therefore, the specimen 78-4b2 was destroyed at the moment in α =0.0126 smaller than the maximum moment in α =0.0133. This showed the need to consider that the cyclic load reduces the bending strength of timber after the compressive yielding.

Rotational Stiffness K_θ

Experimental results of K_θ were about twice as large as the calculated results for all specimens (Fig. 12). This result could be due to the embedment stiffness of the timber under the washer k_{0b} and the timber in the column's butt end k_{0c}. Experimental values of $k_{0b,exp}$ are calculated as:

$$k_{0b,exp}=K_{3,exp}/(x_b \cdot y_b), \qquad K_{3,exp} = 1/(1/K_1 - 1/K_2) \tag{9}$$

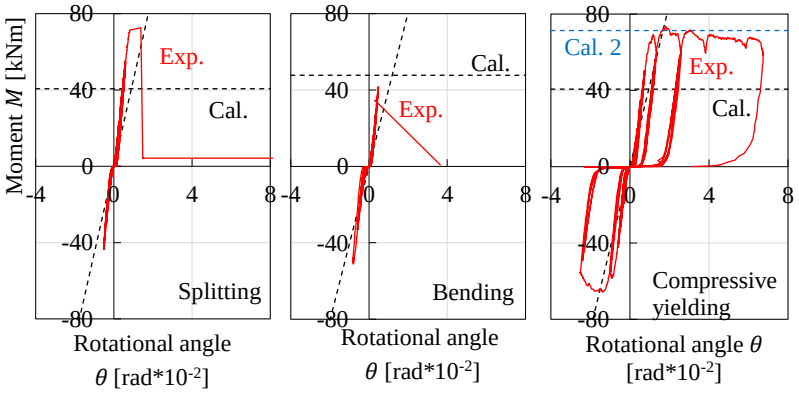
where K_1 is the stiffness of the joints (N/mm), obtained from the vertical displacements of the bolt shaft center D_5', D_6'(Fig. 10) and the load measurements L_2, L_3. D_5', D_6' are given by D_5, D_6, $x_{p,exp}$ and θ. At the line of the bearing length 78 mm in Figure 13, our experimental values $k_{0b,exp}$ shown as Exp. 1 was on average 3.1 times higher than the calculated values (Eq. 2). For the previous experiments, almost all experimental results were higher than the calculated values (Fig. 13). The experimental values of $k_{0c,exp}$ and $x_{p,exp}$ are calculated as:

$$k_{0c,exp} = 2 \cdot \Sigma N/(x_{p,exp}^2 \cdot y_p \cdot \theta), \quad x_{p,exp} = 3 \cdot (d - j) = 3 \cdot (d - L_1 \cdot l/L_2) \qquad (10)$$

Figure 14 shows that the experimental values $k_{0c,exp}$ was on average 1.95 times higher than the
calculated values (Eq. 3). Consequently, our experimental results showed that the current calculated method (Eq. 2 and 3) underestimates the embedment stiffness of the timber under the squared washer and the timber in the column's butt end. This indicates the need to develop a new method of evaluating the embedment stiffness in tensile-bolted joints.

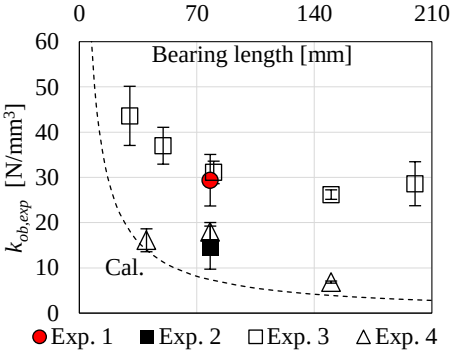
(a). Splitting failure (b). Bending failure (c). Compressive yielding

Figure 11. Failure modes



(a). 78-4a1 (b). 78-4b2 (c). 78-6a2

Figure 12. $M - \theta$ relationship of each failure mode



Note: Exp. 2 is the bending test results by Akiyama, 2022

Exp. 3 is the partial compression test results by Akiyama, 2022

Exp. 4 is the test results of uniaxial tests by

Figure 13. Embedment stiffness $k_{0b,exp}$

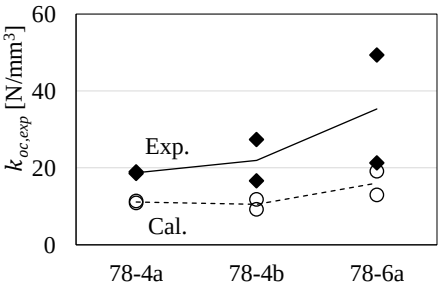


Figure 14. Embedment stiffness $k_{0c,exp}$

New Evaluation Method of Splitting

A previous study by Van (2000) investigated the splitting in dowel-type connections by using G_c, energy release rate, which is a linear elastic fracture mechanics parameter. We proposed a new model for assessing the load-carrying capacity of the splitting failure based on fracture mechanics in tensile-bolted joints. In addition, the proposed model was applied to uniaxial tensile tests of tensile-bolted joints shown in Figure 15 (Totsuka et al. 2022). The test parameters were the washer's dimension and the column's width. Splitting is considered to occur when the amount of strain energy W by the compressive force under the washer reaches the energy to form the crack area ($= G_c \cdot A$). The amount of W is equal to the area of the load-displacement ($P-\delta$) relationship under the washer. Based on the experimental results, the $P-\delta$ relationship can be modeled as an isosceles triangle with a linearly symmetric decrease in the load after the maximum load, resulting in the energy equilibrium condition (Eq. 11).

$$W = 1/2 \cdot P\delta \cdot 2 = P\delta = G_c \cdot A, \quad \delta = T/K_{3,exp}, \quad G_{Ic} = 0.6 \cdot (39.6\gamma_0 - 4.44)^2/G, \quad (11)$$

where G is shear modulus (N/mm^2) and γ_0 is density of the timber (kg/m^3). In fracture mechanics, three failure modes are recognized: mode I (opening), mode II (sliding), and mode III (tearing); G_c in each mode is different. The calculation method of G_c in mode I, $G_{\mathrm{I}c}$, was proposed by Yasumura (2002). Furthermore, our new method originally assumes that the splitting of tensile-bolted joints is a mixed mode of mode I and II as shown in Figure 16. Because G_c in mode II, $G_{\mathrm{II}c}$, has not yet been proposed, experimental results by Kambe et al. (2011), $G_{\mathrm{II}c}$=2.18, was used. Solving equation (11), the maximum load in the splitting failure can be calculated as:

$$P_{split,H} = P_{split,V} \cdot j/l\,, \qquad P_{split,V} = \sqrt{(G_{\mathrm{I}c} \cdot A_1 + G_{\mathrm{II}c} \cdot A_2) \cdot K_{3,exp.}}\,, \tag{12}$$

where A_1 and A_2 are the crack area of mode I and II (mm^2), respectively; $P_{split,H}$ is a horizontal maximum load of the splitting failure in the cyclic tests; and $P_{split,V}$ is a vertical maximum load of the splitting failure in the uniaxial tensile tests. In the cyclic tests, A_2 was assumed three cracks (Fig. 16). In the uniaxial tests, A_2 was assumed two cracks calculated by entire width of the column. The calculated results indicated good agreement with the experimental results, which were 1.03 times that of the calculated results in the cyclic tests and 0.8~1.2 times that of the calculated results in uniaxial tensile tests as shown in Figure 17.

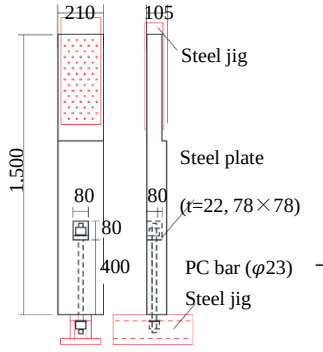
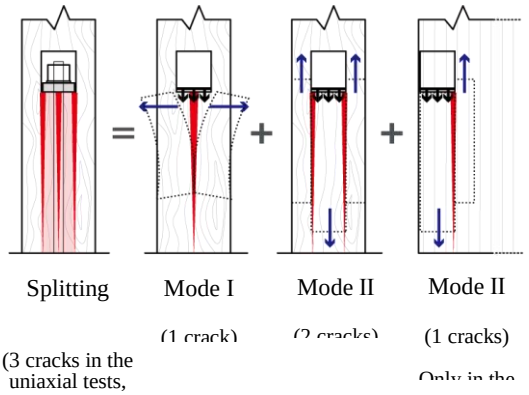


Figure 15. Example dimensions of one specimen in the uniaxial tests



(3 cracks in the uniaxial tests,

Figure 16. Mixed mode

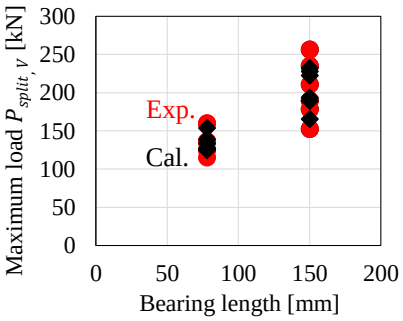


Figure 17. Maximum load in uniaxial tests

Conclusions

・ Among failure modes of tensile-bolted joints, the compressive yielding had the highest ductility, and the splitting and bending failure were brittle. On the other hand, because the specimen observed with the splitting failure had the same dimensions as the specimen observed with the compressive yielding, these two failure modes should be evaluated independently. For the compressive yielding, the experimental values were in good agreement with the calculated values. Regarding the bending failure, the experimental values were smaller than the calculated values. This result could be due to both stress concentration around the specimen's notches and the effect of cyclic loading; the latter reduces the bending strength after the compressive yielding.

・ The experimental results of the rotational stiffness were twice that of the calculated values. A possible explanation for this result is that the embedment stiffness of the timber under the washer was on average 3.1 times higher than the calculated values, and the embedment stiffness of the timber in the column's butt end was on average 1.95 times higher than the calculated values. Because the current calculation method for embedment stiffness focused on dowels, the embedment stiffnesses of the timber both compressed by the square-type plate and in the column's butt end were underestimated. Therefore, additional research is needed to establish a new method of evaluating these embedment stiffnesses in tensile-bolted joints.

・ The calculation method of the splitting using fracture mechanics was proposed. The experimental values were 1.03 times that of the calculated values in the cyclic tests and 0.8~1.2 times in the uniaxial tensile tests. This good agreement demonstrates the possibility of our proposed model of splitting. Future studies are required to gain data on fracture mechanics parameter of mode II, by conducting shear tests of small pieces.

Acknowledgments

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A Review on Adhesive- and Metal-Free Assembly Techniques for Prefabricated Multi-Layer Engineered Wood Products

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Abstract

Engineered wood products (EWPs) are being increasingly used as construction materials. EWPs are currently being made using synthetic adhesives or metal fasteners, which lead to poor recyclability and reusability. Therefore, this review paper focused on emerging adhesive- and metal-free assembling techniques including wood dowels, rotary-dowel welding, wooden nails, and dovetail joining as alternative ways of making prefabricated EWPs. This will contribute towards green construction and optimising the building process to minimise its negative impact on the environment and its inhabitants, while maximising the positive aspects of the finished structure. The respective advantages and shortcomings will be compared with those of equivalent EWPs. In general, the dowel-laminated timber (DLT) provides sufficient load-bearing capacity and even better ductility than EWPs of equivalent size, but its relatively low stiffness under a bending load limits its application as a structural element. Optimised manufacturing parameters such as dowel species, dowel spacing, dowel diameter, dowel insertion angle, dowel shape, etc. could be studied to improve the stiffness. The improved mechanical properties and tight fitting due to set-recovery of densified wood support its use as sustainable alternatives to hardwood dowels in DLT to overcome problems such as the loosening of connections over time and dimensional instability. The rotary welding technology could also enhance the strength and long-term performance of dowel-type joints, but its poor water resistance needs further investigation. The main obstacles to implementing DLT products in the market are missing technical information and design guidelines based on national codes.

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Utilization of High-Grade Yellow-Poplar Lumber for Cross-Laminated Timber Panels

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Dr. Rafael Azambuja - West Virginia University
Dr. Joseph Mcneel - West Virginia University

Abstract

Our prior research indicated that low-grade yellow-poplar has the potential to be used in the production of cross-laminated timber (CLT) panels. Specifically, our previous work demonstrated improving CLT flexural properties by sorting below-grade yellow-poplar by the static modulus of elasticity (MOE_s) instead of using Northeastern Lumber Manufacturers Association (NELMA) No. 2 and No. 3 in parallel and perpendicular layers, respectively. While the previous studies focused on maximizing material yield based on MOE_s, using higher MOE_s classifications and optimized layering within a CLT was not assessed. In addition, prior research did not consider the effects of a board's limiting defects and whether using yellow-poplar with both high MOE_s classifications and higher NELMA visual grades improved the flexural properties of yellow-poplar CLT panels. Therefore, the objective of this research was to evaluate the bending properties of CLT panels made from yellow-poplar lumber selected from the highest 10% of the board's MOEs distribution (MOE_s greater than 2.0 $x10^6$ psi or 13,790 MPa). The research also evaluated the effects of NELMA visual grades on the panel bending performance. Ten 5-layer full-scale CLT panels were produced with boards with MOE_s above 2.0 $x10^6$ psi in the two outer layers. Additionally, the panels were separated into two groups of five panels that had different NELMA grades in the outer layers. The first group of five panels had higher NELMA grades (Select Structural and No. 1), while the other five had lower grades (No. 2, No. 3, and Below Grade). For all ten panels, the inner three layers were composed of boards graded Below Grade with MOE_s between 1.2 $x10^6$ psi and 1.65 $x10^6$ psi (8,274 MPa and 11,376 MPa). Bond line results of shear block testing showed an average of 94% wood failure in all specimens, and 95% of the specimens had at least 50% wood failure. Cyclic delamination results showed delamination of over 5% in 16 out of the 30 specimens. The flatwise bending in the major direction test resulted in a F_b of 2,900 psi (20 MPa), 48% higher than the highest value published in the ANSI/APA PRG 320-2019 (2020) for E and V layups. The MOE result was 1.69 $x10^6$ psi (11,652 MPa), which is lower than E1 and E4 layups. No statistically significant difference was found between the two groups tested using higher or lower NELMA grades in the outer layers. This finding suggests that NELMA visual structural grades may not influence CLT panels when boards are used flatwise orientation and sorted by MOE_s. A comparison of this research to our past research will show how low-grade yellow-poplar lumber traditionally sorted, graded, and used as pallet stock can best be utilized to produce CLT panels that meet ANSI/APA PRG 320 requirements.

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Driving Innovation and Collaboration in Taller Timber Buildings – COST Action HELEN

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Construction accounts for forty percent of the world's energy use and waste production and one-third of carbon dioxide emissions worldwide; it is imperative to shift to sustainable and renewable construction techniques. Engineered timber, a champion of sustainable construction materials, has evolved to a stage that enables the construction of not only family housing, but also taller buildings commonly built from concrete or steel.

An integrated interdisciplinary approach is needed to safely design and build, as well as correctly maintain and recycle taller timber buildings. The design of taller timber buildings should be performed with intensive collaboration among the design team members (e.g. architects, structural, fire, acoustic engineers etc.). We are addressing taller multi-storey timber buildings from a collaborative and interdisciplinary perspective that considers static, dynamic, fire, acoustic, human health and other aspects in parallel and not in isolation. We intend to develop holistic design guidelines that will enable safe construction of taller timber buildings and respect human well-being demands through interdisciplinary analysis and interaction.

COST Action CA20139 "Holistic design of taller timber buildings – HELEN" is working towards optimized holistic approaches to improve the performance of taller timber buildings and to widen their competitiveness and use across the EU and the rest of the world. The Action is currently comprised of 282 members from 42 countries. Events, such as meetings, training schools, and support for research visits allow participants to exchange knowledge and develop strong international networks to meet our goals. This presentation will introduce COST Action HELEN, research objectives, and opportunities for collaboration.

Keywords: Taller timber buildings, Wooden construction, Sustainable building, Design, interdisciplinary, engineering, CLT

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The use of an acoustic camera to evaluate sound transmission through CLT junctions during construction

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Abstract

The growing popularity of CLT buildings and creative designs provide numerous new examples of construction details that must be developed during the building design phase and properly addressed during construction. There are several aspects to consider, of which structural requirements are certainly the most important. However, with respect to sound insulation, there are other requirements that must be considered, although they are often overlooked. In this study, we evaluated CLT partitions in a multi-story building during completion. An acoustic camera was used to identify dominant sound transmission paths that exposed several CLT junctions as critical. In addition, installations through wall penetrations were identified as problematic. The case study results are presented, and examples of good and poor performance are highlighted. The study also demonstrates the practical use of the acoustic camera to detect sound transmission paths during the construction process.

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State of Arts of Hardwood Cross Laminated Timbers (HCLTs) and Outlooks

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Abstract

This presentation discusses the brief results of the research carried out at Virginia Tech since 2017 to produce hardwood CLTs (HCLTs) commercially. There are two aspects of commercially producing HCLTs; the first is producing hardwood lumber to match the specific requirements of the structural grade CLT production, and the second is including hardwood CLTs on Standard for Performance-Rated Cross-Laminated Timber, commonly known as PRG 320. In the first step, we successfully surveyed CLT mills to identify the potential and problems of manufacturing hardwood CLTs and hardwood sawmills to produce and prepare structural grade hardwood lumber (SGHL) for CLT mills. In the second step, we did a log yield study to see the potential of manufacturing SGHL with NHLA grade lumber and also studied the possibility of remanufacturing two common and lower grade NHLA grade lumber to produce SGHL. In the third step, we completed the production of the hardwood CLTs from Yellow Poplar lumber and tested them in the APA laboratory to obtain the required performance data. Based on the observed results, we applied for the change in PRG 320 to include YP as the first hardwood species to manufacture CLTs for structural application. Now we are working on adding hardwood CLTs on PRG 320 standard and producing SGHL from commercially available CANTS.

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Fragility Analysis Approaches to Biodeterioration of Cross-Laminated Timber Connections

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Oregon State University
Jeffrey Morrell
University of the Sunshine Coast

Abstract

Cross-laminated timber (CLT) has rapidly increased in popularity as a building material in recent years. This material is being used to expand the horizons of timber construction, however, like for all materials, there are concerns about environmental hazards. Biodeterioration is an important hazard that should be considered in construction. While the solutions to biodeterioration in mass timber primarily focus on prevention, it is important to characterize the effects of biodeterioration on structures for when they occur. One way to characterize this effect is through fragility analysis. Fragility analysis uses discrete damage states with the response from experimental data to determine probabilities of damage states being reached. These damage states generally can either be descriptive (i.e. does the brittle finish on a wall crack) or more abstract (i.e. does the building reach or exceed a specific drift ratio), but need to be a binary. This method was applied to experimental data of CLT code approved connections from a previous study. The previous study involved two brown rot fungi species, four CLT layups (Douglas-Fir, Spruce-Pine-Fir, Southern Yellow Pine, and Norway Spruce), and five different exposure times (0, 10, 20, 30, 40 weeks). SAWS parameters were fit to the envelope curve data from that study. Defined damage states were determined based on the corresponding displacement in the connection to selected drift ratios using finite element analysis of a full wall. The SAWS parameter distributions were then used to simulate curves for each sample, which were analyzed at the damage states to determine the probability of exceedance for each damage state, creating a fragility curve. These fragility curves were then compared to determine how biodeterioration progresses and affects the function of the connection. Results from this analysis will be discussed and compared between CLT species, decay fungi species, and exposure time to describe the effect of biodeterioration and show the utility of a fragility-based approach.

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Fungal Degradation of Dowel Bearing Strength of CLT and its Effect on Connection Design

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Mr. Jed Cappellazzi - Oregon State University
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Abstract

The dowel bearing strength of wood is critical for connection design. Described as the resistance of the wood to embedding dowel, this property is mainly governed by specific gravity of the wood and diameter of fastener used in the connection assembly. However, numerous biotic agents such as fungi are known to degrade wood, resulting in changes which could impact specific gravity. Hence, proper characterization of changes to the dowel bearing strength of wood caused by fungi and the resulting effect on connection capacity is vital. This study evaluates the impact of two brown rot fungus on the dowel bearing strength of three CLT species over a 40- week period. The average values obtained were consequently used to predict the capacities of floor to wall angle bracket connections exposed to fungal decay using the yield mode equations from the National Design Specification for Wood Construction (NDS). The predicted capacities were compared against actual capacities of the same connections which were subjected to decay by the same fungi for the same period of time.

Generally, as exposure time increased, gradual reduction in the dowel bearing strength of CLT was observed. Additionally, predicted connection capacities and failure mode were accurate in the early stages of decay. Predicted Mode IIIs failures were observed in the physical tested connections. However, as exposure time increased, predicted and tested failure mode and capacity diverged.

This information is useful for repair engineers aiming to determine the extent of damage done to mass timber systems, especially in cases where evaluation of panels for damage proves difficult.

Effect of Thermal Modification on the Sorption Behavior of Thermally Treated Strands Prepared from Low Quality Small Diameter Logs

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Abstract

With the ever-increasing interest in sustainable materials for various applications, the use of cross-laminated timber (CLT), having the ability to transfer forces in 2-directions, has been one of the primary choices as sustainable building construction material. Low quality small diameter logs are widely available in the US forests due to forest thinning operations to mitigate forest fires and maintain healthy forests. Therefore, there is a commercial interest in producing value-added products using these small-diameter logs. One such use proposed by our group is to manufacture CLT using strand-based technology, as it does not require high quality lumber. One of the issues with using CLT is the moisture uptake, which is quite significant when used in external applications. This has resulted in limiting the applications of CLTs. Studies have been conducted on chemically modifying the raw material to increase the dimensional stability and durability of the entire structure. We propose using thermal modification to achieve more dimensionally stable and durable mass timber panels. The talk focuses mainly on the sorption behavior of wood strands, produced from small diameter logs, before and after thermal treatment. The influence of thermal treatment parameters in an industrial autoclave on the sorption behavior of wood strands will be discussed. The presentation will summarize the results of the study conducted on equivalent moisture content (EMC), water absorption and thickness swell, contact angle and sorption isotherms, which were carried out based on the respective ASTM standards. Understanding the variation in EMC and water absorption will help in illustrating whether the thermal treatment helps in reducing the natural water uptake capabilities of the untreated strands. The contact angle analysis will help in detailing the increase in hydrophobic nature if any, that will be imparted on the strands due to thermal treatment. Finally, the sorption isotherms will help understand the hygroscopic behavior of the thermally treated strands. The relationship between the relative humidity (RH) and the equilibrium moisture content of the strands was established at a particular temperature of 23°C to achieve the hysteresis loop representing the sorption and desorption trends, and the difference between the control and the thermally treated strands. The study will help understand the thermal treatment conditions that yield more physically stable strands with minimum water uptake and maximum hydrophobicity. The results will be eventually used in conjunction with the mechanical performance of the treated and untreated strands and the subsequent composites to finalize the appropriate thermal treatment conditions in an industrial autoclave. The results helped establish that the ideal thermal treatment type can produce stable and durable strands, composites made from which can potentially reduce water uptake in the fabricated CLT panels.

Keywords: Sorption and desorption isotherm; Thermal Modification; Cross Laminated Timber; Dimensional stability; Equivalent Moisture Content; Sustainable building construction materials; Wood strand composite.

COMPOSITES- NEW OPPORTUNITIES

Functionalization of Cellulose for biocomposite compatbility: Toughening of P3HB/PLA composites

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Dr. Sunkyu Park - North Carolina State University, Department of Forest Biomaterials
Dr. Lu Wang - University of Maine
Dr. Richard Venditti - North Carolina State University, Department of Forest Biomaterials
Prof. Douglas Gardner - University of Maine

Abstract

Cellulose fibers are a promising reinforcing agent for specialized composite materials made from entirely bio-based materials. However, their hydrophilic nature and surface chemistry cause issues with stress transfer within composites. Esterification is explored as a method for increasing compatibility of composite systems. Traditional esterification methods show a toughening behavior of the composite systems but no increases in strength. Interactions through rheology are also shown to increase. These mixed results are followed up by utilization of a novel DES-mediated reaction which aims to solve issues of fiber structure loss and incompatibility.

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Characterization of PRF resin - Wood Fiber Blends for Potential use in Additive Manufacturing

Prof. Armando McDonald - University of Idaho
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Abstract

Additive manufacturing (AM) of polymers typically uses thermoplastic resins and heat is required to melt the extruded resin and fuse with a previously laid down resin filament. This process is energy intensive. This study examined the use of softwood mill residues (50-90%) with a low temperature cure phenol-resorcinol-formaldehyde (PRF) thermosetting resin for potential use in AM of wood composite materials. The curing behavior of these blends was evaluated using differential scanning calorimetry (DSC) and dynamic rheology. Curing kinetics was determined using the Kissinger and Cranes method. The presence of wood fibers reduced the curing peak temperatures for the wood-PRF resin blends. The activation energy (Ea) increased from 51 kJ/mol to 271 kJ/mol) with the addition of wood for the wood-PRF blends. Frequency sweep flow curves of the green wood-resin blends showed shear thinning behavior with viscosity values between 103 to 108 Pa.s at 30 °C. This clearly shows that the resin-wood blends flowed. Wet wood (50%)-PRF blend was successfully extruded into a rod and shows promise for use in AM. The flexural properties of the cured wood-PRF composites generally showed a reduction in flexural modulus with an increase in wood content.

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Surface modification of bamboo fiber with dopamine associated by laccase for poly(3-hydroxylbutyrate) biocomposites

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Abstract

As the “green” production trend has increased worldwide, it is popular and necessary to manufacture durable, eco-friendly and sustainable materials such as plant fiber reinforced biodegradable thermoplastic composites. However, the poor interfacial compatibility between plant fibers and matrices is a major problem to overcome. In order to improve interfacial compatibility in biocomposite made of bamboo fiber (BF) and biodegradable Polyhydroxybutyrate (PHB), this work, inspired by mussel super adhesion and the “green enzyme” concept, creates a facile, highly efficient and enviromental friendly route based on laccase-catalysed dopamine in situ polymerization under natural environment. The results of the study indicate that polydopamine was not just deposited on the surface of BF by laccase catalysis but also chemically grafted onto BF lignin, forming a more stabilized coating. Meanwhile, the BF’s naturally weak acidic environment keeps it from undesired chemical degradation during the abovementioned modification. Optimal composition of biocomposite with BF treated by polydopamine under 1U/ml concentration of laccase shows improvement on the impact strength, tensile strength, tensile modulus, bending strength, and modulus of elastic by 33.93%, 9.27%, 31.74%, 11.76%, and 12.92%, respectively, compared to the unmodified PHB biocomposite. In addition, the polydopamine modified BF with laccase enhances the thermal stability of the fiber and its biocomposite. Moreover, modification of BF via laccase-catalyzed polydopamine is superior to the conventional method of polydopamine under alkaline condition regarding the interfacial compatibility improvement of BF and PHB. Overall, this work provides an insightful understanding of the mechanism and benefits of laccase-catalyzedf polydopamine modification of BF in a natural environment and contributes to the efficient and environmentally friendly utilization of polydopamine for fabricating high-performance plant fiber reinforced composites.

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Surface Adhesion of Wood Adhesives to Cellulose, Hemicellulose, and Lignin in Wood Bonding

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Dr. Eko Wibowo - Kyungpook National University

Abstract

The chemical heterogeneity of wood cell walls makes it difficult to understand the contribution of wood adhesives to the interfacial adhesion between the adhesives and wood components as the adhesion is a very complex physical and chemical phenomenon. This presentation aims to provide an overall review on the surface adhesion of wood adhesives such as urea-formaldehyde (UF) resins, phenol-formaldehyde (PF) resins, or polymeric diphenylmethane diisocyanate (pMDI) resins to nanocelluloses, hemicelluloses (arabinogalactan and xylan) or lignin in wood bonding. A tensiometer was used to measure the surface adhesion of a liquid droplet of wood adhesives on the film of nanocelluloses, hemicelluloses, and lignin. And the work of adhesion between the nanocellulose or hemicellulose films and UF resins was also calculated by van Oss–Chaudhury–Good method using the contact angle. pMDI exhibited greater adhesive force toward lignin model films compared with other wood biopolymer films, mainly because lignin has abundant phenolic hydroxyl groups and aromatic rings, smother surface, and higher surface-free energy than celluloses and hemicelluloses. The adhesion force and work of adhesion of UF resins on nanocellulose films shows that van der Waals forces are dominant in their molecular interactions, and affected by the molecular structure, surface smoothness and surface free energy. Those of arabinogalactan for different UF resins were greater than those of xylan due to the former film's higher surface free energy, more exposed OH groups, and smoother surface. pMDI result suggests that the surface properties and hydroxyl group content of wood biopolymer provide a significant role on the bonding interaction between pMDI resin and wood biopolymers.

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Bacteria Retted Hemp Fiber/PLA Composites for Automotive Applications

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Ms. Yu Fu - University of North Texas

Abstract

The push for sustainability in all facets of manufacturing has led to an increased interest in biomass as an alternative to non-renewable materials. The objective of this study is to develop a 100% biodegradable hemp fiber – polylactic acid (PLA) composites for automotive applications. Hemp bast fiber mats produced from bacteria retting were used as the fiber reinforcement. Biodegradable PLA pallets were processed into thin polymer sheets which served as the matrix. The hemp fiber mat and PLA plate were laminated in 5 layers, and compression molded into composite panels. An analysis of the fiber to PLA ratio was performed in order to determine an ideal ratio for processing. To analyze the processing a factorial experimental design was conducted around the factors initial fiber ratio (30/70, 35/65, 45/55, and 50/50) and cooling rate (fast cooling and slow cooling). The tensile and bending properties were tested. The physical properties including thickness swell and water absorption were also tested and compared to the currently commercial sheet molding compound (SMC) from fiber glass. The bacteria retted fibers were compared to conventional thermomechanical retted fibers in order to better understand the benefits of the bacteria retting method. The mechanical properties of the bacteria retted hemp fiber-PLA composites were compared to fiber glass/SMC a common automotive composite material. The developed bacteria retted hemp fiber/PLA composites can be a sustainable alternative to existing interior automotive vehicle panels that can biodegrade in landfill at the vehicles end of life.

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Mechanical, Morphological Properties and Crystallization Kinetics of Polypropylene/High Density Polyethylene/Microcrystalline Cellulose composite

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Abstract

Polyolefins are the largest class of commodity thermoplastics, in which polypropylene (PP) and high-density polyethylene (HDPE) are most commonly used, attributed to their individual merits. Post-consumer PP and HDPE are commonly found together in a commingled plastic stream and are challenging to recycle. Polymer blending is one of the most feasible techniques for recycling polyolefins. However, PP/HDPE (PO) blend shows poor mechanical properties because of the phase separation and immiscibility. The objective of this study is to investigate the effects of microcrystalline cellulose (MCC) and a coupling agent on the mechanical properties, morphologies, and crystallization kinetics of the PO blend. The weight ratio of 75:25 was used for manufacturing the PO blend. The PP/HDPE/MCC composites with/without maleic anhydride grafted polypropylene (MAPE) were manufactured with MCC loading levels of 2.5%, 5%, 10%, 20%, 30% by thermal compounding and injection molding. The tensile results indicate that the compatibility of PO blend and MCC was significantly improved by adding MAPE. The tensile strength of the composite with 30% MCC was increased to 32.5 MPa, which is 19% higher than PP/HDPE blend. Compared to the PO blend, the impact strength of the composite without the coupling agent was greater and was further enhanced after being compatibilized with MAPE. The highest impact strength of 2.41 kJ/m^2 was achieved at a 2.5% MCC loading level which is a 49% improvement. MCC demonstrated a satisfactory result in increasing the mechanical properties of the PO blend, especially when being compatibilized with MAPE.

Key Words: Polypropylene, High Density Polyethylene, Microcrystalline Cellulose, Compatibility, Mechanical Properties

Ultra-Lightweight Foamed Insulation Panels Made of Oil Palm Trunk Fibres

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Abstract

Inorganic and polymer-based foamed materials are widely applied in building insulation applications. Rising environmental awareness and a demand for more sustainable technologies encourage the use of renewable resources. Oil palm trunk (OPT) is a suitable raw material for the preparation of insulation board due to its relatively high fiber content, low cost, and abundant availability as a by-product of palm oil production. The present study focuses on developing an environmentally friendly thermally insulating material from oil palm trunk fibers for use in building applications. The effects of variable amounts of surfactant (1%, 2%, and 3% of polysorbate (T80)), wheat gluten (5%, 10%, and 15%), oil palm trunk fibers, and fire retardant on the properties of the resulting board was investigated. In comparison to the reference variant, there was a trend where increased surfactant content resulted in lower density and hence reduced thermal conductivity. On the other hand, such a trend was not obvious within variants with different wheat gluten content, where an optimum thermal insulation effect was observed at 10%. As expected, the compression strength of most variants showed a close correlation with density.

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Melt compounding of spray-dried CNFs/polypropylene and their application in 3D printing

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Abstract

Lignocellulosic materials derived from wood or plant fibers have advantageous properties including low cost, biodegradability and renewability. This eco-friendly material could be an alternative reinforcement for inorganic fillers in polymer matrix composites (PMCs). Cellulose nanofibril (CNF) suspensions produced by a mechanical refining process contain nano- or micrometer-sized fibers with a higher specific surface area of the fibers. The utilization of CNFs in a plastic matrix as a reinforcing material using current melt compounding operations requires a drying process to remove water in CNF suspensions. Spray-dried CNFs particles (SDCNFs) have the characteristics of excellent dispersion and distribution in a polymer matrix attributable to their micrometer size with the spherical shape of individual particles. Furthermore, the SDCNFs make narrower gaps among fibers resulting in retarded crystal growth within the small spaces among fibers. In this study, high-quality powders were manufactured via a pilot-scale rotary disk atomizer, and the bleached kraft pulp (BKP), unbleached kraft pulp (UKP), old, corrugated paper pulp (OCC) that fibrillated by levels of 90% and 100%, were used as feedstock for the spray-drying. The BKP-, UKP- and OCC- SDCNFs were compounded with a polypropylene matrix via a melt twin-co rotating extruder, and maleic anhydride grafted polypropylene (MAPP) was used as a coupling agent. Lastly, the SDCNFs-reinforced PP composites were applied to 3D printing. After injection molding, the maximum increase rate of tensile strength and MOE were 29% and 66%, and flexural strength and MOE were 15% and 27% higher, respectively, compared to the neat PP. The impact strength of 10% SDCNFs reinforced PP was higher than that of 10% wood flour-reinforced PP up to 136%. For the 3D printing, the shrinkage rate of PP was reduced by 39% after adding SDCNFs into the PP, and the printability of PP increased significantly using SDCNFs.

Keywords: spray-dried CNFs (SDCNFs), polypropylene (PP), 3D printing

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Wood fiber production from downed timber for manufacturing wood polymer composite: fiber property characterization

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Abstract

Severe weather events like hurricanes and tornados cause massive damage to forest land, resulting in significant economic losses to forest landowners. Depending on the harvest time, such losses can be compensated by using downed timber for industrial applications such as pulp and paper production and composite manufacturing. This research studied the properties of wood fibers generated from downed loblolly pine (*Pinus Taeda* L.) trees at different maturity (ages 15, 30, and 39 years) with various natural environmental exposure periods of 0, 6, and 12 months. The targeted application is to manufacture wood polymer composites. The wood fiber morpholog**y**, chemical composition, and thermal stability were evaluated, and the effect of environmental exposure and tree age on the wood fiber properties w**as** researched. Different ages of trees and environmental exposure times significantly impact fiber morphologies using the same milling process, as demonstrated by the light microscopic characterization. The wood fibers generated from the 39-year-old tree contain extractives due to the development of heartwood, changing the wood fiber generation process during milling. A chemical composition change was also observed with varying environmental exposure. The moisture absorption properties and thermal stability of the wood fibers produced from the downed timber did not change significantly after being exposed to the environment for 12 months.

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Underutilized wood species for manufacturing laminated strand lumber

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Abstract

Expected changes in the forest species composition, due to bark beetle calamity, and shift from dominant spruce monocultures to the deciduous mixed stand will have a dramatic impact on the wood-based composites industry and even more, pressure will be to maximize the use of lower value forest resources. One approach how to deal with low-quality logs with small diameters is engineered wood products (EWPs), namely, laminated strand lumber (LSL) can be considered as a replacement for solid structural lumber. LSL is one of the high yield new EWPs used as structural composite lumber, consisting of oriented wood strands up to 300 mm long that are bonded and compressed to form panels up to 90 mm in thickness. To reach the goal of using underutilized wood species in LSL it is necessary to carry out several studies for optimization of the cutting process, the influence of strand geometry on physical and mechanical properties of LSL, the effect of adhesive system on bonding performance, and relations between the orientation of the strands and mechanical properties of LSL. Testing of the physical (density, density profile (DP), thickness swelling (TS), water absorption (WA)) and mechanical (tension strength, compression strength, shear strength, shear modulus, modulus of elasticity (MOE), modulus of rupture (MOR)) properties will be carried out. Full-scale testing schemes will be accompanied by a digital image acquisition system to further analyze strain distribution fields during mechanical tests using the full-field digital image correlation (DIC) method. The results from this project will be used for a comprehensive comparison of the physical and mechanical properties of underutilized European wood species (larch, aspen, birch, fast-growing poplar, etc.), which will help to understand the behavior of LSL manufactured from different wood species.

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Development of Bio-based Carbon Particles for Use in Coatings to Improve Indoor Air Quality

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Dr. Laetitia Marrot - Slovenian national building and civil engineering institute

Abstract

Poor air quality is a severe problem linked to public health and environmental concerns. Among the wide range of airborne pollutants, volatile organic compounds (VOCs) have attracted more attention, given their high toxicity and negative environmental impact. Formaldehyde is an example of common indoor VOCs with a low evaporation point. In indoor conditions, formaldehyde is a colorless gas with an irritating odor and high reactivity. A large spectrum of indoor sources, such as flooring materials, carpets, cooking stoves, paints, and wall coverings, can emit formaldehyde. Because of the adverse health effects of formaldehyde, different regulations and occupational health authorities have set a limit threshold of exposure. Among the air remediation techniques, absorption on porous support mediums has been recognized as having the potential for trapping gaseous pollutants under ambient conditions. Carbonaceous materials such as carbon nanofibers, graphene, and activated carbon have been widely applied for the adsorption of a wide range of airborne pollutants. However, these materials are generally very costly and sourced from non-renewable resources. Bio-based carbon (i.e., biocarbon, BC) produced from the pyrolysis of biomass feedstock can be used as porous media, given its natural structure and large surface area. As BC's molecular and structural variations influence the functionality when used as an adsorbent, more research is needed to investigate the changes in BC's properties as a function of pyrolysis temperature. Also, understanding their effect on the formaldehyde removal capacities would help further develop BC as an efficient material for improving indoor air quality. Therefore, this study investigated the efficiency of biocarbon (BC) particles in the adsorptive removal of formaldehyde. BC samples were prepared from Arundo Donax (AD) and olive stone (OS) feedstocks at pyrolysis temperatures from 300 °C to 800 °C. The BC particles were characterized using proximate, physisorption, Fourier transform infrared, and water contact angle analyses. The formaldehyde removal capacity was tested using an electrochemical formaldehyde sensor in a closed glass chamber. The increase in pyrolysis temperature increased the BC's pH, hydrophobicity, and porosity. All the samples achieved a formaldehyde removal capacity ranging between 26% and 64% for BC pyrolyzed at 300 °C and 800 °C, respectively. In BC pyrolyzed at temperatures under 500 °C, formaldehyde capture was governed by diffusion in the noncarbonized organic fraction. In comparison, formaldehyde capture was controlled by a physical adsorption mechanism through pore filling for BC pyrolyzed at 500 °C or above. BC pyrolyzed at 800 °C was more efficient for formaldehyde adsorption due to the well-developed microporous structure. Additionally, physical activation significantly enhanced BC's adsorptive capacity. Further work is on-going to use the BC materials to develop coatings for composite materials and indoor surfaces.

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Spray-dried cellulose nanocrystal-reinforced homopolymer polypropylene composites

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Abstract

The unique properties of rod-like cellulose nanocrystals (CNCs), including high crystallinity, Young's modulus, and strength, make them excellent reinforcement for developing high-performance thermoplastic composites. However, nanoscale CNC is dominantly dispersed in aqueous suspension, which is not appropriate for large-scale industrial production of CNC-based composites manufactured by the melt compounding process. Spray-dried CNC (SDCNC) particles with irregular shapes were proposed as suitable for developing thermoplastic composites. This work aims to develop SDCNC-reinforced homopolymer polypropylene (HPP) composites and evaluate the properties of HPP composites with different SDCNC contents (5, 10, 15, and 30 wt.%). All composites were prepared using an internal mixer and subjected to an injection molding process. The mechanical, morphological, and thermal properties of composites were investigated. The results indicated that the tensile and flexural modulus of elasticity (MOE) of the composites were significantly increased after adding SDCNC particles. The impact strength of the composites was also increased, which could be attributable to establishment of a mechanical interlocking network between SDCNC particles and the HPP matrix. The steady increment in crystallization peak temperatures was observed as increasing SDCNC particle contents in the composites, contributing to the fact that SDCNC particles can act as heterogeneous nucleating agents.

Keywords: spray-dried cellulose nanocrystal, polypropylene, mechanical properties, morphology, mechanical interlocking

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Characterization of recycled wood particles using deep learning

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Abstract

Recycled wood material is commonly used as raw material in the manufacturing of particleboards. Large amounts of the recycling material are post-consumer waste of unknown composition. In countries with low availability of fresh wood, particleboards are made even exclusively from recycled wood material.

The quality of the recycled material varies immensely. Especially recycled fiberboards are seen as problematic for the manufacturing of panels because they absorb large amounts of adhesive, which is sprayed, on the particles in liquid form. The absorption of the binder into the particles reduces the amount available on the surface and finally the strength of the finished product. For cost efficient production it is crucial to reduce the amount of added adhesive but still reach strength values according to standards since the adhesive is usually the most expensive ingredient.

Therefore, it would be beneficial to have a better understanding of the properties of used recycled raw materials to adapt the recipes for production.

In this study particleboard particles made from fresh wood and recycled fiberboards were scanned using a Gre-Con 3D PARTICLEVIEW that records depth maps of the particles passing a laser line scanner on a conveyor belt. The depth maps of labeled particles were used to train a convolutional neural network to classify the proportion of fiberboard particles in mixed recycling material samples.

The 3D PARTICLEVIEW device used is currently an atline or offline measurement device. With small hardware adaptions and the use of artificial intelligence in the data evaluation it could be adapted for online measurements and closed loop production control. This example underlines how deep learning can be an important tool in the optimization of circular manufacturing processes.

Environment-tolerant stretchable sensors based on nanocellulose-carried graphene nanocomplexes

Prof. Jingquan Han - Nanjing Forestry University
Prof. Tielong Cheng - Nanjing Forestry University
Prof. Yiying Yue - Nanjing Forestry University

Abstract

With the development of wearable electronics, designing a strain sensor with high sensitivity, stretchability, durability and environmental stability is necessary but remains challenging. Herein, a high-performance conductive elastomer is reported by incorporating hierarchical cellulose nanocrystal/graphene (MCNC-GN) nanocomplexes into polydimethylsiloxane (PDMS) matrix. MCNCs serve as the dispersant to form stable MCNCGN nanocomplexes and improve their interfacial bonding with PDMS. The composite elastomer possesses excellent tensile strength (~4.82 MPa), elongation at break (~142.4 %), electrical conductivity (~1.0 S m− 1), anti-fatigue and environment-tolerant property due to the synergetic entanglement between MCNC-GN and PDMS molecules. It also has a sensitivity (gauge factor of ~ 173.17), wide sensing range (~100 %) and long-term durability, which can monitor both small/large-scaled and complex human motions, as well as subtle acoustic vibrations even under harsh conditions. This work provides a promising material platform for full-range human body motion detection and acoustic sensing, demonstrating great potential in next-generation wearable electronics.

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Magnetic and physical-mechanical properties of wood particleboards composite (MWPC) fabricated with fe3o4 nanoparticles and three plantation wood

Dr. Roger Moya - Instituto Tecnológico de Costa Rica
Prof. Johana Gaitán-Alvarez - Instituto Tecnológico de Costa Rica
Dr. Alexander Berrocal - Instituto Tecnológico de Costa Rica
Dr. Karla. J. Merazzo - 4BCMaterials, Basque Center for Materials, Applications and Nanostructures

Abstract

This study has the main objective to synthesize in situs Fe_3O_4 nanoparticles (NPs) in fiber particles of three tropical wood *(Pinus oocarpa*, *Vochysia guatemalensis*, and *Vochysia ferruginea*) using two different solutions of Fe^{3+} and Fe^{2+} in an aqueous ammonia solution. The magnetic properties were measured by determining fiber particles' Fe3O4 magnetization parameters (coercivity, remanence, saturation magnetization). The FTIR and XDR spectra were also obtained. After the magnetic wood particleboard (MWPC) was fabricated with 100% magnetic particles (MWPC-100) and a superficial layer magnetized with fiber (MWPC-layer), their physical, mechanics, and magnetic properties were compared. The results showed that Fe_3O_4 NPs content was similar in two Vochyseas species but higher than *P. oocarpa*. Ash content was similar in the three species. It was difficult to demonstrate the presence of Fe_3O_4 NPs in the FT-IR spectrum. The diameter of nanoparticles varied from 51 to 68 nm and the saturation magnetization parameters were low, but these values were higher in *P. oocarpa*. MWPC showed that the use of NPs decreases the density of *P. oocarpa* but increases the density of the Vochyseas species. Swelling and moisture absorption increased in the MWPC-100 of *P. oocarpa* and *V. guatemalensis* but decreased in *V. guatemalensis* composite. The internal bond decreased in MWPC-100, but not in the MWPC layer. Hardness increased in the MWPC layer in *P. oocarpa*, but not in MWPC-100, and this property increased in MWPC-100 and the MWPC layer fabricated with *V. ferruginea* and *V. guatemalensis*.

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Laminated Composites from Native and Invasive Alien Wood Species

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Mr. Bogdan Šega - University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology

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Dr. Maks Merela - University of Ljubljana, Biotechnical Faculty, Department of Wood Science and Technology

Abstract

Invasive alien plant species displace native vegetation, destroy agricultural land, and harm the economy. Many of them are removed and usually burned. However, some of them produce lignocellulosic material that could be used in place of native woody species. The aim of this study was to test the adhesive bonding properties of invasive alien wood species available in Slovenia in suitable sizes for testing. In addition, laminated wood composites were made from invasive wood species in combination with native wood species. The study was divided into two parts. The first part tested the shear strength of adhesive bonds for five invasive wood species: Ailanthus altissima, Aesculus hippocastanum, Robinia pseudoacacia, Gleditsia triacanthos, and Acer negundo. Fagus sylvatica was used as the native reference wood species. Two cold setting adhesives were used: the polyvinyl acetate adhesive Mekol D3 (PVAc) and the polyurethane adhesive Mitopur E45 (PU). The bonded assemblies were cut into shear specimens (EN 204), pretreated and tested (EN 205). In the second part, three different laminated wood composites with laminates of Robinia pseudoacacia (RP), Acer negundo (AN), Ailanthus altissima (AA), Picea abies (PA) and Fagus sylvatica (FS) were bonded with Mitopur E45 polyurethane adhesive and tested in four-point bending (EN 480). It was found that all tested wood species had sufficient bonding quality for dry specimens. In this case, the PVAc adhesive performed better than PU, while the PU adhesive performed better than PVAc for bonded specimens exposed to water. Both shear strength and bending properties were strongly dependent on wood density. It was shown that invasive wood species can be used for the production of laminated wood composites. From an engineering point of view, it is advantageous to use stronger wood species with higher density in the outer layers of the composite when it is subjected to bending stress.

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Lattice Structures from Wood Flour and Cellulose Nanofibrils Using Microwave Drying

Dr. Islam Hafez - Assistant Professor

Abstract

This research investigates a novel low-density structure made of woody biomass and cellulose nanofibrils (CNF). This work shows the potential of microwave drying to form lattice structures from wood flour/CNF suspensions. This leveraged technology can produce various lattices structures using various raw materials. The mechanical properties, rheology of the suspension, and various imaging techniques will be presented among others. The evaluation of the structure-process-property relationship will also be discussed. This research offers a unique and new array of wood structures and composites that can be produced by microwave drying and is expected to pave the way for further advancement and development of novel structures from renewable materials.

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Factors Influencing the Fire Properties of Birch Plywood, even on a Small Scale

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Abstract

Plywood is one of the oldest wood-based materials and is also very relevant for timber constructions due to its excellent mechanical properties. The impending climate change will result in a shift in forest structure towards more hardwood species (like beech or birch), that serve ideal properties for the production of high-quality plywood. The nowadays aimed transition to a completely biobased building sector only remains realistic, if the fire properties and burning behaviour of natural building materials are no longer an uncertain factor but can be assessed more precisely and thus be safer for the usage as a construction material. Due to the alternating, layer-by-layer assembly of veneers and adhesives in plywood, the binder type plays a major role in case of fire. Less thermally stable adhesives tend to result in delamination of the layers during a fire incident, which increases the surface by exposing single veneer layers to the heat source. These single sheets are prone to ignite and burn fast with an intense flame and have a sever influence on the fire spread. Although the importance of the glue type is a well investigated field concerning the use of cross-laminated timber (CLT), the influence of the main wood adhesives used in commercial plywood production (urea formaldehyde (UF), melamine urea formaldehyde (MUF), phenol formaldehyde (PF)) on the fire behaviour still gains scientific interest. Therefore, the present study focusses on experiments with a self-built small-scale Single Burning Item Test (Mini-SBI) which corresponds to one third of the original test setups dimensions. For the investigations 9-layered 500 x 500 mm² plywood panels were manufactured in a laboratory hot-press by orienting sliced 1.5 mm birch veneers 90° crosswise, with similar solid contents of UF, MUF and PF wood adhesives. Similar to the standard SBI-Test, the heat release rate (HRR) of the burning samples is measured by oxygen consumption calorimetry. In combination with the fire growth rate (FIGRA) an estimation and comparison of the burning behaviour of the different adhesive systems used for the investigated plywood panels could be carried out within this study. However, the investigations with the Mini-SBI not only show the influence of the adhesive type, but also the significance of the grain direction of the first layer exposed to fire. UF adhered samples showed the highest HRR and with the first veneer grain oriented parallel to the flame also the highest FIGRA value. MUF and PF adhered panels have similar HRR and FIGRA values and more balanced properties with respect to the grain direction, which is an indicator for less delamination. Additionally, ease of ignition tests in accordance with EN ISO 11925-2, (Single-Flame Source Test -SFT), thermal degradation behaviour by means of Simultaneous Thermal Analysis (STA) and proximate and ultimate analysis of the materials were conducted to provide holistic thermal information about the investigated material compositions.

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TIMBER DURABILITY/WOOD PROTECTION

Super-dimensional Stable Wood upon Modification with Enzymatic Hydrolysis Lignin

Prof. Weiqi Leng - Nanjing Forestry University
Mr. Jing Wang - Nanjing Forestry University

Abstract

Cracking, warping, and decaying are the most annoying problems of natural wood in-use. Intensive efforts have been conducted to solve these issues, of which, chemical treatment such as vacuum impregnation of chemical solutions and grafting of functional groups onto accessible cell wall reaction sites are commonly adopted. Although the performance of modified wood was satisfactory, the adverse environmental impact of mostly petroleum-derived modifying agents confined their application scope. Sustainable and green chemicals with comparable effects are more favorable to better protect the earth. Lignin, the second most abundant biomaterial after cellulose, is one of the major components of wood cell wall. The amorphous three-dimensional lignin is hydrophobic and acts as an adhesive to hold the cellulose and hemicellulose together. It is hypothesized that technical lignin can be incorporated into wood to improve its dimensional stability. In this study, we compared the performance of enzymatic hydrolysis lignin (EHL) and alkali lignin (AL) on wood modification via vacuum impregnation and atmospheric pressure immersion. The objectives of this study were to investigate the feasibility of both types of lignin on the modification of wood and to evaluate the performance improvement after lignin impregnation. Deionized water, ethanol, acetone, dioxane, Dimethyl Formamide (DMF), and tetrahydrofuran (THF) were selected as the solvents. Weight percentage gains (WPGs) of samples treated with different lignin solutions were compared and the group with the highest WPG was used for further characterization. Dimensional stability of modified wood, the retention of lignin, microstructural and chemical changes, as well as mechanical properties (including stress strain relations revealed by digital imaging correlation) were systematical evaluated. This facile approach can improve the physiochemical properties of wood and remarkably enhance the outdoor performance of modified wood products. Moreover, using lignin as the natural modifying agent to improve the characteristics of wood will have a great positive impact on the environment.

Keywords: Lignin, dimensional stability, retention, hydrophobicity, mechanical property, digital imaging correlation

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In-depth characterization of bondlines in cross-laminated timber made with preservative-treated lumber

Mr. Cody Wainscott - Oregon State University
Mr. Jed Cappellazzi - Oregon State University
Dr. Gerald Presley - Oregon State University

Abstract

Mass timber construction projects are rapidly increasing in number in North America but this technology encounters durability issues in termite-prone areas. To combat this issue, chemical treatments must be incorporated into mass timber elements to prevent termite attacks. However, pressure treatment is either unfeasible for large panels or may cause problems with bondline integrity if done prior to layup and we sought to investigate this problem. Douglas-fir 2 x 6-inch lumber or untreated cross laminated timber (CLT) panel sections were treated with one of three different preservative systems, pressure treatment with borates, pressure treatment with an all-organics preservative system (PTIP+IPBC) or dip treatment with propiconazole, tebuconazole and imidacloprid + borate (PTI). Treated and untreated lumber was used to manufacture CLT panels using one of two resins, melamine formaldehyde (MF) or Polyurethane (PUR). To determine if the preservatives cause a negative interaction with the adhesives, Dynamic Mechanical Analysis of MF and PUR adhesives between treated veneers was conducted. The positive effect of preservative in the wood can have a negative effect on the resulting curing strength of the adhesive. This can have major consequences in the construction of CLT panels and their overall performance.

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Treatability of the Australian softwood resource: preliminary results

Dr. Jeff Morrell - University of the Sunshine Coast

Abstract

Australia has a sizable estate of exotic pines including *Pinus radiata, P. elliottii, P. pinaster*, and a *P. elliottii/P. caribaea* hybrid that were planted in the early part of the 20th century to provide a steady source of building materials. All have thick sapwood bands that must be protected if the wood is used in exterior exposures. Sapwood is generally easily treated with preservatives and the Australian specifications require 100 % sapwood treatment for both Hazard classes 3 (above ground) and 4 (soil contact). The softwood resource is generally looked at uniformly treatable, but there are increasing instances where species or sources of the same species present treatment challenges. These differences are not surprising since pine sapwood permeability varies between species but also with geographic source, kiln drying regimes and even breeding strategies. In addition, there are questions related to the treatability of the sapwood/heartwood interface which does not react with heartwood indicator but is also difficult to effectively treat. Understanding treatability variations across the softwood resource will help identify the best uses for specific resources as well as aid breeders involved in genetic improvement. Ideally, this issue would be examined on material collected from across the growing regions to assess treatment; however, this would be challenging and costly. Fortunately, a large study of machine grading was initiated as part of a national to assess how changes in industry practices and equipment might have affected the validity of the current grading programs. Timber collected from mills across Australia based upon a pre-determined statistical sampling program was sent to the University of South Australia where it was physically and mechanically assessed to determine how well the results correlated with the assigned grades. A 600 mm long piece of every 90- by 35 mm sample was cut for assessing treatment. This section was then cut into two 225 mm long pieces and a 75 mm long sample. The longer pieces were allocated to be treated with either chromated copper arsenate (CCA) or azoles in light organic solvent (LOSP). The 75 mm long piece was used to determine basic density, growth rate, latewood percentage and heartwood content. The longer pieces were end-sealed to retard preservative penetration before being weighed and commercially treated with CCA or LOSP azole. The samples were weighed after treatment to determine net solution uptake and then allowed to dry/evaporate. Preservative penetration was assessed by cutting three 5 mm thick cross sections from the middle of the 225 mm sample. Sections were sprayed with variamine blue to detect heartwood and either chrome azurol S for copper or PAN indicator for the zinc tracer in the LOSP. The results for the first 650 samples will be discussed in relation to preservative retention and penetration related to timber source, density, and other variables. CCA treatment tended to be more uniform than LOSP treatment, but there were few differences in uptakes with timber source or density. These results are part of a large study that will involve over 2500 pieces.

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The bending moment capacity of the lap and dowel joints fabricated from salvaged CLT panels

Mr. Chih Cheng Chen - Purdue University, Department of Forestry and Natural Resources

Prof. Eva Haviarova - Purdue University, Department of Forestry and Natural Resources

Prof. Daniel P. Hindman - Department of Sustainable Biomatierals, Virginia Tech

Abstract

Cross-laminated timber (CLT) is gaining global popularity as a sustainable construction material. Using CLT, more carbon can be stored in durable products, while nonrenewable resources can be avoided. Although almost all existing CLT structures are made of softwoods, there is growing interest in including hardwoods in making CLTs. Previous studies indicated that the hardwood CLT (HCLT) could meet and exceed the bending stiffness and shear stiffness requirements of the current North American CLT standard, ANSI/APA PRG 320. Thinner HCLT could also offer good panel-type material for furniture manufacturing since furniture production moved almost entirely from the frame-to-plate type of construction with computer numerical control (CNC) production. HCLT, a material with excellent dimensional stability and rigidity, could offer a unique opportunity for CNC furniture and other interior applications. Moreover, it is expected that CLT will be more common in building construction, and more byproducts from cutouts of windows or doors will be available for smaller products. Also, over time, salvaged material obtained from the CLT buildings will be available for repurposed products. The structural integrity of any structure (furniture) is directly related to good joinery. This study investigates the manufacturing feasibility and load-carrying capacity of basic CNC-manufactured joints made of CLT panels. The joinery specimens were constructed from salvaged HCLT panels donated by Virginia Tech, yellow poplar panels, and hybrid panels made of southern yellow pine and yellow poplar. The lap and dowel joints were then tested for bending in compression and tension. The results will contribute to the design and product development of salvaged HCLT panels.

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Durability and Mechanical Properties of Thermally Modified Western Hemlock CLT

Mr. Talbot Rueppel - U.S. Army Corps of Engineers

Abstract

As part of Department of Defense (DoD) sustainability efforts such as the U.S. Army Climate Strategy and the U.S. Army Installations Strategy, the U.S. Army Corps of Engineers (USACE) is collaborating with various non-profits, corporations, and government organizations to study the use of novel Cross-Laminated Timber (CLT) products for use in civil and military installations. Mass timber materials like CLT are sustainable, modular, and lightweight alternatives to steel, concrete, and masonry particularly for floors, walls, and roofs.

To increase the durability and dimensional stability of the end CLT product for use in varying climactic conditions, the lamellae within the panel are thermally modified before bonding. Thermal modification is a natural, non-toxic pyrolysis process in which the lamellae are "baked" in the absence of oxygen. This process permanently alters the chemical structure of the wood – reducing its hygroscopicity and subsequent chance of dimensional changes, fungi, mold, and insect infestation. This presentation will review some of the findings comparing unmodified and thermally modified Western Hemlock CLT.

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Change in Timber Moisture Content with Non-Permeable Packaging to Protect Timber Products in the Supply Chain

Dr. Nathan Kotlarewski - The University of Tasmania

Prof. Gregory Nolan - The University of Tasmania

Abstract

There are direct relationships between wood's equilibrium moisture content, species (or product) properties, the ambient temperature and relative humidity of a location. These ambient conditions change constantly in the supply chain and are normally controlled by wrapping the material and storing the timber in protected shelters. However, other situations occur, and packs of dry timber can be stored outside for long periods with inadequate or damaged wrap. To quantify the risk that this may pose to product value, this research project monitored the change in ambient conditions and the timber's moisture content response in the supply chain to those conditions under different wrapping and exposure circumstance. It aimed to establish useful correlations between exposure to ambient conditions in storage with different non-permeable wraps to protect timber products in the supply chain and to identify the risks to product serviceability due to its change in moisture content. This research monitored the ambient temperature and humidity conditions around and in identical timber packs of plantation *Eucalyptus nitens* under three non-permeable wrap arrangements: fully protected clear, fully protected opaque and poorly protected opaque wraps. The packs were installed and monitored in two different climate zones (Tasmania and Queensland, Australia) and two exposure conditions (interior fully protected and exterior fully exposed environments) in each climate zone. The research was conducted from December 2021 (summer) to May 2022 (autumn). The results suggest that storing wrapped timber in interior environments is preferable to storing it in exposed exterior locations. For a hygroscopic material such as timber, a more stable environment will reduce but not eliminate the amount of change in timber moisture content. The results also showed the significant risk that can accompany wrapped timber's exposure outside. The timber pack that had the greatest change in timber moisture content was transported from an interior environment in Tasmania, Australia, to an exterior environment in Queensland, Australia, and was wrapped in a poor quality (deliberately damaged) opaque wrap. The moisture content of the timber stored in this pack on average increased by 11.9 %. This result quantifies the potential risk by which even well wrapped dry and stable timber can face due to unforeseeable changes in the timber's moisture content in the supply chain.

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Deterioration Concerns in Mass Timber Products

Dr. Beth Stokes - Mississippi State University

Abstract

Mass timber production in the US has increased dramatically over the past few years. According to the 2023 International Mass Timber Report, there are 15 companies operating 19 manufacturing facilities in North America, while WoodWorks reports 1,753 mass timber projects in design, construction, or completed across the US as of March 2023. With this expansion and focus on utilization of large-scale wood products, there should also be an ongoing discussion about adequate protection of wood from its well-known adversaries - namely, UV damage, water intrusion, insects including termites, and wood-decaying fungi. As the use of mass timber products continues to increase, it is very important to address these areas as well as create a dialogue on the application of treated wood in the manufacture of mass timber products such as cross laminated timber and its variants.

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Using Bark for Healthy Indoor Environments

Dr. Matthew Schwarzkopf - InnoRenew CoE & University of Primorska

Ms. Mariem Zouari - InnoRenew CoE & University of Primorska

Abstract

Tree bark has the potential to be upgraded for wood treatment formulations that substitute harmful and petroleum-derived chemicals, and simultaneously extend the functionality of wood in building and construction end-uses. Furthermore, these treatments can play an active role in cleaning indoor air. The BarkBuild project is an international project funded by the ForestValue program in Europe. Research institutes from Sweden, Latvia, Slovenia, Finland, Norway, and Poland have joined to explore how bark-based chemicals can be effectively extracted and utilized as wood protection for exterior and indoor use. InnoRenew is involved with a particularly interesting aspect of this project focusing on the indoor usage of bark-based materials and their role in improving air quality. Indoor air pollution and quality are vital concerns regarding human health within the built environment, especially in industrialized urban areas where human respiratory health can be particularly compromised. Volatile organic compounds (VOCs) enter building spaces through wall and floor coverings, adhesives, building materials and furnishings, insulation products, as well as outdoor pollution that permeates into buildings. Biocarbon, used historically in water pollution remediation, has the potential to be incorporated into indoor building composites to improve indoor air quality and remove VOCs due to its large surface area. Most prior research has focused on biocarbon produced from coal or entire biomass constituents, not solely based on bark-related fractions. The objective of this presentation is to present our work to date on the valorization of spruce bark through thermal conversion into high-added value biochar for air purification.

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Efficacy of Blends of Linseed Oil, Beewax and Turpentine as Preservative Treatment for Ceiba pentandra

Prof. Kojo Afrifah - Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology

Mr. Ebenezer Asiedu-Agyei - Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology

Ms. Marian Justine Adebrah - Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology

Abstract

Preservatives protect wood through their antifungal, insecticidal, antimicrobial and antioxidant characteristics. Environmental concerns have been raised about most traditional preservatives culminating in investigations into environmentally friendly natural substitutes. This study investigated the efficacy of blends of linseed oil, beewax and turpentine as preservative to treat *Ceiba pentandra* a non-durable wood. Combined mixtures option of StatEase Design Expert® 7.0 software was used to generate the combinations for the mixtures of preservatives. *Ceiba pentandra* stakes treated with mixtures of preservatives were exposed to outdoor ground-contact for six weeks to assess their protection against water absorption, decay fungi and termites using visual durability ratings and mass losses. Results of water absorption indicated that coated wood samples (790-1780 g/m^2) had the highest water resistance compared to the uncoated samples (2100 g/m^2). Coated samples water absorption was however well above the limit of 175 g/m^2 for stable end-use set in EN 927-2 performance specification hence not suitable for external application. Preservative retention was greater for stakes treated with high linseed oil content. Resistance of treated stakes to bio-deterioration was generally higher than the untreated samples. High contents of beewax resulted however in lower resistance to termite attack while high contents of linseed oil and or turpentine resulted in high preservative retention and durability against termite attack irrespective of beewax contents.

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Mechanical Properties of Selected Thermally Modified Appalachian Hardwoods

Dr. Abasali Masoumi - Department of Sustainable Biomatierals, Virginia Tech

Dr. Brian Bond - Department of Sustainable Biomatierals, Virginia Tech

Abstract

Thermal modification has been used as an industrial process to improve wood properties, such as increased dimensional stability and decay resistance for many different hardwoods and softwoods. However, heat treatment can result in changes to other wood properties, such as color, water absorption and absorption, mechanical and chemical properties of the wood. In this presentation the authors will discuss the impact of commercial thermal modification on selected wood properties of several Appalachian Harwood species. The mechanical properties of modulus of elasticity (MOE), modulus of rupture (MOR), and dimensional change coefficient compared to controls and thermally modified red oak, soft maple, black cherry, yellow poplar and hickory. All mechanical testing was conducted using ASTM standard D143 with modifications for sample size.

Keyword: Thermal Modification, Wood Treatment, Hardwood Lumbers, Wood Properties, Dimensional Stability

POSTER SESSION

BRIQUETTING TECHNOLOGY: GUARANTEED CONCEPT TO MITIGATE CLIMATE CHANGE AND GLOBAL WARMING

Dr. Idowu Abimbola Adegoke - Federal University Gashua

Mr. Odunayo James Rotowa - Department of Forest Ecology and Silviculture University of Agriculture in Krakow

Mr. Ayobami Adeagbo - Department of Forest Products and Production, University of Ibadan, Nigeria

Dr. Ayodeji Ige - Department of Industrial Chemistry, Kebbi State University of Science and Technology

Abstract

This paper reviews various briquetting technological options through the utilization of biomass (mainly agricultural and forest residues) with the aim of reducing pressure on available forest resources, thereby abating global climate change phenomena. Briquette production has been identified as contributing to improved waste management, domestic waste and waste from schools and other institutions and fecal sludge and agricultural waste can be converted into briquettes. Most urban centers in developing countries face challenges of managing these wastes. The collection of forestry and agricultural wastes from industries, cities and agricultural farms for producing briquettes can contribute to environmental well-being and cleanliness. Waste management through briquette production supports a clean and healthy society thus providing low-cost energy substitute.

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Forests and Forestry Reserves as Security threat in Federal Capital Territory, Abuja Nigeria

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Abstract

Forests are important plant communities that consist of trees and other woody vegetation's that perform life supporting functions on earth. For example, the tree species can serve as diversity conservation and protection of fragile ecosystem; development of parks and event centers for relaxation and social engagements; provision of vegetable and fruits/seeds for foods and medicines; and purification of air, wind break. This paper attempts to examine forests and forest reserves as security threats in the Federal Capital Territory, Abuja, Nigeria. The study is both empirical and theoretical in nature as both primary and secondary sources of data were collected, edited and analyzed for the research. In additions different daily Nigeria's newspapers desk were reviewed. Pictures were taken to support the finding. The results identified the reasons why forests and forest reserves can be security threats. The security threats they posed were examined which include basic hideouts, drinking and smoking, camping sites for insurgents, homeless on highway armed robbers, thieves and other criminals. The study proposed the way out of the present insecure situation, through launching attacks to dislodge the insurgent, protection of forests and forest reserves, reforestation of degraded sections among others. These forests and forest reserves need to be properly harnessed guided, implementation of policy and developed into Recreational parks and tourist centers, that will yield the much-needed revenue.

Keywords: Forest, Forest Reserve, Security Threat

Assessment Of Occupational Hazard Prevention At Oko Baba And Amu Sawmills, Lagos State, Nigeria

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Abstract

Occupational health and safety policies are essential factors that affect efficiency and productivity in any organization. Safety policies that are employed to protect workers in wood processing industries are of great importance because of hazard that is associated with many wood processing industries, particularly in the sawmills. Hazard ranges from mild to severe injuries which may be due to poor management practices in terms of waste disposal, ergonomic hazard, and poorly maintained equipment and machines. The study accesses occupational hazards that workers in the sawmills are exposed to with a case study of the sawmills in Lagos State. A purposeful sampling of workers at Oko Baba and Amu sawmill of Lagos State was conducted being the site for several conglomerates of sawmills. 50% sampling intensity was adopted to cover the 123 sawmills at the two locations. Structured questionnaires were randomly administered among key workers; band saw operators, circular saw operators, planers, and saw doctors. Data collected were tested using chi-square at a 5% level of significance and respondents' compliance was measured on structured point scores. Lower scores indicate no compliance or poor compliance with safety precautions at the workplace. The result shows that the majority of the respondents were married with a larger percentage having only primary education (46.9%) and are exposed to hazards related to sawdust (97%), continuous noise production (99%), body vibration over time (97%) and 58.5% were exposed to smoke, particularly from burning of wood waste. The majority of injuries occurring are within the sawmill with 66.2% representing bruises around the hand and 29.3% other parts of the body. The compliance level on safety precautions at the two sawmills was 52.7%, this may be due to the level of education among all the respondents sampled. The study showed that there is low compliance with occupational health and safety precautions at the sawmills sampled, it is thus recommended that officers of the occupational health and safety officer should visit the sawmill from time to time and sensitize the workers on the use of personal protective equipment as well as the management of the sawmill on proper wood waste disposal and management strategies that will improve the crew's life and further enhance environmental improvement.

Keywords: Occupational health, Ergonomic hazard, Waste disposal, Sawmills, Safety wares

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Exploring the Effects of Temperature on Cellulose-Water Interactions through Computational Simulations

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Summary

In this research, Molecular Dynamics (MD) simulations were employed to study the cellulose-water interaction at temperatures typically used to dry lignocellulosic feedstocks. To that end, a computational model of an Iβ-cellulose crystal was built. The forces between atoms within the crystal were estimated using the CHARMM36 potential, and the water molecules were described using the TIP3P and OPC models. The cellulose-water systems were simulated in an NVT ensemble at five different temperatures. Two different numbers of water molecules, 690 and 2616, were used to solvate the crystal. The average number of hydrogen bonds formed between the -OH groups located on the cellulosic surface and the water molecules for the system containing 690 TIP3P water molecules was (555 ± 13), indicating that most of the water molecules form hydrogen bonds with the cellulosic surface, and this number decreased with increasing temperature. On the other hand, for the systems containing 2616 water molecules, the number of hydrogen bonds formed with the cellulosic surface is less than half (1317 ± 23), indicating that most of the water molecules are not forming hydrogen bonds with the cellulosic surface but with each other. Results for radial distribution function (RDF) calculations indicate decreasing cellulose-water interactions with increasing temperature and changes in hydration layers around the cellulosic surface. In addition, characteristic peaks were identified and related to the presence of water molecules strongly bound to the cellulosic surface. These results provide a new understanding of the cellulose-water interactions with temperature and contribute to developing new approaches to reduce energy consumption during drying of lignocellulosics.

Introduction

The main feedstock of biorefineries is the most abundant and readily available carbohydrate in nature, which is cellulose [1,2]. Two crystalline forms of cellulose are mostly present in wood, namely cellulose I_β and $I\alpha$ [3,4]. Experimental and theoretical studies have confirmed that within a cellulosic crystal, the polymeric cellulosic chains are linked through extensive hydrogen bond networks [5]. The hydroxyl groups in the cellulosic chains interact strongly with hydrogen bond donor-acceptor molecules, such as water, posing a challenge for dewatering and drying cellulosic materials [6].

It is estimated that thermal drying accounts for 20-30% of the total operational cost for lignocellulosic feedstock production [7], in which most of the energy is used to generate steam [8]. Several technologies have been proposed to reduce the energy demand [9,10]. However, the specific energy usage for a modern energy-optimized dryer design is still around 3000 kJ/kg of evaporated water [4,5]. Considering that the theoretical heat of vaporization of water is 2260 kJ/kg, there is still room for improvement in dryer efficiency.

A molecular understanding of the interactions between water molecules and hydroxyl groups in cellulose is critical to determine the factors that drive the dewatering and drying.

Different computational studies have been conducted using MD simulations to provide further insights into the cellulose-water molecular interactions [11,12]. However, most research has focused on understanding intrinsic structural elements, thermal decomposition, or hydrogen bonding in cellulose. In contrast, investigations have not paid attention to the effect of temperature on the cellulose-water interaction in the range of lignocellulosic drying.

In this research, we explore the cellulose-water interactions at a molecular level using computational tools, specifically MD simulations. The goal is to characterize the cellulose-water interaction at temperatures typically found in the dryers, providing new insights into the drying of cellulosic fibers and aiming to reduce energy consumption during drying.

Computational details

All the MD simulations were carried out with GROMACS-2019.2 [13]. The initial configuration of the cellulose crystal was generated using the cellulose-builder software [14], Figure 1. The crystal was placed in the center of a simulation box of dimensions L_x=5.62, L_y=4.52, L_z=15.00 nm. This initial configuration was geometrically optimized using a steepest-decent energy minimizer to eliminate the strain between molecules. The interactions in the crystal were modeled using the CHARMM36 force field for carbohydrates [15]. The temperature was controlled at 300 K with the v-rescale thermostat [16] using a relaxation time of 0.1 ps. In all systems, periodic boundary conditions were used in all directions. The Particle Mesh Ewald (PME) [17] method was used to determine the electrostatic interactions, and the van der Waals interactions were determined using a cut-off distance of 1.25 nm. Dispersion corrections were applied for long-range contributions.

After optimization, the crystal was solvated in water using two different force fields to describe the water molecules TIP3P [18] and OPC [19]. Two different systems were generated, one containing 690 and the other 2616 water molecules. Following a geometry optimization of each solvated system, an MD simulation with a duration of 5 ns was carried out with the NVT ensemble to relax the systems from an energy point of view. Subsequently, MD simulations were conducted at the target temperatures (T=293.15 K, T=325.15 K, T=350.15 K, T=363.15 K, and T=373.15 K) for each system. For these simulations, the temperature was controlled using the v-rescale thermostat [16]. The simulation time step was 0.1 ps, and simulations lasted 100 ns (100000 ps). Data were recorded with a time-step of 20.0 ps.

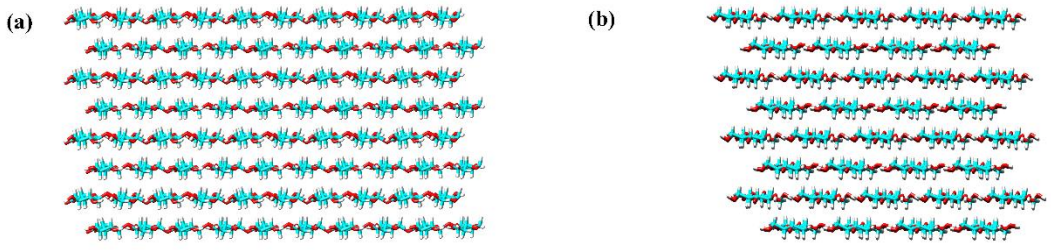

Figure 1. (a) Front view and (b) Lateral view of the I_β-cellulose crystal with different surface planes.

Results and Discussion

A total number of 20 simulations were conducted (5 temperatures, 2 water models and 2 different number of water molecules). At the cellulose surface, the hydroxymethyl groups

can be either exposed to the solvent (-OH groups on the C-2, 3, 6 pointing outward) or buried inside the crystal (-OH groups on the C-2, 3, 6 pointing inward). The radial distribution function (RDF), hydrogen bonding, and molecular orientation of the water molecules on the cellulosic surfaces were calculated using the trajectory files generated after 100ns of MD simulations, Figure 2.

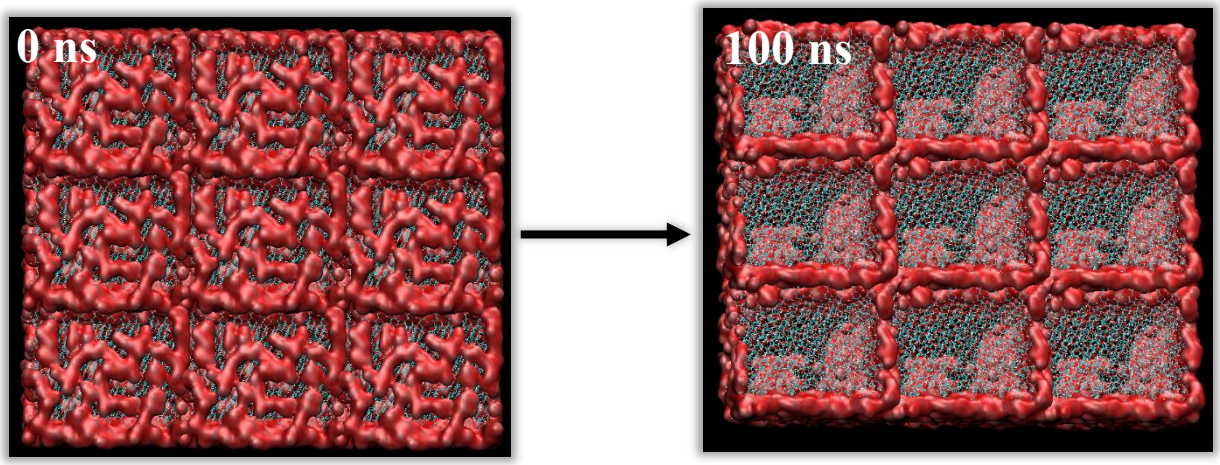

Figure 2: Snapshot of initial (left) and final (right) configuration of a system containing TIP3P water molecules and a cellulose crystal after 100 ns of MD simulation at 293.15 K. The final configuration of the system shows a rearrangement of water molecules around the hydrophilic crystalline planes of the crystal.

The number of H-bonds for systems containing 690 water molecules is close to 1 per water molecule, indicating that this number of water molecules was insufficient to interact with all the -OH groups located on the cellulosic surface, Figure 3. A similar trend was observed for both water models. For the systems containing 2616 TIP3P water molecules, the number of H-bonds formed with the cellulosic surface is less than the number of water molecules present, indicating that the cellulosic surface is saturated with water molecules and the remaining water molecules are interacting with one another, Figure 3a. The temperature effects are detectable for systems containing larger number of water molecules, with a decrease in the number of H-bonding with increasing temperature. Remarkably, the number of H-bonds is larger when the OPC model is used to describe the water molecules. This is reasonable since the OPC model is a four-site model, in which the oxygen atom carries an amount of negative charge favoring the cellulose-water interaction. With increasing temperature, the number of H-bonds was reduced to a threshold value.

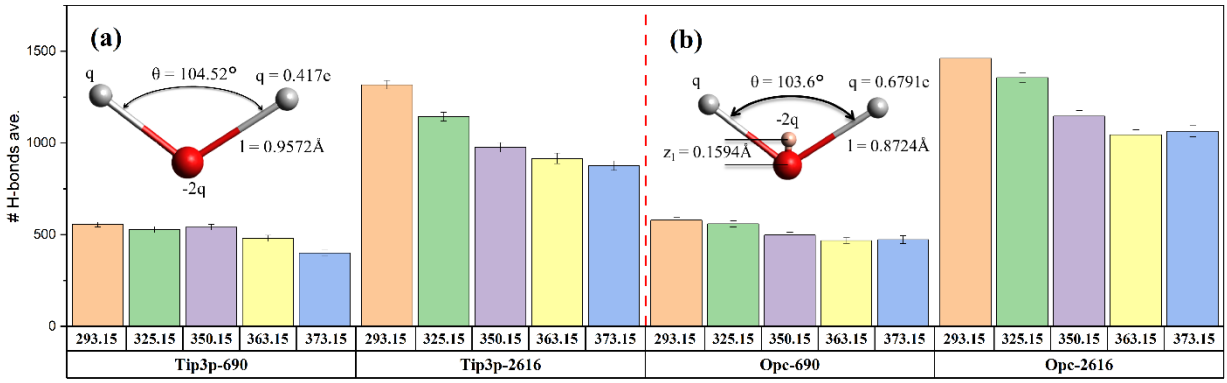

Figure 3: Variation of the H-bonds average number as a function of temperature. H-bonds were evaluated for the cellulose-water interaction with two different water models and number of water molecules. (a) TIP3P water model, (b) OPC water model.

Characteristic peaks indicating hydration layers around the cellulosic surface are found when g(r) is plotted against the distance r from the cellulosic surface, Figure 4. Remarkably, the systems containing 690 water molecules showed an additional peak before the characteristic peak for the first hydration layer, which is attributed to water strongly bound to the cellulosic surface (inset 4a, c). These characteristic peaks are not observed for systems containing 2616 water molecules (inset 4b, d). With increasing temperature, the OPC model allowed to effectively describe the cellulose-water interaction with temperature beyond the first hydration layer for systems containing a lower number of water molecules but failed for larger systems at higher temperatures, 373.15K (see Figure 4b). On the other hand, the TIP3P model described the interaction of water molecules and the cellulosic surface satisfactorily beyond the first hydration layer, with lower radial distribution at increasing temperature, which is observed in Figures 4c and 4d. The results obtained from this theoretical study indicate that saturation conditions must be considered to evaluate the effect of temperature on the cellulose-water interaction. Typically, the cellulose-water interaction has been studied by solvating a computational model of acrystal in a simulation box filled with water molecules. Our approach is different since only a small number of water molecules is used and surface saturation phenomena mainly drive the interaction.

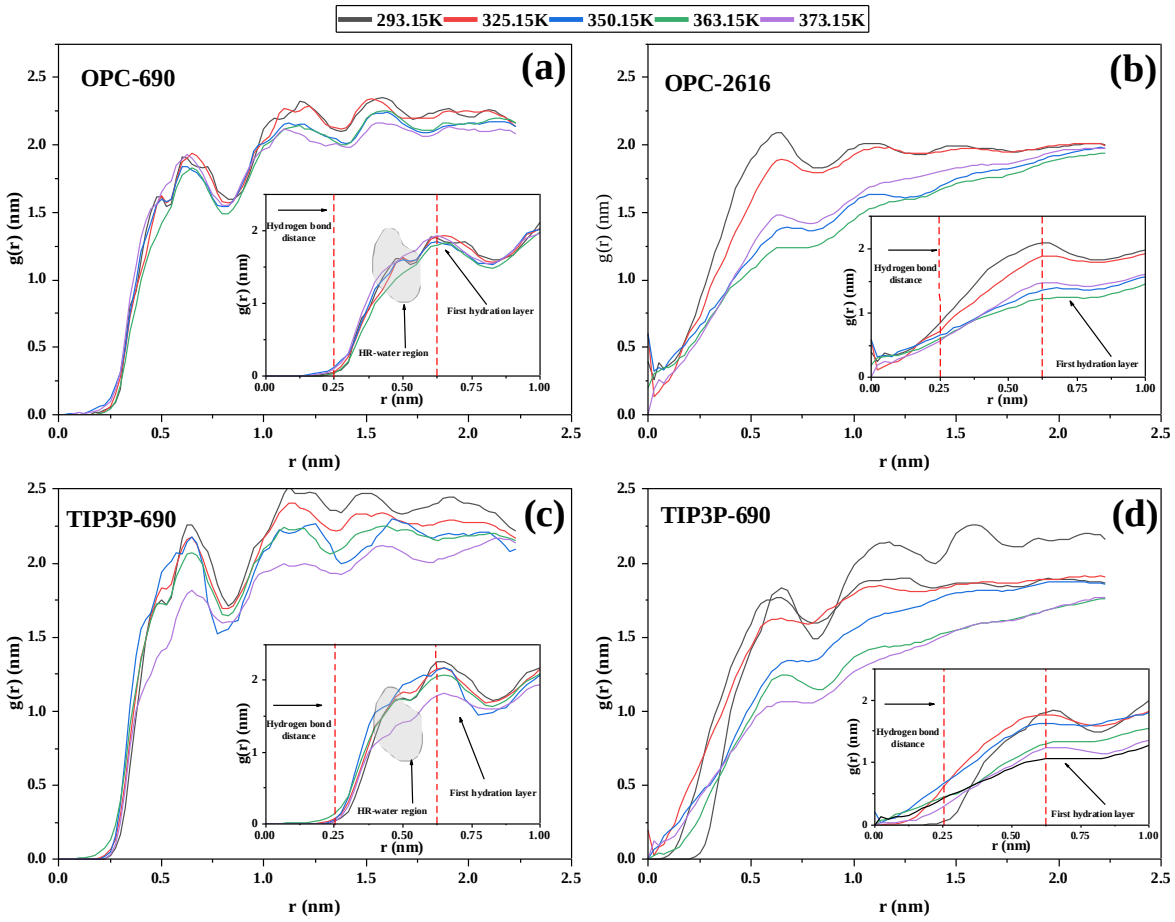

Figure 4: Radial distribution functions of water molecules around exposed hydroxylic groups on the cellulose crystal. (a) TIP3P-690 water molecules (left), zoom in between the H-bond distance and the first hydration layer (right). (b) TIP3P-2616 water molecules. (c) OPC-690 water molecules. (d) OPC-2616 water molecules.

Conclusion

A computational study of the molecular interaction between a Iβ-cellulose crystal and water was carried out. This study was conducted at temperatures typically employed for lignocellulosic drying. The selected water models predicted the expected reduction in hydrogen bonds with increasing temperature beyond the first hydration layer. Furthermore, an additional peak in the radial distribution function was detected for the systems containing fewer water molecules and was related to the water molecules strongly bound to the cellulosic surface, known as hard-to-remove water. This fundamental study reveals the dynamics of water molecules with temperatures found in the dryers, providing an atomistic understanding of the drying phenomena of lignocellulosics. More complex systems involving lignin and hemicelluloses will be evaluated for future work.

Acknowledgments

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Proceedings of the 2023 SWST International Conference
Asheville, North Carolina, USA

Educating Architects and Builders about Opportunities for Thermally-modified Wood Products from Low-value Hardwood Species

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Dr. Henry Quesada - Purdue University

Dr. Omar Espinoza - University of Minnesota

Abstract

We identified through previous work that the best way to increase the use of thermally modified wood (TMW) from low-value, underutilized hardwood species is to focus on educating the architectural community – those who specify its use in buildings and products. For example, our previous work concluded that approximately 80% of architects are not aware of the advantages and applications of TMW. Research from the University of Minnesota revealed that professional builders have mixed perceptions of TMW compared to other competing product alternatives, suggesting a large opportunity for educating these professionals about the economic and environmental benefits of TMW. Based on this knowledge, we developed and delivered National education and training activities through the American Institute of Architecture (AIA) to significantly increase awareness of current uses, architectural projects, properties, and comparisons to other materials. This poster presents information about our efforts to reach the building community with information about TMW to increase its use.

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Asheville, North Carolina, USA

Surface Energy and Surface Wettability of Wood and Cellulosic Materials by Inverse Gas Chromatography

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Dr. Anett Kondor - Surface Measurement Systems

Mr. Armando Garcia - Surface Measurement Systems

Dr. Majid Naderi - Surface Measurement Systems

Abstract

Surface energy is an important physico-chemical property in numerous industrial applications and processes. It shows a strong dependency on various macroscopic properties and relates to many crucial interfacial phenomena, including adhesion and wetting behaviors. Most natural materials like wood and cellulose are energetically heterogeneous. This heterogeneity could be due to material variability, impurities, defect sites, amorphous regions, composites, or co-processed mixtures of materials. Therefore, it is often difficult or even misleading to characterize the surface energy of these materials with a single value. Also, the quality and performance of cellulose-based composites depends strongly on the interaction of the components at their interface. If interfacial adhesion is sufficient, then stress can be effectively transferred from the matrix to the wood/cellulose fibers. Additionally, the surface energy and surface area of natural fibers are directly related to compatibility, dispersibility, and reinforcement quality. To enhance the adhesion properties at the interface, fibers are often exposed to surface treatments such as oxidation and sizing. Finally, environmental conditions like temperature and moisture exposure can alter the surface and interfacial properties of cellulose-based materials.

For the above reasons, it is important to fully characterize the surface energy and wettability properties of wood and cellulosic-based materials. In this research, surface areas and energies of wood materials and cellulosic fibers from different origins and surface pretreatments have been determined by Inverse Gas Chromatography (IGC). IGC is a well-known technique used for the surface characterization of industrial and natural materials and it provides the required sensitivity to study surface adsorption. Recent advances in IGC theory and applications have developed new methods for determining surface energy distributions for solids using IGC. This approach allows for the determination of surface energy values at defined specific surface coverages and determination of surface energy profiles. These measurements more accurately represent the anisotropic nature of most solids.

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CHEMICAL-MORPHOLOGICAL ANALYSIS OF DENSIFIED ASH WOOD

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ABSTRACT

The effects of a thermal densification treatment on anatomic structure, chemical components and natural durability of the wood *Fraxinus americana* (ash) are presented on this study. The following equipment and methods, SEM microscopy, FTIR spectroscopy and the soil method according to ASTM D 2017 (white rot fungi *Trametes versicolor* and brown rot fungi *Gloeophyllum trabeum*) were used for the tests. The controlled factors on the densification process were, temperature 120, 140 and 160ºC, compression rates 20, 30 and 40%, and moisture contents 12 y 30%. The densification treatment produced a softening effect of the cell walls of the wood, causing viscous compaction in early wood. Regarding chemical composition, significant changes were observed mainly in those specimens exposed to maximum compression, meanwhile the extractives and carbohydrates were degraded due to longtime of exposure to elevated temperatures. Due to this degradation, a relative increase in lignin contents was observed. The hydrolyzed holocelluloses generated crosslinks with the polymeric chains of lignin. The alfa cellulose contents were reduced resulting in an increase in amorphous cellulose (beta cellulose) and inverse. Most of the specimens exhibited losses, 9% and 62%, regardless of the processing conditions and fungi tested. The FTIR studies exhibited selective degradation of chemical components, lignin for specimens exposed to *T. versicolor* and carbohydrates for *G. trabeum* respectively.

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Humidity-responsive design based on pinecone function - a collection of fabrication principles

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Abstract

Many inspiring case studies are written in complex and complicated scientific language focusing more on material engineering than the designer's needs, which hinders the utilization of known procedures in the art and design. The pinecone is an excellent example to demonstrate this phenomenon. It opens when it is dried and closes when wet. The designer would need to know its function in a very simplified way. Biomimicry offers the abstraction method of this physical phenomenon and leads it to scripting sketches and procedures. Finally, reproducing the original effect could be used using currently known techniques and materials to find applications in innovative design ideas.

This work presents existing principles for the artificial fabrication of natural hygro-morphs and suggests interesting biomimetic analogs for design ideas. The intention is to identify the variety of available solutions for humidity-responsive materials, composites, or 3D-printed structures inspired by a pinecone. We are looking for the most straightforward low-tech, low-cost ideas that can be easily re-interpreted into wood-based and humidity-responsive sustainable design ideas. With this approach, the designer will have access to visually understandable instructions in the form of infographics sketches and simple instructions to achieve their design ideas and the properties related to the ability of humidity response.

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Small-scale production and application of some sustainable biochar and charcoal production technologies

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Prof. Rado Gazo - Purdue University, Department of Forestry and Natural Resources
Prof. Eva Haviarova - Purdue University, Department of Forestry and Natural Resources

Abstract

Fabricating an efficient and cost-effective biochar and charcoal retorts is most economical when farmers/producers have the materials on hand and the skills (i.e., welding) needed for the manufacturing process. Inappropriate technologies affect the yield, quality of charcoal or biochar produced and their resulting level of environmental pollution. However, as farmers gain more knowledge, understanding and skills in manufacturing these different technologies at their convenience, they make the rightful decisions in advocating sustainable agricultural practices. We reviewed 15 existing biochar and charcoal production technologies using desk study. Three appropriate retorts from these were selected, prototyped and their production and usage variables (yield efficiency and the quality of biochar/charcoal produced) were tested with four agricultural residues (corn cob, corn husk, sorghum residue and solid wood). After this, expert recommendations on the design properties for the retorts were incorporated to promote their usage for small-scale productions. An extension plan was then developed for effective implementation and collaboration by relevant stakeholders and industries, especially in developing countries.

Keywords: Biochar, Charcoal, Extension Plan, Retort, Yield Efficiency

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Effect of steam treatment on the surface and adhesive properties of maple wood

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Abstract

The thermophysical properties of wood species have been widely studied. The heat transfer in wood depends on the geometry of wood sample as well as porosity, moisture content, and many other factors, e.g. thermal modification parameters. Chemical modification of wood using thermal pre-treatment represents frequently used method for preparation of wood with higher hydrophilicity or hydrophobicity.

The influence of water steam treatment on the properties of maple wood was investigated. The results and their analysis indicate that the studied physical and chemical properties of treated maple wood were noticeably changed. Hydrophobicity of maple wood has increased after steam modification, resulting in increased dimensional stability of thermally modified wood. The increase of water contact angle on the treated maple wood surface was confirmed, too. FTIR-ATR and XPS analyses of steam modified maple wood provided essential information about chemical changes and confirmed a slight decrease in oxygenic functional groups content as well as an increase in carbon content on the maple wood surface. SEM measurements detected considerable changes in the relief of steam-treated maple wood.

Key words: maple wood, steam treatment, chemical changes, contact angle

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The role of eco-innovations in the hardwood-products sector for the development of a sustainable society

Prof. Manja Kuzman - University of Ljubljana Biotechnical Faculty
Prof. Dick Sandberg - Luleå University of Technology, Wood Science and Technology
Prof. Eva Haviarova - Purdue University, Department of Forestry and Natural Resources

Abstract

Innovative production methods and manufacturing processes create economically competitive products that open new possibilities for the construction sector. The hardwood sector is currently not well developed but could be extended to make a considerable contribution to the green transition of the construction sector. Over the last few decades, crucial changes have occurred in societal views about wood products and how we should utilize global forest resources. Increased environmental awareness has brought forests to the forefront of global ecological discourse. Evolving trends in sustainable, bio-based economies and solutions of our societies resulted in higher demands for forest-based materials to produce more sophisticated bio-based products. Technology is crucial in moving towards a higher added value of hardwood construction materials in a green economy. The worldwide thriving timber-construction sector and its rapid development beyond the limits of high-rise buildings demand high-performance materials, which could be made possible by including hardwoods. We will present eco-innovative solutions in architecture with examples of recently realized projects and their involvement in different design stages. We will also feature examples of educational programs and student outputs dealing with eco-innovations in the hardwood.

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Challenges and Success of Urban Wood Businesses

Dr. Frederik Laleicke - North Carolina State University, Department of Forest Biomaterials
Mr. Kyle Kapp - North Carolina State University, Department of Forest Biomaterials

Abstract

Urban wood products, such as live-edge furniture, have seen rapid growth in recent years due to their unique aesthetics, wood craftsmanship, environmental consciousness, and history. The background of urban wood business owners is diverse, and there is no set path to starting, owning, and operating such a business.

This study presents the results of a survey that explored the backgrounds, strategic priorities, and typical challenges of starting an urban wood business. The results showed that half of the participants did not have a wood background. Many operations are started mid-career by individuals shifting from a successful industry occupation to an independent, labor-intensive venture. One of the major challenges faced by new businesses is the transition from start-up to a reliable and consistent source of income. Market access and sales, but also machine operation and maintenance are some of the major barriers.

Transporting and moving heavy logs is crucial to any successful urban wood business and a major financial burden. It is often assumed that urban wood businesses can source all of their wood for free, but the survey showed that most participants pay for their logs. The cost is commensurate with the species, quality, and provenance of the logs.
A strong and appealing social media presence is a key factor for the success of urban wood businesses. Building networks and relationships, as well as marketing a personal brand and story, are crucial components of success for these operations. This study outlines what it takes to start and run a successful urban wood business.

Key Words: Urban Wood, Business, Sustainability, Entrepreneurship, Marketing

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Cellulose Nanomaterial-based Film for Grease-resistant Food Packaging Application

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Abstract

The common uses of plastic for food packaging are advantageous in many cases because of its easy processability, low cost, and excellent resistance to water, oil, and grease penetration. The per- and poly-fluoroalkyl substances (PFASs) treated paper using the conventional paper manufacturing process has also achieved similar functionalities to prevent oil, water, and grease passages. One of the major concerns about using PFASs is that it has been identified as responsible for thyroid-related diseases, kidney diseases, developmental toxicity, immunotoxicity, metabolic disruption, and cancer. Furthermore, PFASs are highly persistent when disposed into the environment with the packaging, which causes significant negative impacts on the whole ecosystem. Due to the health and environmental concerns of packaging made of plastic and PFAS-coated paper, food packaging industries are now open to more options. Cellulose nanomaterials (CNs), such as cellulose nanofibrils (CNFs) and cellulose nanocrystals (CNCs), are ideal alternatives. CN is non-toxic, sustainable, and renewable nano-scaled cellulosic material from natural cellulose sources like wood, grass, cotton, tunicate, etc. CNFs are spaghetti-shaped fibers containing large fiber networks, while CNCs are rice-shaped crystals. The key concept of using CNs to resist oil/grease is that oil/grease cannot strongly interact with the strong hydrogen bonding contained in CN-based films. This research demonstrated CN films with different CNF/CNC ratios provided oil/grease resistance (a kit rating of 12) comparable to PFAS-based paper. The properties of the films have been characterized by mechanical property tests, contact angle analysis, surface energy calculation, grease resistance test, and pore size distribution. The pore size distribution of pure CNF films drastically reduced at the highest CNC loading level of such films. In terms of mechanical properties, all CN-based films showed higher tensile strength, strain at break, and tensile energy absorption values compared to commercially available parchment paper, butcher paper, pan liner, and copy paper.

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Anatomy, Density, and Chemical Properties of Eucalypt Wood Affected by Abiotic Stress

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Dr. Braz Demuner - Suzano
Dr. Jose Tarcisio da Silva Oliveira - Federal Univesity of Espirito Santo

Abstract

The Eucalyptus genus is well-adapted and highly productive under Brazilian edaphoclimatic conditions. Its widespread use results from decades of studies and investments in forest improvement and management. However, despite considerable efforts to guarantee the productivity and quality of the plantations, the trees can face atypical climatic conditions and develop diseases caused by abiotic factors, such as Eucalyptus physiological disorder (EPD). This work aimed to investigate the effects of EPD on the anatomy, density, and chemical content of the wood of one eucalypt clone. To perform this study, five-year-old trees were felled from two adjacent stands showing two levels of EPD symptoms (higher and lower). The results indicated that besides being visually affected by the EPD, the eucalypt clone also had the wood anatomy and chemistry properties affected by the disturbance. However, the EPD did not influence the specific gravity of the wood.

Keywords: tree plantations; abiotic stress; growth disorders; wood properties.

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Sustainable Design, Eco Chair: A Concept Design That Service The User And The Environment

Mr. Rico Ruffino - North Carolina State University, Department of Forest Biomaterials

Abstract

Upholster furniture in landfills has increased in number as the years press forward. Furniture is an item that has limited end-of-life options. It can be reused by Donating it to another individual or family member or reupholstering it, but that is rare because of cost factors, or throwing it in the trash and sending it to a landfill because all the components are hard to separate for recycling. Unfortunately, more often than anything, furniture ends up in landfills that potentially harm the environment.

The solution resides in Sustainable Design, where the design system is from an omni-centered point of view. This design system's intention is for all objects, systems, and processes. Omni-centered point of view is designing to consider all elements that the design encounters from conception to the end of its life cycle. This process is an adaptation to design thinking, adding a more advanced layer, still changing it to a more holistic process where one can work in and out of different aspects of the process.

The Eco chair is a club chair piece of furniture that utilizes a sustainable design process. We conducted a study at NC State Sustainable Design Lab of a conceptual design and process of a piece of upholstered furniture that applied these concepts for the Sustainable Furnishing Council's 15th year anniversary at High Point Furniture Market. We applied a more omni-centered point of view that considered more sustainable materials and the development of upholstered chairs to disassemble down to their base components constrained to the same material. Meaning, that all wood was constrained to only wood, all foam isolated to only the foam, and so forth with the following material. This design is beneficial because it gives the owner more options, if desired, to reuse, recycle, or reorder each component, allowing the chair to last an extended amount of time, keeping it out of landfills, and the option of recycling when needed. The materials used in this process were as follows: the frame and feet developed from sustainable-sourced white oak, seat and back natural latex foam, padding Cocolok fiber, covering layer flax fiber, glueless pocket springs, Tencel wadding for around the seat and back cushion. The fabric is Live Smart powered by Reprieve and minimal metal hardware in the feet bolts and interlocking hooks that attach all sections of the chair design. By integrating a Sustainable Design System, we successfully created a truly unique piece of furniture that is better for the user and the environment that will stay out of landfills.

Key Words: Sustainable Design, Omni-Centered, Natural Latex Foam, Cocolok, Sustainable Sourced Lumber, Tencel, Reprieve

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The efficiency of deadwood particles as a formaldehyde scavenger in particleboard

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Abstract

Synthetic adhesives based on formaldehyde are mainly used for the manufacture of wood-based panels. These adhesives are characterized by certain problems associated with the release of hazardous volatile organic compounds (VOCs), including free formaldehyde, from finished wood-based panels. Due to the problems caused by formaldehyde emissions, many countries have issued regulations to reduce formaldehyde emissions from wood-based panels. Therefore, the development of highly efficient ultra-low formaldehyde emissions is necessary for the sustainable production of wood-based panels. The volume of deadwood increases annually because of changes in environmental, climatic, and hydrological conditions. Millions of cubic meters of infested trees (beetle-killed trees are very common) are now standing in Europe forests. On the other hand, during the last decade, manufacturers of wood-based panels have been facing an acute problem of a shortage of conventional raw materials. We can assume that excessive dryness and low content of extractive substances, as well as long storage time of deadwood, are the factors that could lead to a decrease in formaldehyde release. Therefore, the purpose of this study was to evaluate the possibility of using wood particles from deadwood as a formaldehyde scavenger in the production of particleboards. Three-layer particleboards with different content of deadwood particles (0%, 25%, 50%, 75%, 100%) were produced. Conventional urea-formaldehyde (UF) resin was used for gluing the particles. The physical and mechanical properties of the boards, as well as the formaldehyde content in the boards, were determined. In addition, the effect of adding melamine-urea-formaldehyde (MUF) resin to UF adhesive on the properties of the boards was investigated. Replacing conventional sound wood particles with deadwood particles leads to deterioration of the physical and mechanical properties of the boards. The boards from deadwood particles absorb more water and swell more. The bending strength (MOR), modulus of elasticity in bending (MOE), and internal bonding (IB) values for boards with 100% deadwood particles are reduced by 26.5%, 23.1%, and 72.4%, respectively, compared to reference boards from sound wood particles. Despite this, a significant advantage is that boards made from 100% deadwood particles are characterized by 34.5% less formaldehyde content than reference boards made from conventional sound wood. Moreover, adding 3% of MUF resin to UF adhesive increases MOR, MOE, and IB by 44.1%, 43.3%, and 294.4%, respectively.

Key words: particleboards; deadwood; formaldehyde emission; urea-formaldehyde adhesive; bending strength; internal bond strength; modulus of elasticity; thickness swelling

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Oak wood pre-treated by radio-frequency plasma

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Abstract

The radio-frequency (RF) plasma significantly increases hydrophilicity of the wood due to formation of various polar groups (e.g. hydroxyl, carbonyl, carboxyl, etc.). Wood macromolecules also cross-link, what leads to the increase in scratch resistance and to the improvement of barrier properties of the wood. The increased surface polarity improves the wettability and hydrophilicity due to oxidation reactions during modification of wood by cold plasma. FTIR spectrum of wood is basically a mixed spectrum of cellulose and lignin with characteristic peaks of both –OH bonds, and in the fingerprints wave numbers, which is particularly low for C–O–C, CH_2 and COO bonds, typical for polysaccharides. FTIR spectra have a maximum of 2985 cm^{-1} belonging to –CH_2 groups. The absorption bands of non-polar CH_2 groups of oak wood treated by RF plasma decreased and the absorption bands belonging to polar –OH groups increased. The integrated intensities ratios of oxygen function absorption with the majority of polar –OH groups contribution with a maximum at 3400 cm^{-1}, and in comparison a maximum of non-polar –CH_2 groups with a maximum at 2985 cm^{-1} (–CH_2 groups) sym an increase of the ratio P(OH)/P(–CH_2) during plasma treatment of the oak wood has been found. An increase of the ratio P (OH)/P (–CH_2) during RF plasma treatment of the oak wood can be observed. The ratio P (OH)/P (–CH_2) correlates with time of oak wood RF plasma treatment. The large increase of the integrated intensities ratio was observed from value 10.2 (native wood) up to value 31.6 (RF plasma-treated wood, 120 s). The polar component of the surface energy is associated with the presence of acid-base forces (electron donor-acceptor bonds). The surface free energy and its polar component of oak wood increased with time of plasma activation from 65 up to 81 $mJ.m^{-2}$ and the polar component of the surface free energy increased from 18 to 30 $mJ.m^{-2}$.

Key words: oak wood, radio-frequency plasma, wettability, surface free energy, surface chemistry

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Reduction of formaldehyde emissions from wood-based panels glued with UF resins modified with collagen and keratin

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Abstract

Polycondensation urea-formaldehyde (UF) resins are the most used adhesives in the woodworking industry. Their use is widespread due to their relatively low price, high reactivity, availability of raw materials, and ease of use. They provide a transparent brittle joint after curing, but their main disadvantage is the intensive emission of formaldehyde. In this study, the naturally occurring biopolymers keratin and collagen were selected and tested as potential agents in reducing formaldehyde emissions from wood-based panels. Collagen is the widespread animal protein component of skin, tendon, bones and ligament. Keratin is the main component of hair, fur, feathers, hooves, horns and the outer surface of the skin. These samples were studied by differential scanning calorimetry (DSC). The antioxidant activity of the samples was determined in a suspension of polyethylene glycol, and the Berthelot-Hood temperature function was chosen to estimate the stability. The substance has a protective effect, i.e., it behaves as an antioxidant if the protection factor PF > 1. All tested samples of biopolymers met this condition in the selected temperature interval. X-Ray photoelectron spectroscopy (XPS) was used for qualitative and quantitative determination of basic elements of samples prepared from collagen and keratin. The differences between the spectra of thermally modified samples are for all elements and also for sulfur in its reduced form C-S (S2p signal at ~ 163 eV) and oxidized form SO_2 (S2p signal at ~ 168 eV). FTIR spectra confirmed the reactivity of UF resin with biopolymers and creation of stronger methylene and peptide links.

Emission of formaldehyde was tested according EN ISO 12460-4 by desiccator method and quality of gluing according to standards EN 314-1 and EN 314-2. Measured values confirmed a decrease in formaldehyde emissions for all additives compared to the reference value. The most significant decrease in fd emissions up to 30.7% was achieved with the application of 3.0% crushed horn. The highest shear strength of 3.7 MPa was achieved by applying a 1.0% concentration of crushed horn. The standard EN 314-2 requires a shear strength value of 1.0 MPa for the glued joint, and all prepared samples far exceed this required minimum. Collagen and keratin samples prepared for this study might therefore have a great potential for application as the environmentally friendly formaldehyde scavengers of wood-based composites.

Key Words: Wood Composites, Urea-Formaldehyde Resin, Collagen, Keratin, Plywood, Formaldehyde Emission

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Longitudinal Compression Strength and Stiffness of Wood including Joints with Mortar or Epoxy Adhesives

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Abstract

The stress-strain behavior of wood is crucial when it is used for structural purposes. The anisotropy of wood is often simplified to orthotropy, which makes it easier to determine the reliable elastic constants of the material, especially when using special orthotropic samples. However, the strain distribution when compressed parallel to the grain is not homogeneous, with the largest strains often appearing near the steel loading plate. This area of the largest strain is referred to as the "damage zone".

In this study, the behavior of the damage zone when compressed parallel to the grain was investigated using various materials, including steel plate only, mortar and epoxy structural adhesives near the butt-end of the wood. We conducted compression tests parallel to the grain on specimens with dimensions of 100 mm in height and cross-sectional areas ranging from 25x25 to 200x200 mm. The experimental parameters were the dimensions of the specimens and the materials used to contact the butt-end of the wood specimens.

Our findings revealed that specimens with mortar had the lowest maximum stress and Young's modulus, while those with epoxy structural adhesives had the highest. Additionally, the strain in the damage zone of specimens with mortar was the largest, while that of specimens with epoxy structural adhesives was the smallest. These results suggest that mortar has a detrimental effect on the Young's modulus and strength of the damage zone. Conversely, the use of epoxy structural adhesives in timber connections has the potential to mitigate the influence of the damage zone.

Keywords: Compressive strength, Compressive stiffness, Wood, Joints, Damage zone, Longitudinal direction

Introduction

The stress-strain behavior of wood is crucial when it is used for structural purposes. The anisotropy of wood is often simplified to orthotropy, which makes it easier to determine the reliable elastic constants of the material, especially when using special orthotropic samples. However, the strain distribution when compressed parallel to the grain is not homogeneous (Totsuka et al. 2021), with the largest strains often appearing near the steel loading plate (Brabec et al. 2015, Totsuka et al. 2022). This area of the largest strain is referred to as the "damage zone," while the zone between the damage zones is known as the "middle zone." The Young's modulus of the middle zone is commonly referred to as the "Young's modulus of longitudinal." It is worth noting that the Young's modulus of the damage zone is only about 2% of the Young's modulus of the middle zone (Totsuka et al. 2022). Previous studies of the behavior of the damage zone have only focused on its behavior with steel plates. In composite beams of concrete and timber (e.g., Gutkowski et al. 2008 and Taazount et al. 2013), the behavior of the damage zone with concrete is important. It is equally important to consider the behavior of the damage zone with epoxy structural adhesives because the adhesives are often used for timber connections.

In this study, the behavior of the damage zone when compressed parallel to the grain was investigated using various materials, including steel, concrete, and epoxy structural adhesives near the butt-end of the wood.

Materials and Methods

Specimens

Table 1 shows an overview of the test series of specimens. The specimens were made from glulam of Japanese cedar (*Cryptomeria japonica*) and Japanese larch (*Larix kaempferi*). The dimensions of the specimens were 100 mm in height, *L*, (longitudinal direction) and 25x25 to 200x200 mm in cross-sectional area. The thickness of the glulam laminae was 30 mm and the width was the same as the specimen width. The experimental parameters were the cross-sectional area of the specimens and the materials used to contact the butt-end of the wood specimens, including steel plate only (benchmark), non-shrink grouting mortar, and epoxy structural adhesives, shown in Figure 1. A total of 130 specimens were prepared by manufacturing 6 or 4 specimens per series; see Table 1. To eliminate the effect of variability, the specimens of the same dimensions were cut from one glulam. The specimens had typical wood characteristics, adhesive layers, and finger joints, however, the specimens of series 25A, 25AL and 100B did not have adhesive layers and finger joints. The mean density of the cedar specimens was 0.41 g/cm^3 and that of the larch specimens was 0.63 g/cm^3. The mean moisture content of the cedar specimens was 11.6 % and that of the larch specimens was 11.9 %. Mortar or epoxy-filled specimens were created by making a formwork with a 10 mm margin at the butt-end of the wood to fill the margin with mortar or epoxy. Epoxy-bonded specimens were created by applying a thin layer of epoxide between the wood and the steel plate and bonding them together by compression. The specimens with mortar cured for more than a month and the specimens with epoxy adhesive cured more than 24 hours.

Table 1: Overview of specimens and experimental data.

Series	*n*	Contact material	Cross-section	Wood	Max. strength		Young's modulus	
			A (mm2)		mean (N/mm^2)	CV	mean (kN/mm^2)	CV
25A	6	Benchmark	25x25	Cedar	29.8	0.10	4.86	0.13
	6	Mortar filling	25x25		23.9	0.06	2.26	0.23
	6	Epoxy filling	25x25		30.7	0.05	3.78	0.17
	6	Epoxy bonding	25x25		35.7	0.10	6.35	0.14
25AL	6	Benchmark	25x25	Larch	38.3	0.07	7.04	0.02
	6	Mortar filling	25x25		35.6	0.06	3.15	0.36
	6	Epoxy filling	25x25		40.8	0.05	6.48	0.09
100A	6	Benchmark	100x100	Cedar	30.5	0.02	2.73	0.03
	6	Mortar filling	100x100		19.2	0.09	1.47	0.14
	6	Epoxy filling	100x100		28.3	0.04	3.27	0.20
	6	Epoxy bonding	100x100		29.0	0.05	2.29	0.18
100B	6	Benchmark	100x25	Cedar	33.1	0.05	4.05	0.08
	6	Mortar filling	100x26		27.0	0.04	2.18	0.17
	6	Epoxy filling	100x27		33.0	0.09	4.91	0.12
	6	Epoxy bonding	100x28		34.1	0.03	5.11	0.15
200A	4	Benchmark	200x200	Cedar	26.3	0.07	4.66	0.26
	4	Mortar filling	200x200		18.7	0.03	2.16	0.38
	4	Epoxy filling	200x200		27.4	0.00	22.6	0.00
	4	Epoxy bonding	200x200		32.8	0.14	8.16	0.32
200B	6	Benchmark	200x50	Cedar	29.2	0.03	5.44	0.28
	6	Mortar filling	200x50		22.8	0.07	1.53	0.32
	6	Epoxy filling	200x50		28.3	0.02	3.16	0.41

6	Epoxy bonding	200x50	29.4	0.02	11.3	0.08

n: number of specimens, CV: coefficient of variation.

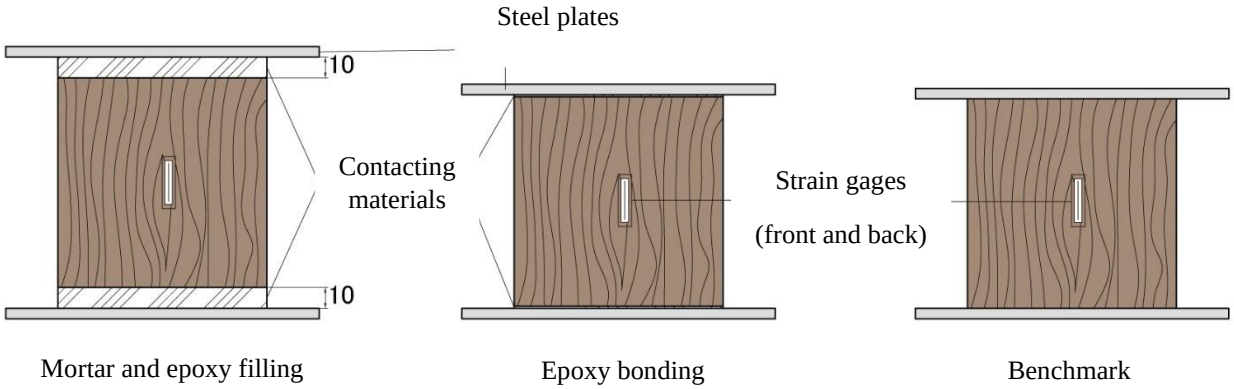


Figure 1: Specimens of steel plate only, mortar filling, epoxy filling, and epoxy bonding.

Test methods

The compression tests were carried out on a universal testing machine with a load cell, a spherically seated loading-head, and two displacement transducers to measure the displacement of the total height of the specimens under displacement control at a rate of 0.003 *L* mm/min according to ASTM D 143(2022) as shown in Figure 2. The 2D deformations and local strains in a surface were determined by the DIC system by a digital camera. A 2D optical system captured images at a frequency of 0.2 Hz during the test. The images were processed with the DIC software (GOM correlate, GOM, Braunschweig, Germany). This software uses an automated computer algorithm to determine local displacements and strains according to deformation images. For all specimens, a speckle pattern, which consisted of black dots on a white surface, was painted on the face of these specimen's face.

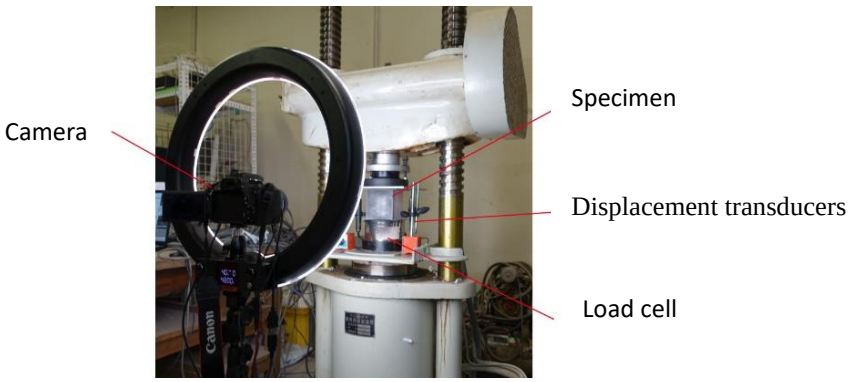


Figure 2: Test setup of compression test

Results and Discussion

Maximum stress and Young's modulus

The maximum stress, σ_{max}, obtained from the experimental results of each specimen and the Young's modulus of the only wood, *K*, (hereinafter called Young's modulus) are shown in Table 1. The Young's modulus was an apparent value that takes into account the damage zone and middle zone. The values were calculated using the following equations.

$$\sigma_{max} = P_{max}/A \tag{1}$$

$$K = \frac{k \cdot L}{A} \qquad (2)、\quad k = \frac{0.4P_{max} - 0.25P_{max}}{\delta_{0.4P_{max}} - \delta_{0.25P_{max}}} \qquad (3)$$

Where P_{max} is the maximum load and δ_t is the deformation at *t*. δ_t of the mortar- and epoxy-filling specimens were obtained excluding the deformation of the mortar, and epoxy by the following equation.

$$\delta_t = \delta'_t - \frac{P_t \cdot l}{E \cdot A} \tag{4}$$

Where P_t is the load at *t*, *l* is the thickness of the mortar or epoxy, and *E* is the Young's modulus of the mortar (29.7 kN/mm^2) or epoxy (3.42 kN/mm^2). Due to the initial slip, the range for obtaining the Young's modulus was set at 0.25-0.4P_{max}.

A comparison between the maximum stress or Young's modulus and the cross-sectional area is shown in Figure 3. The maximum stress decreased as the cross-sectional area increased. For all cross-sections, the maximum stress of the mortar-filled specimens was about 20% lower than that of the benchmark specimens. The Young's modulus of the mortar-filled specimens was also lower than that of the benchmark specimens. On the other hand, the epoxy-bonded specimens showed a tendency to have a higher Young's modulus than the benchmark specimens, except for 100B, and their maximum stress was the highest among all specimens. Moreover, the size effect of the maximum stress on the epoxy-bonded specimens was the smallest.

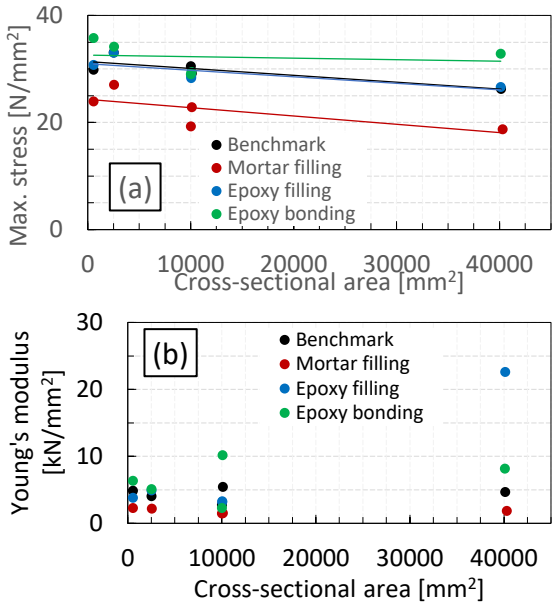


Figure 3: (a)Comparison between the maximum stress and the cross-sectional area. (b)Comparison between Young's modulus and the cross-sectional area.

The Young's modulus of the middle zone, K_{mid}, (commonly known as the longitudinal Young's modulus of wood) was obtained from the values of the strain gauges attached to half of the specimens (Figure 1).

$$K_{mid} = \frac{0.4P_{max} - 0.25P_{max}}{(\varepsilon_{0.4P_{max}} - \varepsilon_{0.25P_{max}})A} \tag{5}$$

Where ε_t is the strain measured by the strain gage at t. The ratios of K_{mid} and K were calculated to investigate the influence of the damage zone and show in Figure 4. Since K was smaller than K_{mid} due to the influence of the damage zone, the ratio closer to 1 indicated less influence of the damage zone. The ratios of the epoxy-bonded specimens were closest to 1, indicating the smallest influence of the damage zone, while the ratios of the epoxy-filled and benchmark specimens were comparable. On the other hand, the ratios of the mortar-filled specimens were the lowest, indicating the largest influence of the damage zone. Therefore, it can be considered that epoxy bonding is the most effective method for reducing the influence of the damage zone.

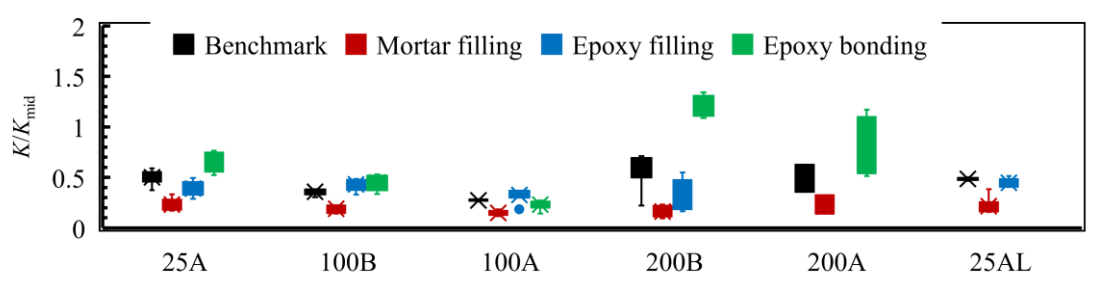


Figure 4: The ratios of K_{mid} and K.

Strain distributions

The strain distribution at $0.4P_{max}$ was investigated using DIC. Figure 5 shows the representative results of the series 25A and 100B. In all cross-sectional sizes, the length and strain of the damage zone were greater for the mortar-filled specimens than for the benchmark and epoxy specimens. Additionally, the benchmark and epoxy specimens showed kink band fractures in the middle and damage zones, as shown in Figure 6(a). However, for the mortar-filled specimens, only kink band fractures were observed in the damage zone, as shown in Figure 6(b). It is considered that stress concentration due to high moisture content near the butt end by mortar placement and the mismatch between the roughness of the wood and that of the mortar are the causes. The strain in the damage zone was significantly reduced in the epoxy-bonded and filled specimens compared to the benchmark specimens, indicating that epoxy can potentially reduce the influence of the damage zone.

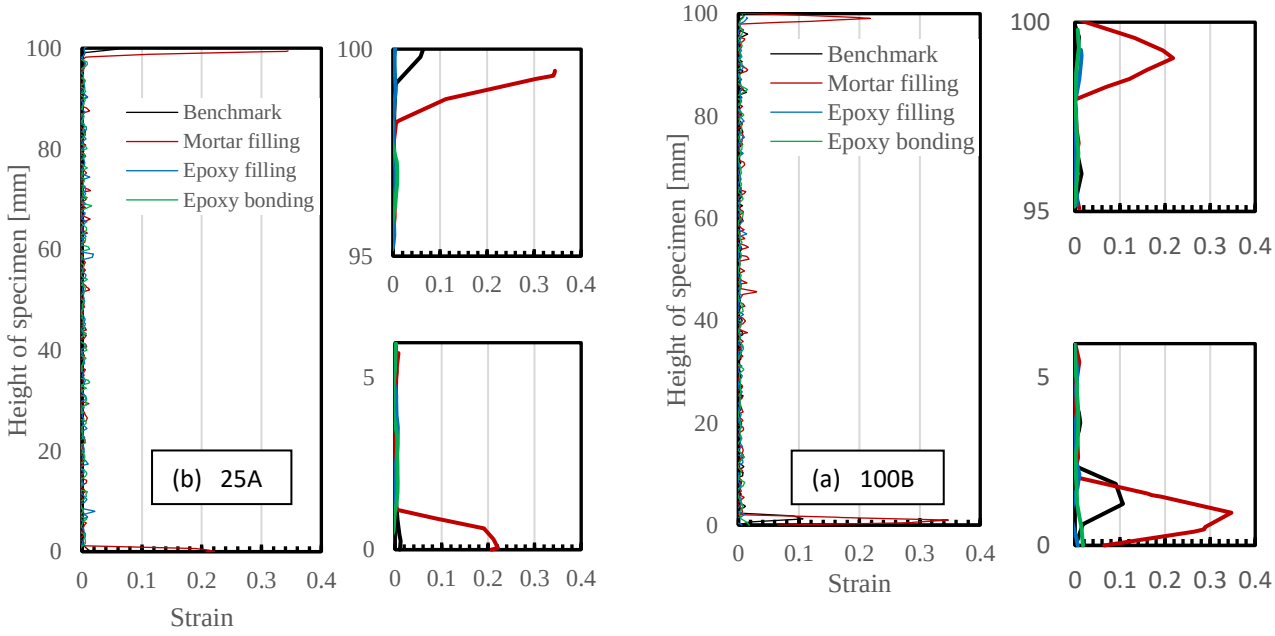


Figure 5: Strain distribution at $0.4P_{max}$ of the series 25A and 100B.

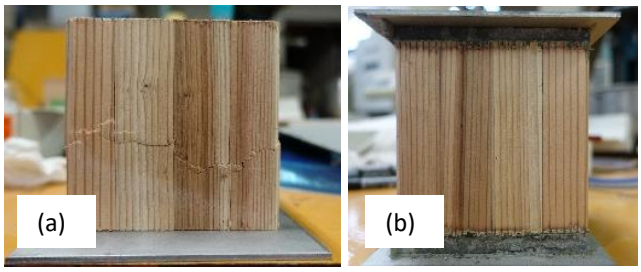


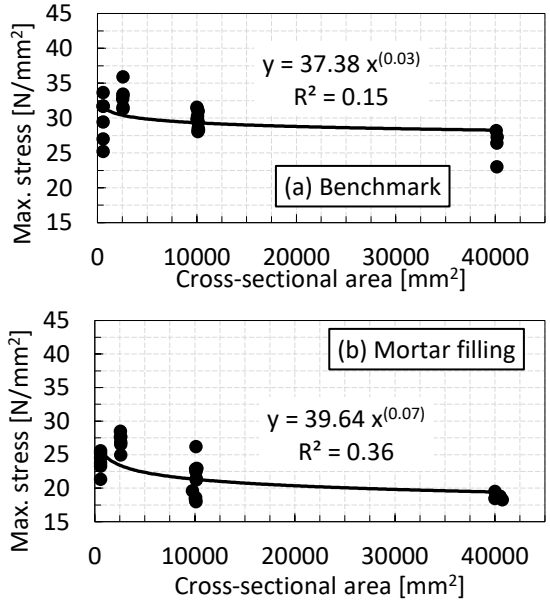
Figure 6: Faiure conditions after experiment. (a) Benchmark specimen. (b) Mortar filled specimen.

Size effect of compression strength and Young's modulus

It is known that size effects exist in the compressive strength parallel to the grain of wood, where the variability in compressive strength increases as the cross-sectional area or volume increases, and the mean value of the compression strength decreases (Fryer et al. 2018 and Totsuka et al. 2022). The size effect parameters, *S*, (Weibull 1939, Eq. (6)) for maximum stress were obtained for each material used to contact the butt-end, as shown in Figure 7.

$$\frac{\sigma_1}{\sigma_2} = \left(\frac{A_1}{A_2}\right)^S \tag{5}$$

The *S* of the benchmark specimens (*S*=0.03) and epoxy filled and bonded specimens (*S*=0.04) were almost same and that of the mortar filled specimens (*S*=0.07) was bigger than that of the other specimens.



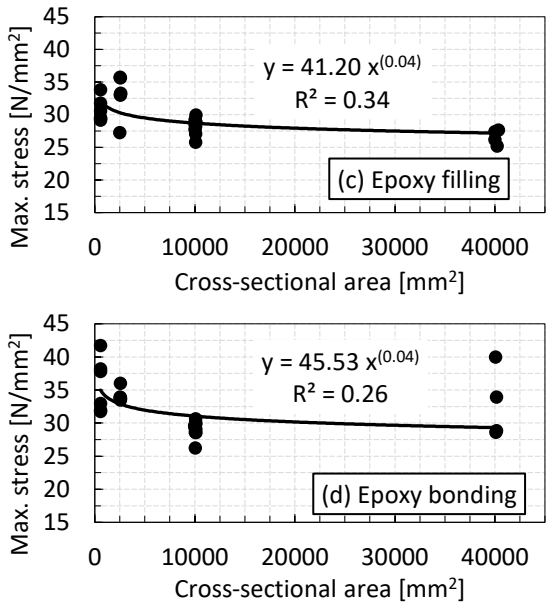
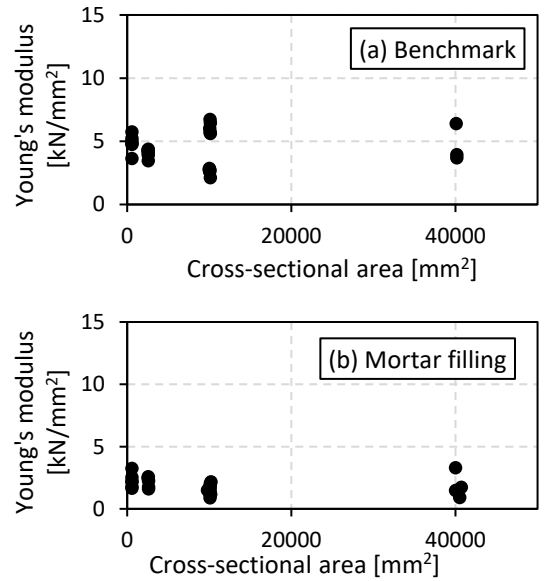


Figure 7: Size effect of muximum stress.

It is known that, similar to compressive strength, there is a size effect on the Young's modulus in longitudinal compression of wood. Figure 8 shows the relationship between the cross-sectional area and the Young's modulus for each material used to contact the butt-end. The mean values were connected by a straight line, indicating that there was no tendency for the Young's modulus to decrease as the cross-sectional area increased. In the previous study (Totsuka et al. 2022), it was noted that there is a few size effect on the Young's modulus when there is little roughness on the butt end of the wood. Therefore, it is considered that there was no size effect on these specimens because the machining was done with high processing accuracy, and the cut surface had little roughness.



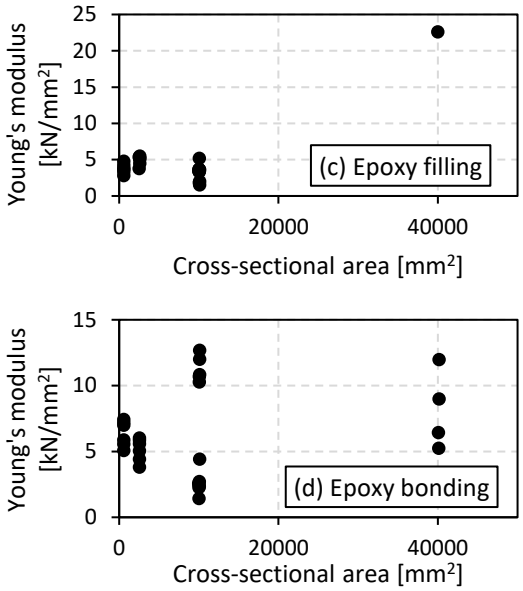


Figure 8: Comparison between cross-sectional area and Young's modulus

Conclusions

Compression tests parallel to the grain were conducted on 130 specimens, which showed that the presence of epoxy on the butt-end of the wood has the potential to reduce the influence of the damage zone on the maximum stress and Young's modulus. On the other hand, the presence of mortar on the butt-end of the wood may potentially decrease its maximum stress and Young's modulus.

In the epoxy specimens, the maximum stress and Young's modulus were the same as or higher than those of the benchmark specimens. Additionally, the strains near the butt-end of the wood were smaller than those of the benchmark specimens. Therefore, it is considered that using epoxy can reduce the influence of the damage zone, and a thinner layer of epoxy (i.e., epoxy bonding) can achieve an even greater reduction effect. The mortar specimens showed a significant decrease in both the maximum stress and Young's modulus compared to the benchmark specimens, and the influence of the damage zone was greater.

In addition, the size effects of the cross-sectional area were observed for all specimens (the benchmark, mortar filled, epoxy filled, and epoxy bonded specimens), especially in the mortar specimens where it was particularly pronounced. There was no tendency for the Young's modulus to decrease as the cross-sectional area increased. It is considered that there was no size effect of the Young's modulus on these specimens because the machining was clean and the cut-wood surface had little roughness.

Acknowledgments

We would like to express our gratitude to TAIHEIYO MATERIALS CORPORATION for providing the mortar used in the experiment.

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Analytical Timber Spaced-Column P-M Interaction Diagram

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ABSTRACT

International codes do not allow the application of bending moment along with axial compression on timber spaced-columns except for minor dead-load related moments. This study attempts to derive interaction between axial load and bending moment on spaced (built-up) columns using gussets. The capacity is determined by the use of Finite Element Modeling (FEM), especially for slender spaced columns. The approach considers a) buckling (local or global) stability of the whole column and b) compressive strength of members considering allowable stresses. Two lengths of 3m and 6m were selected for the FEMs and buckling load were obtained to determine three-dimensional P-M diagrams. An attempt was made to fit equations to the obtained P-M curves. Although the study is purely analytical, it highlights important missing aspects of spaced-column design and should be supported with experimental studies in the future. The results of this work might help to improve international timber design codes.

Significant efforts are underway to enhance the utilization of structural timber in construction, while an international race to construct taller timber high-rise buildings is gathering momentum. Several countries, including Canada, USA, New Zealand, and Europe, have established wood research centers to foster a sustainable construction industry and promote the widespread use of structural wood. The extensive application of timber in both regular and high-rise buildings may require the adoption of spaced column designs capable of accommodating bending moments.

Keywords: Mass Timber, Spaced-Column, P-M Diagram

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Life Cycle Assessment of Alkaline Peroxide Mechanical Market Pulps from Wood and Wheat Straw: A Comparison

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Abstract

Alkaline Peroxide Mechanical Pulps (APMP) from wood and wheat straw have been studied to determine their carbon footprint. Different inputs were considered to quantify their environmental burdens, such as chemical charges, fuel to produce steam, overall electricity required, and the CO_2 emissions associated with each biomass cultivation. When comparing conventional wood pulp to wheat straw pulp, the latter is believed to require less mechanical energy during the pulping process. In these terms, APMP from wheat straw showed a lower carbon footprint when compared with wood pulp, being the results highly sensitive to electricity sources and the type of fuel utilized to generate steam.

Keywords: Life cycle assessment, environmental burdens, APMP, biomass, carbon footprint.

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Influence of different modification processes on birch plywood densification

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Abstract

The utility parameters of wood-based materials used in the building industry can be improved through suitable modification. One modification method is the process of wood densification, where significantly higher strength parameters of wood can be achieved with an increased value of bulk density. In the case of solid wood, this modification is primarily used for woods with a lower bulk density, but in the last decade, the possibilities of densification of wood-based composite board materials have appeared. In the experimental study, the effect of different types of modification process was verified for a seven-layer plywood birch board (grade CP/CP, gluing class 3 for external usage). Thermo-mechanical modification (TM) and thermo-hydromechanical modification (THM) were performed. The TM method combines heat treatment with mechanical compression perpendicular to the fibres. In the experiment a temperature of 180°C was used during pressing, a compression of 3 MPa for 10 min, and stabilization of the boards under load in the press for 16 hours without temperature. The THM method combines the action of heat, pressure and saturated steam in the experimental plasticization of the boards by exposing them for seven days to conditions of temperature 30°C and humidity of 85%. The compression and stabilization of the boards were identical for the TM method. For the resulting modified product, the basic parameters of the densification process were determined, namely the compression ratio and the density ratio. The achieved physical properties of the modified plywood boards were also verified (density, equilibrium moisture content at 20°C and 65%, and determination of swelling in thickness after immersion in water and water absorption). The effect of various modifications on the strength parameters of the boards (determination of bending strength and modulus of elasticity in bending) was also determined. The densification quality was evaluated using the long-term monitored set-recovery effect parameter after cyclic exposure in different humidity conditions. All these parameters were compared to reference samples without densification.

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Circular Forest Products and the trend

Dr. Hui Wan - College of Material and Chemical Engineering, Southwest Forestry University

Abstract

It is assumed that forest products/wood science and technology research, development and education need a clear thought or theory to support and guide. This presentation explains the fundaments of Circular Forest Products, based on Circular economics, Bio-economics and Thermodynamics. It is the call of authors to seek a consensus from our colleagues on the theory, from its definition, scope, and reasons of developing the theory. Then based on the definition of Circular Forest Products, the authors share the thought of how to conduct it and the trend observed.

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Synthesis and Application of Carbon Dots as Environmentally Friendly Modifier for Low-molar-ratio Urea-formaldehyde Resins

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Dr. Ziqi Zhu - College of Materials Science and Engineering, Nanjing Forestry University
Mr. An Shen - Nanjing Forestry University

Abstract

Formaldehyde pollution from wood-based composites bonded with urea-formaldehyde resin is always an important issue for public concern. In this context, producers have been forced to lower the formaldehyde-to-urea (F/U) molar ratio to satisfy the formaldehyde regulations worldwide, but this approach inevitably leads to the declining bonding performance of resin, because the resin polymers enriched with amino rather than hydroxymethyl groups can hardly form highly branched structures during resin curing. In this regard, appropriate crosslinkers should be needed to react with superfluous free amino and further increase the crosslinking degree of cure resin structure. In this study, carbon dots (CDs) enriched with aldehyde groups were facilely synthesized by hydrothermal treatment of vanillin, the aldehyde content reached 21.9 mmol/g, which was more than three times of vanillin. The reactivity of surface-contained aldehyde was investigated through reacting CDs with urea under the same condition as UF resin synthesis. As a result, in acid and alkaline reaction conditions, the content of aldehyde groups decreased by 71.2% and 43.4%, respectively. Meanwhile, based on elemental analysis, the nitrogen content of aldehyde functionalized CDs after the reaction increased to 26.9% and 5.4% respectively, indicating the high reactivity of CDs toward amino groups on resin polymer chains. The aldehyde-CDs were used as feedstock for making low-molar-ratio UF resin (100 mg of CDs per kg of urea). Plywood panels bonded with the CDs-modified resin exhibited a higher tensile shear strength of 0.88 MPa, which was 46.7% increase in comparison to the reference. The deeper investigation revealed that these CDs enriched with aldehyde groups can generate strong physicochemical interactions with UF resin polymers, including I) the formation of strong covalent bonds; II) hydrogen bonding interactions, III) the entanglement of polymer chains exerted by the CDs nanoparticles. Taken together, this work will provide a new modification strategy and theoretical basis to the synthesis of environmentally friendly UF resin with excellent bonding performance.

Key Words: Urea-formaldehyde Resin, Bonding Performance, Branched Structure, Carbon Dots, Aldehyde Groups

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Solar Energy-Driven System for Lignin Oxidation: An Emerging Strategy for Promoting the Development of Lignin-Based Resins

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Dr. Pei Yang - College of Materials Science and Engineering, Nanjing Forestry University
Dr. Minzhi Chen - College of Materials Science and Engineering, Nanjing Forestry University

Abstract

The increasing public awareness of health concerns has brought high higher demand for the environmental-friendliness of wood-based panel products. To this end, urea-formaldehyde (UF) resin, which is the most commonly used adhesive inwood panels industry, has been improvedby reducing the formaldehyde-to-urea (F/U) molar ratio during resin production.However, this strategy is always at the expense of bonding performance. The intrinsic reason is that the branched hydroxymethyl groups on the resin polymers were remarkably decreased with the reduction of molar ratio, andthe formed linear polymers with low molecular weightis insufficient to forme highly crosslinked structure during resin curing process.To resolve the above-mentioned issue,continuous efforts have been put into increasing the branching degree of traditional low-molar ratio UF resinthrough co-condensation reactions using efficient and available modifiers.Compared to the synthetic petroleum-based feedstock such as melamine, lignin, as a natural and renewable organic compound, can potentially improve the branched structures oflow-molar-ratio UF resins owing to its polyphenolic structure.Nonetheless, the low reactivity and non-uniform structure of lignin make barriers forthe formation of co-condensation structure with UF oligomer. In this regard, appropriate modification is required to enhance the reactivity of lignin before it can be used as modifier. However, most of the developedstrategies for lignin modification rely on the use of organic solvents, toxic chemicals and metal catalysts;also, the severe reaction condition is a big hurdle to overcome for the ulitization of lignin-derived product. In this research, we constructed a light-driven multi-radicals oxidation system by employing functionalized carbon dots with tunable photocatalytic activity and oxidizing peroxymonosulfate, which can transform industrial lignin into monomeric or oligomeric products under mild conditions. After photocatalytic oxidation reaction, the weight-average molecular weight of alkali lignin (AL) oxidized products decreased from 2026 Da to 1041 Da, indicating that AL molecules were fragmented into smaller units. These products not only exhibited a low methoxy content, but also contained abundant aldehyde and carboxyl groups. The modified lignin-urea-formaldehyde (LUF) resin with a final F/U molar ratio of 1.0 were prepared by adding oxidized products at the initial stage of hydroxymethylation. The introduction of lignin oxidized products can effectively promote the formation of three-dimensional polycondensates, and thus resulting in the improvement of bonding performance of modified LUF resins. Compared with UF resins, the wet shear strength of three-layer plywood bonded with LUF resin could reach 0.78 MPa, which met the recommendation required by National Standard of China: plywood type II (≥0.7 MPa).

Key Words: Urea-formaldehyde Resin, Industrial Lignin, Carbon Dots, Peroxymonosulfate, Photocatalytic Oxidation, Enhanced Bonding Performance

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STUDENT POSTER COMPETITION

Long-term Response of Wood-Based Composites in Variable Climate Conditions

Mr. Oluwafunbi Adeleye - Oregon State University
Prof. Lech Muszynski - Oregon State University
Prof. John Nairn - Oregon State University
Prof. Mariapaola Riggio - Oregon State University

Abstract

Response to variable climate conditions is a limiting factor in long-term structural use of wood-based composites (WBCs). Wood and some adhesives subjected to sustained loads while exposed to variable climates experience deformation that cannot be accurately predicted using available models. An advanced realistic model based on reliable experimental data is needed.

The primary objective of the research was to develop a reliable integrated 3D numerical model for predicting long-term response of engineered wood-based composites exposed to loads under variable climate conditions. This model will allow interpretation of experiments and predicting performance of engineered wood products (EWP) elements in structures. Previous research suggests that the material characteristics for the model should be determined experimentally on the material level in elementary loading modes (tension and compression).

The experimental procedure is designed for effective separation of strain components contributing to the strain measured on specimens subjected to sustained load and variable humidity. The mechano-sorptive component was determined by subtracting the elastic deformation and free hygro-expansion measured in reference tests. Preliminary tests indicated that viscoelastic creep could be safely neglected. All displacements were measured by comparing successive digital images of the specimens using digital image correlation (DIC) software.

Measurements were conducted on specimens of solid wood and engineered wood products. The presentation will include discussion of the experimental setup and procedure as the data analysis on a set of preliminary results.

Keywords: mechano-sorptive, deformation, climate

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Leachability and Biological Decay Resistance of Zinc Oxide Eugenol Organic Cement Treated Wood

Mr. Courage Alorbu - University of Idaho
Prof. Lili Cai - University of Idaho

Abstract

Eugenol (EG) is an essential oil of phenolic constituent that is sourced from numerous plants including clove, cinnamon, and bay leaves. Despite its highly volatile nature, EG has been extensively used as an antimicrobial and antiseptic biocide in the pharmaceutical and medical fields. Specifically, eugenol reacts with Zinc oxide (ZnO) to produce Zinc oxide eugenol (ZnO-EG) which is a stable organic cement used by dentists in sealing and relieving pain associated with tooth cavities. The aim of our current study is to investigate the feasibility of incorporating Zinc oxide eugenol (ZnO-EG) organic cement in wood to improve the volatile and possible leaching of EG and the biological resistance of treated wood against four common wood decay. Briefly, ZnO-EG was formed in wood in-situ by first impregnating wood with different concentrations (1, 2.5, and 5%) of nano ZnO solutions followed by eugenol treatment. The presence of ZnO-EG in wood was confirmed using Fourier transform infrared spectroscopy, Thermogravimetric analysis, and X-ray computer tomography. The retention and mass gain recorded for ZnO-EG treated wood after treatment was as high as 770 kg/m^3 and 11% respectively. After leaching test, the mass gain recorded for 5% ZnO-EG treated softwood and hardwood samples was 9% and 10% respectively, which confirms the stability of ZnO-EG in wood thereby reducing the volatility and leaching of EG regardless of wood species. Decay resistance test on ZnO-EG treated wood exposed to two brown-rot fungi, *Gloeophyllum trabeum* (*G.t.*) and *Rhodonia placenta (R.p.)* and two white-rot fungi, *Trametes versicolor (T.v.)* and *Irpex lacteus (I.l.)* revealed significantly lower mass loss of about 3% whiles control groups recorded mass loss > 23% regardless of leaching and type of decay fungi. These findings confirm that ZnO-EG cement could be considered as a potential sustainable green preservative for wood protection, especially for outdoor applications.

Keywords: Zinc oxide, Eugenol, Dental Cement, Leaching, Sustainability, Wood preservation

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Reuse, Recycle, Incinerate, or Landfill? LCA-based Environmental Implications of End-of-Life Scenarios for Mass Timber Buildings

Ms. Christina Bjarvin - University of Washington

Abstract

In the face of a warming planet, steps must be taken to reduce the greenhouse gas emissions associated with our building industry, which is a significant contributor to global greenhouse gas emissions. Large, prefabricated wood elements such as mass timbers have great potential to achieve these reductions as they help displace high embodied carbon materials like steel and concrete. Furthermore, storing wood carbon in buildings benefits the climate because it delays the eventual release of biogenic carbon into the atmosphere. While these climate impacts have been assessed for the construction phase of mass timber buildings, relatively few life cycle assessment (LCA) studies have evaluated the climate impacts for the buildings' end-of-life (EoL) phase.

This research assesses the climate impacts of four EoL scenarios for mass timber panels: reusing as mass timber, recycling into particleboard, incinerating, and landfilling. We calculated the embodied carbon and carbon storage benefits associated with the construction, deconstruction, and EoL processing of hybrid mass timber buildings in the U.S. Pacific Northwest. These impacts were integrated into a novel dynamic LCA model over a 160-year time horizon. Of the four selected EoL scenarios, the reuse and recycle scenarios had the lowest global warming impact and emerged as climate-preferred scenarios. The lower impact associated with the reuse and recycle scenarios is due to the low fossil carbon emissions during EoL processing and extensive biogenic carbon storage benefits. These results highlight the importance of efficient wood use through reusing and recycling.

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The bending moment capacity of the lap and dowel joints fabricated from salvaged CLT panels

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Prof. Eva Haviarova - Purdue University, Department of Forestry and Natural Resources
Prof. Daniel P. Hindman - Department of Sustainable Biomatierals, Virginia Tech

Abstract

Cross-laminated timber (CLT) is gaining global popularity as a sustainable construction material. Using CLT, more carbon can be stored in durable products, while nonrenewable resources can be avoided. Although almost all existing CLT structures are made of softwoods, there is growing interest in including hardwoods in making CLTs. Previous studies indicated that the hardwood CLT (HCLT) could meet and exceed the bending stiffness and shear stiffness requirements of the current North American CLT standard, ANSI/APA PRG 320. Thinner HCLT could also offer good panel-type material for furniture manufacturing since furniture production moved almost entirely from the frame-to-plate type of construction with computer numerical control (CNC) production. HCLT, a material with excellent dimensional stability and rigidity, could offer a unique opportunity for CNC furniture and other interior applications. Moreover, it is expected that CLT will be more common in building construction, and more byproducts from cutouts of windows or doors will be available for smaller products. Also, over time, salvaged material obtained from the CLT buildings will be available for repurposed products. The structural integrity of any structure (furniture) is directly related to good joinery. This study investigates the manufacturing feasibility and load-carrying capacity of basic CNC-manufactured joints made of CLT panels. The joinery specimens were constructed from salvaged HCLT panels donated by Virginia Tech, yellow poplar panels, and hybrid panels made of southern yellow pine and yellow poplar. The lap and dowel joints were then tested for bending in compression and tension. The results will contribute to the design and product development of salvaged HCLT panels.

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Global Warming Mitigating Role of Forests in Washington State, by Land Ownership Type

Ms. Lieke Droog - University of Washington
Prof. Indroneil Ganguly - University of Washington
Dr. Francesca Pierobon - University of Washington

Abstract

Western Washington and Oregon are known for their fast-growing forests and forest industry. With 2.7 billion board feet of annual mer-chantable log production, Washington is the second largest producer of wood products in the United States. There is an increasing focus on the potential of using forests and resulting wood products as carbon sinks. It is, therefore, interesting to obtain a better understanding of Washington's forest industry's role in climate change mitigation.

This paper analyzes the relative importance of wood products and existing harvest practices in mitigating climate change using a temporal framework. Accordingly, this research utilizes data on (i) various forms of biomass fluxes in the forests, including forest growth, natural mortality, and harvest losses, (ii) post-harvest biomass loss in the forests and the wood products manufacturing, (ii) biomass storage and losses in the economy (buildings, furniture, etc.), (iii) landfilling and recycling practices, and (iv) fossil emissions associated with all the processes, including harvest, transportation, and manufacturing.

The assessment resulted in a per-acre comparison between the global warming mitigation potential of the included forest management practices. The results revealed that intensive forest management (as is practiced by WA's corporate forests) sequestered and stored the highest amount of atmospheric carbon and exhibited the most prominent global warming mitigation potential (climate positive). Moreover, WA's federal forests (i.e., USFS forests), which are relatively unmanaged, though being net climate benefitial, were some of the worst performing in terms of global warming mitigation. This is primarily due to the higher rate of natural mortality and lower rate of sequestration in the unmanaged forests, as compared with their managed counterparts. The biomass flux analysis showed that forest biomass loss, due to natural tree mortality, disease, and fire, in man-aged forests (e.g., corporate forests) is substantially lower (14% of total growth) than that in the unman-aged USFS forests (70% of total annual growth). The study highlighted the critical role wood products play in Washington's carbon flux and in helping keep atmospheric carbon sequestered in the economy.

Keywords: Carbon sequestration, forest management, wood products

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Assessing the Potential use of a CBD Extraction Byproduct as a Wood Finishing Product

Ms. Avani Flanagan - Eastern Illinois University
Dr. Isaac Slaven - Eastern Illinois University

Abstract

An increasing demand for CBD products for use as non-psychoactive therapeutic remedies has caused the Global Cannabidiol (CBD) Market to take off. As this industry grows, so does its wastes and byproducts. A commonly used extraction method known as the ethanol extraction process results in the creation of *CBD TAR*, a dark-colored non-Newtonian material formed by the unwanted fats, waxes, and lipids that are removed from CBD oil during the process of winterization. This material, which is hard and brittle at room temperature but becomes increasingly vicious at higher temperatures, briefly resembles other plant-tar materials such as creosote or bitumen. Upon first inspection, *CBD TAR* presented possible waterproofing capabilities signifying its potential use as a wood-finishing product or protectant. This finishing solution was created by mixing *CBD TAR* with Acetone in a ratio of 75g:150ml. The objective of this study is to test *CBD TAR's* impact on water absorption and adsorption rates on both composite and solid woods to discern if its use as a wood finish performs comparably to other typically used finishes. Boiled linseed oil and hempseed oil were chosen for comparison finishes due to their all-natural composition. Southern yellow pine and white ash were used as solid wood samples to ensure both hardwoods and softwoods were explored within the study. In addition, composites such as OSB, particle board, and a hemp composite (Hempwood®), were tested for spring-back capabilities as a result of repetitive 24-hour soaking periods after being treated with the varying finishes. By collecting data on water absorption, spring-back, and penetration of *CBD TAR* as a wood finish and comparing it to typical wood finishes, this study aims to test its potential use as an additional value-added product of the CBD industry and reduce the overall number of waste-streams.

Key Words: CBD byproduct, wood-finish, ethanol extraction, tar, hemp composites, hempseed oil, Cannabidiol, winterization, water absorption

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Comparative Life Cycle Assessment of Laboratory Scale Biological and Thermochemical Hemp Retting Processes

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Dr. Hongmei Gu - USDA Forest Service, Forest Products Laboratory
Prof. Sheldon Shi - University of North Texas
Dr. Felix Wu - Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Abstract

The increasing interest in using natural fibers has promoted research into emerging methods for fiber retting, particularly biological retting. The processes of hemp bast fiber retting, forming, and drying offer the opportunity to commercialize raw hemp fibers into value-added products such as natural fiber reinforced composites. Thermochemical retting is being widely used to obtain lignocellulosic fibers to make fiber-reinforced composites. The newly developed biological retting process for raw bast fibers through pectinase initiated bacterial retting has been developed in the lab-scale setup. The focus of this study was to compare the process energy consumption and environmental impacts of this bacteria retting with the traditional thermochemical retting. The Gate-to-Gate LCA models of the two retting processes were constructed in SimaPro software to run the comparison analysis using the TRACI (The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) method for environmental impacts and Cumulative Energy Demand (CED) method for energy consumptions. This work demonstrated the advantages of using biological retting methods from an environmental standpoint. The results showed about 24% gate-to-gate cumulative energy demand (CED) reduction for the biological retting, and 20-25% lower environmental impacts in global warmings, smog formation, acidification, carcinogenic, non-carcinogenic, respiratory effect, ecotoxicity, and fossil fuel depletion when compared to the thermochemical retting.

Keywords: Hemp bast fiber; biological Retting; Life Cycle Assessment; environmental impact; cumulative energy demand

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Utilization of CNC nanoparticles prepared via ultrasonic spray dryer as reinforcement for PVA-composite films

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Prof. Douglas Gardner - School of Forest Resource, University of Maine, Orono, ME, 04469; Advanced Structures and Composites Center, University of Maine, Orono, ME, 04469
Prof. Yousoo Han - School of Forest Resource, University of Maine, Orono, ME, 04469; Advanced Structures and Composites Center, University of Maine, Orono, ME, 04469

Abstract

Poly (vinyl alcohol) (PVA) is environmentally safe, inexpensive, lightweight, and has good chemical and thermal resistance, leading to its application in the food packaging industry. The attempt to use cellulosic fibers as a reinforcing material to the PVA matrix has been reported in the last few years due to its biodegradability, non-toxic characteristics, and to increase the strength properties of the PVA matrix. Among cellulosic fibers, cellulose nanocrystals (CNCs) are a well-known material for the utilization of reinforcement attributable to their nano-size, narrow size distribution, and high aspect ratio resulting in an increase of transparency and mechanical properties of the PVA film. In addition, an appropriate drying technique should be used to ensure that the dried fibers maintain their nano dimesnions after drying and are well distributed and dispersed in the matrix. This study produced nano-sized spray-dried CNC particles via an ultrasonic-assisted spray-drying method called nano-spray dryer (B-90), followed by the analysis of morphological properties of CNC nanoparticles via a high-resolution SEM. The average size of CNC particles was 530 nm after drying a 1wt.% suspension via the ultrasonic spray dryer. The tensile index of nano CNC-reinforced PVA composite film increased to 35% after adding 16% of CNC particles to the PVA matrix, compared to neat PVA film. Furthermore, it was confirmed that the transparency of composite film improved as the average size of CNC particles decreased.

Keywords: Polyvinyl alcohol (PVA), Cellulose nanocrystals (CNCs), Nano-spray dryer

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Experimental Study of Reinforcement by Self-tapping Screws on Glulam Beams

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Abstract

For column-beam connections in timber structures, bearing strength and stiffness perpendicular to the grain are often dominant, and therefore improving these are important to develop large and high timber structures. One method for enhancing bearing capacity and stiffness is to reinforce the beam by self-tapping screws. Bejtka and Blaß previously proposed equations for predicting the bearing capacity and stiffness of the beam reinforced by fully threaded screws (the Model of Karlsuruhe) and conducted experiments to verify the applicability.

In the present study, experiments were conducted to assess the bearing capacity and stiffness of beams reinforced by the screws for more extensive variables that had not been previously examined. The results were used to verify the applicability of the previously proposed equations. Moreover, the applicability for partially threaded screws and for load cases using a support that is as large as the load area (load case B) is verified.

The three failure modes proposed by Bejtka and Blaß (pushing-in failure, buckling failure, and timber failure at the screw tips) were observed in the experimental results. However, many of the experimental results did not match the predicted failure modes and bearing capacities. The discrepancy between the predicted and experimental bearing capacities for timber failure indicated that the estimated length of the effective area for timber failure may be underestimated. The predicted bearing capacities for pushing-in failure were in agreement with the experimental results. In contrast, the predicted bearing capacities for buckling failure were found to be less than the experimental results. It is considered that using ∞ as rotational stiffness for the screw head is better than using 0 when predicted bearing capacities for a single screw are calculated. Additionally, we proposed the methods for partially threaded screws and load case B that was not proposed in the Model of Karlsruhe. In the case of partially threaded screws, bearing capacity could be calculated using the length of the threaded part as the penetration length of screws. In the case of load case B, the bearing capacity could be calculated using the coefficient of the load distribution $k_{c,90} = 1.18$. The predictions using the proposed methods were in concordance with the experimental results.

Keywords: Column-beam connections, Glulam beams, Compression perpendicular to grain, Reinforcement, Self-tapping screws

Introduction

Recently, developments of connections characterized by high strength and stiffness have become increasingly prevalent because of the expanding utilization of timber structures in the construction of medium to large-scale buildings. At column-beam connections in timber structures, bearing strength and stiffness perpendicular to the grain are often dominant (Hassan et al. 2014). Consequently, increasing the bearing strength and stiffness perpendicular to the grain is important in achieving connections of high strength and stiffness. One method for enhancing bearing capacity and stiffness is to reinforce the beam by self-tapping screws like piles in a loaded area (Fig. 1) (Dietsh et al. 2015, Aloisio et al. 2022). Bejtka et al. (2006) has proposed equations (the Model of Karlsruhe) for predicting the bearing capacity and stiffness when reinforced with fully threaded screws, and they conducted experiments to verify the equation's applicability.

In the present study, experiments were conducted to assess the bearing capacity and stiffness of reinforced beams by the screws for more extensive variables that had not been previously examined. The experimental results were utilized to verify the applicability of the equations proposed by Bejtka et al. (2006).

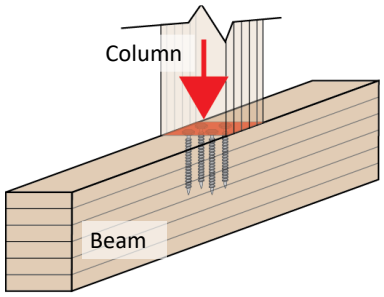


Figure 1: Reinforcement by using self-tapping screws.

Materials and Methods

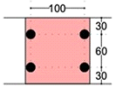
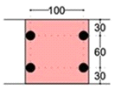
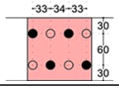
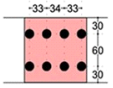
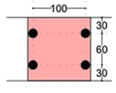
Table 1 lists an overview of the specimens. The specimens were homogenous glulam of Japanese cedar, *Cryptomeria japonica* (average MC: 10.2 %; average density: 369 kg/mm^3), and Japanese larch, *Larix kaempferi* (average MC: 11.8 %; average density: 497 kg/mm^3), with dimensions of 120 mm x 990 mm x 300 mm (width x length x height).
Figure 2 shows the self-tapping screws used in the experiments. The experimental variables included number of screws (0, 4 or 8), penetration length of the screws (140, 200 or 260 mm), diameter of the screws (8 or 10 mm), the thread configuration of the screws (fully or partially threaded), an arrangement of the screws (see Table 1), and load conditions (Case A and B in Fig. 3). Case A shows a specimen with reinforced area on one side supported by the continuous support. Case B shows a specimen with reinforced areas on both sides supported

by a support that is as large as the loaded area. There were 3 samples each of 18 series, for a total of 54 specimens.

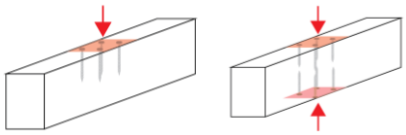
All specimens with screw reinforcement were pre-drilled with a diameter of 5 mm (screw diameter 8 mm) or 6.5 mm (screw diameter 10 mm) in a length of approximately 100 mm by using an impact driver. The screws were drilled at a right angle, and the heads of the screws were flushed with the timber surface in all cases. The loaded area was 120 mm x 120 mm. The loading speed was 0.03 ~ 0.05 mm/s (Sumino et al. 2020). The specimens were monotonically loaded through a steel plate. The load was then measured by the load cell between the steel plate and the force device. The displacement of the height of the specimen was measured.

The material tests were conducted on Japanese cedar and larch for compression perpendicular to the grain according to EN408 (2012). The average of compressive strength and elastic modulus of the six specimens each were 2.04 N/mm^2 and 216 N/mm^2, respectively, for Japanese cedar, and 3.41 N/mm^2 and 399 N/mm^2 for Japanese larch. The tensile tests of single screws were conducted according to JIS A 1503 (2022). The average tensile strength of the fully threaded screw with diameter of 8 mm and 10 mm were 1,312 N/mm^2 and 1,240 N/mm^2, respectively.

Table 1: Overview of specimens and experimental results and predictions.

Series	Screw						Experimental results		Prediction by the Model of Karlsruhe				
	Wood	Length [mm]	Number	Diameter [mm]	Thread configuration	Arrangement	Load case	Failure mode	Bearing capacity [kN] (Ave.)	Failure mode	Bearing capacity [kN]			
											Buckling	Pushing-in	Timber	Bearing
C0		—	—	—	—	—	A	Bearing	68.7	—	—	—	—	66.2
C2-2-140		140	4	8	Fully		A	Pushing-in	114	Timber	131	127	95.7	—
C2-2-200	Japanese cedar	200	4	8	Fully		A	Pushing-in	143	Timber	131	151	125	—
C2-2-260		260	4	8	Fully		A	Pushing-in	167	Buckling	131	173	155	—
C2-2-260P		260	4	8	Partially		A	Pushing-in	113	No evaluation method				
C2-2-260T		260	4	10	Fully		A	Pushing-in	198	Timber	171	186	155	—
C0D		—	—	—	—	—	B	Bearing	52.1	—	—	—	—	66.2
C2-2-140D	Japanese cedar	140	4 (8)	8	Fully		B	Pushing-in	108	No evaluation method				
C2-2-140D i		140	4 (8)	8	Fully		B	Pushing-in	101	No evaluation method				
C2-2-260D i		260	4 (8)	8	Fully		B	Buckling	138	No evaluation method				
C2-4-260	Japanese cedar	260	8	8	Fully		A	Buckling	258	Timber	196	280	155	—
C2-4-260P		260	8	8	Partially		A	Pushing-in	156	No evaluation method				
C2-4-260T		260	8	10	Fully		A	Timber Pushing-in	260	Timber	275	305	155	—
L0		—	—	—	—	—	A	Bearing	104	—	—	—	—	110.6
L2-2-260	Japanese larch	260	4	8	Fully		A	Buckling	221	Buckling	178	246	258	—
L2-2-260T		260	4	10	Fully		A	Buckling	277	Buckling	219	262	258	—
L2-2-260P		260	4	8	Partially		A	Pushing-in	195	No evaluation method				
L2-2-260PT		260	4	10	Partially		A	Pushing-in	207	No evaluation method				

a. Fully threaded screw. b. Partially threaded screw.



・Case A. ・Case B.

Figure 3: Specimen summary

Experimental Results and Discussion

Table 1 lists the observed failure modes and bearing capacities.

The maximum load was taken as the bearing capacity for specimens that showed a definite maximum load. Otherwise, the bearing capacity was calculated according to EN408.

The three failure modes proposed by Bejtka et al. (2006) (pushing-in failure as shown in Fig. 4 and blue line in Fig. 7, buckling failure as shown in Fig. 5 and yellow line in Fig. 7, and timber failure at screw tips as shown in Fig. 6 and green line in Fig. 7) were observed in the experimental results.

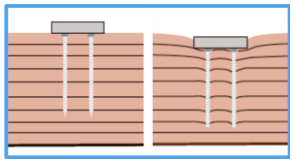


Figure 4: Pushing-in failure

Figure 5:

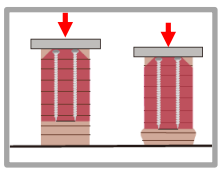


Figure 6:

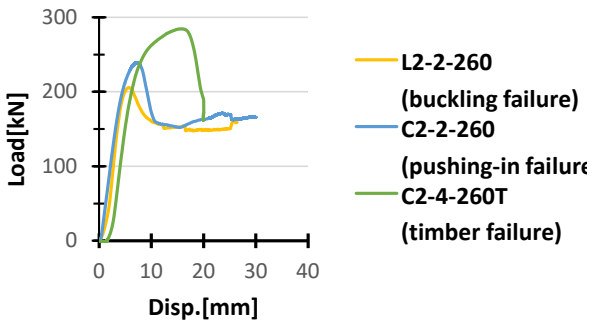


Figure 7: Load-displacement relationships.

The bearing capacities and stiffness obtained from the experiments were compared for the following experimental variables: penetration length of screw, number of screws, diameter of screws, thread configuration, and load case (see Fig. 8).

- The bearing capacity and stiffness were enhanced by increasing the penetration length of the screws used for reinforcement. When the length of full threaded screws was 260 mm (C2-2-260), the bearing capacity and stiffness of the reinforced specimen were respectively 2.43 and 1.56 times greater than that of the non-reinforced specimen (C0).
- The bearing capacity and stiffness were increased by using a greater number of screws used for reinforcement. In the case of the reinforced specimen (C2-4-260T) which used 8 screws with a 10 mm diameter, the bearing capacity and stiffness were respectively 3.78 and 1.82 times greater than that of the non-reinforced specimen (C0).
- The bearing capacity and stiffness tended to be enhanced by increasing the diameter of the screws used for reinforcement. The bearing capacity and stiffness of the reinforced specimen when the diameter of screws was 10 mm (C2-4-260T) was respectively 1.01 and 1.13 times higher than when the diameter of screws was 8 mm (C2-4-260). The failure

mode changed the buckling failure (C2-4-260) to the pushing-in failure and the timber failure (C2-4-260T). This suggests that there may be an upper limit to the effect of reinforcement by using screws in enhancing bearing capacities.

- The bearing capacity and stiffness with the partially threaded screws were less than that with the fully threaded screws. The bearing capacity and stiffness of the specimen reinforced by the partially threaded screws with the 8mm diameter (C2-2-260P) were respectively 0.68 and 0.87 times that by the fully threaded screws with 8 mm diameter (C2-2-260). Thus, the same evaluation method used for the fully threaded screws is underestimated when the partially threaded screws are used for reinforcement.
- The bearing capacity and stiffness for load case B (C2-2-260Di) were slightly less (0.83 and 0.88 times, respectively) than that for load case A (C2-2-260). Regarding the specimen reinforced by fully threaded screws with 140 mm penetration length for load case B, the bearing capacity of this specimen with staggered screw arrangement (C2-2-140Di) was slightly less than that of the specimen with screws placed in the same position on both sides (C2-2-140D).

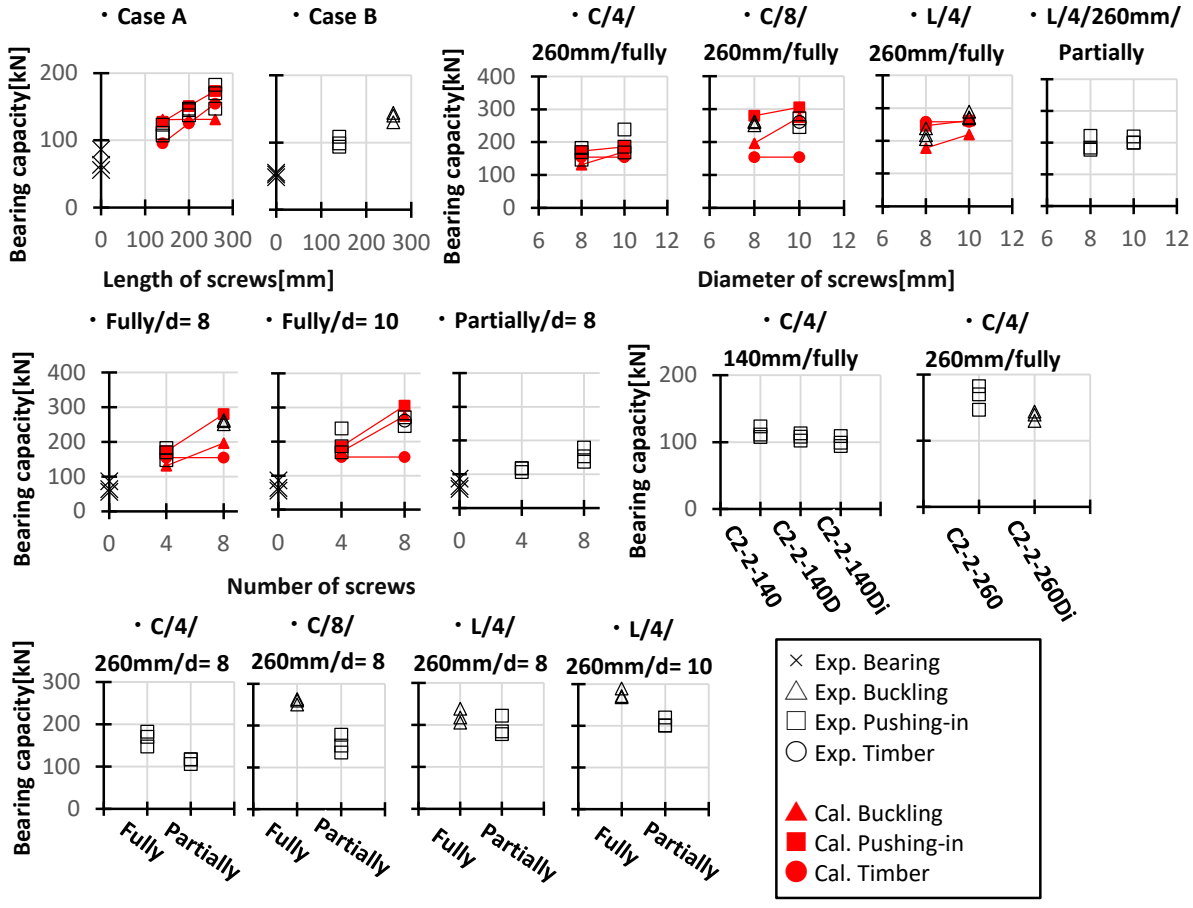


Figure 8: Experimental bearing capacities and predicted bearing capacities.

Comparison between Predictions and Experimental Results

The predicted bearing capacity of a beam reinforced by using self-tapping screws is calculated using Equations (1), (2) and (3) in the Model of Kalsuruhe (Bejtka et al. 2006).

The minimum of the three values obtained by the equations is the predicted bearing capacity, and then the predicted failure mode is determined.

The bearing capacities of the experiments were compared with the predicted bearing capacities from the Model of Karlsuruhe (see Table 1). Many of the failure modes in experimental results did not match the predicted failure modes. Some of the findings from the comparison include:

- The bearing capacities for timber failure did not match and the predicted values were less than the experimental values (see Table 1).
- The predicted bearing capacities for pushing-in failure generally agreed with the experimental values, considering the failure modes of the experimental results. Furthermore, the comparison of the capacities of one screw for pushing-in failure $R_{a,d}$ showed that the predicted values generally matched the experimental values (see blue areas in Table 2).
- The bearing capacities for buckling failure did not match and the predicted values were less than the experimental values. The comparison of the capacities of one screw for buckling failure $R_{c,d}$ showed that the predicted values were less than the experimental values (see yellow areas in Table 2).

Buckling failure : $R_{90,d} = n \cdot R_{c,d} + k_{c,90} \cdot l_{ef} \cdot b \cdot f_{c,90,d}$ (1)

where

$R_{c,d} = \kappa_c \cdot N_{pl,d}$ (1.1)

$\kappa_c = 1 \quad (\bar{\lambda} \leq 0.2)$

$\kappa_c = \frac{1}{k+\sqrt{k^2-\bar{\lambda}^2}} \quad (\bar{\lambda} > 0.2)$ (1.2)

$k = 0.5 \cdot \left[1 + 0.49 \cdot \left(\bar{\lambda} - 0.2\right) + \bar{\lambda}^2\right]$ (1.3)

$\bar{\lambda} = \sqrt{N_{pl,d}/N_{ki,d}}$ (1.4)

Pushing-in failure : $R_{90,d} = n \cdot R_{ax,d} + k_{c,90} \cdot l_{ef} \cdot b \cdot f_{c,90,d}$ (2)

where

$R_{ax,d} = 0.6 \cdot \sqrt{d} \cdot {l_s}^{0.9} \cdot \rho^{0.8}$ (2.1)

Timber failure at screw tips : $R_{90,d} = b \cdot l_{ef,2} \cdot f_{c,90,d}$ (3)

$R_{90,d}$: Bearing capacity, n : Number of screws, $R_{c,d}$: Capacity of a screw for buckling failure

$k_{c,90}(= 1.5)$: Coefficient for the load distribution (DIN 1052:2004)

l_{ef} : $l_{ef} = l + max\{l\,; 30\ mm\}$ for single-sided load distribution (DIN 1052:2004)

: $l_{ef} = l + 2 \cdot \max\{l\,; 30\ mm\}$ for double-sided load distribution (DIN 1052:2004)

l : Length of the load area, b : width of the beam

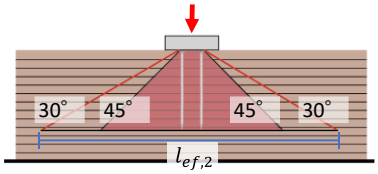


Figure 9:

Load distribution for the timber failure at the screw tips.

Table 2: Capacities of one screw for the pushing-in failure and the buckling failure.

series	Ave)Exp.	Ave)Cal.	Cal./Exp.
C2-2-140	11.3	15.3	1.35
C2-2-200	18.6	21.1	1.13
C2-2-260	24.5	26.7	1.09
C2-2-260T	32.3	29.9	0.93

series	Ave)Exp.	Ave)Cal.	Cal./Exp.
C2-4-260	23.7	17.0	0.72
C2-4-260T	23.8	29.9	1.26
L2-2-260	29.1	17.0	0.58
L2-2-260T	43.1	27.4	0.64

Improved Prediction of Bearing Capacity

The rotational stiffness K for the screw head, $K = 0$ or ∞ (Fig. 10), affects the predicted bearing capacity for the buckling failure based on the Model of Karlsuruhe. In this study, the predicted values were calculated with $K = 0$ because the surface of the screw heads is flushed with the beam surface. However, the predicted values were less than the experimental values. Therefore, the predicted values were calculated with $K = \infty$ and were generally concordant with the experimental values for the specimens of Japanese cedar. Furthermore, this can be inferred from the buckling of the screws after the experiments (Fig.5). On the other hand, for Japanese larch, the predicted values were slightly less than the experimental values. This suggests that the density of Japanese larch influenced the experiments; these densities were outside of the range for the densities estimated in the Model of Karlsuruhe. It is considered that the predicted values should be calculated with $K = \infty$ in cases where the surface of the screw heads is flushed with the beam surface and, that these values were underestimated in the high-density specimens. However, additional investigations are necessary to discriminate the rotational stiffness K, $K = 0$ or ∞.

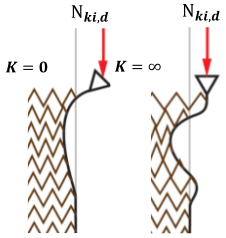
The effective length of the plane formed by the screw tips, $l_{ef,2}$ (Fig. 9), is essential to calculate the predicted bearing capacity for the timber failure. The experimental values of the effective length ($l_{ef,2}$) were approximately 1,070 mm. This indicates that compression was occurring in all cross sections of the specimen. The angle of the load distribution affects the effective length ($l_{ef,2}$) where the angle is 45.0 º in the Model of Karlsuruhe (Fig. 9). The angle in the experiments was approximately 30.6 º in the case of assuming $l_{ef,2} = 990$ mm. Additionally, it was observed that the angle was not 45º from the results of Digital Image Correlation (Fig. 11).

Some methods to improve the predictions by the Model of Karlsuruhe based on the investigations of the present study include:

- The bearing capacities of one screw for the buckling failure could be calculated with $K = \infty$.

- The effective length $l_{ef,2}$ could be calculated with 30.0 ° in the case of predicting the bearing capacities for timber failure.

The predictions of failure modes and bearing capacities, taking into account the improved methods, were generally in agreement with the experimental results in Figure 12.



a. $K = 0$ **b.** $K = \infty$

Figure 10:

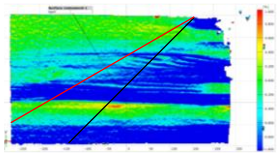


Figure 11: Result of Digital Image

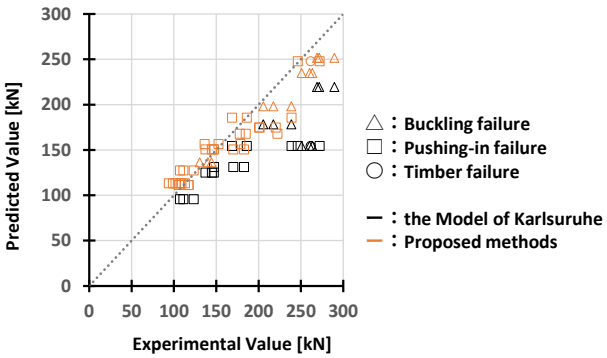


Figure 12: Results of improved predictions.

Methods of Partially Threaded Screws and Load Case B

The method to calculate the bearing capacities with the partially threaded screws is not indicated in the Model of Karlsuruhe. Therefore, this was calculated according to the assumption that the length of the threaded part $l_s'$is the penetration length of the screws l_s (Fig. 2). The predictions generally agree with the experimental results.

The bearing capacities with load case B were calculated in the same manner as the calculation with load case A because the method for load case B is not indicated. However, the predicted values were higher than the experimental values. The coefficient for the load distribution of load case B was calculated with $k_{c,90} = 1.18$ from the experimental results (C0D).

According to the investigations, the following methods are proposed for calculations in the case of partially threaded screws and load case B:

- In the case of partially threaded screws, the penetration length of the screws l_s could use the length of the threaded part l_s'.
- In the case of load case B, the bearing capacities could be calculated using $k_{c,90} = 1.18$.

The predictions calculated with the aforementioned methods generally agree with the experimental results (Fig. 12). However, additional investigations are necessary to determine the coefficient $k_{c,90}$ of load case B.

Conclusion

In the present study, effectiveness for bearing capacity by reinforcement with self-tapping screws was investigated through experiments. The results show that the bearing capacities of reinforced specimen series were a maximum 3.78 times larger that of the non-reinforced specimen series. Additionally, the bearing capacities of reinforced specimens were affected by several variables: penetration length of screws, number of screws, diameter of screws, threaded configurations, and load case.
From comparisons between predictions and experimental results, many of the failure modes in experimental results did not match the predicted failure modes from the Model of Karlsuruhe. Therefore, based on the investigations of the present study, some methods to improve the predictions from the Model of Karlsuruhe include using $K = \infty$ to calculate predicted bearing capacities for buckling failure and using effective length $l_{ef,2}$ with 30.0 ° to calculate that for timber failure. Furthermore, using the length of threaded part as the penetration length of screws (for partially threaded screws) and using $k_{c,90} = 1.18$ (for load case B) could be used to calculate the predicted bearing capacities.

The predictions including the aforementioned methods were generally in agreement with the experimental results. However, the number of specimens in this study is relatively small; thus, additional investigations are necessary to increase the certainty of the findings.

Acknowledgments

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Proceedings of the 2023 SWST International Conference
Asheville, North Carolina, USA

Introducing WOOD*VERSITY

Ms. Lena Maria Leiter - University of Natural Resources and Life Sciences, Vienna
Ms. Lisa Laggner - Kuratle Group AG, Leibstadt, Aargau
Ms. Kristina Loike - Swiss Wood Innovation Network, Zürich
Ms. Teresa Grassmann - Rubner Timber Engineering, Brixen

Abstract

In the Austrian wood value chain only 19 percent of employees are women, and the proportion is even lower in management positions. According to the Austrian Economic Chambers, on average only every sixth position in the wood industry is filled by a woman. Therefore, it is important to offer a platform to connect to each other. WOOD*VERSITY offers inclusive online networking meetings for students, recent graduates and professionals of the wood, paper and forestry sector in the DACHI+ region (German speaking). We are especially targeting the female audience. The focus is to exchange and support each other in questions around job, career, specialization, salary negotiation and many more, but especially to network and share exciting as well as formative experiences. We want to connect women* in the wood, paper and forest industry and thus help to shape the industry together. Our events are inclusive, and EVERYONE is welcome! So, click in (https://woodversity.com/) and connect with us! So far, we held several events on topics like "career entry in the wood industry" and "working abroad", but also more consequential issues such as "women in the wood building sector" or "women in management positions". Over 80% of our attendees are female, and most of them come from Central Europe. As the events are held in German, this is not surprising. However, we are pleased that we have now also been able to reach expats in Scandinavia and Canada.

Keywords: women in wood, women in paper, women in forestry, inclusion, together we are strong, networking

Proceedings of the 2023 SWST International Conference
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End-Grain Flooring from Underutilized Raw Materials: Solution to Extend and Enhance the Hardwood Resource

Mr. Dan Meyer - North Carolina State University, Department of Forest Biomaterials
Dr. Frederik Laleicke - North Carolina State University, Department of Forest Biomaterials

Abstract

This project will examine the technical feasibility of manufacturing end-grain flooring from small-diameter hardwood timber and kiln-dried hardwood lumber end-trimmings—two underutilized raw material streams with the potential to improve forest management and the economic vitality of hardwood lumber producers. Hardwood silviculture prescriptions generally require the harvesting of both large and small-diameter trees to reduce overcrowding and fuel loads; maintain ecological diversity; improve forest health and resilience; and meet growth and productivity objectives. However, the lack of high-value markets for small-diameter hardwood timber provides little economic incentive to harvest small-diameter trees. As a result, high-grading, diameter-limit, and other forest degrading harvesting practices are widespread. At the same time, hardwood sawmills and concentration yards perpetually struggle against the pressures of high sawlog prices, high manufacturing costs, and low lumber prices. Adding value to hardwood mill residues would increase the viability of these companies. Our research will address knowledge gaps and manufacturing challenges presented by these two raw material sources, including drying strategies for juvenile wood that is generally not considered useful for lumber; mechanical properties of end-grain blocks manufactured from that wood; and high-value product yield potentials from kiln-dried sawmill waste. Small-diameter Red Oak and White Oak logs will be squared into 4” and 6” cants. Half of those cants will be dried in cant form; the others first cut into one and two-inch-thick slices and then dried. Testing of various drying strategies will determine least-degrade methods, comparing restrained vs. unrestrained drying; aggressive vs. conservative drying schedules, and drying of green vs. air-dried material. Because kiln-dried sawmill end-trimmings are of various dimensions and often have significant wane, warp, end-checking and splits, mill studies will first quantify what percentage of this raw material is of suitable size and quality to be manufactured into end-grain flooring blocks. Finally, select mechanical testing—including hardness, compressive strength and dimensional stability—will determine the suitability of both resources for end-grain flooring. The selection of Red Oak and White Oak as test species will allow performance comparisons with known properties of traditional flatsawn solid Oak flooring.

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Functionalization of Cellulose for biocomposite compatbility: Toughening of P3HB/PLA composites

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Abstract

Cellulose fibers are a promising reinforcing agent for specialized composite materials made from entirely bio-based materials. However, their hydrophilic nature and surface chemistry cause issues with stress transfer within composites. Esterification is explored as a method for increasing compatibility of composite systems. Traditional esterification methods show a toughening behavior of the composite systems but no increases in strength. Interactions through rheology are also shown to increase. These mixed results are followed up by utilization of a novel DES-mediated reaction which aims to solve issues of fiber structure loss and incompatibility.

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Effect of Surface Thermal Treatment on Colors of Three Hardwood Species: Application of Artificial Neural Network

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Prof. Eva Haviarova - Purdue University, Department of Forestry and Natural Resources

Abstract

Darker-colored wood species usually have higher values, many of which are tropical endangered or protected species. Chemical stains and coatings may offer equivalent hues, but environmentally conscious consumers prefer non-chemical options. Thermal treatment (TT) is one of the options with additional advancements. It could generate darker color and improve some material properties, but it is costly and time-consuming. This study aimed to evaluate a new type of TT: Surface Thermal Treatment (STT). Three commercial hardwood species (White Ash, Yellow Poplar, and Red Oak) with pale color were selected and treated under variable temperatures and times. Artificial Neural Network (ANN) was used to model the color change as the relationship between temperature and time. Results indicated that STT could achieve efficient thermal modification. The combination of temperature and time brought different color shades to all wood species. Application of the ANN model can simulate the process results fast with a high degree of accuracy (R^2=0.96), allowing us to rule out nearly 95% of the potential combinations, execute a minimal subset of trials, and save a considerable amount of time.

Keywords: Artificial Neural Network (ANN), Color Difference, Surface Thermal Treatment (STT)

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Hygrothermal Simulation of a Wood-fiber Insulated Panel (WIP) Wall Assembly in Selected Climate Zones

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Mr. Jacob Snow - University of Maine
Mr. Benjamin Herzog - University of Maine
Dr. Stephen Shaler - University of Maine

Abstract

Decarbonization of current and future building stock is widely viewed as a major step on the pathway to achieving climate mitigation targets. Environmentally sustainable wood-based building materials can be utilized to increase energy efficiencies (heating/cooling) of existing buildings and new construction. The solution we propose herein are Wood-fiber Insulated Panels (WIPs), consisting of a wood fiber insulation (WFI) core adhesively bonded to engineered wood composite faces. WFI has shown great potential to be a cost-neutral, drop-in replacement for fossil-based insulation with several additional attributes, such as: vapor openness, excellent sound attenuation, and low embodied carbon. Domestic manufacturing of WFI by TimberHP (Madison, ME), North America's first WFI manufacturer, will begin production in 2023, thereby increasing the availability and affordability of these potential core materials domestically. The hygroscopic nature of WFI allows for seasonal moisture migration through the wall assembly, preventing water accumulation inside the envelope. The objective of this research was to analyze the hygrothermal performance of an example WIP wall assembly, comprised of cross laminated timber (CLT), wood fiber insulation (WFI), wood structural panels (WSP), and a weather resistant barrier, using WUFI Pro software to assist in refining the WIP wall design(s). Simulations were performed in selected climate zones (cold/very cold, mixed/hot humid, marine) to predict the moisture conditions inside the wall envelope over time (5-year simulation). The results regarding the moisture content, temperature (T), and relative humidity (RH) distributions and mold growth risk indexes were analyzed and will be reported at the conference. The analysis provides an understanding of how the envelope responds to interior and exterior climactic conditions and can be used to identify moisture related performance issues such as mold and fungal attack. Future work is to include field testing for verification of the WIP assembly design(s).
This work was supported by the US Department of Agriculture's (USDA) Agriculture Research Service [grant 58-0204-1-180]. In addition, this work was supported by the Department of Energy [DE-EE0010137]

Keywords: wood fiber insulation, hygrothermal simulation, decarbonization, wood fiber insulated panel

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Wood Property Variation Within Douglas Fir Trees Grown at Different Spacing

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Prof. Bogdan Strimbu - Oregon State University
Dr. Joseph Dahlen - University of Georgia

Abstract

Wood properties such as density, microfibril angle, and stiffness are critical elements which dictate the quality and utilization of a given wood. These properties vary within trees, but detailed examination of property variation is limited owing to time and cost of measurement on a large number of samples. Near infrared (NIR) Hyperspectral imaging (HSI), offers a non-destructive, rapid method of property evaluation and this study aims to use this technique to examine wood property variation within Douglas-fir trees grown at different spacings using NIR HSI.

A total of 21 DF trees aged 25 years from 6 different spacings were destructively sampled. Wood discs were obtained from the stump to the top of the tree. Bark to bark radial strips were further obtained from the discs. Images were collected of the entire radius using the Specim FX17 HSI with wavelengths ranging from 931-1718 nm. Zones were identified to provide samples for SilviScan (microfibril angle, Density, and stiffness) and Fiber Analyzer (tracheid length and width). Wood spectra extracted from HSI images using Matlab will be used for anatomical and physicomechanical analysis. Models, statistical analysis, and associated graphics will be done using R.

Data will be presented on within tree variability of selected wood properties of DF as well as models to predict the variability. Wood properties based on these models have the potential to be incorporated into growth and yield systems and aid in more efficient wood utilization.

Key Words: Wood Quality, Near Infrared Spectroscopy, Hyperspectral Imaging, Wood variability, Non-destructive Sampling

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Factors Influencing the Fire Properties of Birch Plywood, even on a Small Scale

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Abstract

Plywood is one of the oldest wood-based materials and is also very relevant for timber constructions due to its excellent mechanical properties. The impending climate change will result in a shift in forest structure towards more hardwood species (like beech or birch), that serve ideal properties for the production of high-quality plywood. The nowadays aimed transition to a completely biobased building sector only remains realistic, if the fire properties and burning behaviour of natural building materials are no longer an uncertain factor but can be assessed more precisely and thus be safer for the usage as a construction material. Due to the alternating, layer-by-layer assembly of veneers and adhesives in plywood, the binder type plays a major role in case of fire. Less thermally stable adhesives tend to result in delamination of the layers during a fire incident, which increases the surface by exposing single veneer layers to the heat source. These single sheets are prone to ignite and burn fast with an intense flame and have a sever influence on the fire spread. Although the importance of the glue type is a well investigated field concerning the use of cross-laminated timber (CLT), the influence of the main wood adhesives used in commercial plywood production (urea formaldehyde (UF), melamine urea formaldehyde (MUF), phenol formaldehyde (PF)) on the fire behaviour still gains scientific interest. Therefore, the present study focusses on experiments with a self-built small-scale Single Burning Item Test (Mini-SBI) which corresponds to one third of the original test setups dimensions. For the investigations 9-layered 500 x 500 mm² plywood panels were manufactured in a laboratory hot-press by orienting sliced 1.5 mm birch veneers 90° crosswise, with similar solid contents of UF, MUF and PF wood adhesives. Similar to the standard SBI-Test, the heat release rate (HRR) of the burning samples is measured by oxygen consumption calorimetry. In combination with the fire growth rate (FIGRA) an estimation and comparison of the burning behaviour of the different adhesive systems used for the investigated plywood panels could be carried out within this study. However, the investigations with the Mini-SBI not only show the influence of the adhesive type, but also the significance of the grain direction of the first layer exposed to fire. UF adhered samples showed the highest HRR and with the first veneer grain oriented parallel to the flame also the highest FIGRA value. MUF and PF adhered panels have similar HRR and FIGRA values and more balanced properties with respect to the grain direction, which is an indicator for less delamination. Additionally, ease of ignition tests in accordance with EN ISO 11925-2, (Single-Flame Source Test -SFT), thermal degradation behaviour by means of Simultaneous Thermal Analysis (STA) and proximate and ultimate analysis of the materials were conducted to provide holistic thermal information about the investigated material compositions.

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Outreaching and Informing Society about Sustainable Construction through Social Media

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Abstract

Moving to a sustainable oriented society new concepts and findings related to sustainable construction are being developed. With the ambition to transfer the knowledge to the society different communication paths are being used. In this study we investigated what kind of messages should be shared on institutional social media channels (Facebook, Twitter, and LinkedIn) about sustainable construction related topic in order to create more engagement of the audience. We performed the study in the frame of a research project Engineered wood composites with enhanced impact sound insulation performance to improve human well-being financed by Slovenian Research Agency and the Austrian Science Fund. The content and materials used were prepared and posted on institutional social media channels of the research institute InnoRenew CoE. The study consisted of two rounds of weekly social media posts. In each round 15 posts were published weekly on the same day and time, and engagement monitoring also occurred weekly. Three different types of posts were created, that varied each week. Type 1 was written informative content related to the research field of wood composites, sound insulation, building acoustics, human well-being and modelling of the floating floor and other project research activities. Type 2 was image content related to the project research activities and research equipment used, with short text caption of the image, while posts of type 3 were image content with people – researchers working on the project research activities and with research equipment used with short text caption of the image.

The analyses of the audience engagement revealed the type of messages that are attracting the audience on the three social media channels. We compared data from round 1 and round 2 but found no significant difference between the two rounds. Overall, we found out that posts of type 3 are resulting in highest number of likes, reach and clicks on Facebook, impressions and engagement on LinkedIn and Twitter. The social media channel that performed best was LinkedIn, where we recorded the highest number of likes, engagement and impressions across all types.

This finding can serve to other communication practitioners and researchers to improve their communication and dissemination activities on social media.

Key Words: sustainable construction, communication, social media, engagement, research project outreach

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Individual Tree Analysis via Person-Carried Laser Scanning (PLS) in Forest Stands

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Abstract

Knowledge about growing stock and biomass allocation in the forest is essential for a thorough planning and a sustainable production of the resource wood. Nowadays forest inventory practice only provides rough estimates for the total stocking volume, but there is no information about the individual tree. Person-carried laser scanning (PLS) is a highly automatized technology to create 3D point clouds from forest stands. Every tree is represented in great structural detail by a digital twin. Irregular shapes and defects of the stem require an individual tree analysis before harvesting to maximize the usability of the wood. This study presents an automatized software to extract and measure single tree point clouds from data captured with PLS. The trees were segmented by cluster analysis and a region growing algorithm. Splines were used to subsequently measure multiple stem diameters, and stem volume and crown parameters were extracted. The diameter at breast height and total tree height were measured most accurately with PLS, thereby also the stem volume of the single trees. The measures were compared to manual measurements from traditional forest inventory via root mean square deviation (RMSD) and bias.

PLS can efficiently measure whole forest stands before harvesting operations and provide accurate data to the forest owner. Possible uses of the individual tree files are detection of wood quality parameters (e.g., forks) or a quality grading according to the density of branches. A material and energy-efficient use of the resource wood requires to consider the individual tree characteristics and should be a necessary step in the future wood supply chain.

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Developing potential value-added product of Small-Diameter Timber in Indiana

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Abstract

Small-diameter timber (SDT) from hardwood plantation forests and urban wood is an abundant and underutilized resource. In Indiana, for example, we need to address the utilization of SDTs from walnut plantations. However, since SDT is typically too thin, weak, and with various defects, processing and finding value-added products are complicated. To solve the issue, SDT material producers are looking for potential value-added processes and innovative product designs that could utilize these resources, other than fuel wood, mulch, and energy production.

This project aims to investigate the possibilities of adding higher value to SDT, developing better solutions for material processing, and proposing various innovative products. Four scenarios of value-added products are showcased based on the different types of semi-products, such as timber, lumber, chip, and chemical extraction. The case study will be developed for each category, for example, using timber for landscaping elements, lumber for school furniture, and chips for innovative composite panels. The results will provide a vision/option for SDT producers and the forest products industry. The goal is to contribute to SDT value-adding and sustainable manufacturing.

Keywords: Small-diameter timber (SDT), forest products industry, value-added process, product development

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Hemp Hurds Alkaline Peroxide Mechanical Pulp for Hygiene Tissue Applications

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Mr. Ramon Vera - North Carolina State University, Department of Forest Biomaterials
Dr. Ronalds Gonzalez - North Carolina State University, Department of Forest Biomaterials

Abstract

This work focuses on using hemp hurds APMP pulps for hygiene tissue applications. A hot water wash at 90 ºC for 2 hours was used as pre-treatment. For the chemical impregnation step, the following charges were utilized 6% NaOH + 6%H_2O_2, 8% NaOH + 6%H_2O_2, and 8% NaOH + 8%H_2O_2. For all impregnations, the temperature was 90 ºC for 2 hours. The yield and brightness were as follows: 82.6% and 68.4% ISO; 81.5% and 67.9% ISO; 80.4% and 68.3% ISO showing clearly that increasing the chemical charge slightly diminishes yield without improving brightness. Thus, the lowest chemical charge was chosen as optimal. For mechanical properties comparison handsheets using the hemp hurds pulp at optimal conditions and BEK were made. Hemp hurd was bulkier (6.7 cm^3/g) than BEK (4.4 cm^3/g). Had a higher tensile index (21.7 Nm/g) than BEK (11.2 Nm/g). And slightly more absorbent (6.1 g/g) than the benchmark (5.8 g/g). Although BEK fibers were still softer (22.4 dB TS7) than hemp hurds (25.0 dB TS7).

Keywords: Mechanical Pulping, Hygiene Tissue, APMP, non-woods

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In-depth characterization of bondlines in cross-laminated timber made with preservative-treated lumber

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Mr. Jed Cappellazzi - Oregon State University
Dr. Gerald Presley - Oregon State University

Abstract

Mass timber construction projects are rapidly increasing in number in North America but this technology encounters durability issues in termite-prone areas. To combat this issue, chemical treatments must be incorporated into mass timber elements to prevent termite attacks. However, pressure treatment is either unfeasible for large panels or may cause problems with bondline integrity if done prior to layup and we sought to investigate this problem. Douglas-fir 2 x 6-inch lumber or untreated cross laminated timber (CLT) panel sections were treated with one of three different preservative systems, pressure treatment with borates, pressure treatment with an all-organics preservative system (PTIP+IPBC) or dip treatment with propiconazole, tebuconazole and imidacloprid + borate (PTI). Treated and untreated lumber was used to manufacture CLT panels using one of two resins, melamine formaldehyde (MF) or Polyurethane (PUR). To determine if the preservatives cause a negative interaction with the adhesives, Dynamic Mechanical Analysis of MF and PUR adhesives between treated veneers was conducted. The positive effect of preservative in the wood can have a negative effect on the resulting curing strength of the adhesive. This can have major consequences for the construction of CLT panels and their overall performance.

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Spray-dried cellulose nanocrystal-reinforced homopolymer polypropylene composites

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Abstract

The unique properties of rod-like cellulose nanocrystals (CNCs), including high crystallinity, Young's modulus, and strength, make them excellent reinforcement for developing high-performance thermoplastic composites. However, nanoscale CNC is dominantly dispersed in aqueous suspension, which is not appropriate for large-scale industrial production of CNC-based composites manufactured by the melt compounding process. Spray-dried CNC (SDCNC) particles with irregular shapes were proposed as suitable for developing thermoplastic composites. This work aims to develop SDCNC-reinforced homopolymer polypropylene (HPP) composites and evaluate the properties of HPP composites with different SDCNC contents (5, 10, 15, and 30 wt.%). All composites were prepared using an internal mixer and subjected to an injection molding process. The mechanical, morphological, and thermal properties of composites were investigated. The results indicated that the tensile and flexural modulus of elasticity (MOE) of the composites were significantly increased after adding SDCNC particles. The impact strength of the composites was also increased, which could be attributable to establishment of a mechanical interlocking network between SDCNC particles and the HPP matrix. The steady increment in crystallization peak temperatures was observed as increasing SDCNC particle contents in the composites, contributing to the fact that SDCNC particles can act as heterogeneous nucleating agents.

Keywords: spray-dried cellulose nanocrystal, polypropylene, mechanical properties, morphology, mechanical interlocking

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Ultra-Lightweight Foamed Insulation Panels Made of Oil Palm Trunk Fibres

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Abstract

Inorganic and polymer-based foamed materials are widely applied in building insulation applications. Rising environmental awareness and a demand for more sustainable technologies encourage the use of renewable resources. Oil palm trunk (OPT) is a suitable raw material for the preparation of insulation board due to its relatively high fiber content, low cost, and abundant availability as a by-product of palm oil production. The present study focuses on developing an environmentally friendly thermally insulating material from oil palm trunk fibers for use in building applications. The effects of variable amounts of surfactant (1%, 2%, and 3% of polysorbate (T80)), wheat gluten (5%, 10%, and 15%), oil palm trunk fibers, and fire retardant on the properties of the resulting board was investigated. In comparison to the reference variant, there was a trend where increased surfactant content resulted in lower density and hence reduced thermal conductivity. On the other hand, such a trend was not obvious within variants with different wheat gluten content, where an optimum thermal insulation effect was observed at 10%. As expected, the compression strength of most variants showed a close correlation with density.

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Mechanical, Morphological Properties and Crystallization Kinetics of Polypropylene/High Density Polyethylene/Microcrystalline Cellulose composite

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Abstract

Polyolefins are the largest class of commodity thermoplastics, in which polypropylene (PP) and high-density polyethylene (HDPE) are most commonly used, attributed to their individual merits. Post-consumer PP and HDPE are commonly found together in a commingled plastic stream and are challenging to recycle. Polymer blending is one of the most feasible techniques for recycling polyolefins. However, PP/HDPE (PO) blend shows poor mechanical properties because of the phase separation and immiscibility. The objective of this study is to investigate the effects of microcrystalline cellulose (MCC) and a coupling agent on the mechanical properties, morphologies, and crystallization kinetics of the PO blend. The weight ratio of 75:25 was used for manufacturing the PO blend. The PP/HDPE/MCC composites with/without maleic anhydride grafted polypropylene (MAPE) were manufactured with MCC loading levels of 2.5%, 5%, 10%, 20%, 30% by thermal compounding and injection molding. The tensile results indicate that the compatibility of PO blend and MCC was significantly improved by adding MAPE. The tensile strength of the composite with 30% MCC was increased to 32.5 MPa, which is 19% higher than PP/HDPE blend. Compared to the PO blend, the impact strength of the composite without the coupling agent was greater and was further enhanced after being compatibilized with MAPE. The highest impact strength of 2.41 kJ/m^2 was achieved at a 2.5% MCC loading level which is a 49% improvement. MCC demonstrated a satisfactory result in increasing the mechanical properties of the PO blend, especially when being compatibilized with MAPE.

Key Words: Polypropylene, High Density Polyethylene, Microcrystalline Cellulose, Compatibility, Mechanical Properties

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WOOD PROPERTIES

Physical and Mechanical Properties of Ten-year old plantation Teak grown in Ghana for structural applications

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2. Institution of Engineering, Ghana (IETGh.)

Abstract

Demand for timber in Ghana continues to be on the ascendency due to the many good attributes of wood and the vital roles timber play in human living as a material for building and other constructional activities, fuel, furniture production, as well as for medicinal applications. The demand is mounting enormous pressure on the forest and posing a threat to the existence of water bodies and biodiversity in general. To supplement the timber stock in the natural forests, efforts have been made to consciously establish plantations for various exotic timber species including *Tectona grandis* (Teak). However, timber users do not have adequate information on some of such plantation teak to encourage maximum acceptance for utilization in respect of their ages. This study therefore evaluated the physical and mechanical properties of ten (10) year old Teak using BS standards. Two trees were selected from a plantation in Jukwa in Hemang Lower Dankyira District. Results indicated average values of 614kg/m^3, 80 N/mm^2, 12,914 N/mm^2 and 36 N/mm^2 respectively for density, MoR, MoE, and Compression strength parallel to the grain. On the whole, whereas density was higher than those of other studies, MoE was better than even those of 50 to 70 years teak, but MoR and compression strength suffered relatively lower values than in literature. The MoR and compression strength therefore limits the use of 10year teak for high load bearing construction members, but it could be used for some relatively light structures such as furniture.

Keywords: Density, Biodiversity, Plantation Teak, Hemang Lower Denkyira, Wood construction.

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Densification of Low-density Australian Hardwood Species

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Abstract

Density is one of the most important characteristics of wood as it is strongly correlated to its mechanical properties. Wood modification techniques have been used to help valorise under-utilised wood materials and increase their performance with respect to durability, mechanical characteristics, and new forms and functions desired by consumers and designers alike. Densification has been used since the early 1900s to make various low-density wood species stronger, harder and more resistant to surface abrasion. Australian *Eucalyptus* species commonly grown in Tasmania are fast growing and represent an important source of timber both for export and domestic markets. Although they have good physical and aesthetic properties, the timber industry is mostly limited to selling these species either for woodchip production or for limited indoor applications as they have a relatively low-density profile when compared with other hardwoods. Therefore, increasing their density could open new market opportunities.

This project focused on increasing desirable material characteristics of Tasmanian hardwood species for use in several non-structural product groups. More specifically the objective was to evaluate the effect of thermo-mechanical densification process on the density profile of densified wood of thinned and pruned plantation *Eucalyptus nitens* and regrowth Tasmanian oak. Benchmarks and subsequent testing and analysis of the densified samples have been assessed with a focus on the occurrence, amelioration, and controllability of spring back. Colour change, machinability, adhesion, and gluability were also considered. The post-densification assessment of densified lamellas included spring back, colour change, set recovery via direct exposure to water, set recovery via temperature and humidity cycling, pull-off strength test to test adhesion of coatings, and delamination.

Both Tasmanian oak and *Eucalyptus nitens* have been densified successfully, showing no sign of spring back. Factors such as species, pre- and post-treatment conditions, compression ratio, pressure applied, pressing time, and pressing temperature influenced the process, quality, and properties of the densified material. A comparison of the average set recovery results following the moisture content cycling suggests that both *Eucalyptus nitens* and Tasmanian oak species were stable following the densification process and would be suitable for dry-use environmental conditions *i.e.*, capable of producing sufficient dimensional stability to make the densified wood serviceable under conditions in which the EMC does not exceed 17% if unprotected.

Key Words: Eucalyptus, densification, low-density, hardwoods

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Densification of Commercially Important Appalachian Hardwood Species

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Mr. Luke Chaddock - West Virginia University
Dr. Balazs Bencsik - West Virginia University
Dr. Levente Denes - West Virginia University
Dr. Joseph Mcneel - West Virginia University

Abstract

The density of wood is considered one of the most important indicators of its mechanical properties. Currently there are several processes that have been studied and applied to increase the density of several softwood and hardwood species. The general process of densifying wood implies the collapse of cell walls due to thermal, mechanical and/or chemical treatments. In this research we compared two simple treatments of wood densification on low grade / low value hardwood species that grow commonly throughout the Appalachia, and their effects on their physical and mechanical properties. The species studied here were yellow poplar (*Liriodendron tulipifera*), red oak (*Quercus rubra*), soft maple (*Acer saccharinum*), and basswood (*Tilia americana*). The densification methods considered 1) combination of chemical and thermomechanical processes, and 2) combination of hygrothermal and thermomechanical processes. For treated and untreated wood some of the properties measured were density, equilibrium moisture content, water absorption, dimension stability, compression parallel to grain, modulus of rupture (MOR), flexural modulus of elasticity (MOE), surface chemical modification, and cellular morphology. Preliminary results indicate that using Method 1), the density resulted 130%, 110%, 75%, and 67% higher than control samples for basswood, yellow poplar, red oak, and soft maple, respectively. For method 2), the density was 55%, 120%, 36% and 46% higher than control samples for basswood, yellow poplar, red oak and soft maple, respectively.

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Sensitivity and Uncertainty Analysis for Modeling Water Absorption in Wood

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Mr. Charles Boardman - Building and Fire Sciences Unit, USDA Forest Products Laboratory, Madison WI, USA
Dr. Samuel Glass - Building and Fire Sciences Unit, USDA Forest Products Laboratory, Madison WI, USA
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Abstract

Hygroscopic properties of wood strongly influence the deterministic outcome of hygrothermal simulations that are widely used to estimate moisture levels in wood-frame wall assemblies. The reliability and relevance of the wood property input parameters largely affect the uncertainty and hence the predicting power of the modeling results. Despite their critical importance, property databases for wood and wood-based materials are limited in the literature and often exhibit significant variations with no published uncertainty estimates. Here, we identify the most influential input parameters and quantify their effects using a recently developed and validated approximation method for modeling water transport in wood. Through laboratory measurements and modeling efforts of common wood species, we demonstrate that reliable assessments of the capillary saturation value and vapor diffusion resistance factor at high relative humidity are particularly important for accurate modeling of water absorption in wood. The results contribute improved understanding of the investigative role the sensitivity and uncertainty analysis plays in hygrothermal performance evaluation of wood.

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The Wilcoxon Rank Sum Test is not an Appropriate Test for Comparing MOE or MOR Design Values

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Abstract

Lumber must meet certain strength standards to ensure the safety of buildings. Two of the most important properties are Modulus of Elasticity (MOE) and Modulus of Rupture (MOR), which are measures of a board's resistance to flexure and resistance to breakage, respectively, both under bending load. Within a lumber grade, for any species or species group, so-called design values are published for each of the properties, and monitoring programs are continually implemented over time to detect any changes, specifically degradation, of these properties. For MOE, the design value is based on the population mean, while for MOR, the design value is based on the population 5^{th} percentile. To detect degradation of MOE or MOR, two samples of lumber drawn directly from mills are subjected to vigorous testing and measurement: one sample from the time the currently published design values were established, and one from the current resource. From these samples, MOE and MOR measurements (adjusted for the size and moisture content) are obtained. Using these measurements, a statistical test is performed to assess the likelihood that degradation of the property has occurred over time.

Today, that test is typically the Wilcoxon Rank Sum (WRS) test, a nonparametric statistical test originally designed to detect whether one population is likely to be larger than the other. In the context of this test, what it means to be "larger" is complex, and it does not necessarily align well with the test's intended use in the current application. Further, this test is not focused specifically on the design values; rather, it aims to assess the entire populations. In this work, we discuss the specifics of the WRS test, including its original motivations, its assumptions, and its potential shortfalls. We further explain why this test can be problematic for the specific detection of design value degradation, particularly those of MOE and MOR, using both real and simulated data. It is found that, in many cases the WRS test can erroneously conclude that degradation of the property has occurred even though none has, and in many other cases clear degradation of the property can be overlooked by the WRS test. The reasons for these disparities, called Type I and Type II errors, respectively, vary from case to case and also differ between MOE and MOR.

To address this elevated propensity for error, this work proposes that the WRS test be replaced with alternatives that focus their detection capabilities on the specific design values of MOE and MOR. We further demonstrate that these statistical tests result in lower Type I and Type II errors, compared to the WRS test, using simulated data shown to mimic MOE and MOR observations reasonably well.

Finally, we propose a new step-by-step process for the monitoring program to be implemented in ASTM D1990 which incorporates these new testing methods and increases the clarity of the results.

Key Words: Dimension Lumber, Modulus of Elasticity, Modulus of Rupture, Lumber Strength Property Monitoring, Statistical Testing, Wilcoxon Rank Sum Test, Welch's t-test, Melded Random Quantile Test

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Effect of steaming and furfuryl alcohol impregnation pre-treatments in the spring back, set recovery and thermal degradation of densified wood of three tropical hardwood species

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Abstract

Alnus acuminata, *Vochysia ferruginea* y *Vochysia guatemalensis*, the low-density species, have been previously studied for their potential in the thermo-mechanical densification process. However, their spring back and set recovery values are reported to be high. Therefore, the objective of this work was to investigate and evaluate the effect of steaming and furfuryl alcohol impregnation pre-treatments on spring back, set recovery, and thermal degradation of densified wood of these three tropical hardwood species. The results indicated that both steaming pre-treatment and furfurylation pre-treatment improved the dimensional stability of the densified wood of these three species. The wood densified with furfurylation pre-treatment of these three species presented high spring back values, but low set recovery values compared to the wood densified with steaming pre-treatment. In addition, while comparing with the un-densified wood, the DTG/TG curves of the three species showed that the wood with furfurylation pre-treatment presented a higher chemical modification, related to the structure of hemicelluloses, the amorphous zones of cellulose and lignin. While in the wood densified with steaming pre-treatment, a displacement of the curve was observed only towards higher temperatures, making it more chemically stable. The densified wood of *V. ferruginea* and *V. guatemalensis* presented lower spring back and set recovery values in comparison to the wood of *A. acuminata*, regardless of the treatment applied, suggesting that these two species present better conditions for the densification process.

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EDUCATION ISSUES/RECRUITING

Stages of Preparation of Turkish Timber Building Regulations and Problems Encountered

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ABSTRACT

The building stock in Turkey, according to the Turkish Prime Ministry State Institute of Statistics 2000 data, shows that 1.0% of the buildings have a skeleton system, while 2.2% have a masonry system made of wood. It is known that in countries like the USA and Canada, this percentage reaches 90%-95%. Moreover, in European Union countries, Australia, and New Zealand, efforts are underway to promote the use of wooden buildings. In Turkey, being a seismic-prone country, the Ministry of Environment, Urbanization and Climate Change, along with leading associations and universities such as the Ministry of Agriculture and Forestry, General Directorate of Forestry, TORID, and the National Wood Association, have initiated and expedited studies on the classification of structural wood materials and their use in buildings in recent years. Wooden buildings offer significant advantages, especially in terms of their lightweight and durability against earthquakes. Furthermore, the widespread use of wood contributes to carbon capture, which is beneficial for combating global warming caused by the increase in atmospheric carbon dioxide levels. This article explains the development and stages of Turkish wooden building regulations, while also discussing some technical issues under specific headings.

A recent national regulation for timber buildings is supported by the Turkish Ministry of Environment, Urbanization and Climate Change and a joint study carried out by four leading universities in Türkiye. This paper lists various challenges the team experienced when the international timber codes are studied to generate a comprehensive national regulation. A few major challenges are found to be universal and

others are related to Eurocode 5 and 8. Material properties are referred to EN338 since Türkiye is in customs union with Europe making it impossible to design using material properties available to NDS of the USA. Although more practical formulas have been derived from NDS, the majority of rules had to be similar to EC5 for a complementary approach and compatibility with Europe. Türkiye being in a relatively higher seismically active zone compared to Europe, the major difficulty was determining if a floor is rijit, flexible, or semi-rijit, which would greatly influence the member force distribution and outcome of the design procedure. Although many northern European countries allow reinforced concrete decks for serviceability and rigid diaphragm action, extra mass generates substantial earthquake forces is another restraint we have tried to avoid for timber buildings in Türkiye. The glulam chapter is included in the national regulation and the mismatching structural properties between different active Eurocodes are determined causing various troubles. The connections of beams and columns in European building examples are oftentimes semi-rigid or intentionally pinned, where the horizontal earthquake and wind forces are dominantly transferred by 'rigid' slabs and carried by shear walls made by CLT or reinforced concrete cores. Connection and system design responsibility has been left to the designer engineers as design approaches may be in a variety of different ways. These and some other questions and concerns raised during the preparation of our national timber building regulation are also listed in this paper, which might be useful for designing engineers and code developers.

Keywords: National Timber building code, Design, Turkish, Turkiye

INTRODUCTION

The use of wooden structures has gained prominence, especially in the 21st century, in developed countries due to climate change and sustainable construction. Leading the way in the utilization of wooden structures are the United States, Canada, European Union countries, Australia, and New Zealand. Wooden materials are now being employed not only in residential and office buildings but also in hotels, stadiums, airports, and bridges. In Turkey, various efforts by associations such as TORID and the National Wood Association, along with the positive approach of our President and its inclusion in the strategic plan, have been made possible with the contributions and initiatives of the General Directorate of Forestry (OGM) under the Ministry of Agriculture and Forestry, as well as our Ministry of Environment, Urbanization, and Climate Change (MoEU). Consequently, significant strides have been taken in Turkey toward the widespread adoption of wood, and these efforts are progressing rapidly. As part of these endeavors, wood design courses have been introduced in universities across the country. Notably, METU has been offering wood design courses for the past 7 years, and Van Yüzüncü Yıl University for the past 10 years, making them leading institutions in this field.

Concurrent with these studies, around 2000 wood beam strength tests were conducted through collaborative efforts involving Boğaziçi University, Istanbul University, Kocaeli University, and Middle East Technical University, initiated by OGM in 2020. As a result, wooden classes have been introduced and registered in Europe as well. The next logical step after achieving domestically produced structural wood material is the establishment of a comprehensive, detailed, and traceable national regulation. To this end, a project supported by MoEU was implemented in 2022, led by METU in partnership with Kocaeli University, Mimar Sinan Fine Arts University, and Van Yüzüncü Yıl University. This article presents a study that examines the project's work from a scientific perspective.

The use of wood in buildings offers several advantages for our country. Firstly, in our earthquake-prone nation, wood exhibits strength comparable to reinforced concrete. Unlike concrete, which is weak in tension, wood possesses high strength in both tension, compression, and bending, while being approximately 1/5th the mass of reinforced concrete, making it 80% lighter. The reduced mass of wooden structures, accounting for only 20% of a reinforced concrete structure, leads to lower forces on the elements during earthquakes. Therefore, it is evident that wooden structures, which boast similar strength to reinforced concrete, provide significant advantages in terms of earthquake performance. As stipulated in the regulations, floors in wooden buildings should not be made of reinforced concrete, unlike in northern European countries with no or very little seismic risk. The inclusion of concrete in the flooring, even as a hybrid with wood, significantly increases earthquake forces and diminishes the advantage of wood's low mass. For instance, instead of a 5 cm thick reinforced concrete floor, a 25 cm thick wooden flooring can be used with the same mass. Utilizing wood as a box beam or I beam allows for the creation of lightweight and durable floors.

The second most significant advantage of using wood is its environmental compatibility and negative environmental footprint. Structural wood is produced by trees utilizing solar energy, and it does not pose high energy or carbon dioxide (CO2) emission issues that are associated with the production of materials such as concrete, steel, aluminum, and so on. On the contrary, trees in the forest absorb CO2 from the atmosphere during wood production, release oxygen (O2) into the atmosphere, and utilize carbon in the process of wood production. Instead of being released into the atmosphere, the captured CO2 remains trapped as a carbon sink as long as the building is in use. This process represents a cohesive and sustainable approach to addressing the growing challenge of climate change. Moreover, after the building completes its life cycle, wood can be recycled and repurposed for various applications such as pallets, OSB (oriented strand board), MDF (medium-density fiberboard), chipboard, HDF (high-density fiberboard), or converted into paper by extracting cellulose.

In 2016, an experiment was conducted on 20 healthy adults to examine the physiological effects of wooden structures and wooden interiors on building occupants. The study observed that wooden environments were associated with lower levels of tension and fatigue compared to non-wooden environments. Furthermore, it was found that wooden environments positively impacted the autonomic nervous system, respiratory system, and visual system of the individuals (Zhang et al., 2017).

There are studies indicating that people living in wooden buildings experience higher levels of happiness and better overall health. This article provides a summary of the challenges encountered in the regulatory studies on wooden buildings, which offer significant advantages, as well as the proposed solutions and general regulatory efforts."

Figure 1 - Wooden walls with different patterns. Office rooms measuring 3.8 m x 3.2 m x 2.8 m (Zhang et al., 2017).

SCOPE AND SUBJECT HEADINGS OF THE WOODEN BUILDING REGULATION

When we started working on the Wooden Building Regulation, the first topic considered was 'design according to strength.' However, it became clear that a section on 'material' should precede the strength phase. To ensure compatibility with Europe, specifically due to our customs union agreement with the European Union, the decision was made to use the EN338 standard for material studies. Since subsequent stages involved strength calculations, priority was given to addressing earthquake considerations, as highlighted in the advantages section. Our Earthquake Code (TBDY-2018) aligns closely with US regulations, with Chapter 12 added based on the 'Specific Rules for Timber Buildings' section of Eurocode 8, providing guidance on designing wooden building load-bearing systems under seismic effects. Although the focus was initially on US wood regulations for compatibility with earthquake calculations, further reviews of Canada, Australia, New Zealand, and Eurocode 8 were undertaken.

Following the selection of material properties from the EN standard, it was observed that there was a lack of compatibility with the USA (NDS) standard. Adapting the US specification, which involves numerous calculations, into a tabulated format posed significant challenges and required extensive research. However, since many features such as buckling and strength calculations of joints are addressed similarly in international standards, and earthquake calculations are fundamentally compatible across different specifications, our wooden building code studies were primarily directed towards EN norms, including load combinations.

The information in this context has been periodically compared with other international regulations, and adjustments have been made to ensure convenience and clarity within our country. These adjustments include factors such as buckling calculations, material moisture, and time coefficients.

When examining the current regulations, it becomes evident that, in addition to designing based on material and strength, an essential element is designing for 'usability limit situations'. Controls for 'usability limit states,' integral to the design, have been incorporated in addition to sizing based on material and strength. Given the lightweight nature of wooden structures and their low modulus of elasticity, precautions must be taken to address potential oscillations and vibrations under moving or wind loads, ensuring comfort conditions are maintained. Measures to address this issue can be

categorized into two main areas: a) displacement control and limitation, and b) vibration control. Both methods have been thoroughly examined and incorporated into the draft regulation.

Another crucial section to be included in the Wooden Building Regulation is the design for fire safety. Through an extensive review of internationally recognized specifications, documents, and research on this topic, specific guidelines for designing wooden structures to withstand fire have been developed as a separate section. Chapter 6, titled 'Design Against Fire,' covers this topic in great detail.

In order for the draft of the Wooden Building Regulation to surpass the regulations and standards of many countries and provide a comprehensive framework, the aspect of 'insulation,' which is considered integral to holistic design, has been studied and included under a separate section. The topic of insulation is examined under three main subheadings: 'heat insulation,' 'sound insulation,' and 'water insulation'. The topics are further explained under each section below.

ANALYSIS, ELEMENT DESIGN AND EARTHQUAKE IN WOODEN BUILDINGS

The analysis of wooden structures reveals several distinctions compared to other types of structures. Firstly, it should be emphasized that there are various construction techniques employed in wooden buildings. Some of these include:

1) Frame-type wooden buildings composed of columns and beams.
2) Wall-bearing systems.
    a) Lightweight wall frame systems.
    b) Systems constructed with solid cross-laminated timber (CLT) elements for walls.
3) Hybrid systems.
    a) Horizontal load-bearing systems incorporating reinforced concrete, steel, or CLT.
    b) Systems with floors consisting of both wood and reinforced concrete.
    c) Systems utilizing wooden bearing elements in conjunction with wooden + steel bearing elements, such as columns, beams, or wide-span arches.
    d) Structures where some walls are masonry while the ceiling and columns are partially wooden.
4) Mixed systems like Hımış, where the walls are partially filled inside the wooden frame with materials like bricks, stones, and mud bricks.
5) Historical structures.

Each of these construction techniques presents unique characteristics and considerations within the realm of wooden structures.

In the regulation studies, focus was primarily placed on modern wooden structures, while hybrid systems were excluded due to time constraints and the extensive variety of types. A warning was included in Section 1.8.3.4, stating that while general structural mechanics rules can be used for material strengths and stress distribution calculations in hybrid systems, factors such as temperature expansion coefficients, long-term creep properties of wooden elements under load, changes in deformation and load capacity due to humidity fluctuations, heat transmission coefficients, and performance during fire should be carefully considered. Precautions should be taken in advance to address potential issues.

Wood materials used in wooden structures generally exhibit a linear load-displacement relationship up to the characteristic strength limit. Hence, linear analysis methods, along with reduction coefficients and response spectrum methods, can be employed. However, it is crucial to account for additional flexibility at the connections between elements and at the joints themselves to accurately determine element forces. Neglecting stiffness reductions at joint points within frame systems may lead to erroneous calculations of displacements and element forces in hyperstatic systems. Specifically, for in-plane stiffness of flooring and load-bearing walls (e.g., light frame systems and glued laminated wood CLT systems), stiffness calculations should consider both internal and external connections.

In the design draft, a notable factor for wooden structures is the diversity in connection and material types, resulting in different behaviors of nails, screws, wedges, bolts, and other connections used in artificial columns or beams. Each connection type, such as nails or screws, may have distinct properties (e.g., twisted nails). Moreover, besides solid wood, materials like OSB and plywood can be used individually or in combination. The variety of fasteners, combined with different materials, contributes to varying strengths and behaviors for each combination. The draft regulation explains all these combinations and supports them with complex examples.

SERVICEABILITY LIMIT STATE IN WOODEN BUILDINGS

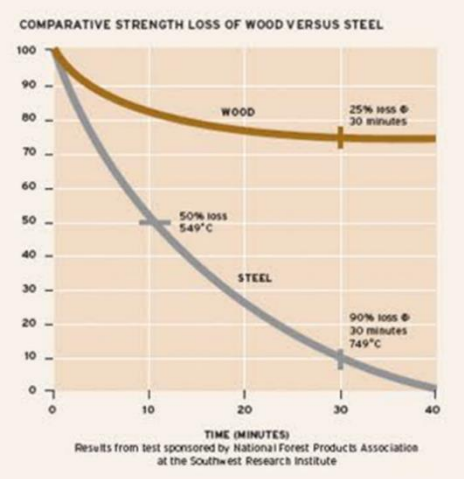
Wooden structures, due to their relatively light materials and lower elastic modulus values, may experience oscillating vibrations caused by factors such as human footsteps, machinery operations, or interaction with wind. To address potential discomfort, measures have been planned in the design process under two categories: a) displacement control and limitation, and b) vibration control. Horizontal displacement limits for wooden buildings and allowable deflection limits for beams are defined to provide static and indirect dynamic protections. Furthermore, vibration-based serviceability checks for floors, as outlined in Eurocode 5, have been further improved as an algorithm and included in the draft regulation.

In Eurocode 5, the method involves assessing the initial velocity of a theoretical effect applied to a 1 N.s slab, along with a table consisting of 'a' and 'b' variables based on the flexibility of the slab (1/stiffness). In the draft regulation, this topic is addressed in Chapter 5.4 under Vibration, providing a detailed explanation. A shortcoming in Eurocode 5 is the possibility of different 'a' and 'b' values satisfying the condition for the same slab. Some European countries address this by accepting a = 1.5. In the draft regulation, an algorithm has been developed to determine the lowest pair of 'a' matching with highest 'b'. Additionally, by creating a continuous graph with four values in Eurocode 5, an equation matching the data was derived to facilitate vibration analysis.

FIRE PROTECTION

One of the most concerning aspects of wooden buildings is the potential for structural elements to ignite and burn in a fire. However, the primary concern lies in the ability of the load-bearing system to withstand the fire without collapsing. Building fire evaluation and design criteria typically include

requirements for not collapsing under specific fire durations, such as 30 minutes, 60 minutes, or 90 minutes. This duration allows sufficient time for the fire department to arrive at the scene and extinguish the fire. For instance, in steel structures where the elements are not protected against fire, the loss of strength can occur much faster (Fig. 2).



Michael E. Parolini, S.E., LEED AP and Michelle Kam-Biron, S.E., SEAOC 2010 convention proceedings

Figure 2 - Fire Resistance Chart of Steel and Wood Structures

During a fire, the temperature inside a room can rapidly rise to 900 degrees Celsius within minutes. It is widely accepted that steel material loses its strength after reaching approximately 600 degrees Celsius due to rapid heat transmission. In contrast, wood maintains its internal temperature despite burning, thanks to the formation of a carbon layer that reduces oxygen access, resulting in slower combustion. Consequently, section loss in wooden elements occurs gradually over an extended period. Large cross-section wooden elements, in particular, exhibit significant fire resistance and can endure the effects of fire for an extended duration (Fig. 3).

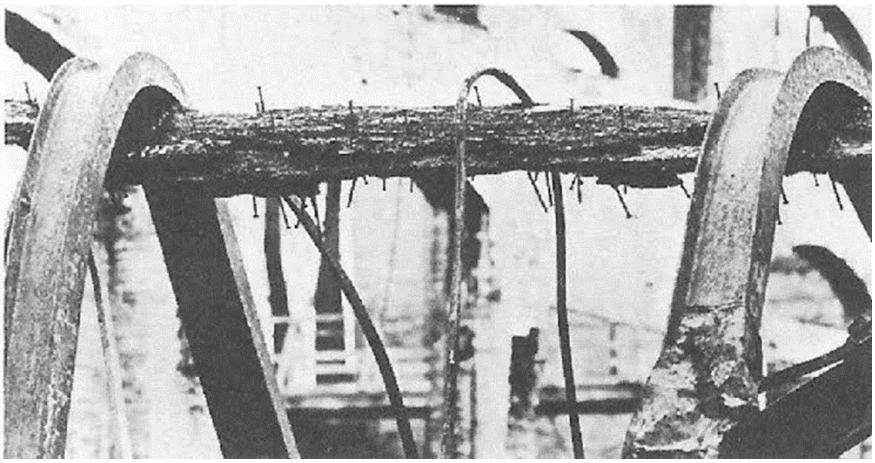


Figure 3 - View of wooden beam molten steel beams (2 IPE) and flooring reinforcement after fire (San Francisco Earthquake 1906)

RESULTS

The use of wooden buildings in Türkiye has gradually declined since the early 1900s, being replaced by reinforced concrete structures. While wood and wood derivative construction techniques such as himis, bagdadi, and shamdolma were once employed in the construction of mansions, mosques, and village houses, the use of wooden structures has become almost non-existent today. However, wooden buildings offer numerous advantages, including their light and strong nature for earthquake resistance, shorter construction periods, absence of heavy cranes requirement, economic viability, positive environmental impact through the production of wood using solar energy and absorption and storage of CO_2 from the atmosphere, as well as their contribution to sustainable building technologies by promoting forest planting, climate preservation, natural life, and prevention of soil erosion.

The developed Turkish Wooden Buildings Regulation in national language considers all design criteria using the latest methods and in parallel with the current existing regulations and specifications in Türkiye. It aims to provide rules and liability criteria with warnings that ensure the safety and well-being of both responsible civil engineers and users without conflicting with existing regulations.

ACKNOWLEDGMENTS

We would like to express our gratitude to the Ministry of Environment, Urbanization and Climate Change and its employees for their support of the project titled 'Determining the Design, Calculation, and Construction Principles of Wooden Buildings,' numbered 2022-03-03-2-06-060. Additionally, we extend our appreciation to the managers and members of TORID and the National Wood Association Associations, OGM for their kind contributions to the Project.

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A Social-Impact Audit Tool for Students Learning Social-LCA

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Abstract

A social impact audit evaluates the effect of a product or service on people, including workers, consumers, local community, surrounding society, children, and other interested parties. Just as in a Social Life Cycle Assessment (S-LCA), it identifies hotspots or points of contact between stakeholders and various aspects of a material's life cycle that can be socially damaging. The social dimension of sustainability is difficult to evaluate, made more so by the challenges associated with obtaining enterprise-level data. Granta Design has developed a spreadsheet-based social impact audit tool that introduces students to the concept of social life-cycle assessment. Country-level data from the United Nations, World Bank, and non-governmental organizations are mapped to each of the social impact categories listed in the UNEP Guidelines for Social Life Cycle Assessment. While lacking the granularity provided by enterprise-level data, the social assessment allows the students to explore various scenarios to arrive at useful conclusions. The tool introduces the student to the protocols of enterprise-level audit and full S-LCA and provides them with valuable insights into the dimension of sustainability that is difficult to digest. This presentation describes the social impact audit process as implemented using the Granta tool.

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Collaborative efforts to promote wood-focused undergradaute programs in the US.

Dr. Eric Hansen - Oregon State University

Abstract

At the 2021 SWST Annual Convention, Bob Smith of Virginia Tech lead a conversation about how wood-focused programs might cooperate to collectively promote our programs. Because of COVID, participants were almost exclusively from the US. This initial conversation led to a series of virtual conversations and a commitment by a consortium of 10 universities to jointly develop a promotion and communications campaign. The consortium is made up of: Auburn, Idaho, Maine, Michigan Tech, Mississippi State, North Carolina State, Oregon State, Purdue, and Virginia Tech. Each university contributed equally to a fund allowing us to engage with a professional marketing firm, Monte. Extensive background information was gathered by Monte and a conceptual approach developed. By the 2023 Annual Convention we will be able to show the overall concept, something we expect to be live by late summer.

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Understanding student willingness to participate in research: Exploring factors that influence motivation and engagement

Dr. Dean Lipovac - InnoRenew CoE & University of Primorska
Prof. Mike Burnard - InnoRenew CoE & University of Primorska & University of Helsinki

Abstract

Participant recruitment is a crucial element in the success of any research study conducted on people. However, researchers face challenges in recruiting participants, especially with the increasing demands on participants' time and the proliferation of research studies. This study aims to investigate factors that influence student willingness to participate in research, with a focus on the importance of research topic, data collection method, study duration, effort required from participants, compensation, and data privacy.

This study used a mixed-methods approach, combining quantitative and qualitative data collection and analysis. A total of 50 undergraduate and graduate students from various disciplines at a university in Norway were recruited to participate in the study. Participants first completed a questionnaire that assessed their willingness to participate in research in relation to different characteristics of studies, such as data collection method or study duration. Next, they were presented with three research scenarios, each of which can examine how people respond to indoor environments furnished with wood. Participants were asked to rate their likelihood of participating in each scenario and provide open-ended responses to explain their decisions.

This study provides valuable insights into the factors that influence willingness to participate in research. It highlights the importance of carefully designing research studies that are interesting, relevant, and non-invasive. It also emphasizes the need for researchers to consider the time and effort required of participants and ensure that adequate measures are in place to protect personal information and ensure data anonymity. The findings of this study can be used to guide the design of future research studies and improve participant recruitment.
The willingness of people to participate in research is a critical issue for researchers. This study examines the importance of several factors in influencing participant motivation and engagement. By understanding the role of these factors, researchers can design studies that attract more participants who are more motivated to participate, ultimately improving the quality of research.

Co-designing a professional bachelor's degree program: challenges and opportunities working with industry stakeholders

Prof. Mike Burnard - InnoRenew CoE & University of Primorska & University of Helsinki
Prof. Andreja Kutnar - InnoRenew CoE & University of Primorska
Prof. Klavdija Kutnar - University of Primorska

Abstract

The University of Primorska is implementing a new professional bachelor's degree program targeting those already working in the wood sector or with interest in joining the sector as part of its recent Green, Digital, and Inclusive initiative. The new program, Sustainable Built Environments, was co-designed with industry stakeholders and potential students to ensure its content and methods are relevant, build useful skillsets, and will lead to more jobs and increased innovativeness in wood-sector companies. Through a series of co-design workshops, stakeholders provided input on priority course content, methods for teaching and learning, formulating meaningful internships, and how post-graduation transitions to industry should take place.

In addition, the program is designed as a joint study program with international partner to facilitate knowledge transfer into Slovenia and to increase the international networks of graduates.

Collaboration with stakeholders during the design process and the advantages of a joint study program are expected to create a more enticing opportunity and drive enrollment in the program. The co-design process is being monitored and assessed for its utility in the field and may shape similar activities at the University of Primorska. The results of the process will lead to both a new degree program and generate knowledge on the design process for curriculum.

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Wood science in a changing world: Where are we going ?

Prof. Rupert Wimmer - University of Natural Resources and Life Sciences, Vienna

Abstract

This presentation briefly reviews the historic development of wood science and technology, which finally commenced in the late 1800s. With respect to societal megatrends, some of the recent developments in wood research and education are looked at closely. This is followed by reviewing developments in publishing during the past 20 years, with an extraction of those research themes that seem to have become more prominent. It is concluded with a future perspective on where we are going as a science community, interrelated with needs by industry and the society as a whole.

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WOOD PROPERTIES

Composite laminates thermoformed into structures with large curvatures from wood-based prepregs for interior automotive applications

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Composite Materials and Engineering Center, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA

Abstract

Wood and wood-based products have been used for many decades with many traditional structural and non-structural applications. In the current need for sustainable materials, wood and its by-products are leading, due to being environment friendly with proven applicability. The team at Composites Materials and Engineering Center of Washington State University has been involved in developing wood-strand based prepregs, analogous to synthetic fiber prepregs, that can be thermoformed for both automotive and aerospace interior applications. The aim is to substitute the currently used synthetic materials with a recyclable and sustainable option. Previous work has established the ideal parameters for fabricating wood-strand prepregs from recyclable vitrimer polymer and thermoforming them into flat laminates. This talk will focus on extending the study to establish the ideal layup for achieving higher strength and stiffness values in the flat laminates. Mechanical and thermal performance of the panels will be detailed. The established thermo-forming parameters will be further used to achieve single-axial forming using vee-bending, double-axial forming using dome-shaped mold and multi-axial forming using a wafer mold. The ideal forming parameters observed from the study will be reported while understanding the limitations and opportunities in the processes. Dimensional stability of these structures with large curvatures will be observed to align with the requirements of automotive interior applications. The analyses of the various single and multi-axial bending will help detailing the vast applications that the proposed renewable and natural fiber based prepregs can potentially have. The study will also help establish the background for other natural fiber based prepregs, from both woven and non-woven structures, increasing the applicability and usage to aerospace and other non-structural interior applications.

Keywords: Wood strand prepregs; Wood composites; Liquid thermoplastic resin; Vacuum assisted resin transfer molding; Thermoforming; Large curvature structures; Natural fiber panels; Sustainable structures

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Eco-audit: A Tool for the Exploration of the Environmental Impact of Materials

Dr. Perry Peralta - North Carolina State University, Department of Forest Biomaterials
Dr. Ilona Peszlen - North Carolina State University, Department of Forest Biomaterials

Abstract

A material goes through four stages of life: production from feedstock, manufacture into product, use of the product, and disposal at the end of product life. Environmental life cycle assessment (E-LCA) documents the resources that are consumed and the emissions that are generated in each of the stages of a material's life. Standards are in place that detail the process of performing an E-LCA. Although numerous software is available, carrying out an E-LCA requires skills and experience. It is also expensive and time-consuming. Thus, at NC State University, we first provide our undergraduate students with the necessary material and energy balance background (SMT 203), before they can take an E-LCA class (PSE 476). We are now also introducing the eco-audit method to first- and second-year students, so they can start exploring the environmental impact of material utilization early in their college career. This gives the students insight into the inner workings of environmental assessment without the burden associated with a full E-LCA. Eco-audit is simple and provides quick feedback, which are especially useful during product design. While eco-audit is only an approximation, it is sufficiently sharp to identify the most damaging phase of a product life, thereby allowing the student to do "what-if" explorations when evaluating alternative materials, manufacturing options, use patterns, and end-of-life choices. The following presentation describes the eco-audit method and how it is implemented in the classroom.

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The Effect of Surface Treatment on Triboelectric Activation of Wood by Brushing

Ms. Lena Maria Leiter - University of Natural Resources and Life Sciences, Vienna
Prof. Rupert Wimmer - University of Natural Resources and Life Sciences, Vienna

Abstract

Wood is one of the most important natural resources that is renewable and widely industrially used. The disintegration of wood by sawing, cutting, chipping, shredding or defibration is one of the most important process steps in the wood industry. During all disintegration processes friction occurs between the processing tool and solid wood, or any other wood-based material. This friction is causing surfaces to become electrically charged. Wood is an electrically semi-conductive material. Its electrical conductivity is influenced by the wood moisture, the wood density, and the overall anatomical structure. In this research the extent of triboelectric activation of wood surfaces was investigated by using a wood brushing machine. The electrical surface field strengths were continuously detected using a self-designed experimental setup. To understand the conducted surface treatment effects, two wood species, i.e., beech and poplar, were measured: (1) after densification, (2) after steaming, (3) after heat treatment at 120° and 180°C, respectively, and (4) also on untreated control samples. Overall, it is shown that wooden surfaces can be electrically charged and that the introduced charges are significantly influenced by the applied settings. Preliminary data showed that densification of the samples did lead to an increased electric surface field strength. Tailoring surface charges can be an asset for new technical applications, such as chemistry-free primer treatments prior to wood coating.

Keywords: electrical field strength, triboelectricity, wood machining, wood processing, wood surface

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Wood Property Variation Within Douglas Fir Trees Grown at Different Spacing

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Prof. Laurence Schimleck - Oregon State University
Prof. Scott Leavengood - Oregon State University
Dr. Gerald Presley - Oregon State University
Prof. Bogdan Strimbu - Oregon State University
Dr. Joseph Dahlen - University of Georgia

Abstract

Wood properties such as density, microfibril angle, and stiffness are critical elements which dictate the quality and utilization of a given wood. These properties vary within trees, but detailed examination of property variation is limited owing to time and cost of measurement on a large number of samples. Near infrared (NIR) Hyperspectral imaging (HSI), offers a non-destructive, rapid method of property evaluation and this study aims to use this technique to examine wood property variation within Douglas-fir trees grown at different spacings using NIR HSI.

A total of 21 DF trees aged 25 years from 6 different spacings were destructively sampled. Wood discs were obtained from the stump to the top of the tree. Bark to bark radial strips were further obtained from the discs. Images were collected of the entire radius using the Specim FX17 HSI with wavelengths ranging from 931-1718 nm. Zones were identified to provide samples for SilviScan (microfibril angle, Density, and stiffness) and Fiber Analyzer (tracheid length and width). Wood spectra extracted from HSI images using Matlab will be used for anatomical and physicomechanical analysis. Models, statistical analysis, and associated graphics will be done using R.

Data will be presented on within tree variability of selected wood properties of DF as well as models to predict the variability. Wood properties based on these models have the potential to be incorporated into growth and yield systems and aid in more efficient wood utilization.

Key Words: Wood Quality, Near Infrared Spectroscopy, Hyperspectral Imaging, Wood variability, Non-destructive Sampling

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Impact of needle diameter on resistance drilling to assess wood quality of southern pines

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Dr. Geoff Downes - Forest Quality Pty Ltd
Dr. Marco Lausberg - Wood Quality Consulting
Dr. Jonathan Harrington - Scion
Dr. David Lee - University of the Sunshine Coast

Abstract

Use of the IML PD series Resi instrument is rapidly becoming a routine method among Australian forest growers for wood quality assessment. The major driver in the commercial uptake of the IML Resi is that, when data interpretation is facilitated by the web-based trace processing platforms, it is fast, cheap, and sufficiently precise for commercial use.
The accuracy of a tool for wood density prediction based on drilling resistance might be affected by needle (drill) diameters or imperfections (e.g., uneven needle coating and varying tip size). Currently it is not known to what degree needle diameter or other geometric imperfections are an issue for quantifying wood density and stiffness.

To quantify the effect of Resi needle diameter twelve new Resi needles were used with a single IML Resi PD 500 to obtain cross-sectional traces of a southern pine (*Pinus elliottii* var. *elliottii* x *Pinus caribaea* var. *hondurensis*) log. Standard settings for softwoods were employed (feed speed 200 cm/min and 3500 rpm). The diameter across the 12 needles ranged from 3.08 to 3.30 mm and each needle was tested 44 times.

We found a significant difference in average drilling resistance (DR) which ranged from 31.7 to 34% among the needles. The maximum difference in DR between needles was 2.3% which would translate to 15.4 kg/m^3 difference in predicted basic density. This difference occurred when needles with extreme diameters were tested, either very small (3.08 mm) or very large (3.21 - 3.30 mm). With one exception, there was no measurable difference in DR for needles in the typical 3.11- to 3.20-mm diameter range.

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BIOMASS/BIOENERGY – MEET THE NEED WHILE PROTECTING THE ENVIRONMENT

Comparative Life Cycle Assessment of Laboratory Scale Biological and Thermochemical Hemp Retting Processes

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Dr. Hongmei Gu - USDA Forest Service, Forest Products Laboratory
Prof. Sheldon Shi - University of North Texas
Dr. Felix Wu - Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Abstract

The increasing interest in using natural fibers has promoted research into emerging methods for fiber retting, particularly biological retting. The processes of hemp bast fiber retting, forming, and drying offer the opportunity to commercialize raw hemp fibers into value-added products such as natural fiber reinforced composites. Thermochemical retting is being widely used to obtain lignocellulosic fibers to make fiber-reinforced composites. The newly developed biological retting process for raw bast fibers through pectinase initiated bacterial retting has been developed in the lab-scale setup. The focus of this study was to compare the process energy consumption and environmental impacts of this bacteria retting with the traditional thermochemical retting. The Gate-to-Gate LCA models of the two retting processes were constructed in SimaPro software to run the comparison analysis using the TRACI (The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) method for environmental impacts and Cumulative Energy Demand (CED) method for energy consumptions. This work demonstrated the advantages of using biological retting methods from an environmental standpoint. The results showed about 24% gate-to-gate cumulative energy demand (CED) reduction for the biological retting, and 20-25% lower environmental impacts in global warmings, smog formation, acidification, carcinogenic, non-carcinogenic, respiratory effect, ecotoxicity, and fossil fuel depletion when compared to the thermochemical retting.

Keywords: Hemp bast fiber; biological Retting; Life Cycle Assessment; environmental impact; cumulative energy demand

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Hemp Hurds Alkaline Peroxide Mechanical Pulp for Hygiene Tissue Applications

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Mr. Ramon Vera - North Carolina State University, Department of Forest Biomaterials
Dr. Ronalds Gonzalez - North Carolina State University, Department of Forest Biomaterials

Abstract

This work focuses on using hemp hurds APMP pulps for hygiene tissue applications. A hot water wash at 90 ºC for 2 hours was used as pre-treatment. For the chemical impregnation step, the following charges were utilized 6% NaOH + 6%H_2O_2, 8% NaOH + 6%H_2O_2, and 8% NaOH + 8%H_2O_2. For all impregnations, the temperature was 90 ºC for 2 hours. The yield and brightness were as follows: 82.6% and 68.4% ISO; 81.5% and 67.9% ISO; 80.4% and 68.3% ISO showing clearly that increasing the chemical charge slightly diminishes yield without improving brightness. Thus, the lowest chemical charge was chosen as optimal. For mechanical properties comparison handsheets using the hemp hurds pulp at optimal conditions and BEK were made. Hemp hurd was bulkier (6.7 cm^3/g) than BEK (4.4 cm^3/g). Had a higher tensile index (21.7 Nm/g) than BEK (11.2 Nm/g). And slightly more absorbent (6.1 g/g) than the benchmark (5.8 g/g). Although BEK fibers were still softer (22.4 dB TS7) than hemp hurds (25.0 dB TS7).

Keywords: Mechanical Pulping, Hygiene Tissue, APMP, non-woods

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Microscopic Characterization of the Bonded Joint of Basalt Fiber-modified Polyurethane Adhesive

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Ms. Lenka Scheinherrová - Czech Technical University in Prague, Czech Republic
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Mr. Jan Vanerek - Faculty of Civil Engineering, Brno University of Technology, Czech Republic
Mrs. Markéta Machálková - Tescan Orsay Holding, Brno
Mr. Petr Klímek - Tescan Orsay Holding, Brno

Abstract

Microscopic analysis was performed on samples made according to EN 302-1 from beech wood (Fagus sylvatica L). For gluing, Casco 2010 single-component polyurethane moisture-curing adhesive was used, modified with basalt fibers of different lengths with a diameter of 13 μm mixed into the adhesive up to 5% by weight. The microscope used (FIB-SEM) combines a Xe plasma-focused ion beam for sample preparation and a field-free ultra-high resolution scanning electron microscope for imaging. During microscopic analysis, images were taken and subsequently analyzed in both transverse and longitudinal directions. Similarly, the bonded joint was analyzed in 3D using an in-chamber microtome. In particular, the general structural information of the bonded joint, the porosity of the specimen, the wood-adhesive interface, the adhesive-fiber interface, the distribution of reinforcing fibers, etc. were analyzed. The techniques used were found to allow successful data acquisition for 3D visualization and subsequent data analysis. It was also found that the adhesive wetted and adhered very well to the surface of the basalt fibers, although the surface of the fibers was not treated in any way. The visualization also shows that the fibers used contributed to the 3D crosslinking of the adhesive.

EARLY-STAGE RESEARCHER

A concise visual depiction of firewood use in Africa, with a focus on the Federal Capital Territory of Abuja, Nigeria

Mr. Michael Adedotun - Department of International Development Michael Adedotun Oke Foundation

Abstract

The professing usage of the firewood is very prominent with the issues of the cost of the cooking gases and an ordinary man cannot afford it, which resulted in the depletion of the forest zone and left the environment in a depleted means. The study of the use of firewood, with human consumption and commercial marketing systems. The different communities were visited to ascertain, town hall, consultative forum, focus group, informal and formal discussions, home visits, one on one interview were conducted in various communities such as Kaida, Phase One, Along Specialist Road, Old Kutunku, and Dagiri. On-line moderating, virtual meetings, and debates were organized. According to the field survey, there is no formal firewood marketing here, and vendors only set the prices. Concerns about quality and quantity standardization are primarily issues that affect daily living and usage. Work-related activities such as cooking for general family consumption are also included. To bake bread and fry fish. More research is needed to determine how using firewood for cooking affects one's health and the best practices that must be developed to ensure that firewood is effectively marketed.

Keywords: Firewood, Populace, cost, Gwagwaalda

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Comparative Evaluation of Various Fillers on pMDI Resin Performance

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Dr. Munkaila Musah - Department of Environmental Conservation, University of Massachusetts, Amherst, MA.
Dr. Osei Asafu-Adjaye - Auburn University, Forest Products Development Center
Dr. Yucheng Peng - Auburn University, Forest Products Development Center
Prof. Brian Via - Auburn University, Forest Products Development Center

Abstract

In this study, the possibility of using different fillers; Cellulose Nano Crystal (CNC), Cellulose Microcrystalline (MCC), Wood Flour (WF), Soy Flour (SF), Talc, and Calcium Carbonate as partial substitutes in Methylene diphenyl diisocyanate (MDI) resin was evaluated. There has been concern recently about the use of MDI resin due to the environmental effect of isocyanate, which is dominantly present in the resin, as well as the cost of the resin. Different fillers were used in this study as substitutes at their allowable substitution percentages. This study focused on the possibility of replacing more MDI resin with biodegradable filler without compromising the integrity of the resin and the mechanical strength of the studied plywood from both Southern Yellow Pine and Oak. Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and thermogravimetric analysis (TGA) were conducted to study the effect of modification on the bond-line quality of the final product. The impact of different fillers on the adhesion properties of the MDI resin was tested on the plywood according to the American Society for Testing and Materials (ASTM D – 906-64) standard. The results showed that the shear strength of the modified MDI resins ranged from 0.3 to 1.083 MPa and 0.35 to 1.178 MPa for plywood made with Oak and Pine, respectively. The modified samples with soy flour showed significant improvement in the shear strength, with 261% and 236% higher shear strength than the control (MDI) for samples from hardwood and softwood, respectively. Partial substitution of MDI resin with soy flour at 25% substantially improves MDI resin's adhesion properties.

Keywords: Methylene diphenyl diisocyanate (MDI) resin, Wood Adhesives, Environmental Concerns, Biodegradable Fillers and Adhesion properties.

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Leachability and Biological Decay Resistance of Zinc Oxide Eugenol Organic Cement Treated Wood

Mr. Courage Alorbu - University of Idaho
Prof. Lili Cai - University of Idaho

Abstract

Eugenol (EG) is an essential oil of phenolic constituent that is sourced from numerous plants including clove, cinnamon, and bay leaves. Despite its highly volatile nature, EG has been extensively used as an antimicrobial and antiseptic biocide in the pharmaceutical and medical fields. Specifically, eugenol reacts with Zinc oxide (ZnO) to produce Zinc oxide eugenol (ZnO-EG) which is a stable organic cement used by dentist in sealing and relieving pain associated with tooth cavities. The aim of our current study is to investigate the feasibility of incorporating Zinc oxide eugenol (ZnO-EG) organic cement in wood to improve the volatile and possible leaching of EG and the biological resistance of treated wood against four common wood decay. Briefly, ZnO-EG was formed in wood in-situ by first impregnating wood with different concentrations (1, 2.5, and 5%) of nano ZnO solutions followed by eugenol treatment. The presence of ZnO-EG in wood was confirmed using Fourier transform infrared spectroscopy, Thermogravimetric analysis, and X-ray computer tomography. The retention and mass gain recorded for ZnO-EG treated wood after treatment was as high as 770 kg/m^3 and 11% respectively. After leaching test, the mass gain recorded for 5% ZnO-EG treated softwood and hardwood samples was 9% and 10% respectively, which confirms the stability of ZnO-EG in wood thereby reducing the volatility and leaching of EG regardless of wood species. Decay resistance test on ZnO-EG treated wood exposed to two brown-rot fungi, *Gloeophyllum trabeum* (*G.t.*) and *Rhodonia placenta (R.p.)* and two white-rot fungi, *Trametes versicolor (T.v.)* and *Irpex lacteus (I.l.)* revealed significantly lower mass loss of about 3% whiles control groups recorded mass loss > 23% regardless of leaching and type of decay fungi. These findings confirm that ZnO-EG cement could be considered as a potential sustainable green preservative for wood protection, especially for outdoor applications.

Keywords: Zinc oxide, Eugenol, Dental Cement, Leaching, Sustainability, Wood preservation

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PHYSICO-MECHANICAL PROPERTIES OF SELECTED SPECIES SUBJECTED TO THERMO-OIL TREATMENT

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Dr. Bola Ogunleye - Federal College of Forestry, Ibadan
Dr. Lawrence Aguda - Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria

Abstract

One challenge faced by the wood industry is the hydrophobic nature of wood which has resulted in dimensional instability of wood in service as wood continuously absorbs and gives off moisture to the environment. As a result, this research examined the effect of thermal modification on the physical and mechanical properties of *Gmelina arborea, Triplochiton scleroxylon* and *Hevea brasiliensis* using palm kernel oil. Colour change was observed while density, compression strength, Modulus of rupture, and modulus of elasticity were measured. Samples of sizes 20 ×20×60mm and 20×20×300mm were collected and treated using palm kernel oil at varying temperatures of 170 ºC and 190 ºC for 30 minutes and 45minutes respectively. The Average Density values varied from 375.83 kg/m3 at 170°C to 431.70 kg/m3 at 190°C for obeche, 470.56 kg/m3 to 474.59 kg/m3 for *Gmelina arborea* and rubber from 539.17 kg/m3 to 510.47 kg/m3. The Average Compression strength values varied from 25.38 N/mm2 at 170°C to 27.50 N/mm2 at 190°C for obeche, 42.87 N/mm2 to 45.16 N/mm2 for *Gmelina arborea*, and rubber from 28.83 N/mm2 to 25.37 N/mm. The Average Modulus of Elasticity values varied from 4264.63 N/mm2 at 170°C to 4891.66 N/mm2 at 190°C for obeche, 8496.72 N/mm2 to 7405.64 N/mm2 for *Gmelina arborea*, and rubber from 5159.17 N/mm2 to 4613.07 N/mm The Average Modulus of Rupture values varied from 67.32 N/mm2 at 170°C to 60.45 N/mm2 at 190°C for obeche, 78.54 N/mm2 to 74.52 N/mm2 for *Gmelina arborea*, and rubber from 63.83 N/mm2 to 58.16 N/mm2. It was observed that the color of the wood samples became darker after treatment. However, the dimensional stability of wood samples was enhanced when thermally modified. In General, thermally modified wood is of high use for applications where appearance and high strength are not paramount.

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Efficacy Of Plant Extracts Against Fungi of Wood

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Abstract. Wood is naturally susceptible to biodeterioration owing to its organic nature. This has consistently put pressure on forest resources. Increasing population and other infrastructural developments have also exerted pressure on tropical forests. Synthetic chemicals have been developed to mitigate the effects of wood biodeterioration, elongate the lifespan of wood, and reduce pressure on the forest. However, synthetic chemicals used in wood preservation have negative effects on the environment. Environmentally friendly organic materials have been used to mitigate the effects of chemicals on both humans and the environment. Plant extracts are readily available and environmentally friendly, thereby reducing the cost and eliminating the toxicity and environmental effects of conventional wood preservatives. Various parts of different wood species are useful for suppressing and eliminating fungal growth. Therefore, it is imperative to review the attributes of tropical wood species that have proven efficacy as wood preservatives.

Keywords: Efficacy, biodeterioration, plant extract, synthetic, wood preservation, environment friendly

INTRODUCTION

Owing to its unique characteristics, wood has remained one of the most significant renewable natural resources available to humans throughout history (Hingston et al. 2001, Wang et al 2005). However, non-durable wood is treated with preservatives to prevent decay caused by wood-boring crustaceans and mollusks, fungi, and insects (Craig et al. 2001, Yalinkilic 2000). When wood is used as a building material, it is typically treated with a chemical preservative to prevent damage caused by aggressive biodeteriogens (Craig et al. 2001). Therefore, the development of methods for extending the service life of wood has always been of interest to researchers in the timber industry (Wang et al. 2005).

Effective synthetic wood preservatives, such as copper-based agents (i.e., chromated copper arsenate), triazoles (azaconazole, propiconazole, tebuconazole), pentachlorophenol, and

boron-based fungicides (Edlund et al 1999; Freeman and McIntyre 2008; Lesar et al 2012), have been utilized for this purpose. However, because of environmental and health concerns, the use of many of these chemicals has been restricted, necessitating the development of alternative wood protection agents and methods based on nontoxic natural products (Lesar et al 2012, Edlich et al 2005; Singh and Singh 2012).

Today, eco-friendly wood protection is the subject of extensive research, encompassing a variety of approaches. Since the growth of wood-degrading fungi is dependent on the availability of water, one method is moisture control using natural hydrophobic agents, such as lubricants and resins of plant origin or plant oils (Gonzalez-Laredo et al. 2015, Humar and Lesar 2013, Patachia and Croitoru 2016, Terziey and Panov 2011). Utilizing plant extracts with biocidal properties and incorporating them into the wood structure (Singh and Singh 2012, Gonzalez-Laredo et al 2015, Teaca et al. 2019) is a second method for extending the service life of the wood. The purpose of this article is to provide an overview of current research on various plant extracts with proven biocidal activity that may be beneficial for protecting wood against fungi.

A REVIEW OF PLANT EXTRACTS USED IN WOOD PROTECTION

In some regions of the world, plant derivatives have been used for generations to improve the appearance and durability of wooden products, such as furniture and strolling poles. With the introduction of synthetic and inorganic compounds, which have proven to be more effective against wood-degrading organisms, the use of plant-derived products for wood protection has become less appealing. However, there is an urgent need to supplant synthetic and inorganic compounds with organic biocides because of their toxicity to human health and negative environmental impact. The chemical compounds Alkaloids, flavones, flavonoids, phenolics, terpenes, tannins, and quinones are abundant in plants. Secondary metabolites account for up to 30 percent of a plant's dried mass and play a crucial role in defense against microbial pathogens, herbivores, and various forms of abiotic stress. Numerous plants have been used by humans as remedies and food additives since the discovery of phytochemicals and their unique properties. Recognizing the chemical structure and functions of specific plant components permits the development of efficient methods for their extraction from plant tissues and their commercial application in pharmaceuticals, cosmetics, functional foods, and coloring agents. As biopesticides, insecticides, and fungicides to protect crop plants and biodegradable materials (Mazid et al. 2011, Adamczyk et al. 2017, Vasconsuelo and Boland 2007, Bhagat et al. 2014), there is also considerable interest. Diverse plant extracts with antifungal properties are of interest as potential sources of natural substances that can be used as alternative wood preservatives against degradation. The high availability of plant material in general and the possibility of using industrial waste from the processing of various crops can increase the economic viability of the entire process of obtaining them, thereby allowing for the potential widespread application of plant preservatives in the wood industry.

Efficacy of Essential Oils

Essential oils are natural mixtures of volatile secondary metabolites of various plants that can be extracted from plant materials via distillation, mechanical expression, or solvent extraction. They contain a variety of chemical compounds that are responsible for the distinctive aroma of the plants from which they are extracted. The primary components are terpenes, which include alcohols, aldehydes, hydrocarbons, ethers, and ketones, with demonstrated biological activity, including antioxidant, antibacterial, and antifungal properties. Essential oil-containing plants have been used for centuries in folk medicine and as flavoring and preservative agents in food (Masango 2005, Edris 2007, Kalemba and

Kunicka 2003). Their composition and potential therapeutic activities, such as anti-inflammatory, antimicrobial, antiviral, anticancer, antidiabetic, and antioxidant, have been extensively investigated (Edris 2007, Kalemba and Kunicka 2003, Swamy et al. 2016). They are potentially useful as preservatives for a wide variety of products (Herman et al. 2013, Prakash et al. 2015, Pandey et al. 2017) due to the growing interest in biodegradable, non-toxic natural substances with antimicrobial properties. Also, some attempts have been made to use essential oils from common plants, herbs, and seasonings as wood-protecting agents due to their demonstrated antifungal properties against mold and wood-decaying fungi (Voda et al. 2003, Hussain et al. 2013, Bahmani and Schmidt 2018; Kartal et al 2006; Pánek et al. 2014, Xie et al. 2017, Zhang et al. 2016)

Various essential oils have been tested in vitro against various fungal species to determine their effectiveness. Using the agar dilution technique, Voda et al. (2003) found that anise, basil, cumin, oregano, and thyme oils were highly effective against brown-rot fungus Coniophora puteana and white-rot fungus Trametes versicolor. They determined that thymol, carvacrol, trans-anethole, methyl chavicol, and cumin aldehyde were the most effective compounds in inhibiting the proliferation of both fungi. Additional research has revealed a correlation between the molecular structure of oxygenated aromatic essential oil compounds and their antifungal activity against wood-rotting fungi (Voda et al 2004). Chittenden and Singh (2011) demonstrated in vitro that 0.5% concentrations of cinnamon and geranium oils are antifungal against the brown-rot fungi Oligoporus placenta, C. puteana, Antrodia xantha, sap stain fungi Ophiostoma floccosum Mathiesen, Ophiostoma piceae, Sphaeropsis sapinea, and Leptographium procerum, and a mold fungus, Trichoderma harzianum (Molecules 2020, 25, 3538, 4 of 24). In addition, they discovered the antifungal properties of aniseed, oregano, and lema (a compound of 50% New Zealand manuka and 50% Australian tea tree) oils against some of the fungi previously mentioned. Zhang et al (2016) reported the antifungal efficacy of purified monoterpenes, including -citronellol, carvacrol, citral, eugenol, geraniol, and thymol, against wood white-rot fungi Trametes hirsuta, Schizophyllum commune, and Pycnoporus sanguinolentus. Xie et al (2017) confirmed the antifungal properties of the essential oils of Origanum vulgare, Cymbopogon citratus, Thymus vulgaris, Pelargonium graveolens, Cinnamomum zeylanicum, and Eugenia caryophyllata against the wood-decaying fungus T. The most active compounds in hirsuta and Laetiporus sulphurous were carvacrol, citron, citronellol, cinnamaldehyde, eugenol, and thymol. Cinnamaldehyde, -methyl cinnamaldehyde, (E)-2-methyl cinnamic acid, eugenol, and isoeugenol inhibited the growth of the white-rot fungus Lenzites betulina and the brown-rot fungus L. sulphurous (Cheng et al 2008). Reinprecht et al (2019) found that among five distinct essential oils (basil, cinnamon, clove, oregano, and thyme), the oil with the maximum antifungal activity against the brown-rot fungus Serpula lacrymans and the white-rot fungus T. The highest versicolor content was observed for basil oil (predominantly linalool) and the lowest for clove oil (predominantly eugenol). These results were confirmed using wood samples treated with specific essential oils. Pánek et al. (2014) investigated the antifungal efficacy and stability of beech wood treated with 10% solutions of ten different essential oils (birch, clove, lavender, oregano, sweet flag, savory, sage, tea tree, thyme, and a mixture of eucalypt, lavender, lemon, sage, and thyme oils) against brown-rot fungus C. T. puteana and T. versicolor. versicolor. After a complex expedited aging procedure, they discovered that the most effective against C. clove, oregano, sweet flag, and thyme oils contained phenol compounds such as carvacrol, eugenol, thymol, and cis-isoasarol trimethyl ether. The mass losses of birch wood were 0.9, 0.666, 0.57, and 0.85 %, respectively. Clove, sweet flag, and thyme oils were the most effective against mold (Aspergillus niger and Penicillium brevicompactum) in the filter paper tests. These lubricants are potentially beneficial for the protection of interior wood. Unsurprisingly,

none of the lubricants examined were efficacious against T. versicolor, which may be due to the unique enzyme apparatus of white-rot fungi capable of degrading lignin and other phenolic compounds. The efficacy of thyme oil against C. pumpkin and Jones et al. (2011) confirmed the presence of niger. In addition, they demonstrated that basil, yarrow, and calendula oils have antifungal activity against C. respectively from P. placenta and P. placenta; however, the two latter oils were only efficacious when used pure. Chittenden and Singh (2011) reported that wood treated with 3% eugenol exhibited high resistance to C, with a mass loss of 1%. puteana, O. placenta, and vitamin A xantha. However, they discovered that eugenol could be readily leached from wood, suggesting that it is unsuitable for the protection of outdoor wood. Kartal et al (2006) treated sugi wood with a formulation containing cassia oil, achieving high wood resistance to brown-rot Tyromyces palustris (0.7% mass loss) and white-rot C. versicolor fungi (3.6% mass loss). Yang and Clausen investigated the antimicrobial properties of seven essential oils, including ajowan, dill weed, Egyptian geranium, lemongrass, rosemary, tea tree, and thyme oil. They discovered that vapors from dill weed oil and immersion treatment of Southern yellow pine samples with thyme or geranium effectively inhibited the development of A. thaliana for at least 20 weeks (Yang and Clausen 2007). Bahmani et al (2018) determined that applying lavender, lemongrass, and thyme oils to Fagus orientalis and Pinus tadea wood could provide effective protection against A. niger, Penicillium commune, C. puteana, T. versicolor in addition to Chaetomium globosum. Salem et al. (2016) demonstrated the antifungal activity of Pinus rigida and Eucalyptus camaldulensis oils applied to the surfaces of Fagus sylvatica, P. rigida, and P. sylvestris wood, and Hussain et al. (2013) reported similar antifungal properties of clove oil applied to indigenous Indian wood.

It has been demonstrated that a wide array of essential oils derived from indigenous plants from all over the globe possess antifungal and antifungal properties. The essential oil from the leaves of the Taiwanese cinnamon tree Cinnamomum osmophloeum Kaneh, containing cinnamaldehyde as the most abundant antifungal component, has been reported to be effective against several white- and brown-rot fungi, such as Coriolus versicolor and Laetiporus sulphureus (Wang et al. 2005). Kartal et al. (2006) also confirmed the antifungal properties of cinnamaldehyde when applied to sugi wood, efficiently enhancing the wood's resistance to brown-rot T. palustris (0.6% mass reduction) and white-rot C. versicolor fungi (3.8% mass loss). Chittenden and Singh (2011) also obtained favorable results for Radiata pine wood treated with a 3% cinnamaldehyde solution, where the mass loss against C was 1%. pumpkin and A. xantha, and approximately 3% versus O. placenta.
The leaf and fruit oils of another Taiwanese tree, Juniperus formosana Hayata, were tested in vitro by Su et al. (2013) for their antifungal properties against seven mold fungi (Aspergillus clavatus, A. niger, Ch. globosum, Cladosporium cladosporioides, Myrothecium verrucaria, Penicillium citrinum, and T. viride), two white-rot fungi (T. versicolor and Phanerochaete chrysosporium), and two brown-rot fungi (Phaeolus schweinitzii and Lenzites sulphureum). -Cadinol and elemol were the most active compounds in the antifungal properties of leaf oil. Owing to the presence of citronellal and citronellol, the leaf oil of Taiwanese Eucalyptus citriodora exhibited high antifungal activity against mold and wood-decaying fungi (Su et al. 2006).

Cheng et al. (2004) reported that the essential oil extracted from Calocedrus formosana Florin leaves has high antifungal activity. C. Formosana is a Taiwanese endemic tree species that is distinguished by its natural resistance to decomposition. The most potent antifungal effect against L. betulina, Pycnoporus coccineus, T. versicolor, whereas L. Two oil compounds exhibited sulphurous properties: -cadinol and T-muurolol. Mohareb et al. (2013) investigated

the antifungal activity of the essential oils of eighteen distinct Egyptian plants against the wood-rotting fungi Hexagonia apiaria and Ganoderma lucidum. The sapwood of Scots pine treated with Artemisia monosperma, Citrus limon, Cupressus sempervirens, Pelargonium graveolens, Schinus molle, and Thuja occidentalis oils exhibited the greatest resistance. In turn, the efficacy of neem oil, which contains the antifungal agent azadirachtin, against S. commune, Fusarium oxysporum, Fusarium proliferatum, and C. Rawat et al. (2018) reported that P. puteana and Alternaria are substitute fungi. Hussain et al. (2013) obtained comparable results by demonstrating that local Indian wood treated with neem oil is resistant to various molds. Several novel strategies for enhancing the antifungal activity of essential oils as wood preservatives are worth mentioning. Among them is the use of essential oil complexes with methyl--cyclodextrin. Cai et al. (2020) exposed Southern pine wood to brown-rot fungi Gloeophyllum trabeum and P. placenta after treating it with compounds of eugenol, trans-cinnamaldehyde, thymol, and carvacrol with methyl--cyclodextrin. Even after leaching, the degradation resistance of wood treated with specific complexes was greater than that of the control samples or wood specimens impregnated with essential oils individually. The use of complexes containing natural compounds such as essential oils appears to have tremendous potential for extending the durability of wood products.

Efficacy of Waxes and Tannins

In addition to oils, resins, tannins, and other plant extracts, the bark of numerous tree species is an abundant source of antioxidant and antimicrobial agents. Tannins have long been used as adhesives and wood preservatives (Lotz and Sleeter 1980, Laks 1988, Lotz and Hollaway 1988, Lotz 1993). Tannins and tannin-derived compounds are difficult to fix in the wood after treatment, but satisfactory wood protection has been achieved using additives, such as ferric chloride and metallic salts (Lotz and Sleeter 1980, Laks et al. 1988, Laks 1991, Lotz and Hollaway 1988, Lotz 1993). Other products derived from the bark, such as bio-oils derived via pyrolysis, have also been evaluated as wood preservatives (Suzuki et al. 1997).

Considering bark as a source of organic biocides, it is important to keep in mind that the bioactivity of bark extracts from diverse sources will vary, as demonstrated by studies evaluating the antifungal properties of barks from various tree species (Yang et al 2004; Yang 2009). Bark components such as lubricants, resins, and phenolic extractives have also been used as adhesives. Brandt (1953) described mangrove tannin–formaldehyde resin as a high-strength water-resistant adhesive. Wattle tannins are recognized as water-resistant adhesives (Plomely 1966). Wax and resin extracted from the epidermis of various pine species, such as Radiata pine and ponderosa pine, have been utilized as bonding agents in the production of wood products (Anderson et al. 1961, Hall et al. 1960). Passialis and Voulgaridis (1999) studied the characteristics of natural waxes extracted from Aleppo pine needles and bark. Wood specimens treated with these waxes exhibited hydrophobic properties, with bark extracts exhibiting greater hydrophobicity than needle extracts. The antimicrobial activity of guayule resin was investigated by Bultman et al in 1991. Resin from the wood and stem of guayules (Parthenium argentatum Gray) protects wood-destroying organisms, such as decay fungi, termites, and marine borers, when impregnated with wood (Nakayama et al. 2001). The disintegration resistance of particleboards impregnated with Pinus bruita bark extracts is enhanced (Nemli et al. 2006). Other characteristics of the board, such as thickness swell, were also improved. Recent research (Si et al. 2011) has demonstrated that phenolic glucosides extracted from the bark of Populus ussuriensis possess antioxidant properties. The potential use of these compounds and antioxidants in the bark of other tree species (Zhang et al. 2006) for wood protection should be investigated.

Efficacy of Wood Extractives

The chemical composition of wood also includes minor amounts of extraneous materials, mostly in the form of compounds known as extractives (usually 4–10%, even up to 30% depending on the wood species, growth conditions, and time of year when the tree is cut) and minerals (ash), primarily calcium, potassium, and magnesium, in addition to manganese and silica (Miller 1999, Nascimento et al. 2013). Bark, foliage, and roots have higher concentrations of extractives than stem wood because of the presence of both inorganic and organic components. These extractives contribute to wood characteristics, including color, odor, flavor, degradation resistance, density, hygroscopicity, and flammability (Fengel and Wegener 2003, Rowell et al. 2013). These wood components can be extracted from wood using solvents such as water, alcohol, acetone, benzene, toluene, ether, or solvent mixtures [e.g., alcohol/benzene or toluene].

Characterization of biologically active components from termite-resistant timbers could result in increased protection of wood against termites through treatment with extracts or synthetic compounds with structures similar to those of the biologically active components (Carter et al. 1978). Hardwood and softwood may contain comparable quantities of extractives, but their chemical compositions are distinct (Fengel and Wegener 2003). Tannins, other polyphenolic compounds, colored substances, essential oils, lipids, resins, lubricants, gum starch, and basic metabolic intermediates are present in varying proportions. These compounds include quinones (Carter et al. 1978, Ganapaty et al. 2004), flavonoids (Reyes-Chilpa et al. 1998, Ohmura et al. 2000, Chen et al. 2004, Morimoto et al. 2006), terpenoids (Chang et al. 2000, Watanabe et al. 2005), and alkaloids. Wood's natural durability is typically proportional to its extractives content and composition (Carter et al 1978; Taylor et al. 2006, Santana et al. 2010, Andrady et al. 2015, Carter et al. 1978, Taylor et al. 2006). When natural extractives compounds from wood and plants are compared to common substances used for wood preservation in terms of their efficacy, the natural ones are generally preferred for safety and versatility due to their biocide and antioxidant properties, as well as their metal-binding ability (Kartal et al. 2006, Syofuna et al. 2012, González-Laredo et al. 2015, Sablik et al. 2016). These extractives reduce the hygroscopicity of wood surfaces, thereby inhibiting the decomposition of a wide variety of biological organisms, including human pathogens, insects, and fungi, with a positive effect on wood durability. Schultz et al. (1995) and Schultz et al. (2002) report that heartwood extracts may exhibit significant antifungal and antioxidant properties. Specific applications of wood and plant extracts include long-term preservation (for condensed tannins), antifungal and subterranean termite protection (for flavonoids), repellency and toxicity against termites (for quinones), and heartwood resistance to fungal decay (for stilbenes). The extraction method and solvents may affect the initial antifungal activity of various extractive groups.
There are native extractive compounds, such as those obtained from the heartwood of durable species, such as black locust (Robinia pseudoacacia L.) and African padauk (Pterocarpus soyauxii Taub.), which exhibit enhanced antifungal activity under laboratory testing conditions by enhancing the resistance to decay of impregnated European beech (Fagus sylvatica L.) wood samples (Sablik et al. 2016).

The presence of condensed tannins (proanthocyanidins or polyflavonoid tannins) in the bark extract of mimosa (Acacia mollissima) and quebracho heartwood extract (Schinopsis lorentzii) is effective for conferring increased fungal resistance in testing against both white and rot fungi (Tascioglu et al. 2013, González-Laredo et al. 2015, Tascioglu et al. 2012) demonstrating that these extractive compounds are effective as wood anti-decay agents in indoor applications, even at low concentrations.

Extracts from the heartwood of certain Amazonian woody species (Rodrigues et al. 2012) demonstrate antifungal activity against soft rot, brown rot, and white-rot fungi, comparable to that of commercially available preservative coatings. The leaf extract of the camphor tree (Cinnamomum camphora) is abundant in biocides (terpene alcohols: terpineol, linalool, and 4-terpineol; a monoterpenoid: eucalyptol, also known as cineole; a terpene ketone: camphor). However, their antifungal activity is limited owing to their volatility and thermal instability. In such situations, fixation agents (i.e., melamine-modified urea formaldehyde resin pre-polymers) are required. As bamboo preservatives, these compounds exhibit good resistance to decay and insects and favorably affect the resulting mechanical properties (Xu et al. 2013).

A combination of certain metals (acting as chelators for some fungal enzymes) and biocide extractives (condensed tannins or proanthocyanidins; gallic acid derivatives derived from tannic acids) is most effective for enhancing antifungal activity when these compounds exhibit a synergistic effect (González-Laredo et al. 2016). Antioxidants acting as scavengers for the free radicals involved in wood decay caused by fungi (Morris and Stirling 2012) are an additional effective method for enhancing the antifungal activity of wood extractives. An extractive compound found in the seeds, leaves, and bark of the neem tree (Azadirachta indica) functions as a biocide against fungi, either alone or in combination with copper sulphate and boric acid (Islam et al. 2009). It is an effective insect repellent (effective against termites, wood-boring insects, and other insects).

Environmental and biological factors influence the efficacy of wood extracts as fungicides, as their antifungal activity depends on their ability to inhibit the development of fungal cells on wood substrates by inhibiting enzymatic processes and other phenomena. Multiple-component biocide systems (such as natural extractives and synthetic antifungal agents) have been shown to protect the wood from decay fungi, mold fungi, and termites for interior applications (Clausen and Yang 2007). Overall, the use of wood extracts as UV stabilizers on a large industrial scale is restricted due to their high-water solubility and ease of leaching from wood.

CONCLUSION

As can be seen, plant extracts have a great deal of potential for wood protection, as they exhibit a wide range of antimicrobial activities. They are renewable, easily accessible or inexpensively obtainable, non-toxic or significantly less eco-toxic than conventional chemical biocides, and environmentally benign. Nonetheless, they have several drawbacks, such as high heterogeneity depending on the source from which they are derived (i.e., essential oils, wood extractives), insufficient retention within the impregnated wood tissue, easy leachability, selective or uneven activity against specific types of fungi, and high susceptibility to biodegradation. The introduction of natural biocides from plant extracts to the market is hampered by discrepancies between laboratory tests and reported field performance, as well as by legislative issues stemming from the need to comply with various directives (relating to construction materials and application of biocides) and the absence of standards defining the quality, composition, performance, and application of specific natural-based protective formulations. Therefore, additional research in the discipline is required. Responding to all of the challenges that face the development of natural preservatives aimed specifically at the protection of wood and wood-based products may be too expensive to be profitable. Therefore, collaborating with other industries interested in the exploitation of specific natural active compounds such as pest control, food, and pharmaceutical applications, may be a viable alternative. The development of new generation natural

preservatives with minimal impact at the end of the treated wood's stage life is a necessity from the standpoints of human health and environmental protection in this day and age when extending the lifespan of wood products is of great interest and importance. Although this review does not exhaust the subject, as there are hundreds of scientific studies on the antifungal activity of natural compounds, it provides a comprehensive overview of the current state of research in the field and the prospects for the development of sustainable alternative wood protection based on natural compounds.

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Outreaching and Informing Society about Sustainable Construction through Social Media

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Abstract

Moving to a sustainable oriented society new concepts and findings related to sustainable construction are being developed. With the ambition to transfer the knowledge to the society different communication paths are being used. In this study we investigated what kind of messages should be shared on institutional social media channels (Facebook, Twitter, and LinkedIn) about sustainable construction related topic in order to create more engagement of the audience. We performed the study in the frame of a research project Engineered wood composites with enhanced impact sound insulation performance to improve human well-being financed by Slovenian Research Agency and the Austrian Science Fund. The content and materials used were prepared and posted on institutional social media channels of the research institute InnoRenew CoE. The study consisted of two rounds of weekly social media posts. In each round 15 posts were published weekly on the same day and time, and engagement monitoring also occurred weekly. Three different types of posts were created, that varied each week. Type 1 was written informative content related to the research field of wood composites, sound insulation, building acoustics, human well-being and modelling of the floating floor and other project research activities. Type 2 was image content related to the project research activities and research equipment used, with short text caption of the image, while posts of type 3 were image content with people – researchers working on the project research activities and with research equipment used with short text caption of the image.

The analyses of the audience engagement revealed the type of messages that are attracting the audience on the three social media channels. We compared data from round 1 and round 2 but found no significant difference between the two rounds. Overall, we found out that posts of type 3 are resulting in highest number of likes, reach and clicks on Facebook, impressions and engagement on LinkedIn and Twitter. The social media channel that performed best was LinkedIn, where we recorded the highest number of likes, engagement and impressions across all types.

This finding can serve to other communication practitioners and researchers to improve their communication and dissemination activities on social media.

Key Words: sustainable construction, communication, social media, engagement, research project outreach

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BIOMASS/BIOENERGY – MEET THE NEED WHILE PROTECTING THE ENVIRONMENT

Thermodegradation of naturally decomposed forest logging residues: Characteristics, kinetics, and thermodynamics

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Abstract

Logging residue has not been utilized fully, especially for logging residues after certain years of harvest. This study investigates the combustion and pyrolysis characteristics of red maple (Acer rubrum) residue after various years of harvest (fresh: FRM, two-year-after-harvest: RM2, and four-year-after-harvest: RM4) and red pine (Pinus resinosa) (fresh: FRP, two-year-after-harvest: RP2, and four-year-after-harvest: RP4) logging residues through thermogravimetric analysis (SDT650, TA Instrument, USA). The nitrogen and air were used as gas with flow of 100 ml/min (mass flow 50 ml/min and balance flow 50 ml/min). The heating process ramp 5, 10, 20, and 40 °C/min from room temperature to 700 °C. The proximate and ultimate analyses and calorific value of samples were also investigated. Additionally, the kinetics parameters (Activation energy, frequency factor, and regression coefficient) would be calculated using four iso-conversional methods (Kissinger-Akahira-Sunose (KAS), Friedman, Flynn-Wall-Ozawa (FWO), and Starink). Our results showed that calorific values of fresh red pine, two-year decomposed, four-years decomposed, fresh red maple, two-year decomposed, and four-years decomposed were 19.78, 19.40, 20.19, 20.35, 19.27, and 19.62 MJ/kg, respectively. Hemicellulose pyrolysis peak only occurred in the hardwood thermodegradation process. Softwood had a higher pyrolysis yield of solid products (16.08-19.30%) than hardwood (11.19-14.67%). The average pyrolysis activation energy (Ea) of hardwood increased with the year after harvest, whereas softwood samples decreased. The average combustion Ea of hardwood samples increased first, then decreased, while that of softwood samples decreased continuously. Enthalpy (ΔH), entropy (ΔS), and Gibbs free energy (ΔG) were also investigated. This research will aid in understanding the thermal decomposition properties of naturally decomposed FLR from various years after harvest, paving the way for their effective utilization.

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Variations in Extractive Content of Scots Pine Sapwood and Heartwood and the Effect on Off-Gassing during Storage of Wood Pellets

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Abstract

Wood pellets have over the years become a preferred solid biomass fuel for heat and power generation because of their enhanced and standardized properties. These quality properties include uniform size, high energy density, and low moisture and ash content, which make them easy to transport and store. However, wood pellets produced from fresh sawdust can form and release gases during bulk storage, a tendency referred to as off-gassing. The off-gassing of toxic gases, such as carbon monoxide, carbon dioxide, and other volatile organic compounds, poses a risk to human health and the environment.

Studies have shown that the off-gassing of wood pellets is mainly caused by oxidation of wood extractives. This study investigated the off-gassing tendencies of Scots pine wood pellets produced from separated sapwood and heartwood, as well as the effect of raw material storage on off-gassing of the pellets. Additionally, the extractive contents of fresh sapwood and heartwood sawdust were also analysed.

The total water-soluble extractives in sapwood were higher than the lipophilic extractives, while heartwood had a higher content of lipophilic than water-soluble extractives. The total lipophilic extractives were 3.9% and 5.7% for sapwood and heartwood respectively. Pellets produced from fresh sapwood sawdust had the highest off-gas emissions of CO, CO_2, and CH_4 and reduction in residual O_2, while those produced from fresh heartwood sawdust had the lowest. The storage of sapwood raw material before pelletization reduced the off-gassing of wood pellets, whereas for heartwood, storage had no significant impact.

Keywords: Fuel Pellets, Off-gas Emissions, Methane, Carbon Oxides, Wood Extractives, Sapwood, Heartwood

Effect of pre-hydrolysis on the hardwood pulp dissolution in ionic liquid

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Abstract

Cellulose is the most abundant and sustainable bio-resource generated on earth. Cellulose and its derivatives have been utilized for various purposes in our daily life. Due to crystalline structure of cellulose, it is extremely difficult to dissolve in common solvents. The cellulose is derivatized to dissolve it, such a process is called the viscose process. Viscose is produced from dissolving pulp, which is produced by the pre-hydrolysis kraft process. Pre-hydrolysis is carried out prior to pulping to remove hemicellulose from the lignocellulosics, which creates problems in viscose processing. Ionic liquids (ILs) are potentially alternative solvents for cellulose dissolution. It is interesting to gather knowledge on how hemicellulose affects pulp dissolution in ionic liquid and the regeneration process.

In this investigation, hardwood pulps were produced by kraft (KP) and prehydrolysis kraft (PHKP) process, and both pulps were dissolved in 1-Butyl-3-methylimidazolium chloride [C_4mim]Cl and 1-Butyl-3-methylimidazolium acetate [C_4mim]CH_3CO_2. The structure and properties of regenerated pulps were characterized by FTIR, TGA, X-ray diffraction and viscosity. The α-cellulose and residual pentosan content were 95.6% and 4.2% in PHKP and 84.3% and 9.9% in KP, respectively. Both pulps were dissolved in different mole ratio of [C_4mim]Cl and [C_4mim]CH_3CO_2 at different temperatures. The solubility of pulp increased with the increase in temperature. There is no significant difference observed between KP and prehydrolysis PHKP. At 100◦C, [C_4mim]Cl and [C_4mim]CH_3CO_2 mixture at the ratio of 4: 6 could dissolve 19.23 wt% and 19.98 wt% of KP and PHKP, respectively in 6 h. All pulps and regenerated pulps showed cellulose I structure, and crystallinity index of regenerated cellulose decreased. As observed in FTIR, the regenerated cellulose showed a stronger absorption band at 1647 cm^{-1} corresponds to the C–O stretching vibration of C–O–H. The viscosity of regenerated PHKP was higher than KP, which affected the strength of produced cellulose film.

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Evaluation of the Physical, Mechanical and Fuel Properties of Briquettes of Ceiba pentandra Sawdust and Delonix regia Seed Pod Flour

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Abstract

Recent increases in energy demand, cost and environmental concerns due to rising population, wars in fossil fuel producing countries and over exploitation of fuel deposits respectively, has resulted in the search for alternative renewable and cheap energy sources. This study investigated the mechanical and fuel properties of briquettes produced from *Ceiba pentandra* sawdust *and Delonix regia* (flamboyant) seed pod flour to address the depleting energy resources and associated environmental repercussions. The briquettes were produced with compacting pressures of 20 and 40 mega pascal and material particle size of < 1.5mm. Evaluated fuel quality and mechanical parameters were ash content, moisture content, volatile matter, fixed carbon, burning rate, and compressive strength in cleft (CS), Impact resistance index (IRI), and shatter index. The data was analysed using analysis of variance at 0.05 confidence level. Except for the high moisture content in *Ceiba pentandra* with a negative consequence on fuel quality all its other fuel properties were better than that of flamboyant seed pods. Increasing compacting pressure and *Ceiba pentandra* content in blends of flamboyant and *Ceiba pentandra* briquettes caused a significant rise in the shatter index, the compressive strength in cleft, and the Impact resistance. Almost all the samples showed a great shatter index (durability)-98% to 99% except those with high flamboyant pods flour content. Generally, the briquette's mechanical durability exceeded 97.5% and satisfied current requirements for quality fuel and favourable transportability, storage, handling, and packaging characteristics.

SUPPLY CHAIN, OPERATIONS, AND MARKETING OF WOOD PRODUCTS, CIRCULAR ECONOMY

Advancing Workforce Wellbeing and Inclusion in the Forest Sector: Insights from Discussions at the Women's Forest Congress

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Abstract

Our research offers a unique perspective on the crucial role of workforce inclusion and wellbeing in promoting economic, social, and environmental sustainability in the forest sector, and draws on collaborative work done during the historic inaugural Women's Forest Congress (WFC) held in Minneapolis, Minnesota, USA, within the fall of 2022. This event was attended by over 500 diverse professionals across the public, non-governmental, and private sectors.

During the WFC, we conducted a research-based workshop that was attended by 60 individuals from within the forest sector who represented diverse subdisciplines, identities, career levels, and backgrounds. The focus of the workshop was to utilize recent research findings on women's willingness to and comfort with engaging in the forestry workforce as the foundation for interactive group discussions. The discussion led to the development participant-sourced recommendations around workplace policy and culture changes to support women in the forestry profession.

During the workshop, discussions were recorded and later analyzed using qualitative methods. The most frequent emerging topics and themes were identified using a thematic analysis approach. Themes were categorized into opportunities and barriers women face around inclusion and career advancement. Data visualization was used to identify and highlight the interdependencies of various factors that contribute to the lack of inclusion and career advancement in the forest sector. This research provides a deeper understanding of women's experiences as they connect to work culture, systems and policy in the forest sector. It should be noted that those who attended the Women's Forest Congress were primarily North American, cis-gender, white, women. As such this research cannot be directly translated to other more diverse communities within North America nor other regions.

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The Use of Wood in the World of Sport: A Sustainability Perspective

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Abstract

Wood is widely used to make sport items and playing grounds, for instance baseball bats, basketball grounds, table tennis rackets and tables, cycling tracks, skis and snowboards, surfboards. The world of sport is of great socio-cultural and economic relevance worldwide, and the global industrial sector related to wood sport equipment is very large indeed. The climate crisis has increased the request of sustainable raw materials and products in many sectors, and wood is being more and more appreciated for its valuable ecological profile, including high carbon storage, low embedded emissions, and ease of reuse and recycle.
In this context, this contribution analyzes the perspectives of the use of wood in sport equipment (WSE), with particular reference to sustainability. To this purpose, various references were consulted, among which the book *Wood in sport equipment – Heritage, present, perspectiv*e (Negro et al. 2022a), the websites of several global producers, the 2021 *Sustainability report* of the International Olympic Committee, and a scientific article on the web-based communication of WSE (Negro et al. 2022b). The information gathered was analyzed through a Strength, Weaknesses, Opportunities and Threats analysis (SWOT). Overall, as can be expected, the increasing attention to sustainability represents an opportunity for the use of wood in sport equipment. Also, sport governing bodies can play a relevant role to support sustainability in the world of sport. Many producers of WSE have considerably increased their environmental commitment over the past years, and various cases can be taken as best practices. Clearly, the interesting perspectives shall be based on the supply of timber coming from legal and sustainable sources, and on wood-based products manufactured through sustainable production processes.

Keywords: wood, sport equipment, sustainability

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Using deep learning for feature segmentation in computed tomography images of logs

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Abstract

Sweden's forest industry plays a key role on the path to a circular bio-economy, but of the annually harvested forest only 20% are transformed into products with a long lifetime and a high rank in the material cascade (e.g., sawn timber). A main reason is the lack of an integrated information flow throughout the whole sawmill process – as common in other industries – which is due to the unclear properties of the felled logs when they arrive at the sawmill. With the help of computed tomography (CT) it is possible to observe the internal features of a log in 3D and optimize the process based on this data, and in the past few years, industrial CT scanners have been installed in several Swedish sawmills.
Hence, the vision behind this project is to predict and optimize which products to produce, which quality they will have, and to which customer they will be sold – before making the first saw cut. This opens the opportunity to maximize the share of products extracted from a log that are high up in the material cascade.

To achieve our vision, the following sub-problems need to be solved in a way that can be automated: 1) reduction of noise and undesired components in the CT reconstructions of logs to make essential log features (e.g., knots) visible for further data processing, 2) segmentation of essential log features with high accuracy and reliability, 3) prior-to-sawing prediction of the quality-relevant properties of sawn timber, and 4) prior-to-sawing optimisation of the processing of logs into sawn timber for maximum value and raw-material utilisation, based on the characteristics of the available raw material and on the customer needs.

In this study we a applied a convolutional neural network (U-Net) to a dataset of CT scans of 750 Norway Spruce logs, with the goal to automate the segmentation of sapwood, heartwood, sound knots, dead knots, and pith. Data labelling was done manually, using the open-source software 3D Slicer, and the model was trained within the open-source MONAI framework. Subsequent studies will focus on improving the CT-image reconstruction algorithm, followed by training a joint, task-adapted reconstruction and segmentation model for an improved segmentation accuracy. The resulting data will be the input for the prior-to-sawing prediction of the strength and stiffness of sawn timber, in order to achieve more accurate strength grading.

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Evaluating Circular Economy Scenarios at the End-of-Life of Buildings: Application of a CE Framework on a Mass Timber Building in Canada

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ABSTRACT

The concept of Circular economy (CE) emerged in 1990 to address environmental concerns in a linear economy. The 3R framework (Reduce, Reuse, Recycle) is widely associated with CE. However, CE strategies went beyond this initial framework and now, a comprehensive list of these strategies includes 10Rs.

The construction industry has a significant impact on the environment, making it challenging to transit to circularity and achieve environmental sustainability. A major obstacle to this transformation according to literature is the absence of guidelines and regulations on how to apply CE strategies and to evaluate them. Studies on CE and the construction sector show the interest towards applying CE in this sector; however, the number of constructed buildings based on CE approaches are few.

This study initially introduces a framework that was developed to assess the implementation of CE strategies at the end-of-life (EoL) stage of the buildings. The framework was adapted from previously established frameworks in the literature and designed to evaluate the application of nine different CE strategies. Then, the framework is being used in a case study of a mass timber building to evaluate the impacts of CE strategies at the EoL stage. The building was chosen to be a six-floor residential building in Montreal, Quebec, Canada, and was designed in accordance with the National Building Code of Canada and its application in the province of Quebec. In this case study, the pertinence of the framework and the impacts of CE strategies are evaluated from the environmental aspect by the life cycle assessment (LCA) method. To do this evaluation, different scenarios for the treatment of materials at the end-of-life of the building are defined. These scenarios that include a real-life scenario for the treatment of materials at the EoL of the buildings in Quebec, were chosen to apply different levels circularity through the framework.
LCA results indicate the extent to which adopting circular approaches for various materials can influence environmental outcomes. The results show that to be considered superior to other scenarios,

implementing CE strategies must bring minimum improvements to environmental performance results.

The objective of this work fills the gap in the literature and provides a framework which can aid in evaluating the application of CE strategies at the EoL of the buildings.

Keywords:
Circular economy, Strategies, Construction sector, Buildings, Environment, Life cycle assessment, CE Framework

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End-Grain Flooring from Underutilized Raw Materials: Solution to Extend and Enhance the Hardwood Resource

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Abstract

This project will examine the technical feasibility of manufacturing end-grain flooring from small-diameter hardwood timber and kiln-dried hardwood lumber end-trimmings—two underutilized raw material streams with the potential to improve forest management and the economic vitality of hardwood lumber producers. Hardwood silviculture prescriptions generally require the harvesting of both large and small-diameter trees to reduce overcrowding and fuel loads; maintain ecological diversity; improve forest health and resilience; and meet growth and productivity objectives. However, the lack of high-value markets for small-diameter hardwood timber provides little economic incentive to harvest small-diameter trees. As a result, high-grading, diameter-limit, and other forest degrading harvesting practices are widespread. At the same time, hardwood sawmills and concentration yards perpetually struggle against the pressures of high sawlog prices, high manufacturing costs, and low lumber prices. Adding value to hardwood mill residues would increase the viability of these companies. Our research will address knowledge gaps and manufacturing challenges presented by these two raw material sources, including drying strategies for juvenile wood that is generally not considered useful for lumber; mechanical properties of end-grain blocks manufactured from that wood; and high-value product yield potentials from kiln-dried sawmill waste. Small-diameter Red Oak and White Oak logs will be squared into 4” and 6” cants. Half of those cants will be dried in cant form; the others first cut into one and two-inch-thick slices and then dried. Testing of various drying strategies will determine least-degrade methods, comparing restrained vs. unrestrained drying; aggressive vs. conservative drying schedules, and drying of green vs. air-dried material. Because kiln-dried sawmill end-trimmings are of various dimensions and often have significant wane, warp, end-checking and splits, mill studies will first quantify what percentage of this raw material is of suitable size and quality to be manufactured into end-grain flooring blocks. Finally, select mechanical testing—including hardness, compressive strength and dimensional stability—will determine the suitability of both resources for end-grain flooring. The selection of Red Oak and White Oak as test species will allow performance comparisons with known properties of traditional flatsawn solid Oak flooring.

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Circular economy in wood construction through additive manufacturing of fully recyclable walls

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Abstract

To strengthen the environmental potential of renewable raw materials, especially wood, a new concept for fully recyclable bio-based wall elements for houses, assembled by additive manufacturing, is presented. The novel concept has closed-loop characteristics, starting from material conversion, to manufacturing, application, recycling, and the full re-use towards another construction phase. The employed materials are fully circular, with conceptually no waste production. The bio-based material mixture includes wood particles, in combination with a sodium lignosulfonate – starch blend, called Biomix. The presentation describes the basic approach and reports first data about the achieved mechanical performances. The additive manufacturing technology is based on a 6-axis industrial robot, in combination with a 3D-printing head that is fully self-developed. At this state the printing is focused on laminar structures to create house walls. The entire concept is accompanied by life-cycle analyses, with a comparison to competing wall systems. The data obtained so far approves the feasibility and potential of the new approach.

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Production Technology in the Wooden Single-Family House Industry – A Case of Reasoning against Automation

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ABSTRACT

Swedish producers of wooden single-family houses have for a long time being accused of lagging behind other industries in terms of production technology. In the emergence and the spreading of concepts like Industry 4.0 or Smart Manufacturing, new technologies are available, with the respective automated equipment. Some companies have already invested in such, e.g., automatic stud fitting or multi-functional bridges. Others are about to do so, or at least seriously reason and reflect about it. In order to make an appropriate investment decision, a company has to consider different factors and thoroughly discuss and evaluate them internally. The aim of this single case study is to identify the factors the case company used as decision-criteria for investing in a higher degree of automation or not, and how the responsible managers reasoned on each factor before the final decision was made. The empirical material was gathered by deep interviews and the result shows seven factors of importance: investment costs, operating costs, production capacity, flexibility, quality, space and working environment. After comprehensively debating and evaluating those factors, the company decided against a higher degree of automation in favor of more manual work. This shows that automated operations and the use of new technologies is no end in itself.

KEYWORDS:
Prefabrication, automation, operations management, wood building industry, decision criteria.

INTRODUCTION

In Sweden, wooden houses dominate the market for single-family houses for many decades, accounting for about 80 to 90 % market share (Schauerte 2010, Schauerte et al. 2016). In total, 588 companies are registered in this industry; yet, only 141 companies have more than 5 employees and about 50 companies have more than 10 employees (TMF 2022, Schauerte and Vestin 2019). During the past two decades, the terms *prefabrication* and *industrialized house building* were gaining prominence, meaning that companies move on-site building activities into their factories i.e., off-site. There are a number of challenges related to on-site activities (Lessing 2006), which could be dealt with in a positive way when carried out in a controlled off-site environment (Steinhardt and Manley 2016). According to a.o. Apleberger et al. (2007), off-site production can increase the quality of the final product whilst decreasing total costs, as its major advantages are better control and efficiency of the processes involved. However, few companies currently utilize the potential that is associated with off-site production (Schauerte and Vestin 2019), including an increased level of automation (Popovic and Winroth 2016).

In other industries, a paradigm shift towards *Industry 4.0*, *Smart Manufacturing* or *Smart Factory* (there are varying synonymous terms in different countries for what is meant to be the fourth industrial revolution) already dominates the agenda for development on all possible

levels. This includes a significant change in production (Dombrowski and Wagner 2014), where digitalization is key for the automation of manufacturing processes (Kagermann et al. 2013). However, in the Swedish industry for wooden single-family houses, manual ways of working still are applied to a large extend (Vestin et al. 2018), even though semi and fully automated production solutions exist (Lindblad et al. 2016, Landscheidt et al. 2017), like e.g., stud fitting or multi-functional bridges. Moving from a craftmanship mentality to a digitalized and automated production system is a change that hardly can be done in one step. Organizational culture, knowledge of implementation and related education are crucial factors that need to be considered (Höök and Stehn 2008, Stendahl 2009, Carlsson et al. 2022). Yet, at its essence, moving towards a higher degree of automation is about deciding on an investment and related to risk taking (Andersson et al. 2007). The hazards must be weighed against the benefits and the factors being evaluated often mirror the individual firms' current state and situation.

Therefore, this study is aiming at identifying factors that a Swedish wooden single-family house producer used as decision-criteria for investing in a higher degree of automation or not and how the responsible managers reasoned on each factor before the final decision was made.

THEORETICAL BACKGROUND

This section outlines the use of automation and robotization in wooden single-family house industry and brings forth research that addresses the value creation specifications of automated and/or digital solutions compared to manual and/or analog options.

The automation level in manufacturing industry overall is increasing with the development of digitalization within the era of Industry 4.0 (I4.0) (Alcácer and Cruz-Machado 2019). In the construction industry using concrete and steel as materials for building robotic technologies have been proposed since the 1980s e.g., (Chea et al. 2020, Davila Delgado et al. 2019, Warszawski and Sangrey 1985). The interest in automation in the wood construction industry is increasing (Lachance et al. 2022) and advantages with robotic prefabrications are brought forth e.g., assembly precision and reduction of construction mistakes (Eversmann et al. 2017). The traditionally low-level automated industry of wooden single-family house prefabrication is increasingly considering the adoption of automation (Nilsson et al. 2023). Automation in the prefabrication industry is gaining movement, yet robotic applications are still scarce and are not fully industrialized (Lachance et al. 2022). Prefabrication of wooden single-family houses is characterized by large variations in production flora, requiring technical solutions and automation equipment with flexibility that promptly and easily can be reconfigured, as well as operating in a fluctuating market (Nilsson et al. 2023). Nevertheless, traditionally, robotic automation in other industries such as automotive, has seldom needed such a level of flexibility. Therefore, it is crucial for the wooden single-family house industry to improve understanding of the possibilities and value specification of investing in automation or not thus support decision making regarding technological advancements.

Technological advancement is underway and is expected to take the manufacturing industry into the era of I4.0 (Alcácer and Cruz-Machado 2019, Kagermann et al. 2013). There is the belief that increased automation and digitalization will always create value for production processes. However, this is not always the case, and it is recognized that there are barriers when specifying the value of digitalization projects, such as leadership support, resource allocation and competence (Sten et al. 2021). Improving value specification is challenging and lacks methods to overcome barriers for value specification that can support decision

making regarding technological investments (Sten et al. 2021). Strategic technological investments may not always be chosen based on models incorporating a multitude of possible aspects, including the organizations' ability to judge the advantages of added value with technology, thus manufacturing companies are struggling with decision-making surrounding novel technologies (Carlsson et al. 2022). There may also be an ambiguity between deciding to keep the manual and analog approach in relation to approach novel digital solutions (Eriksson et al. 2023). It is argued that considering only the economic aspect and investment costs is not sufficient and a more holistic view of possibilities with I4.0 technologies including ecological and social perspectives should be regarded (Müller and Voigt 2018). The aspects of increased quality, human safety, improved ergonomics, removing repetitive work tasks may create value that are not necessarily focused on production efficiency. In addition, studies have highlighted the uneven effects of automation on the workforce, e.g., shopfloor workers face lower earning and employment rates while other workers gain from robot adoption (Acemoglu et al. 2023). Furthermore, characteristics and prerequisites of Small and Medium-sized Enterprises (SMEs), such as is often the case with wooden single-family house industry, and their approach to I4.0 is lacking research (Müller and Voigt 2018). The research presented here addresses an in-depth case incorporating several decision factors drawing on different aspects of value specification of automation at an SME case company in the wooden single-family house industry.

METHOD

The research at hand was designed as a single case study. Single case studies investigate complex issues in a real-life environment and concern a specific subject such as an organization (Crowe et al. 2011, Yin 2017). Here, the decision makers' reasoning on decision factors for investing in automation or not was studied at a specific chosen case company. Sampling was done in a non-random way, using the key informant approach, which is characterized by gathering information, relevant to the problem investigated, provided by a person that can be regarded as a proxy for a larger group of people being involved in the investigated issue. Key informants are regarded as particularly valuable, as they have a broad overview as well as deep involvement in the topic at hand. They probably possess most knowledge of the problem at hand (Parsons 2022). Here, a group of employees with different backgrounds were involved in the decision-making process investigated. This group was led by the company's Chief Operation Officer, COO, who thus was chosen as the key informant for the present study.

THE CASE COMPANY

The case company is active in the Swedish industry for wooden houses since the 1940s and has three different production facilities. One for the prefabrication of single-family houses (F1), one for prefabricated volumetric modules (F2) and one for the prefabrication of both single-family houses and components for the volumetric modules (F3). F1 is the company's main facility and has been for many years. F2 was inaugurated in 2017, serving different market segments like dwellings and apartments. This includes, among other things, even a different building system, compared to the housing produced in F1 and F3. As the company's capacity boundaries in F1 were limiting further growth, a nearby competitors' existing production facility was acquired. This facility, however, needed some renewals, especially on the shop floor. Before investing, a thorough evaluation of various alternatives has been done.

RESULTS FROM THE CASE STUDY

This section outlines the results from the data gathered from the case study. The case company's decision criteria factors are each addressed and the reasoning behind the pro and cons from each factor is described.

DECISION FACTORS AND REASONINGS

Before investing, a thorough evaluation of various alternatives has been made. Alternatives ranged from unsophisticated bottom-of-the-range working stations to complex systems and solutions involving automation and robotics. Many considerations and evaluations have been made prior to the investment decision. The decision criteria applied were chosen based on the company's long-time experiences and the decision makers' knowledge in the field. The most important factors in that process have been investment costs, maintenance and service costs, production capacity, flexibility, quality, available space and working environment. The reasoning for each factor was as follows.

Investment Cost

A cost estimation was made by comparing an automated solution with a ten-year payback time, and one additional assembly operator for the same period. As the yearly cost for an assembly operator sums up to approximately 500,000 SEK, this would equal a potential investment in automation to be around 5,000,000 SEK. Given the company's monetary boundaries, a combination of both automation equipment and an operator was excluded. Two clear counter-poles became apparent: invest in labor OR automation.

Maintenance and Service Costs

A higher degree of automation implies higher costs for maintenance and service. How much higher is hard to estimate without being given offers from suppliers. Yet, no technical inquiry or request was made. This would be the next step in case a decision is made for automation equipment. Independent of higher maintenance costs, a potential dependency on service from the equipment supplier or another third part potentially would arise. This becomes apparent in the case of disruptions of operations. In that case, it is essential to restart operations as fast as possible. Based on cycle times of about 30 to 45 minutes, grave consequences would emerge after a two-hour disruption and a complete production shutdown would occur. The labor costs for a one-day shutdown sum up to about 25,000 SEK. Thus, the question of handling operation disruptions is crucial when evaluating investment alternatives and constitutes a risk factor per se. Furthermore, service costs for providing control files were considered. Often, an adjustment of current files in the CAD system is required, which even implies license and development costs as well as continuous work to guarantee that the control files remain correct. This additional work and the costs involved of the construction department are generally hard to approximate, yet, definitely not inconsiderable.

Production Capacity

Due to product variation, production constraints can occur at different working stations in the production line, depending on e.g., number of windows, type of panel or length of the wall. Thus, it is important to have buffer zones on the production line. One recurring constraint is the mounting and adjusting of windows and doors. This work must be done manually and often sets the time for the remaining stations. With that in mind, the remaining station times should not exceed 30 minutes, as the production line, with its total cycle time, would not benefit from a shorter station time than 30 minutes if some tasks were automated.

Flexibility

In the company at hand, all houses are produced based on every single customer's demands. There are no standard products, but each wall is unique. Even though the walls seem to be identical, changes occur. A regular stud may be changed to a laminated one, to increase the load bearing or a wall might be strengthened with a steel beam. Wall corners vary, as do wall heights, to name but a few variations. With the current automation offerings from suppliers, such changes cannot either not be made or solutions are ineffective. Consequently, such changes would need to be handled on manual stations parallel to the production line. This would not be rational, and the available manual stations are already occupied. Future requirements for the wall construction are expected to be limited to new and better materials. Yet, this possibly means that additional working tasks might be added, and that the production line needs to allow for additional space and stations. Thus, automation equipment would limit the flexibility needed.

Quality

Applying a high level of automation can result in achieving certain quality objectives that might be impossible to reach by manual work only. However, does a potential increase in quality add some significant value as well or is the improvement negligible? The automated nailing of façade panels can be taken as an example. The machine is nailing with a precision that is almost impossible to achieve by manual nailing and at the same time, it adds value for the customer. Nevertheless, the other side of the coin, that needs to be looked at, is the fact that we are working with wood. Tolerances in dimensions on the timber represent very special circumstances when automating certain production steps. Nailing panels, boards or beams that vary some millimeter in some direction or are slightly bent or curved, is done without any considerable extra effort when done manually. By holding the piece of timber and feeling it with the fingers, the operator can guarantee that the workpiece is just right in place, e.g., considering the wall opening for doors and windows. This would, however, be a complex and thus complicated operation in an automated machine. There are plenty of such challenges related to wood that cannot be seen in the drawings.

Available space

In the case of investing in automation and machinery, the respective workplace often needs to be safeguarded to provide security for employees. Additional requirements on emergency paths through the facility, especially in case of automation, further impede facility planning. As the facility at hand does not offer a large-scale shop floor, this was a bottleneck to be considered.

Working environment

The operators' working environment is a vital and important part of decision making. By automating, the company has the opportunity to reduce or eliminate heavy and burdening working tasks. It is obvious that automation comes with many advantages related to the working environment. However, it nevertheless needs to be considered that also machines can change the working environment for the worse. In this case, the height for working benches was such an issue. One of the suppliers, for manual working benches, could adjust the benches' height according to the request. This was not possible for suppliers of automated equipment. The working environment and how it can be improved needs to be examined for each single working station.

DISCUSSION

Today, the Swedish wooden single-family house industry has a relatively low automation level and is accused of lagging behind other industries. When discussing this issue with

industry representatives, many defend themselves by mentioning that wood, as building material, has special characteristics compared to other materials and that the final product is complex and often not homogenous. Studs, e.g., can be twisted in different ways and show tolerances that cannot be found in the drawings. For load bearing reasons even steel beams can occur. Wall corners, heights and -thickness also can vary. This makes operations more complex to handle. If the level of automation is to be increased, these characteristics call for automatic solutions that are flexible and can reconfigured easily and fast. However, traditionally automation solutions for the industry at hand lack such requirements. Further, it would not be meaningful to automate a working station that is not constituting a bottleneck.

There are arguments claiming that it is vital for all manufacturers to keep moving towards increased digitalization and automation (Alcácer V and Cruz-Machado 2019). This should even be true for the case company at hand; yet higher service costs for CAD administration were regarded as negative and should be avoided. The case company constitutes a clear example of reasoning against increased automation. This prompts a discussion on the pros and cons for automation in general and regarding the industry at hand there might be a risk of further falling behind with technology. New business models, e.g., as the one described in Popovic et al. (2022), suggest a more advanced platform thinking that allows a mass-customization approach. That model suggests, among other things, a closer cooperation between a company's R&D department and suppliers of automation equipment. The need for improved models and methods for understanding value specification of automation and supporting decision making is obvious. Such models should not only consider cost and investment criteria. Introducing novel technologies successfully also depends on organizational aspects e.g., leadership and culture, as well as requiring up-skilling and re-skilling related to knowledge and competence among workers (Carlsson et al. 2022, Grahn et al. 2021).

CONCLUSION

This case study provides a deep understanding of how a wooden single-family house company can consider adopting automated processes. The case company reasoned against a higher level of automation and instead opted for more manual production, basing their decision on seven factors of importance: investment costs, operating costs, production capacity, flexibility, quality, space and working environment. The result is interesting as it demonstrates how companies, especially in existing low-level automation industries, may struggle to create sufficient added value towards automation.

More research into making decisions about when to automate or not is needed. This includes models not only incorporating investment costs, but also encompassing aspects of human safety and ergonomics, possibilities for flexibility and reuse of equipment. Thus, highlighting social and environmental aspects of sustainability towards supporting, not only the wood building industry but manufacturing industry as a whole, on decision-making of whether and when to embrace of automation and other digital technologies in the era of Industry 4.0.

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Individual Tree Analysis via Person-Carried Laser Scanning (PLS) in Forest Stands

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Abstract

Knowledge about growing stock and biomass allocation in the forest is essential for thorough planning and a sustainable production of the resource wood. Nowadays forest inventory practice only provides rough estimates for the total stocking volume, but there is no information about the individual tree. Person-carried laser scanning (PLS) is a highly automatized technology to create 3D point clouds from forest stands. Every tree is represented in great structural detail by a digital twin. Irregular shapes and defects of the stem require an individual tree analysis before harvesting to maximize the usability of the wood. This study presents an automatized software to extract and measure single tree point clouds from data captured with PLS. The trees were segmented by cluster analysis and a region growing algorithm. Splines were used to subsequently measure multiple stem diameters, and stem volume and crown parameters were extracted. The diameter at breast height and total tree height were measured most accurately with PLS, thereby also the stem volume of the single trees. The measures were compared to manual measurements from traditional forest inventory via root mean square deviation (RMSD) and bias.
PLS can efficiently measure whole forest stands before harvesting operations and provide accurate data to the forest owner. Possible uses of the individual tree files are detection of wood quality parameters (e.g., forks) or a quality grading according to the density of branches. The material and energy-efficient use of the resource wood requires considering the individual tree characteristics and should be a necessary step in the future wood supply chain.

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Managing timber's moisture content in the supply chain, construction and in service

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Dr. Nathan Kotlarewski - The University of Tasmania

Abstract

There are direct relationships between wood's equilibrium moisture content (EMC), species (or product) properties, the ambient temperature and relative humidity of a location. These ambient conditions change constantly in the supply chain, affecting the timber's actual moisture content (MC) and its consequent dimensional change.

This paper will report on a project that was designed to collect and assess first-generation information covering the temperature and humidity conditions found in the Australian timber supply chain: from the producer's store to the finished building in service, and the MC responses of common species and wood products stored in those conditions. The research used static monitoring units installed and measured over a period of up to a year in twenty-eight sites across four climate zones from cool temperate (CZ7) in Tasmania to subtropical conditions in Queensland (CZ2). The sites included five exposure conditions: in roofed shelters, inside store buildings, on construction sites, and in service in unconditioned and fully conditioned buildings. Each static unit included nine species and product samples of known initial MC exposed to ambient conditions and a sensor collecting ambient temperature and humidity. The samples were weighed at regular intervals, with over 700 readings taken across the sites throughout the study.

Analysis of the results shows that species and products have individual EMC. Engineered wood products (EWP) generally have a lower EMC than solid timber species, with hardboard lower than LVL and LVL lower than its constituent radiata pine. Species of EMC vary with the type of wood (hardwood and softwood) and other factors by more than 2%, with Blackbutt *E.* pilularis the highest and Spotted gum *Corymbia* maculata the lowest. The average MC also varied by more than 4% in the supply chain across all species. Construction sites had the highest average MC and conditioned buildings the lowest.

The paper will detail MC variation across sites in the same climate zone and between climate zones and identify potential risk to product stability and value as it moves through the supply chain. A potential framework for future risk assessment for products in the supply chain will also be presented.

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Wood vs concrete rhetoric in building supply chain

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Dr. Pipiet Larasatie - University of Arkansas at Monticello
Dr. Eric Hansen - Oregon State University

Abstract

Wooden structures are commonly said to be less safe than concrete buildings, as the material is vulnerable to external threats such as fire, wind, insects, moisture, and mold. Therefore, in many places in the world, nature has been converted to a concrete jungle. Aiming for a sustainable built environment, government, architects, and engineers are increasingly specifying/using mass timber, a highly suitable substitute for concrete-based building. The "threat" from wood and competition between the materials has resulted in accusatory advertising campaigns and other rhetoric about the "other" material. A sustainable built environment requires use of both materials, typically in concert, so although the materials compete, they are often complementary. Therefore, the rhetoric between the two camps does not benefit society or sustainability. This project aims to capture the arguments employed by both sectors in this "material warfare". An initial result will be presented by utilizing content analysis.

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Workforce Diversity in the US forest sector: what can data tell us?

Dr. Jaana Korhonen - Oak Ridge Institute for Science and Education (ORISE)
Prof. Rajat Panwar - Oregon State University

Abstract

The challenge of the post-pandemic world is to make businesses more resilient to future shocks, which implies the different vulnerabilities need to be understood. As employee recruitment and retention have become increasingly critical for business success, attracting and retaining diverse talent has become more important, particularly as many companies face a talent gap in their supply chain and operations. How well forest sector is prepared for these people-related vulnerabilities in the future?

According to the U.S. Bureau of Labor Statistics' Employment Projections Program for 2022, the total labor force is projected to increase from approximately 161 million employees in 2020 to 170 million employees in 2030, representing a 5.5% increase in the overall labor force compared to 2020 levels. However, this growth is not distributed evenly among demographic groups, and the share of minority employees and women is expected to increase.

This study aims to collect, systematize, and analyze diversity data in the U.S. Forest sector, focusing on the forestry and logging (113), wood products manufacturing (321), and paper manufacturing (322) sectors, based on the North American Industry Classification System (NAICS). Our study will examine data related to race/ethnicity, gender, age, native- and foreign-born status, and immigration for specific occupations within each NAICS classification.

The goal of this report is to provide evidence on the current state of diversity in the U.S. Forest sector and discuss its implications for future research and practice. We also aim to discuss the challenges and opportunities in integrating employee-related data into business decision-making and strategic planning at the sectoral level.


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An Agriculturist, Entrepreneurship expert, a freelancer Journalists. He worked as the Chief Agricultural Superintendent in the Federal Capital Territory Administration Of Agricultural Development Secretariat, under the Federal Capital Territory Agricultural and Development Project. Block Supervisors in Kwaita Kwali area council of the Federal Capital Territory, an Extension's experts, technical advices on Agriculture to farmers and supplies them with the necessary inputs, dissemination of Agricultural information, ideas and transfer of Technology being developed by agricultural research stations. Michael graduated from Ahamdu Bello University Zaria, where he obtained Post Graduate Diploma in Farm Management and Extension, Agricultural Economics and Extension, Rural Development.


Idowu Abimbola Adegoke

My educational background in Forestry stems from undergraduate to PhD level. My scientific research journey started from Forestry Research institute of Nigeria as a research Officer for over ten years while I later moved to the University as a lecturer. My research focuses on renewable energy development through utilization of biomass wastes via various bio-energy routes. Adegoke has a PhD in Forest Resources Management (wood and fibre science option) from University of Ibadan, Nigeria.


Oluwafunbi Adeleye

I hold a bachelor's degree in Wood Products Engineering from the University of Ibadan, Nigeria.I am currently a master's research assistant at the Wood Science and Engineering department, Oregon State University. I am investigating the mechano-sorptive properties of wood-based composites with the aim of improving its strength and durability in building construction. I enjoy playing soccer, puzzle solving and painting.

 Sailesh Adhikari

Sailesh has been working on different projects to produce hardwood CLTs commercially since 2017. He had Ph.D. under the supervision of Dr. Henry Quesada and Dr. Brian Bond in 2020 from VirginaTech. He has been working as a postdoc with Dr. Quesada and Dr. Bond since 2020 at the Department of Sustainable Biomaterials at Virginia Tech.

 Kojo Afrifah

Dr. Kojo Agyapong Afrifah is an alumnus of Michigan State University, USA and currently a lecturer at the Department of Wood Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi-Ghana. His areas of specialization are in Wood Science and Technology and Packaging Science and Technology. His research focuses on bio-based and petroleum-based plastics and materials, natural fiber plastic composites, food and medical packaging, distribution packaging, postharvest management systems and renewable energy from sawmill and agricultural residues.

 Abiodun Alawode

Abiodun Alawode is an avid researcher in wood science and investigating sustainable ways of developing wood products. Abiodun is currently a Postdoctoral Researcher at Forest Products Development Centre, Auburn University. He completed his PhD in Wood Science at Stellenbosch University. His PhD work focused on developing environmentally friendly wood adhesives from waste residues of seed kernels of Irvingia species as an alternative to those from fossil fuels. The aim of the project was to use wood and agricultural residues in the development of sustainable building materials. The study linked different fields of study, including agro-forestry, wood composites and waste management.


Courage Alorbu

I am Courage Alorbu, a PhD student at the Department of Forest, Rangeland and Fire Sciences at the University of Idaho, USA. My current research objective focuses on developing bio-based and sustainably green preservatives for wood protection against fungi, termites, fire and weathering activities. This will help enhance confidence in the use of treated wood in various applications and will also serve as my way of contributing to the green and sustainability agenda which is focused on making the world a better place for generations to come.


Olusola Samuel Areo

Dr Olusola Samuel Areo is a Principal Research Fellow at the Forestry Research Institute of Nigeria (FRIN), Ibadan. He had a postgraduate Diploma in Education from (NTI) in (2012). His Ph.D. thesis focused on wood properties and natural durability of *Artocarpus altilis* wood as a lesser-used wood species which brought breakthroughs to solving the problem of ineffective utilization of forest products and provide information for the wood users in Nigeria. He has vast experience in Forest operations activities, Dr. Areo supervised the production of furniture items used by staff in the institutes.


Matthew Arvanitis

Matthew Arvanitis received a PhD in applied statistics at the University of California at Riverside in 2018. He currently serves as a research mathematical statistician at the Forest Products Laboratory. His research interests include the analysis and evaluation of lumber properties and the applications of engineered wood products, Other research interests include distribution and copula theory, nonparametric statistical inference, and econometric analysis.


Nelson Barrios

Graduate student in the Forest Biomaterials Ph.D. program at North Carolina State University, USA. Previously worked as an RD&I manager in a chemical company in Valencia, Venezuela. Holds a Bachelor's degree in Chemistry from the University of Carabobo, Venezuela. Published several research articles in peer-reviewed journals. Established collaborations with researchers in different countries such as Canada, France, Brazil, USA. Holder of the Gratzl fellowship 2022. Winner of a scholarship awarded by the German International Exchange Service (DAAD) 2015. Participated in several conferences as an undergraduate student in Venezuela.


Birger Bartuska

Birger Bartuska is a junior researcher at the Competence Center Wood K plus area wood materials technologies. After finishing his masters in wood technology and management at the University of Applied Life Sciences in Vienna on the topic of hemp fiber reinforced thermoplastic composites he is doing his PhD in the field of digitalization and new production technologies in the wood industry.


Benoit Belleville

Dr Benoit Belleville is a wood engineer and the leader of the Sustainable and Renewable Forest Products research group. He holds a PhD in wood science from Laval University, Canada, and his research focuses on wood as a sustainable and renewable material, processing and manufacturing, development and design of high-quality timber products, and utilisation of plantation timber and agricultural resources. He has published over 80 research papers, book chapters, and articles on wood processing, wood technology and wood products manufacturing. His expertise has engaged him in research in Australia, Canada, France, Chile, Lao PDR, and Papua New-Guinea.

 Christina Bjarvin

Christina is in the third year of her graduate studies at the University of Washington. For her Master's thesis, she analyzed the climate impacts of different end-of-life processing options for mass timbers after building deconstruction. She also examined the substitution effects of mass timbers in individual building elements. Her dissertation topic is currently under development, but will likely build off of her previous work on integrating mass timbers into a circular economy. In addition to her Ph.D. work, she has been working as a life cycle assessment project consultant for mass timber buildings and wood products.

 Tolulope Bodunde

My name is Tolulope Bodunde. I am a Nigerian. I graduated from the Department of Forestry and Wood Technology, Federal University of Technology Akure. I am currently working as a research assistant at Forestry Research Institute of Nigeria, Ibadan, Oyo state. My research interest is sustainable forest practices, wood modification and utilisation. With a strong academic background in Forestry, I am committed to advancing the field through research and collaboration with industry professionals.

 Martin Bohm

My research involves assessment of structure and properties of wood, optimization of wood-based materials and natural fiber composites for the intended use, and modification of adhesives and surface treatments. As part of the Materials and Environment Workgroup, I deal with the evaluation of the interaction between building materials and the environment.

Brian Bond

Associate Dean for Extension, Outreach and Engagement; Professor and Extension Specialist, Department of Sustainable Biomaterials, Virginia Tech

Daniel Burnett

Dan Burnett is the Vice President – North America for Surface Measurement Systems. He received his bachelor's degree in Professional Chemistry from Eastern Michigan University in 1997. He received his Ph.D. degree in Chemical Engineering from the University of Michigan in 2001. Since joining SMS in 2001, he has continued his interests in sorption science and surface chemistry on a range of materials including: pharmaceutical powders, natural and man-made fibers, polymers, films, and food/flavor systems. Dr. Burnett has authored or co-authored over 35 papers in peer-reviewed journals and presented at numerous national and international conferences.

Avishek Chanda

Dr Avishek Chanda's educational and research backgrounds span the fields of forest products and wood science, the formability of lignocellulosic structures, mechanical engineering and fire-performance analysis. Primary research interests lie in the field of processing wood, natural fibers and natural waste streams into composites and characterizing their processibility, strength and utility for various structural and non-structural applications, the formability of lignocellulosic composites, efficient utilization of low-value biomass to produce novel and upcycled composite products, integration of technologies, fire-performance and fire retardancy of material systems, and applications of lignocellulosic composites for energy-efficient building construction.

Chih Cheng Chen

Chih-Cheng Chen is a Ph.D. student in the department of Forestry and Natural Resources at Purdue University in United States. He is a graduate student at the Wood Research Laboratory working under the supervision of Dr. Eva Haviarova. Chih-Cheng completed his undergraduate degree in the forest product and furniture engineering department at Chiayi University and his master's degree in the School of Forestry and Resources Conservation at National Taiwan University. His research interest mainly focuses on wood furniture engineering. Now, he is working to add value to hardwood and on the topic of hardwood cross-laminated timber strength design.


Zhenghao Chen

Mr.Zhenghao Chen studied Wood Science and Engineering at the Beijing Forestry University, China and graduated as BS in 2018. He then joined the research group of Prof. Shuangbao Zhang of Plant Based Composite and Adhesive at the College of Materials Science and Technology, Beijing Forestry University. He is in a successive master-doctor program since 2018. He peruse his study as a visiting scholar and doing in Washington State University, U.S., and International Bamboo and Rattan Center, China during his years in PhD. He has published 16 research articles, and has applied for 13 national patents as the inventor.


Peter Kessels Dadzie

Engr. Prof. Peter Kessels Dadzie (PhD) is a Ghanaian Associate Professor in Wood Science, Technology and Management at Kumasi Technical University, Kumasi. He has attended conferences and currently credited with thirty-four (34) published journal and conference articles. He serves as a reviewer to seven (7) reputable international journals and, also serves as a national chief expert and judge in planning and executing skills competitions for WorldSkills Ghana -Wood and Furniture Section. Prof. Dadzie research into wood residue utilization, wood products development, wood durability, and properties. He is married to Mrs. Mary-Ann Kessels Dadzie and has four children.


David DeVallance

Dr. David DeVallance is the Associate Dean for the College of Science and Technology at the Commonwealth University of Pennsylvania and an Adjunct Associate Professor at West Virginia University. Dr. DeVallance also served as the Vice Rector for Internationalization at the University of Primorska (UP), Group Leader for Renewable Materials Composites (RMC) at the InnoRenew CoE, and Associate Professor and Program Coordinator in the Wood Science and Technology Program at West Virginia University. He received a B.S. in wood products processing and manufacturing from the Pennsylvania State University and his M.S. and Ph.D. in wood science from Oregon State University.


Lieke Droog

Lieke Droog is a second year PhD student in the Centre for International Trade in Wood Products (CINTRAFOR) at University of Washington's School of Environmental and Forest Sciences. Before starting her PhD program at the University of Washington, she obtained a bachelor's degree in Industrial

Engineering and Management at Inholland University and a master's degree in Industrial Ecology at Delft University of Technology and Leiden University in the Netherlands. Her research is focusing on environmental assessments using LCA and quantifying the global warming mitigation potential of forest stands and wood products combined.


Natalia Farkas

Natalia Farkas is a Research Physical Scientist in the Building and Fire Sciences Unit at the Forest Products Laboratory. Her current research interests are in wood-moisture relations and developing moisture control strategies for wood-frame wall assemblies.


Avani Flanagan

Growing up in Crystal Lake, IL, my love for science and engineering had always been highly encouraged. I decided to follow my interest in the topic at Eastern Illinois University, where I graduated with a BS in Engineering Technology. At Eastern, I received the opportunity to participate in research mentored by Dr. Isaac Slaven who later encouraged me to apply for graduate school. Since then, I have been working as a graduate assistant while pursuing an MS in Technology Management with a certificate in quality systems and an MS in Sustainability with a focus on energy management.


Yu Fu

Yu Fu is a Ph.D. student and research assistant at the University of North Texas. Her research focuses on biomass-based composites, the degradation properties of biobased materials, and formaldehyde emission mechanisms from wood.


Vilius Gendvilas

I am a postdoctoral researcher working at the University of Sunshine Coast in Queensland, Australia. Currently working on the project whose main objective is focus on assessing and managing mid-rotation wood quality in Australian softwood plantations to produce fit-for-purpose logs. I have experience in both softwood and hardwood silviculture, wood quality peculiarities and how to link knowledge relevant to wood processing industry and end-users. I have technical and theoretical skills to perform wood quality assessments using non-destructive and traditional methods. I have experience in using the resistance drilling - Resi and handling Resi data.


Alexandra Miguel Guevara Castillo

Alexandra Miguel Guevara Castillo is a chemical engineer with a master's degree in forest products. Currently, she is a PhD student in Universidad de Guadalajara of the program "Doctorado en Ciencia de Biomateriales Sustentables". Her work is centered in wood chemistry and natural durability.


Islam Hafez

Islam Hafez is an assistant professor of composites and adhesives at the Department of Wood Science and Engineering at Oregon State University. He received his PhD in Bioproducts Engineering from the University of Minnesota. He was a postdoctoral researcher and research assistant professor at the School of Forest Resources at the University of Maine. The broad context of his work looks at the structure-process-property relationships of bio-based composites and adhesives. He is particularly interested in the design and manufacturing of composites and the scale-up of promising products and technologies.


Jingquan Han

Jingquan Han received his Ph.D. in Renewable Natural Resources from Louisiana State University (USA) in 2014. He is currently a Professor and Ph.D. supervisor in College of Materials Science and Engineering at Nanjing Forestry University (China). His current research interests focus on the biomassbased soft nanocomposite materials with sustainability, renewability and biocompatibility, including gels, elastomers, membranes, macro/nanofibers, and their advanced applications in multifunctional wearable electronic devices.


Eric Hansen

Eric is currently Professor of Forest Products Marketing and Department Head of Wood Science and Engineering at Oregon State University (OSU). His current research areas are organizational innovation, bioeconomy transition, corporate social responsibility, and strategic marketing. He is co-author of the textbook Strategic Marketing in the Global Forest Industries and Editor of BioProducts Business, a journal published by the Society of Wood Science and Technology.


Eva Haviarova

Dr. Eva Haviarova is a professor of Wood Products in The Department of Forestry and Natural Resources, Purdue University. She is responsible for teaching, research, and extension. She is conducting research in Sustainable Product Development, Value Added to Hardwoods, Woody Biomass Utilization, and Addressing Global Sustainability Issues. She has published over 70 peer-reviewed publications and delivered over 200 professional presentations. Through her extension activities, she works extensively

with all forest product industry sectors. Dr. Haviarova is also a director of The Wood Research Laboratory at Purdue and Past President of The Society of Wood Science and Technology.

Moein Hemmati

Ph.D. student of Environmental Dynamics. Graduated in urban design with a master's degree. Graduated in Architectural engineering with a bachelor of science degree. Research interests: Wood products, Building LCA, Environment


Zahra Hosseini

Zahra Hosseini is a Ph.D candidate in the wood engineering and bio-sourced materials program of the Laval University, Quebec, Canada. She has completed her master's degree in industrial engineering as a double degree program between University of Tehran(Iran) and Arts et Métiers ParisTech(France). The aim of her Ph.D is to study circular economy on wooden buidlings and how this concept can promote the use of wood in buildings and the construction industry. Her area of interests are circular economy, sustainable developement, life cycle assessment and supply chain management.


Wanhe Hu

From 2011 to 2015, I earned a B.S. from Sichuan Agricultural University, where I focused on the fundamentals of biomass (wood and bamboo), such as how to use it effectively, how to identify wood species from microscopy, how to liquefy biomass, and how to separate the chemical components of biomass. From 2015 to 2017, I received an M.A. degree from the Chinese Academy of Forestry Sciences & International Centre for Bamboo and Rattan, with a major focus on Biomass Energy and Materials. From 2018 to the present (Ph.D student), the focus has been on logging residue conversion and wastewater purification.

SUNGJUN HWANG

I am a Ph.D. candidate at the Forest Resources of the University of Maine, and my advisors are Dr. Gardner and Dr. Yousoo. I am conducting research on the manufacture of nano- or micrometer-cellulose particles via different spray-drying techniques. In addition, I am focusing on the utilization of manufactured cellulose particles as reinforcement in thermoplastics and their application in 3D printing.

Md Sarwar Jahan

After completing my M.Sc in Applied Chemistry, I joined BCSIR Labs in 1992 and started my carrier in pulp and paper. I have received Ph.D. degree, and completed postdoctoral research on wood and pulping chemistry. I was a Visiting Scholar at the University of New Brunswick. So far I have published more than 190 research articles in different international journals. My main focus of research is to utilize lignocelluloses in producing pulp, chemicals, and biomaterials.

Peter Jurkovič

Ing. Peter Jurkovič, PhD. is a scientific investigator of the VIPO a.s.in Partizánske, Slovak republic. Doctoral degree graduated at Technical University in Zvolen, in 2006, with the area of optimization of phenolic adhesives with biopolymers for wood products. Author of 1 patents and 4 utility models in the area of application of polycondensation resins for wood based materials. Co-investigator of several European projects solving new technologies of processing and application of protein hydrolysates for application in polymer resins.


Daisuke Kanagaki

Daisuke Kanagaki is a graduate student in Science and Engineering at Chiba University, Japan. His research interests are in the areas of timber engineering, and he has graduated from the Department of Architecture, Faculty of Engineering, Chiba University. He has published his work in research publication of Proceering of the architectural research meetings of Kanto Chapter by Architectural Institute of Japan.


Ogunjobi Kayode

Dr Kayode Ogunjobi is a Senior Lecturer at the Department of Forestry and Wildlife Management, Federal University of Agriculture, Abeokuta, Nigeria. He is committed to teaching, research and extension services. His research focus is in Wood Utilisation and Protection and he has published about forty articles both locally and internationally . He has held several positions within and outside the University. Dr Ogunjobi is the Chairman of the Forestry Association of Nigeria, Ogun State Chapter and member of other professional associations both locally and internationally. He enjoys networking and making impact.


Jaana Korhonen

Dr. Jaana Korhonen is a transatlantic researcher currently affiliated with the Oak Ridge Institute for Science and Education (ORISE). She is located at the USDA Forest Service Southern research Station in North Carolina and is working with forest policy and economics team. Dr Korhonen holds Ph.D. in Forest Economics and Marketing from the University of Helsinki, Finland, and M.Sc. degrees from the North Carolina State University, the US. Her current research focuses on business economics and sustainability of forest-based sector. She applies both quantitative and qualitative research approaches.


Nathan Kotlarewski

Experienced Design Researcher and Industrial Design Specialist in Timber Design and Production with a demonstrated history of working in the Mass Timber Manufacturing Industry. I am currently a Research Fellow in Timber Design and Production at the University of Tasmania. I have a passion for design and technology and driving change through innovation to improve businesses that operate in the wood and wood products sector.


Andreja Kutnar

Dr. Andreja Kutnar is a professor in the field wood science at the University of Primorska and director of the InnoRenew CoE. She was an Executive Board member of InnovaWood for six years and in the years 2020/2021 President of the Society of Wood Science and Technology. Her areas of expertise include wood composites, therm- hydro-mechanical treatment of wood, and adhesive bonding. Her work focuses on research projects in the fields of natural science, technology, sustainable development of the wood industry, environmental impact assessment of new materials, products, and technologies from origin, manufacturing, alteration to reuse or recycle.


Manja Kuzman

Manja Kitek Kuzman is a Professor of architecture at the Biotechnical Faculty, Department of Wood Science and Technology, University of Ljubljana. Her research and teaching interests revolve around developing wood construction, innovative use of wood, sustainable wood products and product design. The research interest also includes energy-efficient timber construction, building modernisation with prefabricated components and architects' perception of engineer wood product, 3D-printing design and healthy-living environment with wood.


Frederik Laleicke

Frederik Laleicke is a Wood Products Extension Specialist and Assistant Professor at NC State University. He specializes in the areas of urban wood utilization, drying, and mass timber. Prior to joining NC State University in 2018, he served as an Assistant Professor (Senior Research) at Oregon State University.


Pipiet Larasatie

Dr. Larasatie is an Assistant Professor of Forest Products Marketing at University of Arkansas at Monticello (UAM). She is an interdisciplinary scholar and social scientist researching forest sector competitiveness and sustainable business management of natural resources. Her current research includes engineered wood industry development and workforce dynamics in the forest sector. She has published in top forestry journals such as *Journal of Forestry, Canadian Journal of Forest Research, and Scandinavian Journal of Forest Research*. She holds a PhD with a focus in Forest Products Marketing/Business and a Graduate Certificate in College and University Teaching from Oregon State University, USA, a Master of Forestry Science from University of Canterbury, New Zealand, and a Bachelor of Forestry from IPB University, Indonesia.


Lena Maria Leiter

Lena is a recipient of a DOC Fellowship of the Austrian Academy of Sciences (ÖAW) at the Institute of Wood Technology and Renewable Materials (BOKU). She is dedicating her PhD scholarship to the field of wood disintegration, with emphasis on triboelectric activation of wood surfaces. She likes to understand wood-tool interactions at molecular level, as well as in context of an industrial application. Lena is part of the Doctoral School “Build like Nature: Resilient Buildings, Materials and Society (Build.Nature)” and has a passion for (wood)science communication.

Weiqi Leng

Weiqi Leng is an Associate Professor at Nanjing Forestry University (NJFU) in China. He received his Master and PhD degrees from Mississippi State University under the supervision by Prof. H. Michael Barnes in 2015. He worked on the nanocellulose project as a post-doc at University of Maine from 2015-2016, and on the cellulose-lignin-derived polyurethane foam project as a research associate at USDA Forest Products Lab from 2016-2018. He joined NJFU in 2018. His major research interests are the modification and valorization of wood and bamboo-based materials including solid wood, cellulose, lignin, as well as their composites.

Dean Lipovac

Dean Lipovac is a researcher at the InnoRenew CoE. He completed a master's degree in applied psychology and a doctoral degree in renewable materials for healthy built environments at the Faculty of Mathematics, Natural Sciences and Information Technologies, University of Primorska, in Koper, Slovenia. His work is focused on researching the effects of the built environment on human mental health. He investigates how different materials used in indoor design influence physiological, emotional, and cognitive indicators of well-being. His long-term aspiration is to help create indoor environments that encourage a healthy mind and a healthy body.

Abasali Masoumi

I am a Ph.D. candidate at Department of Sustainable Biomaterials in Virginia Tech. All my background is in wood science and engineering: high school, B.A., B.Sc., M.Sc. and Ph.D. I have 4 patents and some publication. I worked 8 years for Furniture manufacturing company as a wood products specialist and I

was part time teaching instructor at university. My Ph.D. thesis is about Manufacturing Cross Laminated Timbers. Also, I am involved in 3 other projects: 1- The mechanical and physical properties of Thermally modified Apalachin hard woods; 2- Measuring bond line thickness of hybrid CLT; 3- Improving durability of CLT.


Armando McDonald

Armando McDonald is a Professor of Forest and Sustainable Products in the Department of Forest, Rangeland and Fire Science, University of Idaho (UI) with over 37 years' experience in bioproducts and biomaterials research and development and has presented and published 230 papers. Armando came to UI in 2001 from New Zealand Forest Research. His time at UI is devoted to mainly research and teaching with some service activities. Dr. McDonalds' group is currently investigating: (i) bioplastics, (ii) biocomposites, (iii) wood/stalk chemistry and properties, (iv) biofuels from pyrolysis of biomass and plastics, and (v) natural products chemistry.


Dan Meyer

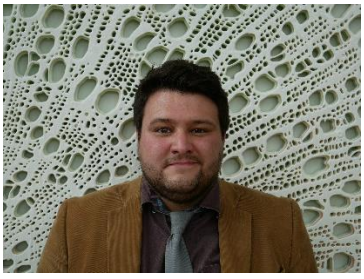
After a 30+ year career in forestry extension, hardwood industry technology transfer, and hardwood market analysis, Meyer is pursuing a doctorate in forest biomaterials, studying ways to improve hardwood forest management (by creating markets for small-diameter timber) and improve the viability of hardwood sawmills (by creating high-end products from kiln-dried sawmill residues). He holds an undergraduate degree in Forest Science from the University of Wisconsin, and an MBA from the University of Memphis).


Griffin Miller

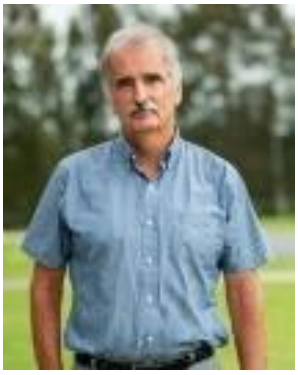
I am a third year PhD candidate at North Carolina State University. I have been working on biomass fractionation, modification and composites for my degree. I am currently acting as a visiting scholar with the University of Maine to gain more experience in composite science and to work in collaboration with Oak Ridge National Lab. I enjoy endurance sports and have loved cross-country skiing in Maine. I also enjoy hand-tool woodworking in my free time, building mostly furniture and small projects. I am excited to share my research and learn more about other areas and people in wood science


Jue Mo

I am Jue Mo, a Ph.D. student at Purdue University in the Department of Forestry and Natural Resources. My thesis is focused on the development of innovative hardwood products, and I have a strong interest in Cross-laminated Timber (CLT) manufacturing and Surface Thermal Treatment (STT). In my free time, I love watching movies and enjoying music. Aslo a big fan of all types of museums and puzzles.


Ian Morrell

Ian Morrell is a Post-Doctoral Scholar at Oregon State University in Corvallis, Oregon. Ian recently completed his doctorate at Oregon State in 2022 in wood science and civil engineering. Ian had previously completed an M.S. in civil engineering at Washington State University and a B.S. in civil engineering at Gonzaga University. His research focuses on mass timber structural systems.


Jeff Morrell

Dr. Morrell is a member of the Centre for Timber Durability and Design Life at USC where he works in the area of timber durability.


Roger Moya

Roger Moya Roque received his B.S from the Instituto Tecnológico de Costa Rica, M.S from Universidad de Concepción-Chile and PhD from Universidade de São Paulo-Brazil. He joined the Forestry School of Instituto Tecnológico de Costa Rica and has served on committees for large number organizations of Costa Rica. He has authored more than 130 scientific papers and 8 books. He is fellow of National Academic of Science of Costa Rica and fellow of International Academy of Wood Science


Nan Nan

Dr. Nan Nan is an Assistant Professor of Wood Science and Forest Products in the School of Agricultural Sciences and Forestry at Louisiana Tech University, USA. She received her Ph.D. in Wood Science and Technology from West Virginia University (USA), a M.S. in Forest Bioengineering and a bachelor's degree in Biology Science from Northeast Forestry University (China). She teaches courses in Wood Science and Forestry. Her research interests include sustainable biomaterials and bioenergy (e.g., bio-based carbon/biochar materials and value-added applications), biomass preprocessing and conversion, and

other innovative wood/forest products. She also serves as an Associate Editor for Forest Products Journal.


Francesco Negro

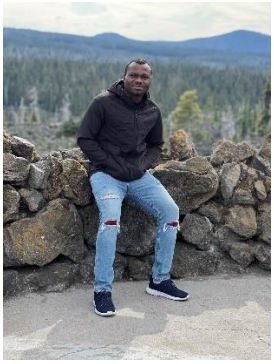
Francesco Negro is Associate Professor in Wood Technology at DISAFA, University of Torino, Italy. He is member of the Executive Board of Directors of SWST, and of the Editorial Board of the Wood & Fiber Science Journal. He is Editor of the book "Wood in Sport Equipment - Heritage, present, perspective". He mainly deals with properties, uses, development and sustainability of wood-based products.


Benedikt Neyses

Born in Trier, Germany. B.Eng. Mechanical Engineering at FH Aachen University of Applied Sciences, Germany, focus on processes and production. M.Sc. Wood Technology at Luleå University of Technology, Sweden. PhD in Wood Science at Luleå University of Technology, Sweden, research on wood densification. Currently Associate Senior Lecturer at Luleå University of Technology, Sweden. Research area 1: Development of a continuous densification process. Research area 2: Using AI to integrate the information flow in the wood industry. Side activity: self-employed design consultant in the climbing industry (climbing walls and grips, routesetting)


Liam O'Brien

Liam O’Brien is a first-year master’s student at the University of Maine. He is advised by Dr. Ling Li. Liam received his bachelors in Forest Operations, Bioproducts and Bioenergy at the University of Maine. During his time as an undergrad he worked at the Advanced Structures and Composites Center and conducted his capstone study on the influence of chemical treatments on thermal properties of cellulose nanofibrils. His current work is centered on wood fiber insulation and cross laminated timber building materials.


Ighoyivwi Onakpoma

Ighoyivwi (Igho) is an international student doing his PhD at Department of Wood Science and Engineering, Oregon State University. Igho is currently in his 3rd year and is focused on research in the effective and efficient utilization of wood. Igho loves playing and watching football (soccer) and spending time with family.


Gloria Oporto

Dr. Oporto’s main research interests are in the field of biomaterials from lignocellulosic sources, novel composites, nano-biocomposites, and in engineered wood-based composites. Main current

research projects: Development of Sustainable Novel Products from the Appalachian Forest, Promoting Climate Smart Forestry Through Forest Carbon Management and Forest Economies Training, Prototype of a Smart Edible Film Using Wood and Fungus Nanofibers.


Byung-Dae Park

Professor at Department of Wood and Paper Sciene, Kyungpook National University in Daegu, Korea since 2006. Research Scientist at National Institute of Forest Sciences (NIFOS), Seoul, Korea from 2002 to 2006


Yucheng Peng

Yucheng Peng is an Assistant Professor in the College of Forestry, Wildlife and Environment at Auburn University. He joined Auburn University in January 2020. Prior to Auburn University, he worked in the packaging industry for several years, holding positions as a materials scientist at Berry Global, In. and engineer at The Coca-Cola Company. His specialty is in polymer processing and forest feedstock based polymer composite formulation design. He also has a research interest in bioproducts, including the thermoconversion of biomass to biocarbon for various applications.


Perry Peralta

Associate Professor and Director of the Sustainable Materials and Technology undergraduate program, North Carolina State University.


Tomas Pipiska

Dr. Pipiska finished his Ph.D. study in 2020 in the field of wood-based composites. His research is focused on adhesives, bonding properties, and wood-based composites.


Brunela Pollastrelli Rodrigues

Brunela Pollastrelli Rodrigues is a Forest Engineer with master's and Ph.D. degrees in Forest Sciences from the Federal University of Espirito Santo, Brazil. She has experience in quantitative wood anatomy, wood identification, and wood properties in general. In recent years, her research has focused more on wood quality from forest plantations, especially studies investigating the influence of atypical climate conditions on eucalypt wood quality.


Christoph Preimesberger

Christoph Preimesberger is a PhD student in the field of fire behaviour of wood. After a BSc and a diploma in Wood Technology from the University of Natural Resources and Life Sciences, Vienna (BOKU), he started a working at Wood K plus (Competence Center for Wood Composites & Wood Chemistry, Austria). There he does fundamental research on the size dependent auto-ignition characteristics of wood and the influence of the temperature and duration of oxidative pyrolysis. Additionally, he works on

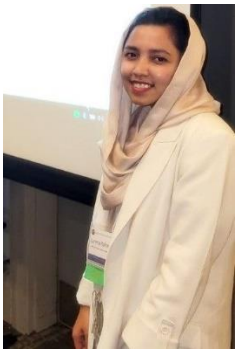
finding novel ways to analyse the fire properties on a small scale to optimize the burning behaviour of wood-based construction materials.


Lea Primozic

Lea Primožič is a PhD student at University of Primorska. She earned a Bachelor's degree from Marketing Communication and Public Relations at the Faculty of Social Sciences, University of Ljubljana. She then decided to continue her educational path at the Faculty of Economics at the University of Ljubljana where she earned her Master's degree in the field of Entrepreneurship. She is working as a PR expert at the research institute InnoRenew CoE. Her areas of interest are marketing communication, economy, science communication of health built environments, timber buildings and sustainable construction.


Rok Prislan

Dr Rok Prislan is holding the position of an assistant professor at the University of Primorska, where he teaches physics. On the research side, he is head of the newly established and equipped acoustics laboratory at InnoRenew CoE. His main research topics are advanced measurement techniques for sound field characterization and geometric modelling of room acoustics. Before joining InnoRenew CoE, Rok was an acoustic designer/consultant, managing over 60 projects in acoustics and noise control. He was responsible for the acoustic design of a wide range of buildings, including theaters, studios and concert venues.


Summia Rahman

Summia Rahman is a Graduate Research Assistant, completing her MS degree in the College of Forestry, Wildlife, and Environment at Auburn University. Recently, She won Auburn University's Three Minute Thesis (3MT) competition and represented Auburn University at the Conference of Southern Graduate School Conference (SGSC) in Raleigh, North Carolina, USA. She completed her Bachelor of Science degree in 2017 and her Master of Science degree in 2019 in Forestry major from Khulna University, Bangladesh.


Talbot Rueppel

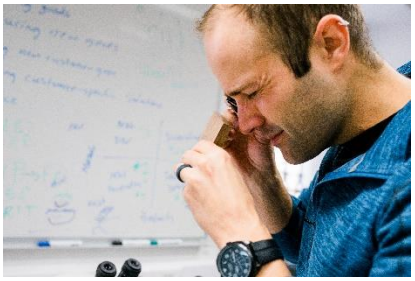
Materials Engineer for USACE at CERL in Champaign, IL. M.S. Wood Science graduate from Oregon State University in June 2022, and B.S. Renewable Materials graduate from the University of Idaho in May 2020. Experience in the dimensional lumber, OSB, paper/packaging industries.


Rico Ruffino

Rico Ruffino is an Assistant Professor in the Department of Forest Biomaterials. Currently, he serves as an instructor for Principles of Sustainable Product Development, Product Visualization, and Sustainable Product Development Capstone. Assistant Professor Ruffino has produced a Sustainable Design and Testing Service Center that aids companies in creating and testing new sustainable product development. He is developing a sustainable materials technology design lab within Hodges Wood Products Facility. It will enable students to design and fabricate more environmentally focused products. Some critical areas are utilizing technology that will streamline the ideation process to minimize resource use.

Tobias Schauerte

2009 Doctor in Forest Industry Production Systems, Växjö University/Sweden.. Since 2010 Assistant Professor in Industrial Engineering, Faculty of Technology, Linnaeus University, Växjö/Sweden. Schauerte has more than 20 years of experience in the wood building market and industry in Sweden and Germany. About 15 case studies were performed with house producers to investigate changeable off-site manufacturing systems, optimization of product and production platforms, factors that facilitate and hinder the market development of wooden multi-story houses and industry analyses. Schauerte is a board member of Forum Holzbau (=Forum Wood Building), Switzerland and since 2021 owner of Wood Building Nordic AB.



Matthew Schwarzkopf

Dr. Matthew Schwarzkopf is a researcher at the InnoRenew CoE and associate professor at the University of Primorska. He earned his PhD in 2014 from Oregon State University (Oregon, USA) with a dual major in wood science and materials science. Matthew holds an MS in wood science from Oregon State University (Oregon, USA 2009) and a BS in forestry from Iowa State University (Iowa, USA 2007). His research current research focuses on agricultural biomass utilization, the wood adhesives, and wood modification techniques.

Ján Sedliačik

Prof. Ing. Ján Sedliačik, PhD. is a teacher and scientific investigator of the Technical University in Zvolen, Faculty of Wood Science and Technology, Slovak Republic. Doctoral degree graduated at Technical University in Zvolen, in 2000, with the work titled: Optimization of polycondensation adhesives for wood products. Author of 19 international patents in the area of application of polycondensation resins for wood based materials. Co-investigator of several European projects solving new technologies of processing and application of protein hydrolysates for application in polymer resins.

Milan Šernek

Professor Milan Šernek received his PhD from Virginia Polytechnic Institute and State University, USA. He is currently a full professor at the Department of Wood Science and Technology, Biotechnical Faculty, University of Ljubljana, Slovenia. He teaches courses on adhesives and wood bonding, wood-based composites and technological process design. His research work includes wood adhesives, adhesive bond performance, bonding of modified wood and properties of wood-based composites. Recently, he has focused on the development and characterization of bio-based adhesives for bonding of wood.

Amy Simmons

Amy Simmons is a senior professional research assistant at InnoRenew CoE and IAM, University of Primorska, Slovenia. She specializes in effective science communication and outreach and researches gender inequality in science, technology, engineering and mathematics.


Workson Siwale

Workson Siwale is a final year PhD student in Environmental and Energy Systems at Karlstad University in Sweden and also a lecturer at Copperbelt University in Zambia. The focus of his PhD research is to increase the body of knowledge on understanding the self-heating and off-gassing of fuel wood pellets during storage. He holds an MSc Degree in Wood Material Science from University of Eastern Finland and a BSc Degree in Wood Science and Technology from Copperbelt University. He is a member of SWST and has previously reviewed manuscripts for publication in the Wood and Fiber Science Journal.


Lee Smith

Dr. Lee Miller Smith received his PhD in Mechanical and Energy Engineering at the University of North Texas in Denton Texas, where he studied under Dr. Sheldon Q. Shi in the Bioproducts Innovation Laboratory. His studies were focused on biomaterials manufacturing with an emphasis on natural fiber composites, pyrolysis, and activated carbon production. Lee is currently working as the Principal Investigator/Project Manager for Z&S Tech an engineering firm focused on bioproduct manufacturing.


Minami Suzuki

Minami Suzuki is a graduate student in the Science and Engineering at Chiba University, Japan. Her research interests are in the areas of timber engineering. She graduated from Chiba University, Japan. She has published her work in the research publication of proceeding of the architectural research meetings of the Kanto Chapter by Architectural Institute of Japan.


Andreas Tockner

Currently in a PhD-program "Build:Nature" which connects forest sciences and wood science, my project is "Person-Carried Laser Scanning in Forest Inventory". Graduated MSc Forest Sciences at University of Natural Resources and Life Sciences (Vienna). Visited Finland and USA for exchange semesters. Personal interest in wood quality and tree physiology


Marina Totsuka

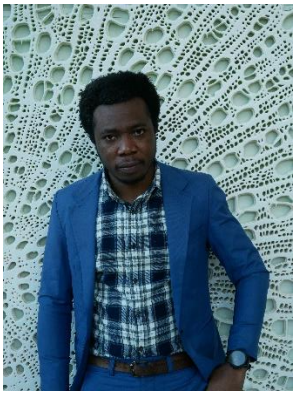
Marina Totsuka is an assistant professor in the Graduate School of Engineering at Chiba University, Japan. Her research interests are in the areas of wood-based materials and timber engineering. She has published her work in research publications including Journal of Wood Science, European Journal of Wood and Wood Products, Journal of Structural and Construction Engineering, and so on. She received her Ph.D. in Agriculture from The University of Tokyo.


Ting-ho Tsai

Ting-Ho Tsai is a master's student at the Department of Forestry and Natural Resources, at Purdue University. As a member of the Wood Research Laboratory, she works with the team and develops potential solutions to utilize abundant and underutilized resources - Small-diameter timber (SDT) in Indiana. For example, she is designing and prototyping products from timber, lumber, and chip. She desires to provide those options to the owners of SDT and forest product manufacturers. Thus, they could reduce underutilized resources and save more carbon in durable and valuable SDT products.

Ahmet Turer

Prof. Dr. Ahmet Turer graduated from METU - Civil Engineering Department in 1993 and pursued his graduate studies at the University of Cincinnati between 1995 – 1997 for M.S. and 1997-2000 for Ph.D. He has been a full-time faculty member at METU Department of Civil Engineering, Ankara, Turkey since 2000. His research interests are timber structures, Structural Health Monitoring & applications, historic structures, structural evaluation and strengthening, forensic structural damage investigation & root cause determination, bridges, strengthening masonry structures against earthquakes, steel structures, storage tanks, solar–hydroelectric–wind energy plants, marine structures, pipe structural damage, and Finite Element Modeling.



Kenneth Udele

Kenneth E. Udele is a graduate student in the Wood Science and Engineering department at Oregon State University, where he is studying to earn a doctorate degree in Wood Science. Born and raised in Ibadan, Nigeria, Kenneth obtained his Bachelors degree in Wood Products Engineering from the University of Ibadan, Nigeria. He also earned a Masters degree in Civil Engineering from the same university. Kenneth arrived the United States in the fall of 2019 to pursue his PhD in Wood Science. His research focuses on durability and performance of mass timber material and systems.


Fernando Urdaneta

Fernando Urdaneta was born in Venezuela, Maracaibo. He obtained his bachelor's degree in chemical engineering. Since August 2022 he has been a Ph.D. candidate at NC state's Forest Biomaterials Department. His works mainly focus on non-wood pulping for tissue and dissolving grade pulp.


Isabel Urdaneta

Isabel Urdaneta was born in Venezuela and got her bachelor's degree as a chemical engineer. She is a first-year Ph.D. student in the Department of Forest Biomaterials at North Carolina State University. Her research field is mainly related to Life Cycle Analyses of pulping processes, process simulation, and cellulose acetylation from wood and non-wood dissolving pulps.


Jan Vanerek

From 2002 until now he is employed as a researcher and academic worker at BUT, Faculty of Civil Engineering in the Czech Republic. As part of the research, he participated in the solution of several projects (basic research, applied research) dealing with the issue of adhesives for load-bearing wood structures, durability of wood, diagnostics of wood structures. Since 2005, he has been an authorized civil engineer (ČKAIT). Since 2003, head of the section Timber preservation and sanitation of the national society WTA CZ.

Cody Wainscott

From Houston Texas and currently pursuing PhD at Oregon State with a certificate in Energy Policy. My interest is in making sustainable biopolymers, energy production and in circulator economy material re-use. In my free time, I enjoy traveling, reading books, and exercising.

Hui Wan

Hui Wan received his bachelor degree in wood processing at Central Southern University of Forestry and Technology, China, his master degree in wood composite at the Royal Agriculture University of Copenhagen, Denmark and his Ph.D. in wood composites at Mississippi State University, USA.
He is working as a deputy director of International Collaborative Biomaterial Research Center at Southwest Forestry University. Before that he worked at Mississippi State University, USA and FPInnovations, Canada. He serviced as an adjunct professor at University Laval for about 10 years.
He was the Past President of Forest Product Society, USA.

Xueqi Wang

Xueqi Wang is enrolled as a second-year graduate student at the School of Forestry and Wildlife Sciences at Auburn University, studying Sustainable Biomaterial and Packaging. She was awarded a bachelor's degree in biological engineering from Nanyang Institute of Technology with an excellent thesis on the degradation of wasted products utilizing the method of microbial fermentation. Currently, she is focusing on a research project about the manufacturing of thermoplastic composites with high performance reinforced by spray-dried cellulose nanocrystals.

Rupert Wimmer

Is a full professor in Natural Materials Technology at the University of Natural Resources and Life Sciences (BOKU) in Vienna Austria, and currently the Past President of SWST.

Pei Yang

Pei Yang earned his Ph.D. degree in wood science and technology from Nanjing Forestry University in 2020. He is currently a post doctor in Nanjing Forestry University. His research interest is primarily focused on the development of copolymer adhesives for composite wood panels.

Lukmanul Hakim Zaini

IASP Scholarship holder, Ph.D. Student in Wood Technology and Renewable Materials at BoKu University, Austria. Lecturer at Faculty Forestry and Environment, IPB University, Indonesia. Visiting Scientist at Gifu University, Japan 2015 and 2016. MSc in Biocomposite Technology from University Putra Malaysia. BSc in Forestry from IPB University; GPA 3.63, Cum Laude, The Most Outstanding Student. Proven analytical skills, scientific and overseas experiences as visiting scientist, research assistant, and author of international journals and books. The Most Prospective Invention 2018 and 2021 (BIC), Best Paper Award at 2016 Asian Bamboo Symposium, 1st runner-up poster presentation at Introp Research Colloquium 2012, Malaysia

Ke Zhan

Ke Zhan is a second-year PhD student in forestry at Auburn University. He received a Master's degree in wood science and technology from Southwest Forestry University in 2021 in China. He also studied as a visiting scholar for three months in National Centre for Timber Durability and Design Life in 2020 in Australia. Ke's research interests focus on polymer composite manufacturing and characterization, polymer rheology and crystallization kinetics, superhydrophobic surfaces. His current research project aims to improve the compatibility of polymer blend by biomass resources, such as cellulose and wood fiber.

Xiaoyan Zhou

Prof. Zhou has 28 years R&D and teaching experience in wood science and technology. She has been engaged in surface modification of biomass materials and development of value-added bio-composites for a long time. Up to now, she has been responsible for more than 30 scientific research projects from government including 4 projects from National Natural Science Foundation of China. 208 papers has been published and 56 invention patents has been authorized. Her successful research on the manufacturing technology of plasma modified environmentally friendly wood composites won the Technical Invention Award from Ministry of Education and China Excellent Patent Award.

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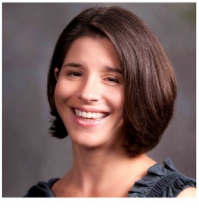

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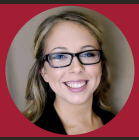

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