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Edited by
Susan LeVan-Green

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Valuable Composites and Adhesives 1

Student Posters

Monday, August 2

Keynote:

Clearing Hurdles to Forest Restoration in the Southwestern United States

Andrew Sanchez Meador
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Abstract
In the southwestern United States, restoration treatments are effective at restoring forest structure and function, preventing severe wildfire, and potentially mitigating the effects of climate change. However, significant hurdles still remain inhibiting ecosystem restoration at landscape-scales, ranging from big data challenges and workforce capacity to policy, economic and planning barriers. The Ecological Restoration Institute at Northern Arizona University works with scientists, policy makers, land managers, and the forest products industry to identify clear solutions to overcome these barriers and increase the pace and scale of restoration treatments. This keynote will provide an overview of issues facing forestry professionals and the five primary hurdles to successful forest restoration, along with potential and recommended solutions, in Southwestern forests and woodlands.

Approaches to Combatting Illegal Logging in Timber Trade

Chairs: Kristen Finch USFS International Programs, USA; Cady Lancaster, Oregon State University, USA

Combatting Illegal Loggins Using Wood Identification: The Global Context

Jason Grant, World Wildlife Fund, USA

Abstract
Not Available

Forensic Wood Identification Resources for Commercial Due Diligence and Quality Management

Cady Lancaster, Oregon State University, USA

Abstract
Not Available

Identification of North American Hardwoods: Wood Anatomists vs Machine Learning Models

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Abstract

Rapid and reliable wood identification is a core element of combating illegal logging, uncovering fraud and misrepresentation of wood products, and producing wood products (e.g., cross ties, wood access mats) where correct processing is species dependent. In this study, we evaluate convolutional neural network-based wood identification models on a large set of commercially important diffuse-porous and ring-porous North American hardwoods. We develop, evaluate and compare the efficacies of deep learning models, for the XyloTron platform, with different label space granularities – separate 23-class and 19-class models for diffuse-porous and ring-porous woods, a unified model with 42 classes, and models based on well-known hand lens identification keys. In doing this, we are able to objectively compare existing keys used by human identifiers within the XyloTron platform across a large set of commercially relevant hardwoods and take a step toward determining if and how wood anatomists fit into the wood identification ecosystem.

The Use of Stable Isotope Analysis to Verify the Origin of Wood

Charlie Watkinson, Agroisolab, United Kingdom

Abstract
Not Available

Exploring the Practical Limits of DNA-based Geolocalization in Forest Trees

Kristen Finch, USFA, International Programs, USA

Abstract
Not Available

Forest and Tree Values: Adequate Land Use, Products and Environmental Threats
Chairs: Frank Owens, Mississippi State University, USA; Ching-Hsun Huang, Virginia Tech, USA

Chip & Ship Pilot Project:
Logistics of suppling wood chips over long distances using railroad transportation

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Abstract

The lack of markets or facilities that utilize low-value woody biomass is one of the biggest barriers to accelerating the pace and scale of forest restoration treatments. Railroad transportation combined with underutilized (empty) intermodal shipping containers may open the possibilities of shipping wood chips long distances to domestic forest products business clusters and foreign markets. We carried out a pilot study to send wood chips from Arizona to South Korea to 1) test the logistics of using railroad transportation while sending woody biomass to oversea markets and 2) investigate loading times, weights, and productivity associated with filling intermodal containers with wood chips. We began an experiment by filling 58 intermodal shipping containers with wood chips at Camp Navajo, near Flagstaff, Arizona. Once filled, Burlington Northern Santa Fe (BNSF) delivered them to the Port of Long Beach, California for shipment by marine transportation to South Korea. During the six-day pilot project, researchers examined the productivity and logistics associated with moving intermodal containers into Camp Navajo, offloading the containers, filling them with chips produced from small-diameter logs by an on-site chipper, and reloading the filled containers back onto railcars. rail infrastructure, including 8,000 feet of new track and electronic rail switches, need to be completed prior to BNSF delivering a unit train (200+ containers/trip) to Camp Navajo. Site improvements, such as a reinforced concrete pad for the container loader, will also need to be completed. Long distance delivery of woody biomass using railroad transportation may be a viable option to deliver forest restoration materials long distance; particularly when considering limited truck driver availability, as well as a desire to reduce road traffic impacts and carbon emissions. Additional demand for wood products could increase forest industry development, employment, and economic stability for communities. Along with these benefits, delivering biomass both domestically and internationally can successfully implement forest restoration treatments needed to address the forest health and wildfire crisis in the US West.

Fundamental and Thermal Characteristics of Forest Logging Residues in the Eastern United States

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Abstract

Flowback water, generated from shale gas production, has been a concern to local environment and ecosystems, since it contains large amount of toxic heavy metal ions. Biochar could be a lower-cost and excellent adsorbent for removing heavy metal ions due to its high micro/mesoporous and surface features. Logging residue can be used as raw material to produce biochar product to purify the flowback water and improve water quality for reuses. In this study, a low-temperature carbonization approach was used to pyrolyze logging residue samples at different temperatures (375 - 475 °C), and different particle sizes (1 - 10 mm) to generate biochar samples. The flowback water was sampled from the local Marcellus shale gas fields. The investigated flowback water samples were diluted 10 to 50 times from the original samples due to the high concentration of the contaminates. The proximate and ultimate analyses were conducted to examine the primary properties of the raw materials. In addition, XPS, BET, SEM, FTIR, and adsorption tests were conducted at different adsorption conditions, such as different pH and temperatures, with three replicates. BET analysis and adsorption capacity results would help optimize the carbonization parameters, while FTIR and SEM analysis assist to illustrate the mechanism of the adsorption process.

Keywords: Woody Biomass, Logging residue, Carbonization, Biochar, Adsorption, Flowback water

Opportunities for Wood Sector in EU Climate Action

Andreja Kutnar, InnoRenew
Slovenia

Abstract
Not Available

International Trends In Innovation and Education

Chairs: Eva Haviarova, Purdue University, USA; Adam Taylor, University of Tennessee, USA

An Exploratory Evaluation of Higher Education Needs in Wood Science in Europe

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Background:

As we enter the third decade of the twenty-first century, climate change and environmental issues remain one of the major challenges for the future of our society. Since the first Earth Day in the early 1970s, society has recognized the increasing impact of humans on our environment. However, it is only recently that we have recognized that one of our most renewable, abundant resources can help us with this challenge. The growing and utilization of trees (which clean our air, store carbon, and filter our water) can help reduce man's impact on the environment. Finding new uses and markets for wood from our forests will allow us to better manage this resource and meet the growing needs of environmentally friendly products for society. In order to create new products and markets, we need young adults who are educated in the sciences and who can utilize wood most effectively.

Wood Science is an applied discipline in which scientists from a variety of fields (chemistry, business, civil engineering, pulp/paper, industrial engineering, physics, and packaging) work with the most abundant, renewable material on earth. Wood Science programs expanded greatly after the turn of the 20^{th} century with the expansion of the housing market and a strong increase in the demand for products manufactured from wood. In most colleges, this discipline grew out of forestry, drawing students with a strong interest in the science of what happens after wood is harvested. There has always been a high demand from the forest products industry for students from our programs. However, the discipline has always lacked appeal to students in high school. Students continue to have a strong misunderstanding, or no understanding, of wood science when choosing their college majors.

The Workshop:

To improve the quality of wood science education in Europe and address the need to attract more students to the discipline, the University of Primorska, in cooperation with InnoRenew CoE, hosted a workshop with the leadership of eight leading wood science programs in the European Union (Table 1) representing seven different countries. Efforts were made to invite department heads or senior representatives of the programs to this workshop. Prior to the workshop, participants were asked to complete a set of questions regarding their individual programs. Each representative provided a 30-minute overview of their particular program to the other attendees of the workshop, including any changes/planned changes. Upon completion of the presentations, an open discussion was held on the opportunities and barriers that exist for improving and expanding wood science programs.

Table 1. *Participating Universities*

Country	Program	University
Austria	University research institute	BOKU - University of Natural Resources and Life Sciences, Institute of Wood Technology and Renewable Materials, Tulln, Austria
Germany	Higher education institution (tertiary level)	HNEE - Eberswalde University for Sustainable Development, Eberswalde, Germany
Croatia	University research institute	SUMFAK - University of Zagreb, Faculty of Forestry, Zagreb, Croatia

Sweden	Technical Universities & Higher Schools	LTU WOOD - Luleå University of Technology, Wood Science and Engineering, SKELLEFTEÅ, Sweden
Austria	Technical Universities & Higher Schools	Salzburg University of Applied Science, Forest Products Technology & Timber Construction, Kuchl, Austria
Hungary	University research institute	USopron - University of Sopron, Faculty of Forestry, Institute of Wood Science, Sopron, Hungary
Slovenia	University	University of Primorska
Czech	University	Mendel University in Brno

Results:

Twenty representatives from eight universities attended the two-day workshop on the University of Primorska campus in Koper, Slovenia. Prior to the workshop, each university was provided a template to use to present their department's program and a questionnaire to complete for discussion. One representative from each university presented their program's information for approximately thirty minutes.

The first question that the delegates addressed was regarding any changes their departments have made in order to remain relevant on campus. Responses can be summarized by stating that they all have attempted to broaden their research base, move toward more collaboration with industry, expand their internal infrastructure in order to meet the new needs of research, and adjust their educational programs to meet the needs of a changing student population. Other responses included increasing their program's visibility on/off campus, hiring new faculty expertise, and adapting to uncertain university budgets.

The university participants were asked to identify the major issues driving change in their departments. The majority of responses included reduced support for wood science programs from the university/government agencies, reduced interest from students for the programs, an increase in focus on sustainability issues by stakeholders, and a lack of diversity within their programs. Other issues included the conservative nature of faculty, online educational opportunities, and an increasingly regulatory environment.

When asked to identify positive changes within their departments in recent years, participants responded that the economy has helped their efforts, along with new faculty positions, and increased industry participation/collaboration. Others responded that they have seen an increase in scientific publications, stronger extramural funding, improvements in teaching/research infrastructure, and in some cases, increased support by the university. There has been an increase in project-based learning in some programs which has improved learning outcomes. When asked what obstacles are impeding change within their programs, participants responded with a lack of resources, upper administration within the university (bureaucracy), and low salaries compared to industry. Others responded that faculties unwillingness to change, decreasing student applications, and low cooperation between faculty and administration were impeding their efforts.

The largest challenges identified by participants were adapting to the demographic and social changes occurring in society, recruiting good faculty and scientists, student recruitment, and a decrease in external research funding. Other items that were recognized as challenges included program visibility, adjusting teaching programs to be more relevant in the 21st century, increasing the retention rate of students in their programs, and increasing the internationalization of the programs.

The participants were then asked to describe our discipline today. Responses included: *"The principles of renewable resources;" "Wood Science has never been more relevant for the planet than today, but we have a problem;" "Wood science education is based on the triple bottom line: natural sciences, technology and the socio-economy;" "Wood science is a slow discipline in a fast changing world;" "Wood science is an interdisciplinary field focusing on material science and management of renewable resources;"* And, a comment that resonates as one of the major challenges we face was, ***"Wood Science is not among the top attractive disciplines for the new generation."***

Participants were then asked who they thought their customers are today and how have they changed.
Comments centered around how students have changed; showing more interest in the environment, more coming from urban areas, and it is still difficult to attract women into wood science programs. Others suggested that the industry has changed dramatically and our programs have not kept up with these changes. There were concerns about where future graduate students would come from and how to attract the new generation of faculty/scientists into the discipline. The decrease in government sponsored research funding has led to more industry research which has shifted the focus from fundamental research to applied research in some universities.

Student recruiting strategies varied among the universities. Some relied on their university or colleges' efforts to attract students, while others had active recruiting efforts for their departments. These include open house days for high school students and their parents, new brochures, workshops for high school teachers, participation in job fairs, and active social media sites. The general feeling was that most programs need to do a better job of recruiting. Finally, we asked individuals what they would like to see as the outcome of the meeting. Responses included more cooperation among wood science programs in Europe, sharing best practices with each other, finding methods to improve their programs, assistance in making wood science education strong and organized in Europe, help in attracting more international students, and eventually the development of a unified approach for a large project across Europe to increase awareness/research in wood science.

Upon completion of the department presentations, participants were asked to identify the top three opportunities and challenges that their wood science programs face. Table 2 summarizes all of their comments. From this list, participants attempted to identify the most important items in each category. Although it was difficult to come to a consensus, major opportunities that the group saw included increasing relationships with industry, capturing the sustainability aspects of wood science, focusing on experiential learning opportunities (practical experience) for students, and building better communication and relationships with all stakeholders. Key challenges that were recognized included the decreasing number of students in programs (student recruitment issues), recruitment of qualified professors/instructors, decline in funding for programs, inertia of faculty to change, promotion of the wood science discipline to stakeholders, and capturing the environmental (sustainability) aspect of wood science in our teaching/research efforts.

When asked how our discipline should change for the future, individual's responses fell into three themes: 1. Modernize the discipline; 2. Gain importance as a discipline/sector; and 3. Become more interdisciplinary or multidisciplinary. To modernize the discipline, suggestions included identifying the future skills, knowledge, and job profiles needed by students. We must remain experts in wood and biomass materials. We are an applied, technical degree focused on serving the industry with bachelor of science degrees; hence, we need to introduce innovative teaching methods using all forms of technology and social media to meet students' needs. To gain importance as a discipline, individuals recommended focusing on wood as the future of sustainable building materials and becoming leaders in coordinating different disciplines for the transformation to a sustainable environment and economy. They also suggested that we need to raise awareness of the importance of wood in solving environmental problems to funding agencies in order to increase research funding. To become more interdisciplinary, recommendations included looking outside of the traditional wood industry for new markets/products and to become recognized leaders in efforts around creating a circular economy. Wood science faculty should reach out to other disciplines and collaborate in teaching and research efforts in order to become more of an interdisciplinary science.

A common theme among participants' responses was that we do not communicate our message to those outside of our own discipline very well. Wood science does not have a common message or brand that is recognized by the public or other stakeholders. It was suggested that we come up with a uniform message ("*Save the World through Wood Science"),* and jointly, develop a communication plan to reach out to everyone.

This message can be conveyed through social media, press conferences, and the development of an effective public relations campaign. Participates believe we need to be more outspoken and self-confident with our external audiences.

Table 2. *Opportunities and Challenges of Programs in Wood Science*

Opportunities	Challenges
Refurbishment of classrooms and labs	Too few students in Wood Technology (masters) - renewal of the education
Focus on practical work for our students	Recruitment of good researchers/teachers
1 week field trip abroad	Long-term financing
Students projects in Ambienta	Quality research and education
Project of obligatory student's practice	Demographic changes
New professor positions were opened	Sociocultural changes
Increasing support of the study programs by companies/industrial partners	Change in study programs (number / specialization)
Increased financial support for PhD studies (2+2 years, increased scholarship)	Keeping up with economic, social, and technical changes
Economy	… and the system
Understanding among employees why our "orientation" is important	Recruitment of professors (we have three (two) open positions in the moment) – being able to work in teaching (high load), in research (able to apply for money), and in transfer and have international cooperation
Now, the industry understands our situation – and start to act with full power (and force the university to act…)	Recruitment of scientific staff / research assistants for research projects
Technological development	Students recruitment in dual study programs (cooperation with companies might be complicated)
Sustainability	Low success rate (around 40%), to long study time (9 semester or more than normal 7)
Our students	High demand of financial resources for maintenance and/or replacement of technical equipment/machines/laboratories
Third-party-financed research projects (and financial income) on all-time-high (more than 1 million €)	Internationalization
High number of scientific /research assistants (assistance in teaching possible)	Funding increasingly difficult – constantly underfinanced
Good financial support for transfer activities / establishment of dual study programs	Keep teaching programs attractive – find and strengthen our USP!
Stronger in referred publications	Bioeconomy not just a buzzword

Stronger in extramural funding (1 Mio / year)	To attract students
Industry collaborations	To attract research projects
Mainly building young team that is motivated	To provide high quality research and, at the same time, high quality education
Joining “fundamental” and “applied” departments	To attract and keep young scientists
Open and warm communication between leadership and employees	Participation in EU founded projects (H2020)
	Attracting talented new students
	Slowly increasing innovation potential of the Hungarian wood industry
	How to become more productive – attract more students and projects
	How to become more visible – get more space in media
	How to make our discipline more attractive
	How to motivate teachers to adjust their approach to students

When asked how the participants believed that we could reach these goals, they suggested a joint initiative of wood science programs in Europe, focused on demonstrating to government funding agencies (EU) that renewable biobased materials are a major solution to climate change and could be the basis for a new economic system, such as the circular economy. Increased collaboration and communication among all EU based wood science programs is needed to push our movement forward. Individuals suggested a follow-up meeting focused on determining how to move forward with this communication effort.

Conclusion

This workshop was based on one held in the United States in May of 2018* at Virginia Tech. Both workshops indicated that wood science programs are unique due to the needs of the local university and community in which they are located. However, programs in both regions indicate that similar opportunities and challenges impact the future of wood science education across the world. Everyone agreed that using wood will greatly help the climatic and environmental problems that we face and that there is a strong need for more students to enter this field in order to help address these issues. There is also agreement on both continents that our educational programs have not kept up with the changes occurring in society, and we do a very poor job of communicating our message to those outside of our discipline. In conclusion, what Smith* stated in the above-mentioned article holds true for the findings of the workshop held in Koper. *"We live in the best possible time in history to capture wood science and forest products education to make a dynamic impact on society's environmental and economic future. Are we up for the challenge?"*

In 2019, Europe laid out their vision to make Europe the first climate-neutral continent by 2050; due to this, the importance of wood is increasing and opening new opportunities. The ambitions to safeguard biodiversity, establish a circular economy, and eliminate pollution while boosting the competitiveness of European industry require that educational programs adjust as well. First, changes are already being seen and new study programs are evolving. For example, in Montpellier (France) a new masters Wood Science program is starting in September 2021. This program is interdisciplinary and is being offered in collaboration with the industry through company internships. Furthermore, at University of Primorska, a new PhD program, Renewable Materials for Healthy Built Environments, started in 2020. The fundamental or predominant field of this program is wood science with emphasis on sustainable construction along with the interdisciplinary integration of other sciences. There appears to be increasing opportunities in Europe for wood science education to help solve our world's climatic issues.

* Smith and Valverde, 2019. *"THE CURRENT AND FUTURE STATE OF WOOD SCIENCE EDUCATION IN THE UNITED STATES"* Wood and Fiber Science, 51(2), 2019, pp. 221-230 https://doi.org/10.22382/wfs-2019-022.

"Back to the Future" the University of Maine's New Sustainable Materials and Technology Major

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Abstract

Over the past several years, the University of Maine faculty responsible for the SWST accredited academic program in forest operations, bioproducts and bioenergy performed an in-depth assessment of the low enrollment program to determine the best path forward to provide a vibrant education in a forest products, materials-based academic curriculum. We reached out to alumni, stakeholders and on-campus students to determine whether an academic program closely aligned with the engineering disciplines would be an attractive alternative to the current offering. We also surveyed what other forest products-based programs in North America were doing as part of the assessment. According to the promising feedback received, we are pleased to introduce the UMaine's new Sustainable Materials and Technology (SMT) major. The Bachelor of Science in SMT involves multiple academic disciplines and aims to produce professionals with strong abilities to assess and communicate the technical foundations of how forest and other plant-based materials can be sustainably produced and converted for a variety of applications ranging from traditional wood products to emerging sustainable materials and bioenergy systems throughout the entire life-cycle of the products. The SMT program outcomes provide a holistic approach to the understanding and application of concepts necessary for product design and the conversion of renewable feed stocks to a wide variety of materials and products. By requiring more science and engineering courses for academic background, the rigor of the new SMT program harkens back to the wood science and technology curricula of the past century. Graduates of the SMT program are prepared for careers in the administration and supervision of sustainable material processing facilities. Specific career areas include: process and production supervision and quality control; sustainable material business/marketing, new product development, and sustainable material procurement.

Undergraduate Research in Mass Timber and Digital Manufacturing: A Multiple Year Experiential Learning Project

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Abstract
Undergraduate research experience has proven to improve student learning and retention. Since 2018, Dept. of Wood Science and Engineering at Oregon State University is offering Research and Extension Experiences for Undergraduates (REEU) with support from the USDA NIFA AFRI Education and Workforce Development program. Over the last three years, 32 undergraduate students have conducted research and gained experience in extension projects for a period of 12 weeks with 22 different mentors from 4 different departments and 2 different institutions. These students come from many institutions nationwide and have diverse backgrounds and experiences. Efforts are directed towards attracting, recruiting, and retaining, a diverse application pool. This presentation will introduce the framework of the REEU site; selection of students, mentors, and projects; successes and lessons learned from offering these experiences; examples of student projects; and plans for the future. Based on interviews with both REEU mentors and mentees, four advantages are highlighted: obtaining new skills, networking benefits, adapting to new situation, and being independent.

DIY Structural Lumber Grading

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Abstract
There have been a number of state laws enacted that enable small mills or forest landowners to mill, grade and use their own structural lumber. These laws provide an exemption from the building code, which requires the use of grade-stamped structural lumber. The context, motivation and status of these laws will be discussed.

Equality and Inclusivity at Research Institutes

Amy Simmons

InnoRenew CoE and University of Primorska, Slovenia

Abstract
Not Available

Pathways to Sustainable Materials Science and Engineering: Enhancing College and Career Opportunities for Minority Women from Rural North Carolina

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Abstract

North Carolina State University's Department of Forest Biomaterials has successfully instituted a STEM-based Sustainable Materials and Technology undergraduate curriculum. Program faculty proposes to extend this success to K-14 students to prepare future workforce in the holistic discipline of sustainability. A grant was obtained from the US Department of Agriculture that focuses on minority women attending community colleges since historically they have been under-represented in the forest biomaterials field. The goal is to expand their opportunities for college and professional careers in sustainable materials science and engineering. This is accomplished by providing a multi-tiered support system at every phase of the student's postsecondary academic career --- specifically through community support, academic mentorship, experiential learning, community research projects, professional development, and university scholarship/admission guidance. The project aims to enhance the participants' scientific and professional competencies, leadership and communication skills, professionalism, critical and problem-solving skills, and team-building ability. In addition to providing project details, the presentation describes the progress made during the project's initial year of implementation and the challenges encountered related to COVID-19. We aim to connect with an audience that is concerned with educational equity especially for women of color.

Tuesday, August 3

Business, Market Developments and Regulations
Chair: Henry Quesada, Virginia Tech, USA

Structural Grade Hardwood Lumber Economic Feasiblity

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Abstract

Expanding Market Opportunities for Fire-Retardant-Treated Wood through Regulation

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Abstract

The 2020 wildfire season in the United States was catastrophic. The National Interagency Fire Center reported 10.27 million acres were burned, which is the highest total observed since accurate record-keeping started in 1983. Previously, the highest total was 10.13 million acres in 2015, but over half of that total was due to landscape-scale fires in rural Alaska. By comparison, in 2020, almost all (>98%) of the acreage burned was in the contiguous U.S.

As one might expect, the costs from direct, indirect, and insured losses increased substantially, too. The $16.5 billion in damages sustained in 2020 was the third-highest total on record. Indirect costs from environmental restoration, business closures, and lost tax revenue could push the season's total cost to as high as $150 billion. While 43 people lost their lives to the wildfires, thousands more are suspected to have died from the effects of wildfire smoke inhalation.

To counter the increasing threats and impacts from ever-intensifying wildfire seasons, communities are making greater use of proactive tactics, such as defensible space and hazardous forest fuels reduction. Closer to homes, another tactic receiving increased usage is home hardening, an approach where the selection of building materials may give owners/occupants more time to evacuate a burning structure while also giving first responders more time to try to save that structure.

One option for home hardening is to use pressure-impregnated fire-retardant-treated wood (FRTW). FRTW products are defined in the 2018 International Building Code (IBC) as "wood products that, when impregnated with chemicals by a pressure process or other means during manufacture, exhibit reduced surface-burning characteristics and resist the propagation of fire." Once through the chemical impregnation process, fire-retardant treatment of wood improves fire performance by greatly reducing the amount of flammable gases released, thus reducing the rate at which flames spread over the surface. Treatments reduce the amount of heat available or released by the volatiles during the initial stages of fire and result in the wood self-extinguishing once the primary source of external fuel is exhausted.

FRTW has many advantages when used to reduce a structure's susceptibility to wildfire. It can be sustainably produced from locally harvested trees, thereby reducing hazardous forest fuel loads while supporting local economies. Because it resists fire, FRTW can be used in the wildland-urban interface (WUI) as allowed in the International WUI Code. It provides permanent, passive protection as the chemicals used to treat the wood do not require power or water to operate, so blackouts and droughts do not hinder FRTW's performance.

Given the dramatic increases in wildfire-related damages over the past few decades, efforts to increase the use of FRTW in the wildland-urban interface are increasing. This paper will provide

an overview of the 2020 wildfire season impacts in the United States, describe the various approaches to wildfire response, define home hardening and FRTW, and then conclude with a summary of recent policy and building code changes and proposals to promote FRTW's use in the market.

Flexible Biorefining For Renewable Feedstocks In Wood Adhesives

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Abstract
The ongoing 'Pro-Enrich' project was developed to create and demonstrate new bio-based value chains that support a circular economy within the EU. Over the last few years this project has implemented a flexible biorefining approach that has processed four types of agricultural by-product feedstock, creating valuable industrial intermediary products that have been used in food, cosmetics, and adhesives for wood products. The adhesives market is currently dominated by synthetic adhesives which have good performance in the manufacturing environment, end-use durability, and favourable cost-to-quality ratio. However, these adhesives rely on non-renewable resources and there is a need for renewable alternatives. This presentation will introduce the Pro-Enrich project and its innovative biorefining process, potential markets for targeted compounds, and evaluation results from end-user trials.

Economic Ripple Effects and Environmental Contributions of Multistory Wooden Building by Input–Output Analysis

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ABSTRACT

The use of timber in multistory buildings is gaining worldwide attention from the perspective of mitigating climate change, such as reducing greenhouse gas emissions and carbon storage. It is also expected to enhance the use of adequately managed forest resources and, through the revitalization of forestry, to demonstrate excellent performance in the carbon dioxide absorption capacity of forests and the development of rural economies. The promotion of multistory wooden buildings contributes to society's sustainable development from environmental and economic perspectives. Input–output analysis is a method to evaluate these perspectives simultaneously. Herein, we designed a residential wooden building model (R model) and a nonresidential wooden building model (nR model) as wooden building structures. Each model contains 4–14-story wooden structures. We estimated the economic ripple effects and greenhouse gas emissions of these models through input–output analysis. An extended input–output table was developed based on Japan's official 2015 Input–Output Table to analyze the use of timber in this study.

Input–output analysis can estimate the economic ripple effects and greenhouse gas emissions caused by an increased demand for a particular product in the industrial classification listed in the input–output table. As CLT and glued laminated timbers are commonly used in wooden multistory buildings, it is advisable to distinguish the relevant industries from other wood industries when conducting an input–output analysis. We developed an extended input–output table in which the glued laminated timber industry was independent of the existing industrial classification list. The building models assumed to be 4–14-story buildings with a floor area of 648 m^2 per floor. The amount of timber in the models was estimated via structural calculation. The volume of timber of the 14-story building was 1859.8 m^3 for the R model and 3039.1 m^3 for the nR model. According to the input–output analysis, the amount of induced production in Japan is 1.62–1.65 times the final demand for each model. The induced production was higher in the nR model than in the R model and was higher in the upper floors of each model. We will further analyze the environmental influences of timber used in the models by extending the industrial classification of greenhouse gas emission intensities.

Keywords: *input-output analysis, economic ripple effect, multi-story building, wood products, sustainable development*

Mass-Timber Panel MTP Industry and its Supply/Value Chain

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ABSTRACT

The mass-timber panel industry is an exception in the traditional commodity-oriented forest products industry at large, even if one compares it to quite sophisticated engineered wood products like glulam, I-joists or LVL. With possible exception for glulam decks, unidirectional nail- or dowel-laminated timber panels and CLT used for industrial mats, all structural cross-laminated timber panels discussed in this presentation are specialty products, custom produced and fabricated for specific projects. Historically, there have been strong incentives for panel manufacturers to enhance and control the project acquisition by integrating a certain level of architectural and engineering design services, project management, and quite often construction services or construction supervision. There are also intrinsic barriers making commoditization of MTPs extremely difficult. The principal issues are the large dimensions and mass as well as the embedded value of individual panels. The industry shows no appetite for carrying the cost of intermittent storage of massive panels and waste generated if standard-sized panels would have to be substantially trimmed for specific projects. Producing prefabricated panels finished for specific design and on-time delivery to the construction site is, for now, the most efficient solution. The panel production is but a stage in an integrated process that begins with project commission and ends with closing the shell of a building. Therefore, the supply/value chain of mass-timber panel industry is more complex than commodity engineered wood products, and involves firms providing architectural and engineering design services, project management, manufacturers of connectors, insulation and siding, as well as construction crews. The interaction of panel manufacturers with their supply/value chain and the level of vertical integration vary substantially between companies and show some regional flavor. The purpose of this presentation is to provide insights in the unique way the MTP industry interacts with its supply chain.

Keywords: cross-laminated timber, mass-timber panels, supply chain, value chain

INTRODUCTION

Organic development of the global mass-timber panel (MTP) industry since early 1990s has produced substantial diversity in manufacturing processes, levels of automation, scales of operation, products and services options as well as in market strategies. The development has not followed typical commodity-oriented forest products industry models and it is difficult to provide an adequate precedent. Existing global PTP operations provide a living laboratory that provides understanding of both the current state-of-the-art as well as the trajectory and future development of the CLT industry. Especially important are insights for how newly emerging markets may develop.

The focus of this paper is focused on the unique way the MTP industry interacts with its supply chain.

MATERIALS AND METHODS

The information included here is derived from three major sources of information: 1) industry surveys (Muszyński et al. 2017, Albee 2019, Larasatie et al. 2021); 2) targeted site tours of CLT/MTP manufacturing lines (Albee et al. 2018, Muszynski et al. 2020); and 3) review of trade journals tracking the development of the CLT/MTP industry (e.g. Jauk 2019) and public web profiles of CLT/MTP companies and CLT/MTP hardware manufacturers (e.g. MHM 2020, TechnoWood 2020, Thoma et al. 2020).

Wherever possible, the data obtained from different sources were verified against each other.

To ensure anonymity, information is presented in aggregate format.

DEFINITIONS

The MTP industry is most prominently represented by adhesive-bonded structural cross-laminated timber (CLT), that is commercially fabricated massive composite panel product comprised of cross-layered pieces of dimension lumber or structural composite lumber (SCL) bound together by structural adhesives. However, this presentation includes some information on similar cross-laminated mass-timber panels made of dimension lumber but bonded with nails or hardwood dowels. While the most apparent distinction between these three is the way the layers are bonded together, they also differ substantially in the raw material sourcing, manufacturing technologies, load bearing capacities, and, consequently in the scope of potential uses. These three have been briefly characterized by Muszyński for two earlier reports (Sanchez et al. 2020, Anderson et al. 2021) as follows:

Cross-laminated timber (CLT), the best known, and the most common of these three, is defined as “a prefabricated engineered wood product made of at least three orthogonal layers of graded sawn lumber or structural composite lumber (SCL) that are laminated by gluing with structural adhesive.” (ANSI/APA 2019). Currently, there are more than 70 CLT manufacturing companies operating all over the world, including at least 7 running two lines at the same location. The global production of structural CLT for 2020 has been projected to about 2 million cubic meters, of which about 65% is still coming from the Alpine region and about 40% from Austria alone (Jauk 2019). Most of the CLT is certified for structural use in many countries and is being used in construction of tall mass-timber structures.

However, at least three companies in North America produce adhesive bonded CLT access mats, rig mats or “temporary timber pavements,” which are considered a non-structural commodity. Now, this is an exception within the exceptionally non-commodity industry.

MHM or **Mass-Timber Wall** is a massive prefabricated cross-laminated panel whose layers, rough sawn boards, are bonded with nails. This product should not be confused with one described as nail-laminated timber or NLT, commonly used as beams and floor panels in timber structures in North America, where all layers are oriented parallel to each other. The MHM technology might had predated the development of the adhesive-bonded CLT, but the real breakthrough came with a Solid Timber Wall system patented in Germany in 2005 as Massiv-Holz-Mauer (lit. mass-timber wall), or MHM (MHM 2020). MHM is fabricated on small scale turn-key three-step Hundegger production lines. The lines consist of specialized molders cutting shallow grooves along the laminations to increase R values of layups, automated layup (Figure 1a), a robotic nailing station and a CNC finishing center. Relatively short fluted aluminum nails do not interfere with cutting tools. The intended use of this product is as load bearing and division walls for low raise buildings in moderate exposure to moisture (below 20%) and at low to moderate exposure to corrosion (MHM 2020, OIB 2017).

There are about 30 licensed MHM plants across Europe, and the latest assessment of their total output in 2018 was about 73 thousand cubic meters (Jauk 2018).

Dowel bonded CLT is a massive prefabricated cross-laminated panel whose layers, rough sawn boards, are bonded with hardwood dowels. This is the latest of the cross-laminated timber products and should not be confused with one marketed in North America as dowel-laminated timber or DLT, for use as beams and floor panels in timber structures, where all layers are oriented parallel to each other. The low moisture content and tight fitting of the dowels at the time of assembly assures durable tight connection once the dowels swell as they gain moisture in the ambient conditions. The panels are assembled in highly automated lines. Only two commercially successful systems are known to-date: 1) developed by Thoma Holz 100 company in Austria (Thoma 2020) and 2) developed by Swiss industrial hardware manufacturer TechnoWood (Nägeli and Webstobe 2019, TechnoWood 2020). By mid-2019 the latter company installed 8 highly automated lines in Europe. Unlike other CLT products, some layers of the dowel bonded CLT are arranged at 45 or 60 degrees to the surface layer direction (Figure 1b). The dowel-laminated CLT panels are intended for use as load bearing wall, floor and roof panels in low raise (up to 4 story) timber structures (TechnoWood 2020).

RESULTS AND DISCUSSION

It is important to stress again that the mass-timber panel industry is an exception in the traditional commodity-oriented forest products industry at large, even if one compares it to other sophisticated engineered wood products (EWP).

GENERAL COMMENTS

All structural cross-laminated timber panels discussed here are specialty products, by which we understand that all panels are custom produced and fabricated for specific projects. If one does not count glulam decks and unidirectional nail or dowel laminated timber panels (NLT/DLT), prefabricated mass-timber structural panels have no serious precedent in timber construction, offering new opportunities in design and construction to professionals intimately familiar with the product. The similarity with precast concrete panel industry is limited to that the later also produces premanufactured components and delivers them to address specific project requirements.

Historically, however, there have been strong incentives for companies to control the project acquisition process by integrating certain level of architectural and engineering design services, project management, and quite often construction services or construction supervision. In this regard, buildings are the actual product of the industry, and the panel production becomes a stage in a process that begins with project commission and ends with closing the shell of a building. In reality, the level of vertical integration varies substantially both between and within the three products discussed.

Another common theme is the existence of intrinsic barriers preventing commoditization of massive cross-laminated panels even in most developed markets. The principal issues are the large dimensions (up to 20 m x 4 m) and mass (up to 5.5 metric tons) as well as the embedded value of individual panels. Contrary to common perception it is the robotized prefabrication that enables the use of MTP in construction, not the other way around Currently, it simply does not make much sense for anyone in the industry to carry the cost of intermittent storage and waste generated if standard-sized panels would have to be substantially trimmed for specific projects. Custom cutting of massive panels at the construction site is next to impossible with currently available technology. Producing prefabricated panels finished for specific design and on-time delivery to the construction site is for the time being the most efficient solution. While there are companies that are starting to offer prefabrication services on "commoditized panels," it remains to be seen how they will fare. All these circumstances define the mass timber panel industry a specialty industry, with products delivered to the market not as standardized panels but as building shells or even finished buildings.

Consequently, compared to commodity-oriented EWPs, the value chain of mass timber panel products is much more complex (Figure 2). Apart from elements common to traditional commodity oriented WEPs: forestlands, harvesting operations, primary processing, specialty hardware manufacturers, adhesives and specialty treatments suppliers and transportation of logs, lumber and components (Figure 2a); the MTP industry supply/value chain must incorporate all elements necessary to complete a structural shell of a building o a finished structure. These necessarily involves architectural firms that serve as sort of external project acquisition gates to the process, civil engineering offices, and project management on one side; and specialized connectors manufacturers, insulation and siding products, and construction crews on the other (Figure 2b). An interesting characteristic is a large role of the providers of specialty software platforms enabling architectural and engineering modeling as well as project integration and smooth communication between all involved parties from conceptual design to building assembly and finishing.

Since the industry is pushing envelope in innovative design and construction technologies, research and development (both internal and funded from public grants) plays much more important role in adding value to the final products, many of which are first of its kind structures hitting headline news. Another element of the supply/value chain whose role is much amplified by the novelty of MTP technology is education and training. The new level of complexity of the production, automated production lines, different position of the manufacturers with thee market and with the supply chain require new types of skills from employees on all levels of the company, from the production floor workforce, through engineering, sales, to the management. MTP companies have are also involved in educating their suppliers, who may need to be alerted to their special needs, often quite different from the everyday market average within the broadly understood forest product sector. The technology provides new opportunities to architects and designers, but again a good deal of education and training is required to capture those opportunities and make the best of them. Yet another area where new approaches and skills are necessary on all levels is the construction, or rather assembly site. Finally, the manufacturers are often involved in public outreach to educate potential investors, communities, local authorities, fire marshals, code and standardization authorities, on the safety, benefits and opportunities of mass-timber in order to secure permissions and invite commissions. Anecdotally, about 50% of the time of the senior personnel of MTP companies in emerging markets is committed to just that: education (Kremer 2018).

Historically, there have been strong incentives for panel manufacturers to get involved and even control the project acquisition, design and construction by getting all parties involved in the process (from investors and architects to contractors) to the table at the same time and possibly early. This unique central position in the process crated both incentives and opportunities for integrating a certain level of architectural and engineering design services, project management, and quite often construction services or construction supervision.

Most adhesive-bonded CLT and all dowel-bonded CLT producing companies show some level of vertical integration within their complex value chains. This trend is well reflected in both surveys Global CLT Industry conducted by the Authors (Muszyński et al. 2017, Albee 2019, Larasatie et al. 2021). Figure 3 illustrates a comparison of the number of companies responding to the survey question on the ownership of the supply chain elements in two surveys of the global CLT industry administered two years apart. The respondents were asked to select the predefined elements of the supply chain: forestland ownership, log transportation, lumber manufacturing, lumber transportation, CLT reansportaton, building engineering, architectural design, real estate ownership, building construction and “other.” The grey bars show responses to survey conducted in 2017 (n=21) and the orange bars represent to the survey conducted in 2019 (n=12). The circles visualize the respondent overlap between these two surveys (n=4). Both show a relatively high fraction of companies involved in some level of vertical integration, particularly when one considers a small sample size don a very small and extremely diverse industry.

Given the inert nature of company structure and narrow overlap between these two surveys, it is possible to pool the data without much risk of diminishing inadvertent impact on the confidence of the overall picture. The four responses overlapping responses from the earlier survey were removed from the pool to avoid redundancy. The pooled data (combined n=32) parsed by number of respondents are shown in Figure 4. When the responses are weighed by annual output volume contributed by the responding companies (Figure 5) it is possible to gain some sense of the choices made by the largest players in the industry: lumber manufacturing, building engineering, panel transportation and construction.

These trends are further corroborated by direct interviews and observations made during site tours.

The most common model emerging from all sources of information combined is one that integrates in one company structure the engineering and detailing services, a level of project management, transportation of element assemblies synchronized with construction sequences and at least some role in construction supervision. Other services are outsourced to closely allied partner companies familiar with the technology (Figure 6a). However, there are companies that offer architectural design offices; transportation; construction services; customized connectors, pre-installation; and, in one case, custom manufacturing of their own windows/doors, floor finishes, insulation, and external siding. Some companies own forestlands and sawmills. On the other extreme, there are also a few small-scale companies that focus exclusively on fabricating panels for external orders, outsourcing all other functions to the parent companies. Examples may be found in Japan and Finland.

Finally there is a growing number of contractors offering integrated construction services in mass timber panels except the manufacturing step alone (e.g. Land Lease, Eurban, Swinnerton; Figure 6b). by the end of 2020, Eurban boasted 311 mass timber/CLT projects realized in the UK. All from imported CLT prefabricated specifically for the projects (Eurban 2020). Although this may be an indicator of a future trend, it is not a common arrangement, and vertically integrated mass timber panel companies seem to benefit from their control of a range of aspects of project development.

SUMMARY

The mass-timber panel industry is an exception in the traditional commodity-oriented forest products industry at large. Structural cross-laminated timber panels are specialty products, custom produced and fabricated for specific projects. Large dimensions, mass and the embedded value of individual panels remain potent barriers for commoditization. Producing prefabricated panels finished for specific design and on-time delivery to the construction site is, for now, the most efficient solution. The panel production is but a stage in an integrated process that begins with project commission and ends with closing the shell of a building. The complex supply/value chain of mass-timber panel industry is reflecting this reality. There are strong incentives for panel manufacturers to integrate at least certain level of architectural and engineering design services, project management, and quite often construction services or construction supervision. The interaction of panel manufacturers with their supply/value chain and the level of vertical integration vary substantially between companies and show some regional flavor.

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LIST OF FIGURES

FIGURE 1

a) b)

Figure 1: A section of MHM showing longitudinal grooves in laminations intended to enhance the thermal-insulation properties of the panels (MHM 2020) (a) and a dowel laminated panel showing the 60-degree layer (photo cr. L.Muszynski).

FIGURE 1
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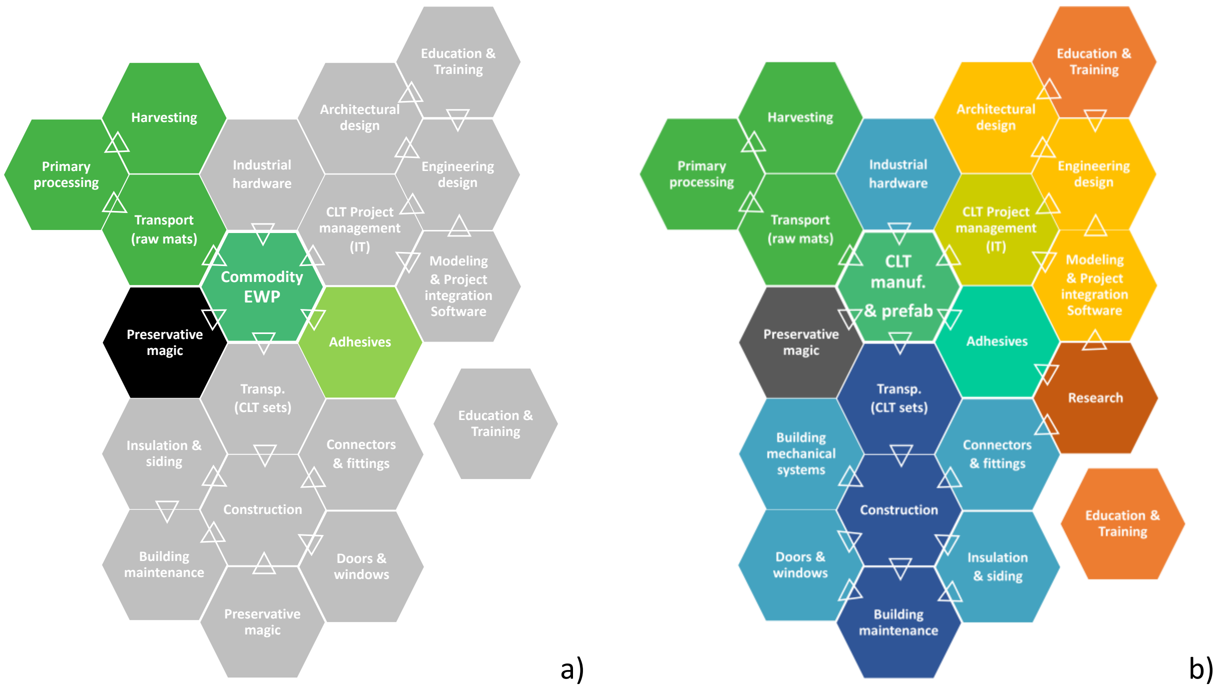

Figure 2: Typical supply/value chain model of an EWP company (a) compared to a possible supply/value chain of a CLT company where the final product is a building (b).

FIGURE 2

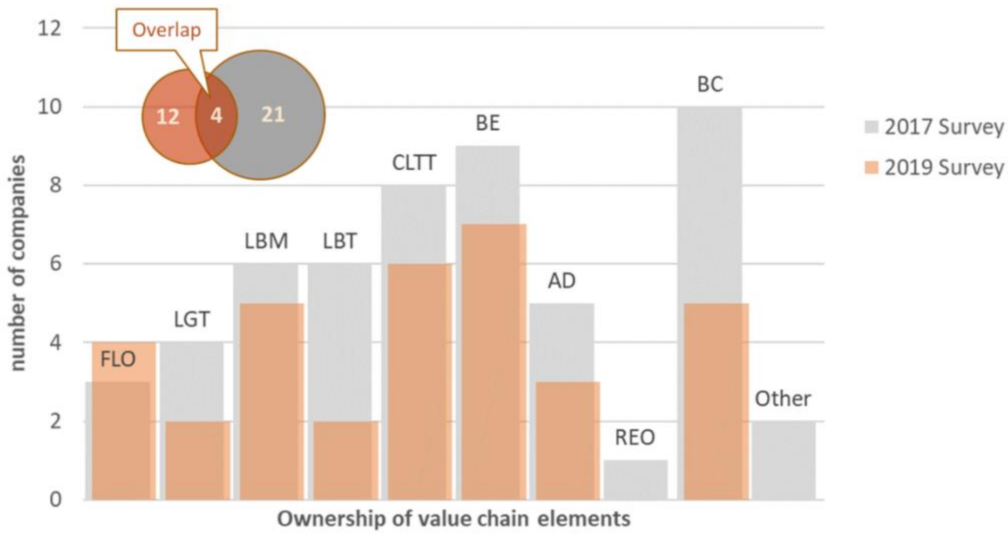

Figure 3: A comparison of the number of companies responding to the survey question on the ownership of the supply chain elements in 2017 (n=21, grey) and 2019 (n=12, orange). The circles visualize the respondent overlap between these two surveys (n=4).

FIGURE 3

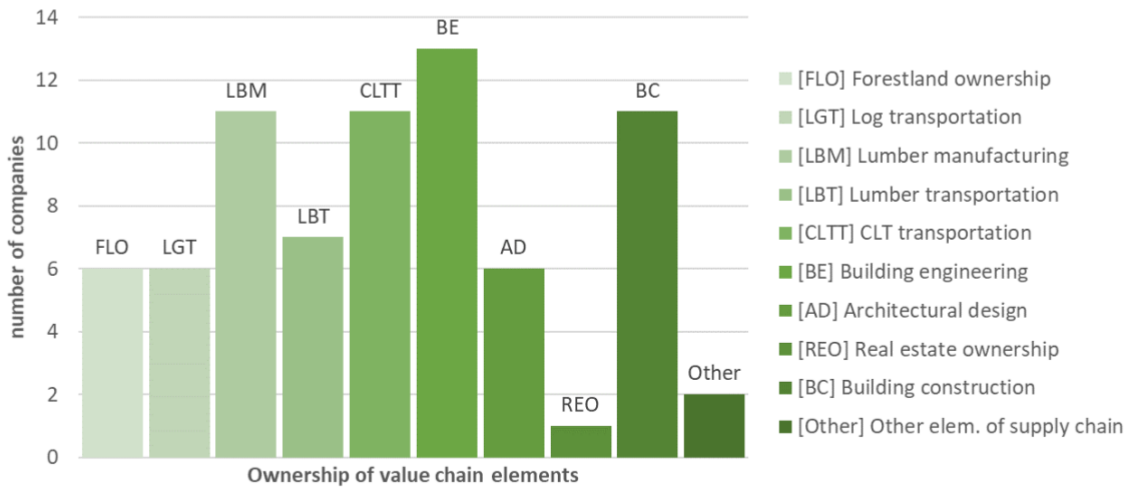

Figure 4: Ownership of the elements of the supply chain by number of respondents (n-29, combined response from 2017 and 2019 surveys, excluding the overlap).

FIGURE 4

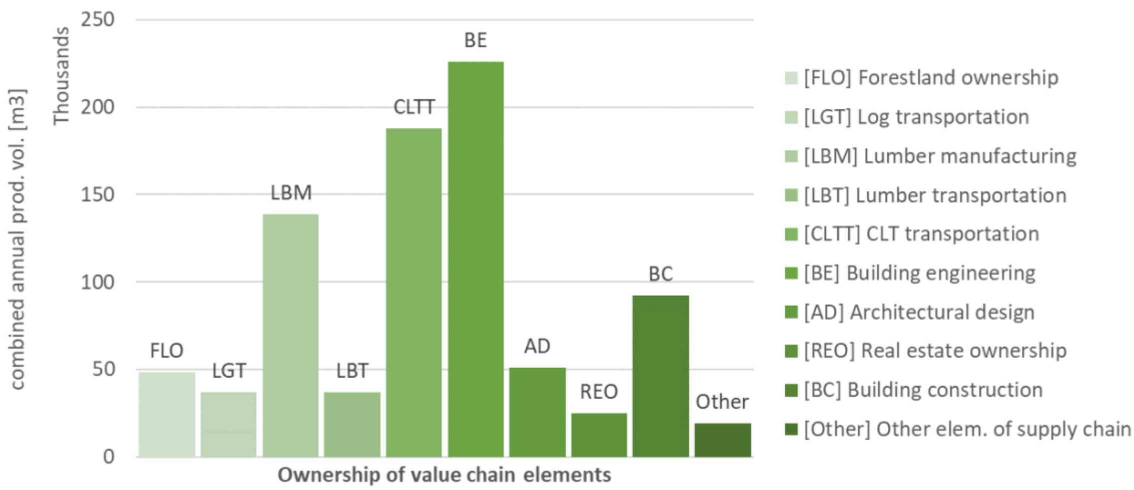

Figure 5: Ownership of the elements of the supply chain by the combined annual production volume represented by the respondents (n=29, combined response from 2017 and 2019 surveys, excluding the overlap).

FIGURE 5

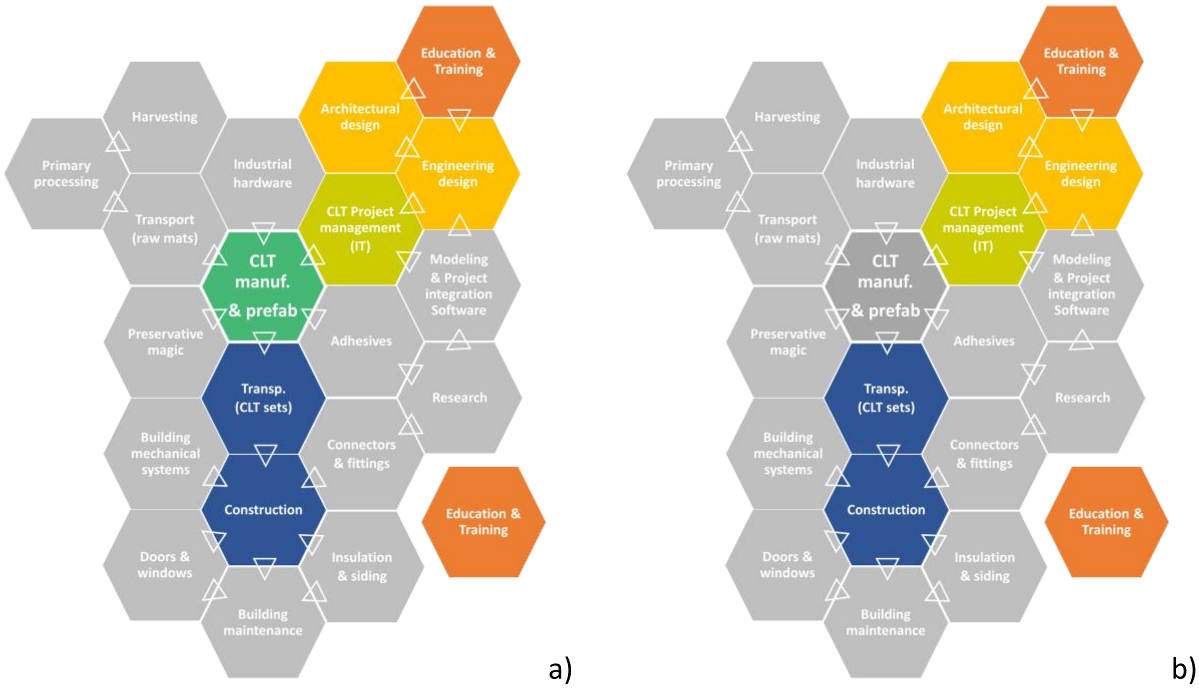

Figure 6: A common scheme of vertical integration of CLT companies (a) and an example of a vertical integration of companies specialized in building with CLT, though not producing panels, like EUrban (b).

How to Use Social Media and Market Updates

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Abstract
Candra Burns from Talking Forests will present 'How to Use Social Media and Market Updates'. Social Media is ever-evolving and Talking Forests keeps up with the changes and needs of the social media platforms to help the students, researchers, and professionals of the forest and wood sectors stay relevant online. Candra will teach you how to use LinkedIn for growth in student research and professional needs in the growing market. She will teach you how to use Instagram which is a growing platform for young professionals, but a space that needs companies to get on board to bridge age, diversity, and sustainability. She will show you how to grow your Twitter which has been the lowest maintenance platform in her 5-year career. Candra has been a digital marketer for global virtual conferences before and during COVID-19 and she will show you how to pivot, gain more audience, retain and recruit members, and show off your research and professional projects in this growing social media market. The tips and tricks she presents are based on 6 years worth of her experience and she is open to new processes and findings that this interactive presentation can spark from the audience.

Sustainable Living and Housing
Chair: Susan LeVan-Green, Wood and Fiber Science Editor, USA

Evaluation of Surface Hardness Tests for Engineered Flooring

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ABSTRACT

Flooring manufacturers are creating new engineered flooring prototypes, and are striving to make a stronger, more economical product in this competitive market. As new prototypes of engineered flooring emerge, there is a need for these products to be tested to measure their properties. A common test for flooring is the surface hardness test used to measure the resistance to indentations in the top veneer wear layer.

The ASTM standard D-143 hardness test, often referred to as the Janka ball test, is used to measure the force needed to embed an 11.2 mm (0.444 in.) diameter steel ball to half its diameter. These values are collected, averaged, and used to describe the specimen's hardness.

Many modern engineered flooring products are manufactured with a thin solid, wood veneer on the top surface that typically ranges from 3 to 5 mm (1/8 to ¼ in.) thick. When the 11.2 mm (0.444 in.) diameter ball is used to measure the surface hardness of this thin this veneer, the ball will penetrate completely through the surface veneer and into the core of the flooring. As a result, the hardness test does not only measure the hardness of the top solid wood veneer, but it also measures the hardness properties of the core materials of the engineered flooring under the veneer. This causes the test to reflect the hardness properties of the core materials instead of the desired measurement of the top veneer. A possible solution to measuring the surface hardness of engineered flooring is to use a smaller diameter ball so that it does not penetrate the thin veneer.

The objective of this paper is to compare the surface hardness measured with the standard sized ball to that of a ball of 5.6 mm (0.222-inch) diameter, half the diameter of a standard ball, on a variety of flooring products and solid wood. The purpose of this research is to investigate the correlation between the standard 11.2 mm (0.444 in.) ball and a 5.6 mm (0.222-inch) diameter ball when conducting the hardness test.

Using the smaller diameter ball could result in a more accurate, representative measurement of the surface hardness of engineered flooring. Such a test would be beneficial to the industry when evaluating new products and comparing to previously published hardness values that were developed for solid wood.

Keywords: Hardness, Janka ball, engineered flooring, solid wood

INTRODUCTION

Engineered wood flooring is produced by a multi-billion dollar per year industry worldwide. Unlike traditional solid wood flooring, engineered flooring is composed of layers of wood veneer glued together to form a floorboard. The top layer, also called the wear surface, is usually a decorative wood veneer that is glued to a core made from a variety of possible materials such as plywood or solid wood strips oriented cross grain to the top veneer. There are many different styles and designs of engineered floorboards. Engineered floorboards may have a bottom layer made from a wood veneer with the grain oriented parallel to the top layer to act as a stabilizing layer to form a balanced composite for maintaining a flat board after moisture content changes, such as a three-layer board. In some cases, no bottom balancing layer is used. Engineered flooring can be considered an advantageous product compared to traditional solid wood flooring because it can be manufactured using smaller, lower quality and lower cost lumber to create a strong yet non-expensive product.

Flooring manufacturers are creating new engineered flooring prototypes, striving to make a stronger, more economical product in this competitive market. As new prototypes of engineered flooring emerge, there is a need for these products to be tested to measure their properties. Common tests for flooring include adhesive durability with moisture content changes, dimensional stability, and importantly, the surface hardness test used to measure the resistance to indentations in the top veneer wear layer. The surface hardness is an indication of how easily the product can be dented in-service– a critical aspect when it comes to flooring quality and consumer satisfaction.

The ASTM standard D-143 hardness test is used to measure the force needed to embed a 11.2 mm (0.444 in.) diameter steel ball to half its diameter. These values are collected, averaged, and used to describe the specimen's hardness. This type of test is often referred to as the Janka ball test and the steel ball used to conduct this test is termed a Janka ball.

Many modern engineered flooring products are manufactured with a thin, solid wood veneer on the top surface that is typically ranges from 3 to 5 mm (.125 in. to .25 in.) thick. When the 11.2 mm (0.444 in.) diameter Janka ball is used to conduct a Janka ball test and measure the surface hardness of this thin veneer, the ball will penetrate completely through the thin surface veneer and into the core of the flooring. As a result, the hardness test performed does not measure the hardness of the top solid wood veneer, but is also includes the hardness properties of the core materials of the engineered flooring under the veneer. Because of this, hardness data reported for many engineered floorboard products is not an accurate reflection of its hardness qualities.

A possible solution to measuring the surface hardness of engineered flooring is to use a smaller diameter ball so that it does not penetrate the thin veneer. This type of experiment has not been documented.

The objective of this paper is to compare the surface hardness measured with the ASTM standard sized 11.2 mm (0.444-inch) ball to that of ball of 5.6 mm (0.222-inch) diameter, half the diameter of a standard ball, on a variety of flooring products and solid wood. The purpose of this research is to investigate the correlation between the standard 11.2 mm (0.444 in.) ball and a 5.6 mm (0.222-inch) diameter ball when conducting the hardness test.

Using the smaller diameter Janka ball could result in a more accurate measurement of the surface hardness of engineered flooring and be beneficial for the industry when evaluating their products and comparing to previously published hardness values.

METHODS/MATERIALS

The primary objective of this project is to compare the hardness measured with the large diameter ball to the hardness measured with the small diameter ball. A 10,000-pound capacity MTS testing machine was used to conduct the hardness tests according to ASTM D 143 standard. Tests were conducted with both the traditional 11.2 mm (0.444 in.) diameter steel ball and the smaller 5.6 mm (0.222-inch) diameter steel ball. The test specimens included solid white oak and four engineered flooring products.

Thirty solid white oak samples were tested with both large and small ball diameters. Two tests were conducted on each radial and tangential surface, and one test was conducted on each end-grain surface totaling 10 tests of each ball diameter ball on each specimen.

On the samples of engineered flooring, 5 tests of each diameter ball were conducted on each product. Four samples of two flooring products were tested and 6 and 8 samples of two other engineered flooring samples were tested for a total of 110 tests for each ball diameter. Only the top face of the flooring products was tested.

RESULTS/DISCUSSION

The results of the hardness tests are shown in the following figures. Figures 1 shows a histogram of the hardness test results for one sample of solid white oak for the large and small diameter balls. The difference between the radial, tangential and end-grain surfaces is seen. The figure shows that for the large diameter ball, the end grain surface has a slightly larger hardness than the radial or tangential surfaces but the difference is not statistically significant at the 0.05% level. No significant differences were detected between the radial and tangential surfaces for the large or small diameter balls. There is a significant difference (0.05 % level) between the hardness measured with the large and small diameter balls.

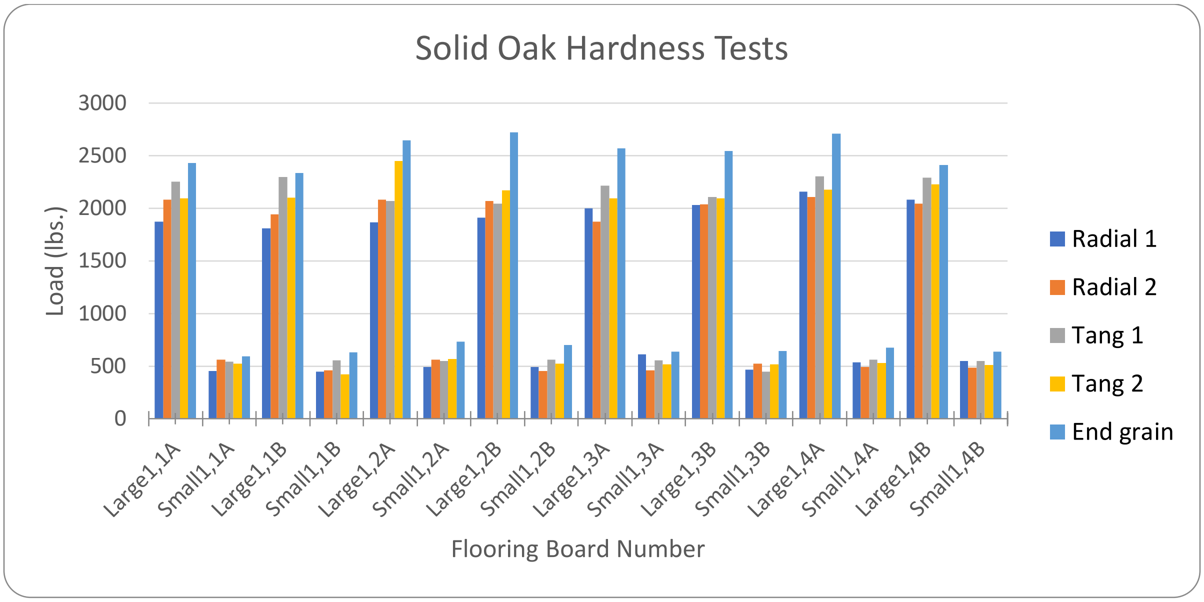

Figure 1: Histogram showing the hardness of white oak samples with the large and small diameter balls.

Figure 2 shows a histogram for one engineered flooring product tested with the large and small diameter balls. As seen in the figure, the hardness values of this product are smaller than solid oak values shown in Figure 1. There is less of a difference in hardness values measured with the large and small diameter test balls than observed with the solid oak samples.

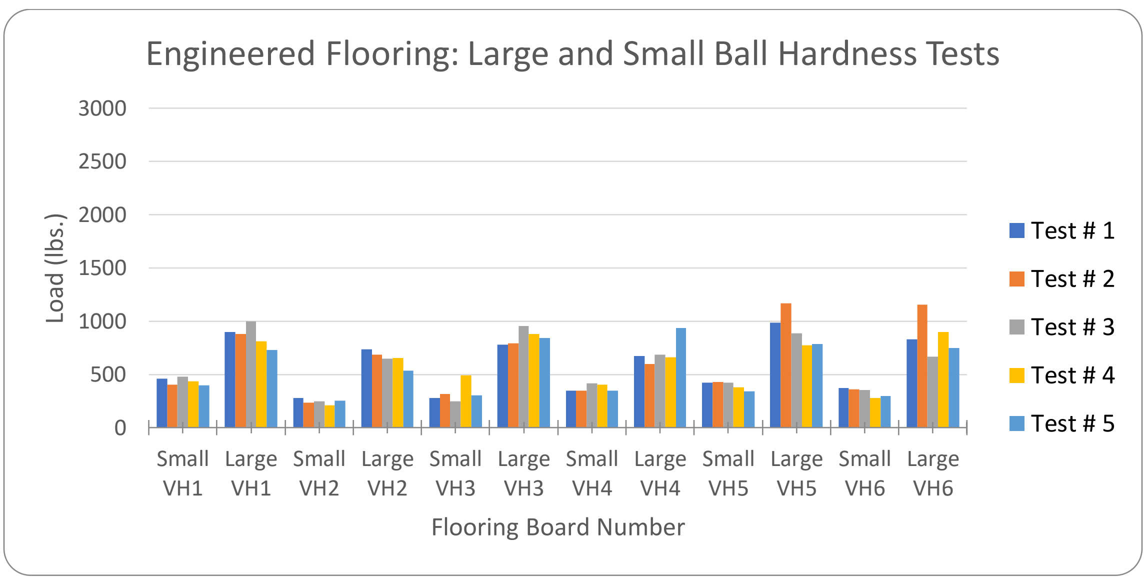

Figure 2: Histogram showing the hardness of six engineered flooring samples with the large and small diameter balls.

Figure 3 shows the relationship between hardness values measured with the large and small diameter test balls for all the solid white oak samples. The figure also shows the regression equation and the correlation coefficient (r^2) of 0.86, indicating a very strong relationship between the large and small diameter hardness values. The strong relationship indicates that the hardness measured with the small diameter ball can be used to predict the hardness of the large diameter ball. This can be used to compare test data for the small diameter ball to published results for the large diameter ball.

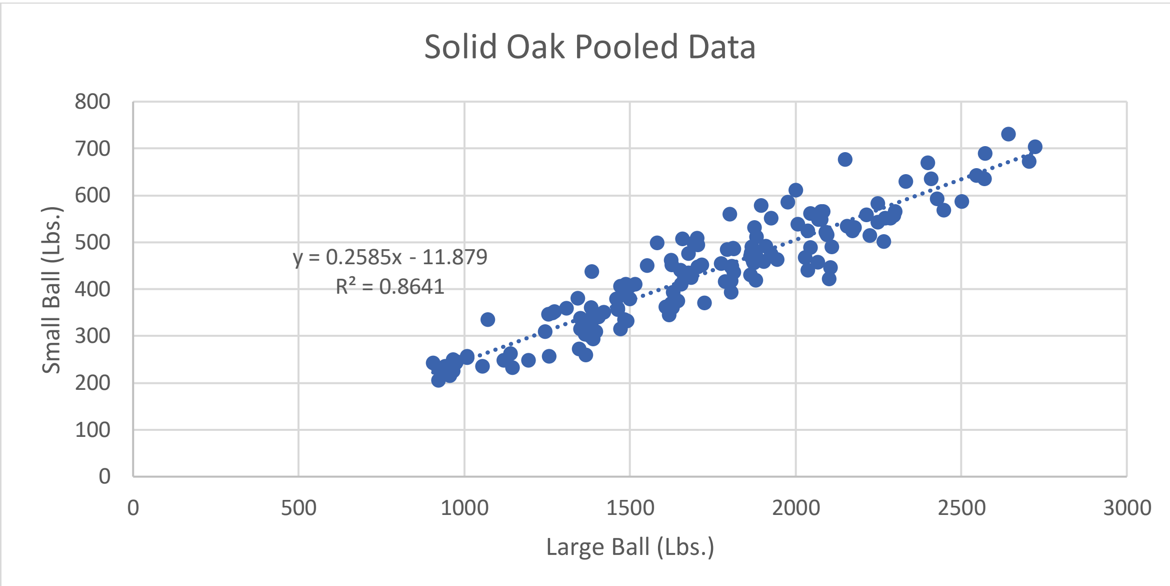

Figure 3: Graph showing the relationship between the large and small diameter test balls for all the solid oak pooled data.

Figure 4 shows the relationship between hardness measured with the large and small diameter test balls for four different engineered flooring products. The figure also shows the regression equation and the correlation coefficient (r^2) of 0.18, indicating a very weak relationship between hardness measured with the two different diameter balls. The likely reason is that even the small diameter ball penetrates through the top veneer and into the softer core material.

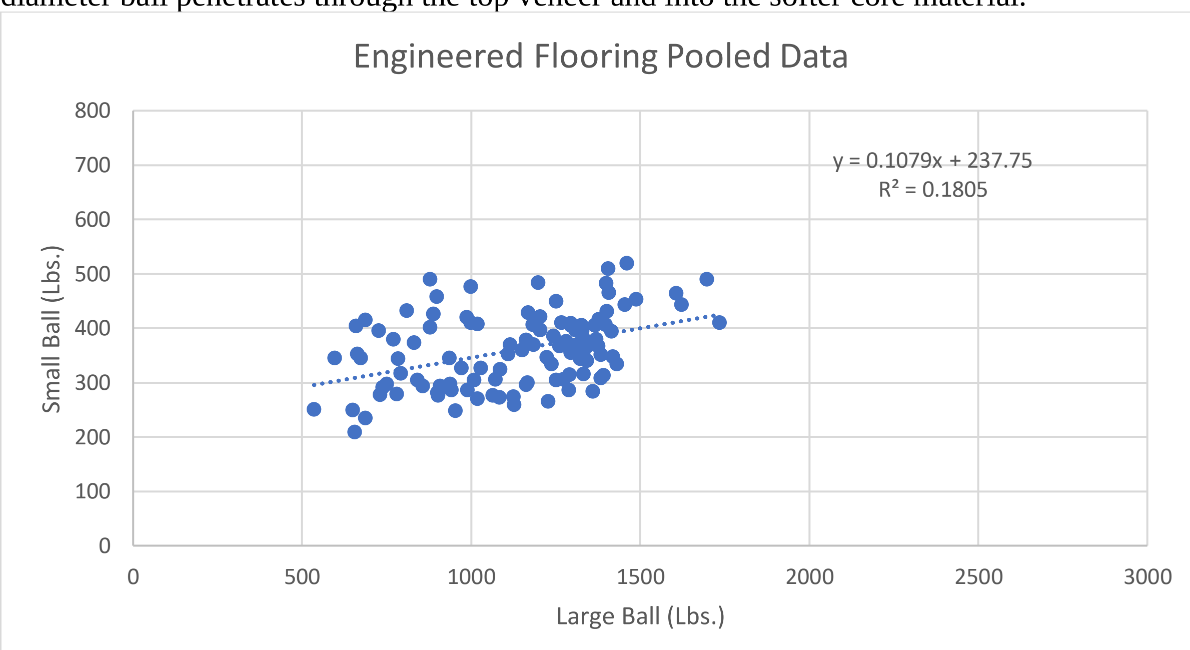

Figure 4: Graph showing the relationship between hardness values measured with the large and small diameter test balls for four different types of engineered flooring.

Figure 5 shows the relationship between hardness measured with the large and small diameter test balls for all the pooled data for the solid oak samples and the four different engineered flooring products. The figure also shows the regression equation and the correlation coefficient (r^2) of 0.67, indicating a moderate relationship between hardness measured with the two different diameter balls.

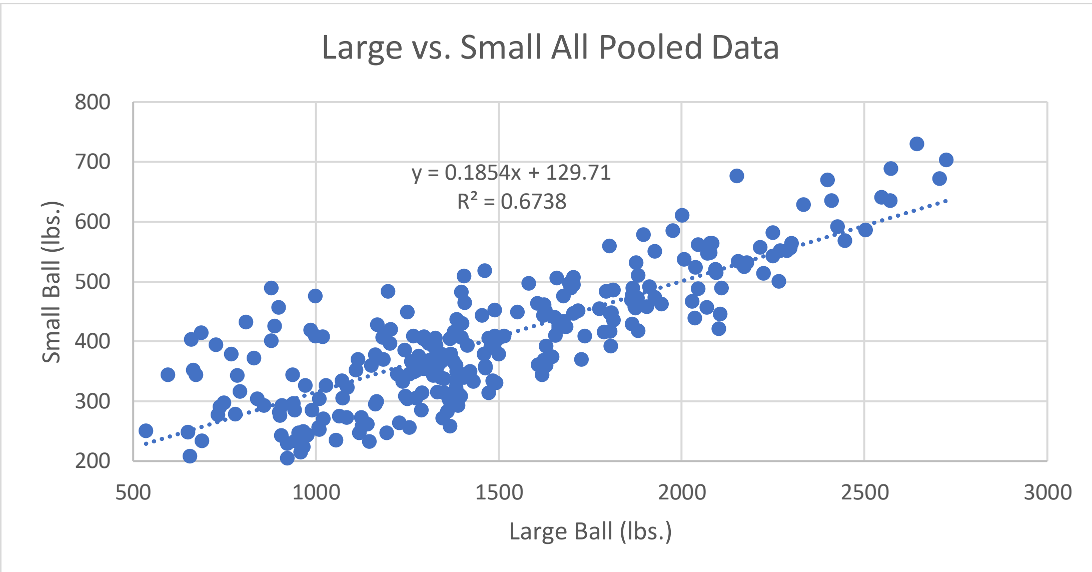

Figure 5: Graph showing the relationship between hardness values measured with the large and small diameter test balls for all the pooled data for both solid wood and four different types of engineered flooring.

SUMMARY/CONCLUSION

The surface hardness was measured with two different diameter test balls on samples of solid white oak and four different products of engineered flooring. The larger ball conforms to the ASTM D-143 standard and the smaller ball is half that diameter.

The study supports the following conclusions:

1) For solid white oak, a strong correlation exists between the hardness measured with the two different diameter test balls. The regression equation can be used to translate test values measured with the small ball to the large diameter values for comparing to published data.

2) For the engineered flooring samples, a weak relationship was found between the hardness measured with the two different diameter test balls. The likely reason is that even with the small diameter ball, it penetrates through the top wear layer veneer and into the softer core material.

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Comparative Whole Building Life Cycle Assessment on CLT Mass Timber Buildings and Concrete Buildings in US Northeast Region.

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Abstract

Mass timber buildings play an important role in transforming the building sector from the major contributor of greenhouse gas emissions into a net-zero carbon emission and sustainable building environment. The impacts from mass timber products used in mid-to-high-rise buildings are investigated with the help of whole building life cycle assessment (WBLCA) using a cradle-to-gate (construction site) boundary system, i.e. from A1 to A5 stage according to EN standard. Comparative LCAs of functional equivalent mass timber and conventional buildings in US Northeast (NE) region to estimate embodied carbon and carbon storage of mass timber utilization at 3-level height individual buildings. The mass timber buildings were designed based on markets for new mass timber buildings compliant to the new building code (). The three pairs of buildings are 8, 12, and 18 stories for commercial and residential mixed use buildings. The mass timber buildings are lighter in mass than their concrete alternatives, account for 50%, 54% and 71% of corresponding 8-,12-,and 18-story concrete buildings, respectively. The use of CLT and Glulam in mass timber buildings substitutes 75-79% of concrete and 62-80% of rebar uses in concrete buildings. The mass timber buildings have 28-50% lower global warming (GW) and other environmental impacts than the corresponding concrete buildings. In addition, the mass timber building also stores 311 to 365 kg $CO_{2\text{-eq}}$ per m^2 of floor area for the building's whole service life.

More wood use in building sector has shown potential benefits from this study. However, it also points out that mass timber use opportunities for reducing global carbon emissions can only be achieved by growing more trees; intensively managing forests for yield and sustainability; sourcing wood and products locally to reduce transportation impacts; producing wood products for long service lives, reuse and recycling potential, etc.

Potential Of Industrial Hemp Towards Environmental Application

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Abstract

Water is an essential resource for life on the planet and for human development. The presence of contaminants like heavy metals, dyes, pesticides, etc. steadily degrades the quality of water and is the major reason for several diseases and damage to human health. The dyes are soluble organic compounds and are produced from pulp and paper industries and textile industries. The release of these colored wastewaters in the ecosystem is a dramatic source of esthetic pollution, causing eutrophication and harming aquatic life. The textile dyes, along with a large number of industrial pollutants, are highly toxic and potentially carcinogenic. Contamination of surface and groundwater by pesticides from agricultural runoff and industrial discharge is one of the main causes of aqueous contaminations the world over. Atrazine is a toxic, non-biodegradable widely used endocrine-disrupting herbicide. Hemp is a multi-purpose crop delivering stalks, seeds, and leaves, which find numerous applications. In this study, hemp hurd derived from hemp (Cannabis sativa L.) is chosen as a raw material to explore its adsorption capacity for methylene blue (MB), Brilliant green dyes, and atrazine herbicide. The effectiveness of the pollutant removal will be conducted using both raw hemp hurd and modified hemp hurd with organic acid/s. Measurement of atrazine and dyes will be carried out in a UV-visible spectrophotometer. The physicochemical properties of the synthesized sample will be studied by scanning electron microscopy (SEM) and Fourier transform infrared (FT-IR).

The effects of contact time and pH on the adsorption will be studied using the batch technique. Thus, low-cost green abundant hemp hurd derived bioadsorbent can exhibit outstanding removal capabilities for herbicide and synthetic dyes.

Short Term Field Durability Test Of Physical Barriers Against Termites In A CLT Wall Envelope System

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Abstract

The production and use of cross laminated timber (CLT) have been growing rapidly in the United States and Canada during the past few decades after its first introduction in Austria in the early 90s. The structural integrity of wood, however, can be compromised by decay fungi and termites. Internationally acknowledged building codes require external wooden walls to be installed on a raised concrete foundation or use a hybrid construction method. A standard CLT wall envelope system described in the North American CLT handbook consists of several layers such as siding, air cavity, vapor barrier and insulation to control heat, water, and air movement. The inclusion of a physical barrier in the standard envelope system can be an alternative approach to prevent subterranean termite attack of CLT walls. In the present study, the effectiveness of using commercial polyethylene flashing and stainless-steel mesh in CLT wall systems as the termite barriers will be evaluated in a short-term field test. Three wall envelope configurations were constructed with 3-ply 11” (width) x 18” (length) CLT panels, cement board sidings, and aluminum spacers. The control configuration did not have physical barrier other than sidings, while the other two configurations had either the polyethylene flashing or stainless-steel mesh barrier. Ten wall envelope specimens were assembled for each configuration. The CLT envelope specimens were installed at a field site in Mississippi in February 2021. After 15 weeks of exposure, the termite damage on the wall envelope specimens will be visually examined according to the AWPA E21 standard.

Capturing Carbon Footprint of the End-of-Life Options for Mass-Timber Panel (MTP) Buildings

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Abstract

The building construction industry accounts for a large share of global energy and natural resource consumption and is a major polluter of the environment through atmospheric emissions and generated waste. A vast majority of buildings continue to contribute to these emissions through their service lives and add to the waste stream when decommissioned at the end of life (EOL). However, materials from end-of-life of buildings can be either a burden that must be disposed, or a resource that can be reprocessed and used thereby reducing use of virgin materials. Buildings executed in mass-timber panel (MTP) technology are no exception. While MTPs are innovative building products revolutionizing multi-story timber construction, the technology is still relatively young and existing MTP buildings are yet to reach their mid-service-life milestones. Current published life cycle assessment (LCA) studies on mass timber products and buildings cover only the cradle-to-gate stages and do not go beyond product fabrication or building construction. This leaves out the assessment of carbon and waste mitigation potential of buildings in-service, when periodic maintenance and repair/replacement of damaged elements are crucial to prolong service life and EOL stage when buildings are decommissioned. While it is expected that the advantage of MTP over traditional materials will also show in the EOL stage it is far from proven. Historically, building design and construction practices are not concerned with effective EOL material management and neither the economic nor climate impacts at the EOL of MTP buildings and their elements are well understood. Key empirical data essential for cradle to grave LCA is missing.

The goal of this presentation is to describe the goals, conceptual framework, and approach of a collaborative project aiming at empirical assessment of economic cost and carbon accounting related with deconstruction, as well as basic strategies for optimizing the design of MTP buildings for successful post-use material recovery/reuse and EOL economic and carbon benefit. The principle premise is that the data can be obtained by using pending and completed

deconstruction and retrofitting projects in actual buildings, as well as tracking medium- and large-scale test structures executed in MTP technology which are assembled and completely disassembled in controlled lab environments.

Behavior of In-plane Butt-joints with 45° Screws in Ponderosa Pine CLT

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Abstract
Cross-laminated timber (CLT) is a structural panel built by gluing perpendicular layers of dimension lumber laminations for mitigation of in-plane anisotropy and superior dimensional stability. The goal of this research is to demonstrate the viability of Ponderosa pine CLT for low-rise modular buildings and to develop design criteria for this application. Currently, Ponderosa pine (*Pinus ponderosa*) harvested in forest restoration projects in the Northwestern United States has a limited market value. The project hypothesis is that its market value may be improved by utilization in CLT for low-rise modular buildings designed to be quickly assembled and disassembled with minimal damage, and well suited to be used in medium-term disaster relief in areas struck by earthquakes, tsunamis, forest fires, etc. By PRG320 standard, Ponderosa pine CLT falls in the category of "custom grade," therefore, in order to be specified in structural design, the mechanical characteristics and the capacity of connections used with such panels have to be experimentally determined.

The Ponderosa pine CLT used within this project has a standard width of 1.2 m (4 feet) to consider local manufacturing constraints. This dimension is smaller than in most standard commercial CLT panels, and to use these panels in a wall or a floor, they have to be joined by means of in-plane connections that are capable of transferring shear between the panels. The stiffness and capacity of these connections systems under reversal loading (e.g. earthquakes) affect the behavior of the multi-panel wall system – the multi-panel wall can act as a single wall, coupled wall panels, or intermediate between both – is essential for the design and analysis of CLT structures with multi-panel walls in high seismic areas.

Out of many options available for in-plane CLT connections, butt joints with 45° screws has been selected for their ease in production and installation. However, the data on the behavior of such connections in CLT is still scarce. In this poster, the experimental procedure aimed at the determination of mechanical characteristics of CLT butt joints with 45° screws will be presented. Eight assemblies of three-ply 100 mm (4 inches) Ponderosa pine CLT have been tested under monotonic and cyclic loading in shear and tension. The force-displacement curves are used to extract the engineering characteristics of the connections: strength capacity, yielding point, ductility, equivalent damping ratio, and dissipated energy. The failure mechanism under shear and tension loading of the butt joints has been analyzed. These results are compared with the results determined on CLT made from other species of wood. The strength and stiffness parameters will be used for designing the modular structure.

Keywords: *In-plane connection, Ponderosa pine CLT, butt joints, connections*

Acknowledgment: This research is supported by USDA Forest Service (wood innovation grants program 17-DG-1162765-742 and 18-DG-11062765-738). The contribution of Collins, Sierra Pacific, DR Johnson, Vaagen Timbers, Katerra, USNR, Anderson Construction, Rothoblaas, SMT, OFRI, TDI, and AkzoNobel is acknowledged. The author is advised by Dr. Mariapaola Riggio, Dr. Lech Muszynski, and Dr. Erica Fischer. Sina Jahedi's contribution to the project is acknowledged.

Connection Performance in Decayed Cross Laminated Timber Members

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Abstract

Good connection performance is important for structural integrity throughout the lifespan of mass timber buildings. However, the hygroscopic and biological nature of the material promotes growth of organisms such as insects, bacteria and fungi which could impact the integrity of the building assembly.

To characterize, the resilience of CLT connections to biological degradation, *Postia placenta*, a brown rot fungus known to attack soft wood species was cultivated under controlled conditions in decay chambers containing cross laminated timber (CLT) connection assemblies. The connection assemblies consisted of two blocks of CLT each 13 X 8 X 4 inches held together by metal L-brackets, simulating, a wall-floor connection in actual buildings. Four wood species including Douglas fir, Southern Yellow Pine, Spruce-Pine-Fir and Norway Spruce were inoculated for a period of 10 weeks and 20 weeks, harvested, and tested. A quasi-static cyclic test based on a CUREE protocol was used to evaluate the shear performance of the connections. Dowel bearing strength tests were also performed to evaluate the impacts of the fungus on the different wood species.

The results of this study will assist in describing the susceptibility of each wood species to fungal attack and evaluate the performance of connections in decayed mass timber building elements. Data generated will assist engineers and builders in applying appropriate safety factors when building with CLT in areas prone to biological degradation.

Valuable Composites and Adhesives 1
Chair: Douglas Gardner, University of Maine, USA

Production of Dry Nano-Scale Cellulose Nanocrystal Powder via Electrospraying for Sustainable Composites

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Abstract
Electrospray drying (ESD) produces nano-scale dried cellulose nanocrystal (CNC) particles using a high voltage electric field and a low feed rate to produce ultra-fine droplets through electro-hydrodynamic atomization (EHDA). CNC suspensions contain high levels of water and are energy intensive to dry. Hydrogen bonding increases CNC size to micron-scale or greater after processing by conventional spray drying (SD). With ESD, coulomb repulsion breaks the surface tension of the CNC suspension. Gravity pulls the mist through a fixed distance, from the tip to the collector, at atmospheric temperature and pressure while droplet evaporation occurs, leaving nano-scale CNC particulates on a grounded collection substrate. A 3% (wt.) CNC suspension with a 40/60 ethanol water mixture was sprayed at a rate of 6 µL min^{-1} with four syringes in parallel containing 11.5 mL each. Particles were collected and dried at 105°C for 2hr. Dried nano-scale CNC is effective at increasing the tensile strength and modulus of elasticity when compounded into a thermoplastic matrix. A counter rotating twin-screw extruder was used to compound 0.5% CNC into a poly-lactic acid (PLA) matrix. Injection molded (IM) tensile samples were produced and mechanical properties were tested. Particles were observed with scanning electron microscopy (SEM) and digital analysis software was used to measure the CNC particle dimensions. Particle sizes of the ESD CNC powder ranged from approximately 40 – 1200 nm in length and 10 – 500 nm in width. Approximately 80% of CNC from the 3 wt.% suspension was collected and ready for thermoplastic compounding. With the addition of 0.5 wt.% CNC, the modulus of elasticity (MOE) and tensile strength of CNC/PLA composite samples were 3.66 GPa and 62.5 Mpa. When compared to the neat PLA, the strength and stiffness increased 12.5 and 9.6%, respectively.

Cellulose Nanofiber/Polymer Composite Mechanical Properties Dependence on Fiber Feedstock

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Abstract
Cellulose nanofibrils (CNFs) are a type of cellulose nanomaterial that have attracted considerable attention from both academia and industry. The appealing attributes of CNFs include being strong, stiff, renewable, biodegradable, low cost, and light weight, making CNFs a favorable replacement for traditional synthetic nanofibers. One application area of CNFs with huge potential is polymer nanocomposites. In a lab setting, CNFs are reported to significantly increase the mechanical performance of polymers using solvent casting production methods, is not a commercially relevant production method. Melt extrusion processing is widely adopted by the polymer composites industry. Melt extrusion typically requires the raw materials to be dried before extrusion. During drying, CNFs can agglomerate and cannot be easily dispersed in viscose polymer melts. The agglomeration of CNFs during drying originates from 1) the high surface tension of water where CNFs are dispersed in after production and 2) the number of hydroxyl groups on CNFs surface. To date, most efforts in using CNFs in polymer composites have been focused on using CNFs made from delignified pulp fibers which possess a large number of hydroxyl groups. If the biomass feedstock is not completely delignified, the resulting CNFs are called lignin-containing CNFs (LCNFs). LCNFs may exhibit better reinforcing ability compared to CNFs attributable to the existence of lignin which reduces the number of exposed hydroxyl groups on cellulose surface. This research will address effect of LCNF feedstock on the mechanical properties of CNF polymer composites.

CHAR RATES and RESIDUAL CHAR DEPTHS in UNPROTECTED CLT FLOOR and WALL ASSEMBLIES AFTER 2-HOUR ASTM E119 FIRE TESTS

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ABSTRACT

Charring rate, or the progress of char depth in a unit of time, is a crucial parameter in numerical modelling of fire performance of structures and in standard calculations of fire rating for mass-timber structural elements. Published data for clear wood specimens show substantial variation in charring rates between and within species. Little is known about the variation of charring rate in mass-timber panels where the presence of knots, adhesives and other inhomogeneities, as well as the position of the panel (wall or floor) may add to the intrinsic variability found in various species of clear wood. Char rate variability across full-scale floor and wall assemblies is important for accurate modelling of the fire performance of CLT structures. Therefore, the objective of this study was to determine the variability and spatial distribution of the char depth in full-scale unprotected CLT assemblies subjected to standard fire tests in horizontal and vertical positions.

This study uses materials and data from a previous research, in which two sets of 175 mm thick 5-ply CLT assemblies were tested for fire performance in loaded condition following the ASTEM E119 protocol one in vertical configuration (3.0 m x 3.0 m walls) and the other in horizontal configuration (4.3 m x 5.5 m floors). Each set included three panels that differed by the combination of wood species and adhesive systems.

Temperatures at each bonding line between layers were measured by embedded thermocouples to estimate char rates at nine positions across each assembly. The charring rates calculated using recorded thermocouples data varied between the nine locations of TC clusters (COV up to 47% for floors and up to 30% for walls), but there was no clear pattern related to the location on the panel. Residual char surface topography immediately after the 2-hour fire exposure was documented on series of digital images used later for creating char surface maps. The assemblies were subsequently cut into 305 mm x 305 mm blocks to measure the residual depth at eight points on the perimeter and create a char front map for each assembly, which combined with char surface topography maps allowed determination of the residual char depth distribution for each assembly.

The char base maps allow the analysis of correlation between char rates calculated based on the residual depth with char rates measured with the nine TC clusters and analysis of potential correlations between the char rates and the residual char depths at various locations. While the shape of char base line might be affected by a variety of non-homogeneities already lost to the fire it was observed that one of the factors was the local shape of annual rings.

KEYWORDS: cross-laminated timber, CLT, char loss, image analysis, char rate, char depth

INTRODUCTION

The fire resistance of structural cross-laminated timber (CLT) elements is determined using the standard ASTM E119 (ASTM E119, 1995) test procedure used for the evaluation of other structural materials. The most desirable behavior for combustible materials such as CLT panels is self-extinction, which progressively converts flame combustion into smoke combustion until the process is terminated. In practice, this behavior is observed when the burnt wood on the surface increases the insulating layer over the intact core material (Crielaard et al 2019). Charring rate, or the progress of char depth in a unit of time, is a crucial parameter in numerical modelling of fire performance of structures and in standard calculations of fire rating for mass-timber structural elements. Published data for clear wood specimens show substantial variation in charring rates between and within species. Char rate variability across full-scale floor and wall assemblies is important for accurate modelling of the fire performance of CLT structures. Although many studies have been conducted on the variation of the char rate under the condition of constant thermal energy (Martinka et al. 2018), additional studies are still needed on the variation of the char rate under the curated progressive temperature conditions as prescribed by ASTM E119. Little is known about the variation of charring rate in mass-timber panels where the presence of knots, adhesives and other inhomogeneities, as well as the position of the panel (wall or floor) may add to the intrinsic variability found in various species of clear wood.
An additional complication is the fact that many CLT products bonded with an older PUR adhesive system, let the char layer fall off when the fire front crosses the bond line, creating an additional heat source inside and exposing the unburned surface of the next layer to the fire (ANSI/APA PRG 320-2018). Alternative systems used to manufacture CLT, and improved new PUR formulations available to manufacturers today, demonstrate ability to anchor char on panels. However, to date, some of the CLT panels already installed in mass timber buildings have been produced with the older PUR formula. While the effect of the residual char layer on the charring rate has been subject of research (Martinka et al. 2018) more empirical data from large scale tests is needed to confirm conclusions reached based on small scale tests.

Therefore, the objective of this study was to determine the variability and spatial distribution of the residual char depth in full-scale unprotected CLT assemblies subjected to standard fire tests in horizontal and vertical positions and to determine its effect on the local charring rates determined from the residual unburned panel depth.

MATERIALS AND METHODS

CLT assemblies

The 5-ply structural graded three cross laminated timber floor (horizontal direction) and wall (vertical direction) assemblies were donated by Smartlam in Whitefish, Montana and DR Johnson Wood Innovation in Riddle, Oregon. All panels were fabricated with 35 mm x 140 mm

lumber, visual grade #2 or better. The total thickness of CLT panels was 175 mm. The area of wall assemblies was 3.0 m x 3.0 m, and floor assemblies was 4.3 m x 5.5 m.
Three types of CLT panels per each direction were prepared: SPF bonded with one-component polyurethane HBE adhesive (PUR), Douglas-fir-Larch with PUR or melamine formaldehyde (MUF).
Each assembly was joined by half-lap joint using SDWS exterior grade timber screws at the center of lap joints with 203 mm spacing. No insulation and adhesives were used on surface of half-lap joint. The floor assemblies were covered on the fire unexposed surface by 13 mm four-ply pine plywood. The plywood was secured with 8d (54 mm) nails from the its edges. Sheathing mass of plywood was 5.86 kg/m^2 (Muszynski et al 2018, Muszynski et al 2019).

Fire test following ASTM E119

The test procedures are described in detail in (Muszynski et al 2018, Muszynski et al 2019). All fire tests were conducted in WFC. Two sets of CLT assemblies were tested for fire performance in loaded condition following the ASTEM E119 protocol: one in vertical (wall) configuration and the other in horizontal (floor) configuration.
The horizontal furnace can accommodate ASTE E119 up to 5.5 m x 4.3 m, and 2.1 m depth. The vertical furnace can also accommodate it up to 3.4 m x 3.7 m, and 0.6 m depth. It utilized natural gas producing diffusion flames manually controlled by WFC operators. The temperature inside furnace complied with the ASTM E119 standard temperature curve through manual control of gas flow and occasional water spray into the furnace when rapid cooling was necessary. The gap between steel frame and CLT assemblies was filled with ceramic wool insulation. The low-intensity water hose was used to extinguish fire on CLT char front layer after the fire test. No hose-stream tests were conducted (Muszynski et al 2018, Muszynski et al 2019).

Char rate during the fire tests (Thermocouple installation)

Temperatures at each bonding line between layers were measured by embedded thermocouples at nine positions on the CLT side to estimate char rates during fire tests by dividing the layer thickness by the time when thermocouples embedded at the bond line reached 300° C, the assumed charring temperature.
The charring rates calculated using recorded thermocouples data varied between the nine locations of TC clusters (Muszynski et al 2018, Muszynski et al 2019).

Residual char surface topography.

Residual char surface topography immediately after the 2-hour fire exposure was documented on series of digital images used later for creating char surface maps.
The overall fire exposed surface image was reconstructed using partial fire exposed surface images taken from various angles after fire tests. Using this reconstructed image, the location and area of the residual char layer after the fire tests were analyzed. This result is described in more detail in Muszynski et al. 2021.
It was assumed that the lost depth of char layers was equal to the thickness of unburnt CLT layers under the pre-condition that char falling off occurred along the adhesive line. Also, the char falling off at each bonding lines occurred sequentially. This could be confirmed in the form of grains of each layer that can be confirmed in the char layer surface of the fire exposed surface recorded after the fire test.
The CLT assemblies used in the experiments were of not edge glued, therefore, after the tests the gaps between laminations were clearly visible due to the lamination volume change in the charring process. The residual char layer was determined based on these lines (Figure 7).

The dimensional changing of CLT during the fire exposure was neglected. The area of the attached char was assessed by manually tracing the edge of the char remaining on fire exposed surface using an image process program. The measured area obtained through two repetitions by different researchers was used to improve accuracy.
The approximate analysis method of the remaining char layer is shown in Figure 8.

Determination of charring rates

After the tests the panels were cut into 305 mm x 305 mm (1 square-foot) blocks to measure the residual depth at eight points on the perimeter and create a char front map for each assembly. Sets of CLT blocks cut into 305 mm x 305 mm, and the residual CLT thickness measurement points of each block after fire tests is shown in Figure 9 (a), and (b). The cumulated char rate was calculated by measuring the residual CLT thickness around the location where the thermocouple was installed.

Determination of the Residual Char Depth

The residual CLT depth maps which combined with char surface topography maps allowed determination of the residual char depth distribution for each assembly. The thickness of the residual char layer was calculated by comparing the residual CLT thickness measured in each block with the photo documentation of attached char front surface. The char rate calculated by residual CLT thickness after fire tests was compared with the number of char falling off layers where were matched with the location of char rate calculation.

RESULTS and DISCUSSION

Maps of the residual depth of unburned CLT after the ASTM E119 testis shown.in Figure 10, Figure 11, and Figure 12. The remaining perimeters of the assemblies show unburned margin covered by the furnace frame and a layer of insulation.

The charring rates calculated using recorded thermocouples data varied between the nine locations of TC clusters (COV up to 47% for floors and up to 30% for walls, **Error! Reference source not found.** and **Error! Reference source not found.**), but there was no clear pattern related to the location on the panel (Table 1).
The char base maps allow the analysis of correlation between char rates calculated based on the residual depth with char rates measured with the nine TC clusters.
The char rates measured by the thermocouples, are much faster in the first layer than that of the second layer. This nuance cannot be appreciated in the cumulative char rates calculated using the residual CLT depth, although these values show a slight difference in the char rate according to the remaining char layer.

While the shape of char base line might be affected by a variety of non-homogeneities already lost to the fire it was observed that one of the factors was the local shape of annual rings.

In the residual depth maps in Figure 10, Figure 11, and Figure 12 the darker blue means deeper burns and faster charring rates. Generally, MUF can hold char layer more than the older PUR system (HBE) during the fire test. Also, floor assemblies held char layer more than walls. DF-L with MUF adhesive is shown similar pattern with DF-L with Polyurethane Adhesive (PUR HBE)

The absence of repeatable char patterns between the three different wall and three different floor assemblies allows us to conclude that no effect of thermal convection inside the furnace on the char rates was observed. The char rates along the half-lap joint show as slightly higher than at the center part of panels away from the joints.
There were statistically significant differences in char rates between panels depending on the adhesive systems, panel positions (horizontal vs. vertical) and depth of locally removed char layers during the test (0.95 confidence level).

The char rates were generally lower in the locations with thicker residual char layers.
About .01 mm/min is the threshold to show statistical differences analyzed by t-test.

There were significant differences (at 0.95 confidence level) in char rates between panels depending on all cases of the adhesive systems, panel positions (horizontal vs. vertical) during the test (Figure *13*).

In the 77% of cases, there were significant differences (at 0.95 confidence level) in char rates between panels depending on depth of locally removed char layers during the test.

CONCLUSION

There were significant differences (at 0.95 confidence level) in char rates between panels depending on the adhesive systems, panel positions (horizontal vs. vertical) and depth of locally removed char layers (77% of cases) during the test.

The areas with thicker residual char layers show lower char rates than the areas with thinner residual char layers (85% of cases).
No local variations of char rates due to thermal convection inside the furnace were observed on the char map patterns.
The char rates differences between the half-lap joint and the center part of the wall panels were observed, though quantification of these differences was challenging.
Mapping final char surface level and char front after fire exposure tests allows refined analysis of mass timber panel fire performance and the effect of residual char layer level.

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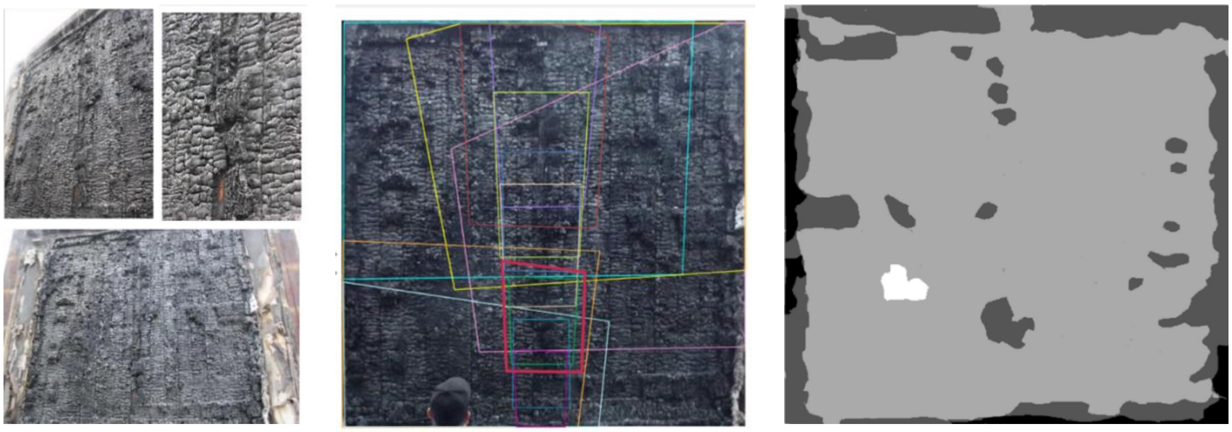
LIST OF FIGURES

Figure 7

Figure 7 A photograph showing the method of determining the remaining char layer: the red dotted line is a 3-layer non-edged glue line, and the blue dotted line is a 2-layer non-edged glue line after fire test. (Muszynski et al. 2021)

Figure 8



(a) (b) (c)

Figure 8. Image description of how the char layer diagram is made: partial fire exposed surface images taken from various angles after fire tests (a), the overall reconstructed fire exposed surface image (b), and the image showing the location and area of the residual char layer after fire tests (c) (Muszynski et al. 2021)

Figure 9

(a) (b)

Figure 9. Sets of CLT blocks cut into 305 mm x 305 mm (a), and the residual CLT thickness measurement points of each block (b) after fire tests.

Figure 10

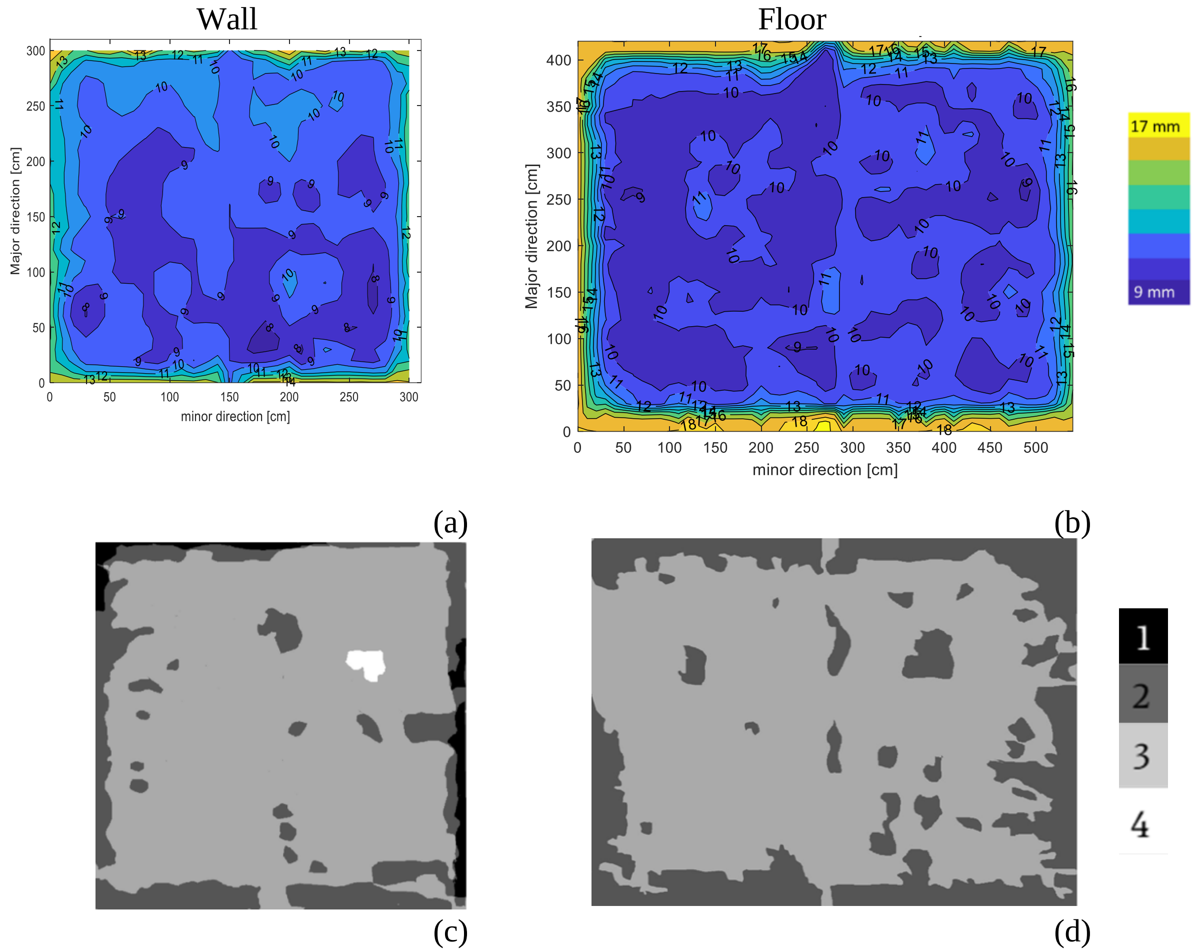


Figure 10. the contour plot of SPF with HBE adhesive (PUR) wall (a), and floor (b) residual char depth after fire test, and remaining char layer *map after fire wall (c) and floor (d) tests* (Muszyński et al 2021).

Figure 11

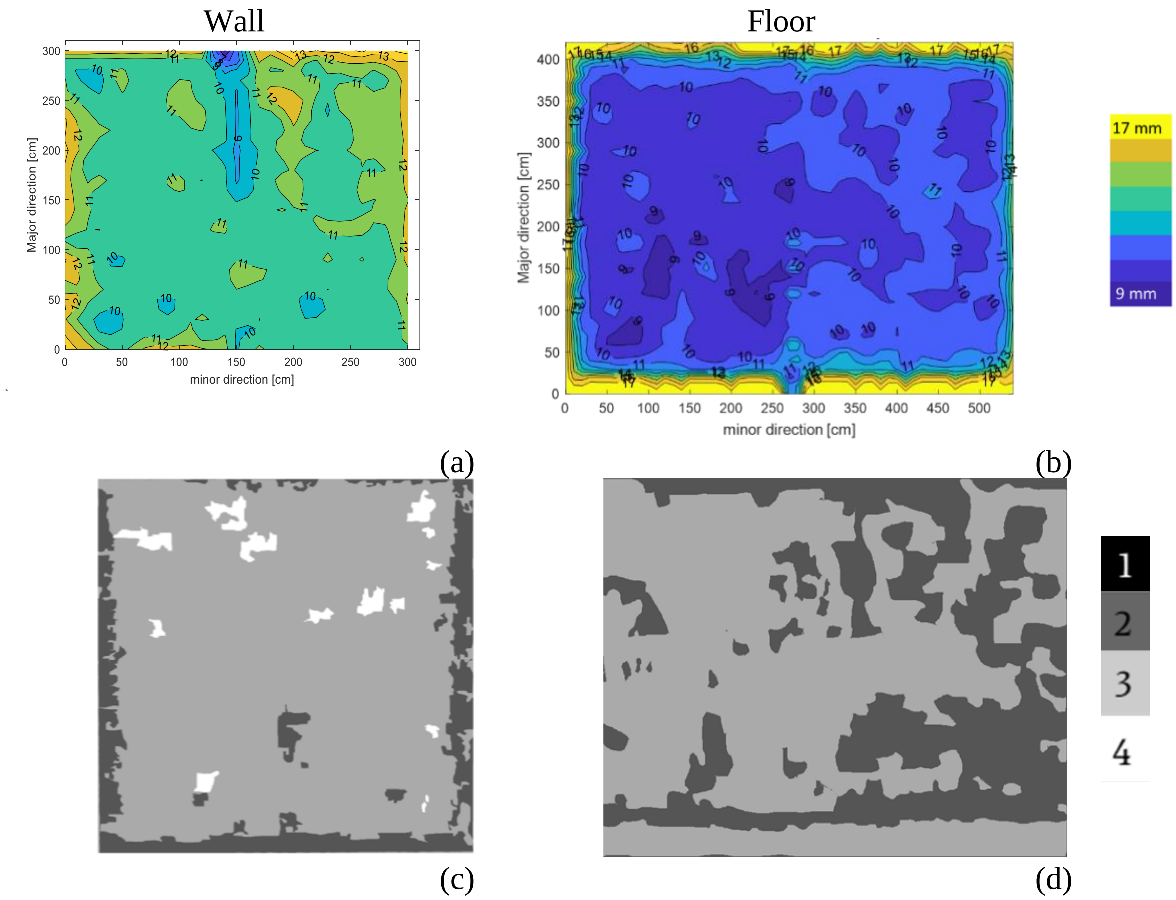


Figure 11. the contour plot of DF-L with HBE adhesive (PUR) wall (a), and floor (b) residual char depth after fire test, and remaining char layer *map after fire wall (c) and floor (d) tests* (Muszyński et al 2021).

Figure 12

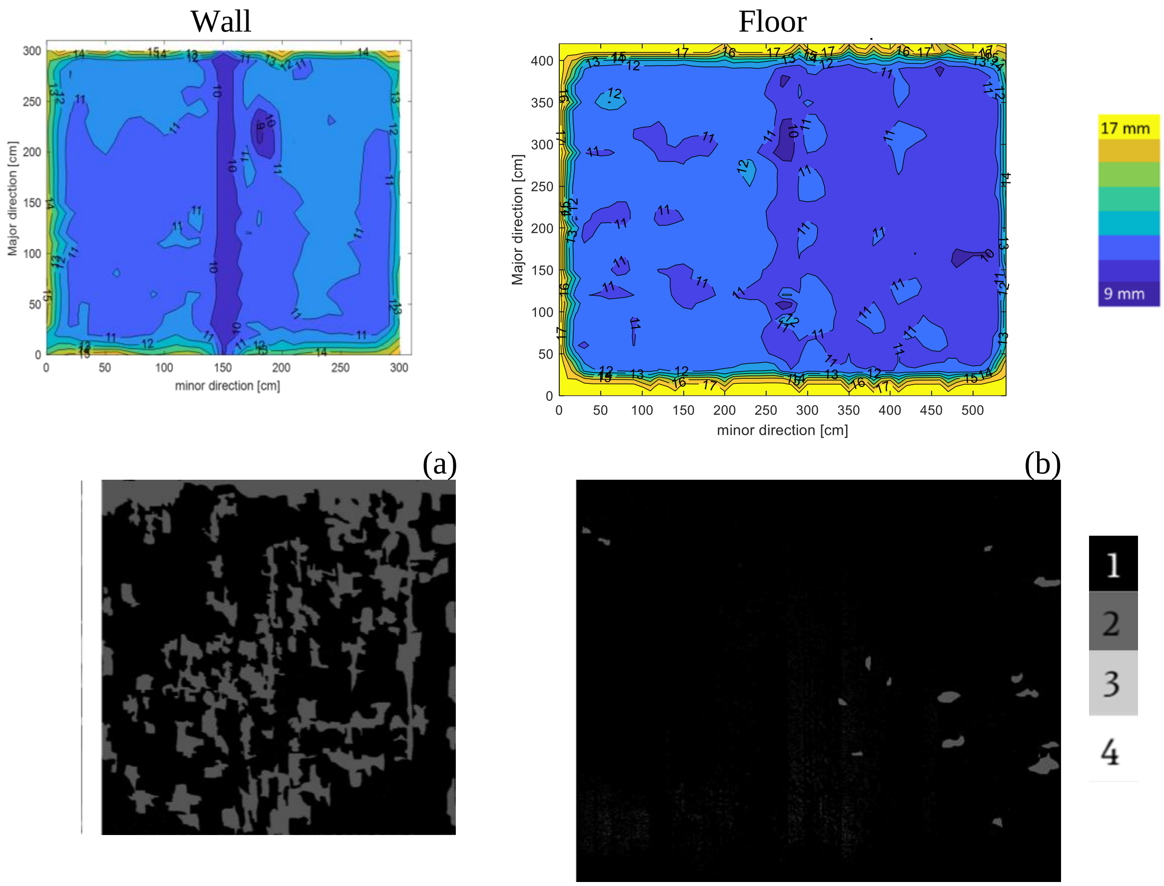
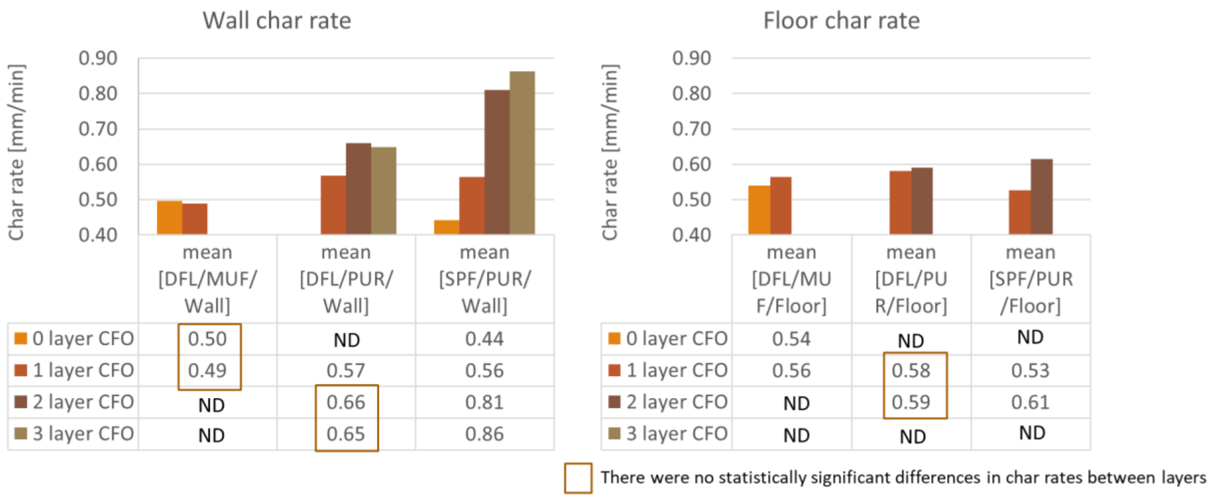


Figure 12. the contour plot of DF-L with MUF adhesive wall (a), and floor (b) residual char depth after fire test, and remaining char layer *map after fire wall (c) and floor (d) tests* (Muszyński et al 2021).

Figure 13



(a) (b)

Figure 13. The summary of char rates depending on each residual char layer of each CLT assembly: the summary of wall (a), and floor (b).

Table 1

Table 1. Average char rate of walls and floors assemblies calculated by measuring the residual CLT thickness around the location where the thermocouple was installed, and time detected when thermocouple is reached at 300 ° C (Muszynski et al 2018)

Walls				Floors			
Assembly	**Layers**	**Mean char rate mm/min**	**BL2/BL1**	**Assembly**	**Layers**	**Mean char rate mm/min**	**BL2/BL1**
SPF PUR	BL1	0.59	2.20	**SPF PUR**	BL1	0.49	1.76
	BL2	1.30			BL2	0.86	
	Cum	**0.81**			**Cum**	**0.61**	
DF-L PUR	BL1	0.55	1.49	**DF-L PUR**	BL1	0.49	1.76
	BL2	0.82			BL2	0.86	
	Cum	**0.65**			**Cum**	**0.63**	
DF-L MF	BL1	0.49	1.90	**DF-L MF**	BL1	0.47	1.68
	BL2	0.93			BL2	0.79	
	Cum	**0.58**			**Cum**	**0.55**	

INDUSTRIAL APPLICATIONS OF SOY FLOUR SUBSTITUTED PMDI”

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Abstract

Soy flour is at least half the cost of Polymeric diphenylmethane diisocyanate (PMDI) pMDI resulting in a potential cost savings. We have furthermore found several benefits across an array of product lines including: plywood, laminate, oriented strand board, particleboard, and medium density fiberboard. This presentation will show the performance of soy-pMDI for these various applications.

Key words: soy flour, adhesives, wood composites

Mechanical Performance of Prototype CLT Layups Made of Restoration Harvested Ponderosa Pine

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ABSTRACT

National forest restoration programs effectively reduce the spread rate of wildfires and pest outbreaks in forestlands. Each year, restoration programs in Western region of the United States yield a substantial amount of small diameter Ponderosa pine logs. The lumber obtained from these trees is considered low-value due to low mechanical properties, substantial presence of juvenile wood, wane, and in some cases blue-stain. United States Forest Service is seeking a value-added market for these logs to offset the high costs of the forest restoration operations. Cross-laminated timber can potentially provide such a market. The goal of this project is to verify a hypothesis that engineering characteristics of custom cross-laminated timber panels made of restoration harvested Ponderosa pine lumber will be sufficient for a class of cost-effective low-rise modular mass-timber construction. The approach was to compare the characteristics determined experimentally on prototype layups with theoretical values predicted using the Shear Analogy method. Three 2.43 m by 3.04 m five-ply panels were fabricated at a pilot-plant line at the Oregon State University, using 2-component melamine formaldehyde adhesive system. Grades No, 2 and 3 and ungraded laminations were assigned to all layers randomly. Standard long- and short-span flatwise bending tests were conducted to derive effective moment capacity, effective stiffness, and shear capacity of the layups. Optical measurement based on digital image correlation principle was used to derive effective shear rigidity of the specimens. The results show that compared to theoretically predicted values prototype cross-laminated layups fabricated with restoration harvested Ponderosa pine with random grade assignment in all layers had higher effective moment capacity, effective stiffness, and effective shear rigidity, but lower than predicted shear capacity.

Keywords:
Cross-laminated Timber; CLT; forest restoration programs; low-value lumber; Ponderosa pine; design values; stiffness; moment capacity, shear.

INTRODUCTION

The forest lands in the western regions of the United States are prone to catastrophic wildfires and pest out-breaks. One effective way to prevent such events is restoration programs, or thinning operations, in which the smaller and weaker trees are selectively harvested to preserve larger and superior trees in the forest land (Graham, et al., 1999). Each year, restoration programs in Pacific NW yield a substantial amount of Ponderosa pine (PP) lumber acquired from small-diameter logs that contain large amounts of juvenile wood, wane, and twist. This lumber is considered low-value (Rainville, et al., 2008), it is not typically used as structural material and have limited market in the US (Collins, 2018).

USDA Forest Service is seeking a value-added market for PP lumber generated in restoration programs to offset the high costs of these operations. Research suggests that cross-laminated timber (CLT) can potentially provide an additional market for the lumber harvested from restoration programs in the Pacific Northwest (Lawrence B. , 2017). CLT is a massive, engineered, wood panel consisting of three or more orthogonally arranged plies of lumber bonded with adhesives. The idea of utilizing lower grade lumber in engineered wood products is not a new concept in the industry. Research on small diameter yellow-poplar (Mohammadzadeh & Hindman, 2015), fast-grown eucalyptus (Liao, et al., 2017), Pinus Radiata (Sigrist & Lehmann, 2014), and sugar maple (Ma, et al., 2021) CLT emphasized that low-grade lumber can provide satisfactory mechanical properties. Hernandez et al. demonstrated that PP lumber obtained from small-diameter trees can be successfully utilized in fabrication of structural glue-laminated timber (Hernandez, et al., 2005). Two studies were conducted at Oregon State University on the feasibility of hybrid CLT panels consisting of low-grade, Lodgepole pine (Larkin, 2017) and mixed restoration harvested species (Lawrence C. , 2017) in core lamellas and showed that hybrid CLT panels had strength and stiffness comparable with *North American standard for performance rated cross laminated timber* PRG-320 basic E3 grade. The goal of this project is to assess the possibility of utilizing restoration PP lumber in all plies of structural CLT without the need for grading the material to maximize the utilization, minimize the waste, and reduce the costs associated with grading.

The target structural application for PP CLT should have potential for utilization of substantial volumes of the material. A parallel study is focused on design of low-rise modular structures based on structural CLT panels fabricated from restoration harvested PP (Bhandari, et al., 2020). Both, the structural design and the PP CLT layup were optimized using an iterative procedure, in which the Shear Analogy method (Kreuzinger, 1999) for generating layups of desired characteristics and the parametric modular design to adjust structural requirements of the building were employed (Jahedi, et al., 2020). Since no structural element loaded in edgewise or in minor strength direction was used in the proposed modular design, the objective of presented study was to determine flatwise design characteristics of the prototype CLT panels in the major strength direction and to compare these empirically derived characteristics with those predicted theoretically.

MATERIALS AND METHODS

The general approach of the study was to determine bending characteristics of prototype CLT panels fabricated in OSU pilot-plant using restoration harvested PP with grades assigned to layers randomly and to compare these empirically derived characteristics with those predicted with the shear analogy method based on the characteristic properties of the laminations. Standard long- and short-span flatwise bending tests were conducted to derive effective moment capacity, effective stiffness, and shear capacity of the layups. The ANSI/APA PRG 320 requires that custom layups meet a set of requirements for bond integrity and structural performance characteristics in major and minor strength direction of the panels as declared for that grade (ANSI/APA, 2019). The bond integrity tests, which include cyclic delamination and block shear test are discussed in a separate publication (Jahedi, et al., prepared for publication).

MATERIALS: LUMBER AND ADHESIVE SYSTEM

The restoration harvested PP CLT panels were fabricated using 2 x 6 nominal dimension PP lumber obtained from Southern Oregon and Northern California restoration operations. The supplier, Collins Co. (Lakeview, OR), kiln dried, and visually graded a portion of the material into “No. 2 or better”, “No. 3”, while the rest of the material was delivered “ungraded.” Grades No, 2 and 3 and ungraded laminations were assigned to all layers randomly. The material was stored in a covered area and the moisture content of the boards at the time of CLT fabrication were 10.8% ± 1.1%. The prototype layups were bonded using two component Melamine Formaldehyde (MF) adhesive (AkzoNobel 1263_9563, Amsterdam, Netherlands).

FABRICATION OF PP CLT SPECIMENS

Per ANSI/APA PRG 320 standard, the material was planned within 24 hr of production on 4 sides using a medium scale industrial planner (LeaderMac, Blaine, Washington) to achieve specified thickness tolerance between boards and refresh the surface for a good bonding. Because the material had significant amounts of wane, the bark-side surfaces of the boards were planned more aggressively, down to 33mm (1.32 in), compared to 35mm (1.375 in) practiced in typical CLT production in the US. Despite this effort the thickness tolerances of the laminations determined on a sample of 16 boards immediately after planning was outside the PRG 320 specifications (max 0.20 mm thickness variation).

Resin and hardener were applied separately using a pilot-line scale resin application line (Hexion, Columbus, Ohio) with two adjustable flowrate pumps connecting to two separate application heads. The resin and hardener were applied at 100:100 ratio and a combined spread rate of 340 g/mm^2. A horizontal pressure (in the panel width direction) of 6.2 MPa, and a 16.6 MPa vertical pressure were applied to the assembly for 3 hours, followed by 16 hours of reduced pressure for curing. Three 2.43 m by 3.04 m prototype 5-ply CLT panels (168 mm gross thickness) were produced and cut up into test specimens required for this project (Table 2) and for bond integrity tests that are reported in a parallel publication (Jahedi, et al., prepared for publication). Visual inspection of the beam specimens revealed interlaminar gaps on some of the specimens cut from the center of the panels. These gaps lead to delamination failures in standard bond integrity tests observed in a parallel study conducted within this project. The working hypothesis is that these interlaminar gaps may have resulted from a combination of poor thickness tolerances (mentioned above) and uneven clamping pressure (pending investigation).

Table 2 List of tests conducted, the standard used, the size and number of specimens.

Required tests	Spec. mark	Related Standard/section	No. Spec.	Standard Span/Depth	This Study Span/Depth*	Actual Dimensions** mm x mm
Long Span Bending	FB	ASTM D198/section 4 - 12	12	30	17.2	300 x 3,040
Short Span Bending	FS	ASTM D198/section 4 - 12	6	5 to 6	6	300 x 1,155

**Achievable span/depth ratio was restricted by the size of CLT press in production line which allows fabrication of panels up to 3.05m length and 2.44m width. The depth of beams was 168mm. **152mm bearing support (on each side) is considered in the length of beams. Half of this is deducted from the actual length to calculate span.*

PERFORMANCE TESTS

ASTM D198 method, sections 4 - 12, third-point bending test was used to determine effective stiffness (EI_{eff}), effective moment capacity (F'_bS_{eff}) and effective shear rigidity (GA_{eff}), Figure 14a. ASTM D198 method, sections 4 - 12, 3-point bending test was used to derive shear capacity (Vs) of the short CLT beams, Figure 14b.

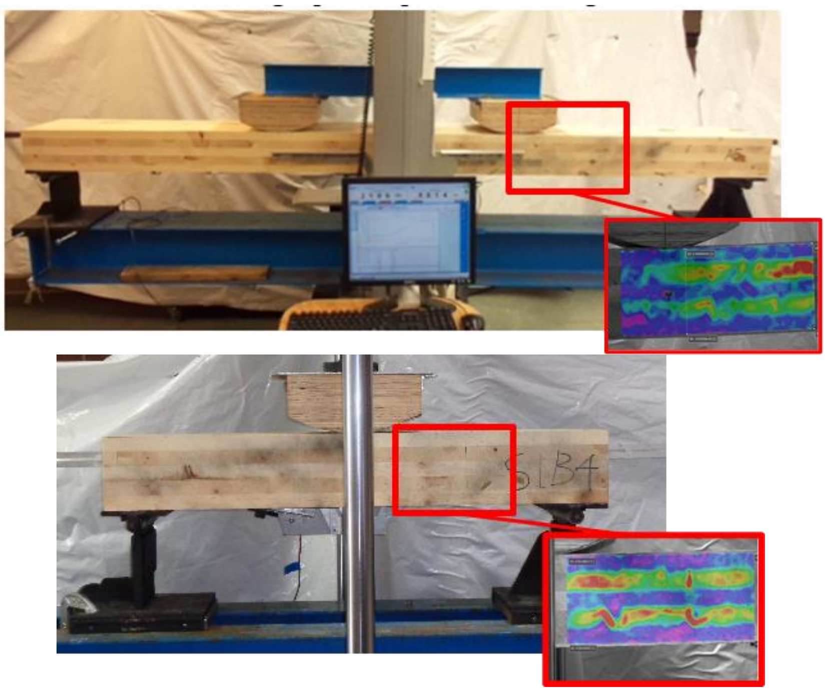

Figure 14, Third-point (top) and 3-point (bottom) bending test setups. Optical system field of view marked as red areas. The LVDT sensors that are extended through the length of beams are installed behind the beams and not shown in the image.

The total deflection of the neutral axis at the center of the beams was measured with a LVDT sensor with a range of 10mm and accuracy of ±0.002mm installed on a yoke suspend at the reaction points. In addition, another LVDT sensor was used in the third point bending test to measure the deflection of the neutral axis in the shear free span of the beam between the loading points. In both test setups, an optical measurement system based on the digital image correlation (DIC) principle (by Correlated Solutions) was used to measure the strain field in the shear span of the beam in order to determine effective shear rigidity (Figure 14). The length and width of the CLT beams were measured with accuracy of ±1.5 mm and the accuracy of thickness measurements were ±0.05 mm. The universal testing machine (Instron, Norwood, USA) was equipped with a 100kN load cell with accuracy of ±0.0001 N.

ANALYSIS

The mechanical properties were derived using equations presented in ASTM D198. The characteristic strength design values, i.e., effective moment capacity and shear capacity, were determined from a 5th percentile tolerance limit of the measured strength values distribution and divided by 2.1 (C_{ASD}) safety factor (PRG-320 section 8.5.3.2). In addition, a load duration adjustment factor (C_D) of 1.6 was applied to compensate for actual duration of our tests (10 minutes) to compare the obtained experimental values to shear analogy design values, which were derived based on a live load duration (ten years). For deflection related design values, i.e., effective stiffness and effective shear rigidity, the averages of respective measured values for all specimens were used. In PRG 320 the design values in Imperial units are given per 1 ft of the width of the structural element. For SI representation of the units, all of the design values were converted from 1 ft of width to 1 m of width. The adjustments are summarized in the set of equations:

Effective moment capacity	$F_b S = \frac{F_b S_{(5th\ percentile)}}{C_D\ C_{ASD}}$	*Effective shear capacity*	$Vs = \frac{Vs_{(5th\ percentile)}}{C_D\ C_{ASD}}$
Effective stiffness	$EI = EI_{(average)}$	*Effective shear rigidity*	$GA = GA_{(average)}$

As shown in Figure 14, average shear strain of the specimens through the entire beam depth were acquired from the shear span of the beam. The area of interest is extended from far right of the camera view, to the load point, with some distance to ensure stress concentration around load point does not impact the results. The average of shear strain $\varepsilon_{xy\ av}$ in all measurement points within the area of interest spaced 7 pixels apart were used in the following equations to derive effective shear moduli of the beams G_{eff}, where, τ_{av} is average shear stress on the cross section of the beam, P is the force exerted, b is width, and h is the depth of the beam.

$$\tau_{av} = \frac{P}{2\ b\ h} \qquad G_{eff} = \frac{\Delta\tau_{av}}{\Delta\varepsilon_{xy\ av}}$$

RESULTS

Modulus of elasticity (MOE), true elastic modulus, shear modulus, and modulus of rupture (MOR) of prototype custom PP CLT is presented in Table 3.

Table 3 Summary of effective mechanical properties of PP CLT prototype specimens.

MOE GPa		**E_{ture}** GPa		**G*** GPa		**MOR** MPa	
Third-Point Test							
Avg	Std	Avg	Std	Avg	Std	Avg	Std
6.0	0.5	6.3	0.5	0.47	0.12	43.4	8.5
3-Point Test							
6.0	0.6	-	-	0.44	0.11	25.1	3.5

No adjustment or safety factors applied to the values. The calculations are based on the sizes presented in Table 2.
** Shear modulus values are calculated using the data acquired from optical measurement system.*

In the table, the average MOR values for short beams tested in 3-point bending includes nominal MOR values assigned to three specimens that failed in rolling shear and three specimens that failed in flexure. These values, with the exception of the nominal MOR determined for 3-point bending, were used to derive the design values. The design values are summarized in five box plots presented in Figure 15. To derive shear capacity from 3-point bending test, only the specimens failed in rolling shear were used.

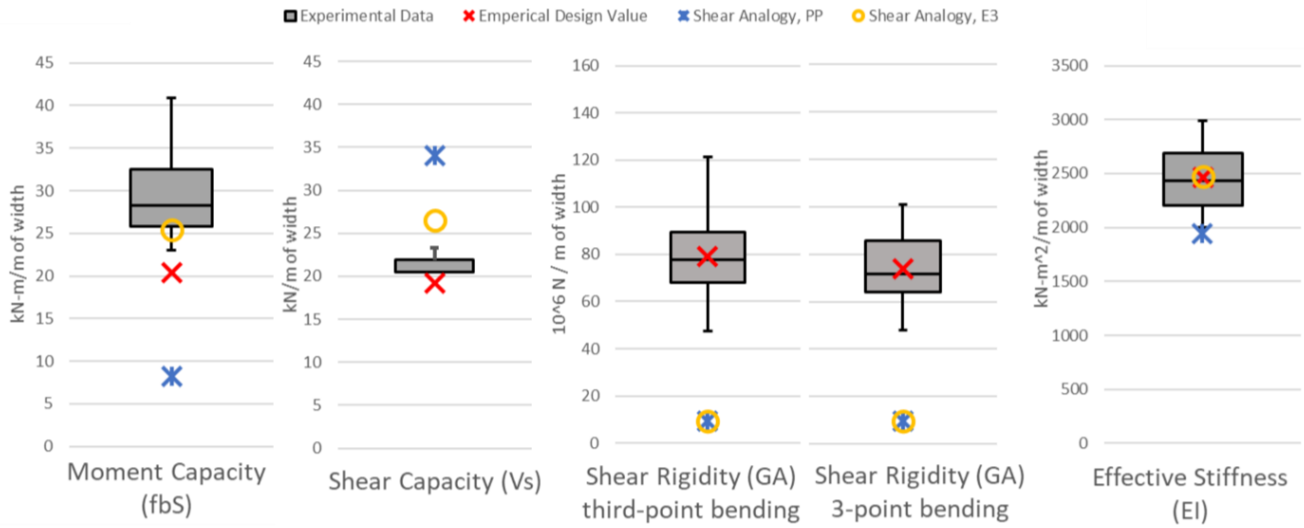

Figure 15. Empirically derived design values of custom PP CLT layup compared to the predictions from shear analogy for PP and PRG-320 basic E3 grade.*

**Design values of PP laminations were acquired from Western Woods Grade No.3, NDS supplement handbook.*

In Figure 15, the gray bars show the distribution of experimentally derived values. The red marks represent the characteristic design values acquired from experimental data (adjusted by applicable factors). Blue marks show the design values predicted from shear analogy method for restoration harvested PP CLT. For the purpose of comparison, the design values predicted from shear analogy method for a PRG-320 E3 basic CLT grade with exactly the same layup as the prototype was presented with yellow markings.

DISCUSSION

The results demonstrate that experimentally derived effective moment capacity (20.4 kN-m/m of width), effective stiffness (2465 kN-m^2/m of width), and effective shear rigidity (79 10^6 N/m of width) values exceed the predictions from shear analogy for PP CLT, while experimentally derived shear capacity (19.3 kN/m of width) is underestimated by 56% of the predicted value. One potential reason for this low shear capacity may be poor bonding quality in the specimens in which the interlaminar gaps were detected. To verify this hypothesis, these results will be compared with characteristics obtained from PP CLT panels fabricated in a commercial manufacturing plant. Furthermore, from the comparison it is obvious that there is a large difference (by a factor of x7.4) between shear rigidity predicted by the Shear Analogy for PP and E3 basic grade with the empirically derived design value. The reason for this may lay in some peculiar assumptions used in the Shear Analogy method. Firstly, the way that PRG-320 uses the Shear Analogy method is to assume that $G_0 = E_0/16$, where G_0 being shear modulus and E_0 is elastic modulus in longitudinal direction. The rationale for this assumption dates back to 1970s from previous experiments on clear specimens that suggest shear modulus is in direct relation with the true elastic modulus and can be estimated from a ratio between 1/12 to 1/20 of true elastic modulus (Samon & Sotomayor-Castellanos, 1990). Applying this assumption to strength-graded lumber the shear modulus would be lower in a lower-grade lumber in proportion with the reduction in its elastic modulus. That assumption contradicts empirical studies suggesting that the shear modulus is independent of lumber grade (Khokhar, et al., 2008) and may be the source of the discrepancies.

CONCLUSIONS

The results of performance tests on pilot-line scale prototype panels fabricated at Oregon State University show that compared to theoretically predicted values prototype cross-laminated layups fabricated with restoration harvested Ponderosa pine with random grade assignment in all layers had higher effective moment capacity, effective stiffness, and effective shear rigidity, but lower than predicted shear capacity. A combination of poor thickness tolerance of the laminations and uneven pressure distribution, causing poor interlaminar bonding, might be the potential reason for low shear capacity values for prototype panels. Future work will include conducting similar set of performance tests on PP CLT panels fabricated in an industrial setting and the comparison with both experimental values obtained from the prototype panels and the predicted values based on shear analogy method.

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A Strong and Highly Light-transmissive Bamboo Composites

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Abstract

Bamboo is one of the most important forest resources, which is widely used in building industry, furniture manufacturing, decoration and packaging. Many bamboo products have been developed, such as laminated bamboo, bamboo curtains, bamboo chipboard and bamboo fabric. Transparent wood product was reported to be successful. However, for the transparent bamboo, there are still many technical issues, such as poor permeability of bamboo, excessive delignification time and vulnerable cellulose scaffold. In this study, bamboo was converted into a transparent material with great optical transmittance and good strength. Bamboo has a much faster regeneration rate than wood, but its high density and high extractive content make it challenging to produce transparent products. This study presents a simple and effective approach that could address this challenge. Pretreatment of bamboo with low concentration sodium hydroxide greatly improved the preparation efficiency of transparent bamboo. The transparent bamboo with a thickness of 1 mm and cellulose volume fraction of 22% made from the pretreated bamboo exhibited an improved total optical transmissivity up to 80%, which was 60% higher than that of untreated bamboo. Compared to transparent wood (TW), although the transmissivity of transparent bamboo was slightly lower, its mechanical strength was almost doubled. Besides, the developed transparent bamboo exhibited a low heat conductivity of 0.203 W m −1 K−1, being about 10% lower than that of TW (0.225 W m −1 K−1) and approximately 80% lower than that of common glass material (0.974 W m −1 K−1). The transparent bamboo would significantly enhance energy-saving performance, being a promising alternative to traditional glass.

Keywords: bamboo composites, cellulose nanomaterials, transmittance, thermal insulation, mechanical strength

Poster Session

Chair; Tamara França, Mississippi State University, USA

Student Posters:

Behavior of In-plane Butt-joints with 45° Screws in Ponderosa Pine CLT

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Abstract

Cross-laminated timber (CLT) is a structural panel built by gluing perpendicular layers of dimension lumber laminations for mitigation of in-plane anisotropy and superior dimensional stability. The goal of this research is to demonstrate the viability of Ponderosa pine CLT for low-rise modular buildings and to develop design criteria for this application. Currently, Ponderosa pine (*Pinus ponderosa*) harvested in forest restoration projects in the Northwestern United States has a limited market value. The project hypothesis is that its market value may be improved by utilization in CLT for low-rise modular buildings designed to be quickly assembled and disassembled with minimal damage, and well suited to be used in medium-term disaster relief in areas struck by earthquakes, tsunamis, forest fires, etc. By PRG320 standard, Ponderosa pine CLT falls in the category of “custom grade,” therefore, in order to be specified in structural design, the mechanical characteristics and the capacity of connections used with such panels have to be experimentally determined.

The Ponderosa pine CLT used within this project has a standard width of 1.2 m (4 feet) to consider local manufacturing constraints. This dimension is smaller than in most standard commercial CLT panels, and to use these panels in a wall or a floor, they have to be joined by means of in-plane connections that are capable of transferring shear between the panels. The stiffness and capacity of these connections systems under reversal loading (e.g. earthquakes) affect the behavior of the multi-panel wall system – the multi-panel wall can act as a single wall, coupled wall panels, or intermediate between both – is essential for the design and analysis of CLT structures with multi-panel walls in high seismic areas.

Out of many options available for in-plane CLT connections, butt joints with 45° screws has been selected for their ease in production and installation. However, the data on the behavior of such connections in CLT is still scarce. In this poster, the experimental procedure aimed at the determination of mechanical characteristics of CLT butt joints with 45° screws will be presented. Eight assemblies of three-ply 100 mm (4 inches) Ponderosa pine CLT have been tested under monotonic and cyclic loading in shear and tension. The force-displacement curves are used to extract the engineering characteristics of the connections: strength capacity, yielding point, ductility, equivalent damping ratio, and dissipated energy. The failure mechanism under shear and tension loading of the butt joints has been analyzed. These results are compared with the results determined on CLT made from other species of wood. The strength and stiffness parameters will be used for designing the modular structure.

Keywords: *In-plane connection, Ponderosa pine CLT, butt joints, connections*

Acknowledgment: This research is supported by USDA Forest Service (wood innovation grants program 17-DG-1162765-742 and 18-DG-11062765-738). The contribution of Collins, Sierra Pacific, DR Johnson, Vaagen Timbers, Katerra, USNR, Anderson Construction, Rothoblaas, SMT, OFRI, TDI, and AkzoNobel is acknowledged. The author is advised by Dr. Mariapaola Riggio, Dr. Lech Muszynski, and Dr. Erica Fischer. Sina Jahedi's contribution to the project is acknowledged.

Cellulose Nanocrystal Coatings on Poly (lactic acid) Film for Food Packaging Applications

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Abstract

Cellulose nanocrystals (CNCs) are among the most promising next-generation materials in the food packaging field. However, the moisture sensitivity of CNCs has a negative effect on barrier, mechanical, and other essential properties of pure CNCs films as a packaging material. Based on this, CNC films laminated with plastic films as an outside layer is a reasonable approach that has been explored. In this research, poly (vinyl alcohol) (PVA) and kappa-carrageenan (K-C) were added into 6% CNC suspensions to overcome the compatibility issue between cellulose nanocrystals (CNCs) and the poly (lactic acid) (PLA) film. This mixed CNCs composite system was used for PLA coating. After drying, another layer of PLA film was laminated onto the coated films to obtain the final sandwich composite structure. Meanwhile, the properties of the CNCs composite system and coating performance of different formulations were evaluated. Although there was a huge difference in viscosity between PVA and K-P mixed systems, both of them could significantly improve the coating quality only at 15wt% addition based on CNCs mass. The laminated PLA/CNC films showed great barrier properties, water vapor transmission rates were around 24 g/(m^2·d), compared with pure CNCs films (444 g/(m^2·d)).

The Effect of Exposure to Elevated Temperatures on Dowel Bearing Strength of Mass Plywood Panels

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Abstract
Not Available

Char rate of Custom CLT Layups Utilizing Ponderosa Pine from Logs Harvested in Western Forest Restoration Programs

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Abstract

Ponderosa pine is one of the major lumber resources of the Western U.S. included in National Design Specification for wood as of Western Wood specie group. Despite the low structural characteristics attributed to Western Woods, our hypothesis is that Ponderosa pine can be successfully utilized in CLT panels for low- and medium-rise structures. While parallel projects are concerned with the mechanical characterization of prototype all-Ponderosa pine layups, little is known about the fire performance and charring rates of this species since it has not been considered for structural uses. Fire tests for CLT elements are required before manufacturers will consider using these in CLT because in certain building types and specific applications. Therefore, the objective of this project is to determine the char rates of unprotected CLT layups fabricated with Ponderosa lumber pine subjected to the standard ASTM E119 temperature curve.

Eight 5-ply (1219 mm x 1829 mm) Ponderosa pine CLT panel specimens were prepared for the fire test. A pair of such specimens were tested in parallel at a time, using a custom steel frame. The specimens represented two adhesive systems (UF, and PUR), and two positions (vertical, and horizontal). Thermocouples were embedded in-plane 305 mm away from the long edge of CLT panels in clusters of five: one at each bond line between layers, and one 5 mm from fire exposed surface. Six such clusters of thermocouples were installed in each panel. All assemblies were subjected to the ASTM E119 test procedure for 150 minutes. Char rates were determined based on temperatures measured at 5 different distances from the fire exposed surface. Charring was assumed when the temperature reached 300 Celsius. Statistical analysis was used to compare char rates between panels tested in vertical and horizontal positions, as well as between panels bonded with different adhesive systems. No significant differences between char rates at the same distance from the exposed surface were detected regardless of installation positions and adhesives, which allowed pooling data from all tested panels for

further analysis. One common feature was significant variation in char rate as the char front moved away from fire exposed surface.
Except for the first 5 mm from fire exposed surface, the mean char rate was faster than the 0.65 mm/min benchmark published in EN 1995-1-2.

Key words: Fire Performance; Char rate; CLT; cross-laminate timber; Custom Layups; Ponderosa pine; Western Forest; Restoration Programs;

Introduction

Ponderosa pine is one of the major lumber resources of the Western U.S. (Chambers et al 2016) included in National Design Specification Western Wood specie group. Ponderosa pine is harvested in large volumes in US Forest Service forest restoration programs aimed at reducing long term wildfire risks in Western United States.
There is a pressing need to find a value-added market for this material to partially offset the high cost of this operation. With the emergence of new CLT industries in the region, there is a real potential to utilize this material for structural engineered wood panels. However, these panels must comply with the performance standards specified in the ANSI/PAPA PRG320 product standard for North American CLT and meet the requirements of a specific project.
A project funded by the 2017 Wood Innovation Program aims to utilize this material in custom CLT layups developed specifically for low-rise modular structures. Another essential prerequisite for the commercialization of this material in other types of structures is to determine its fire performance.
Despite the low structural characteristics attributed to Western Woods, our hypothesis is that Ponderosa pine can be successfully utilized in CLT panels for low- and medium-rise structures. While parallel projects are concerned with the mechanical characterization of prototype all-Ponderosa pine layups, little is known about the fire performance and charring rate of this species since it has not been considered for structural uses. Fire tests for CLT elements are required before manufacturers will consider using Ponderosa pine in CLT for certain building types and specific applications.
Therefore, the objective of this project is to determine the char rate of unprotected CLT layups fabricated by Ponderosa lumber pine subjected to the standard ASTM E119 temperature curve.

Materials & Methods

Test Specimens

Commercial CLT manufacturers operating in the Western US (Smartlam, and Vaagen Brothers Co.) provided the all-Ponderosa pine CLT test specimens. Eight 5-ply 1.2 m (4 ft) x 1.8 m (6 ft) Ponderosa pine CLT samples were prepared for fire test. Four of these samples were fabricated by Vaagen. Other four were cut at Oregon State University from one 5-ply 2.1 m (7 ft) x 8.5 m (28 ft) CLT panel fabricated by Smartlam.

Basic operation of Vaagen Bros. has been processing small logs harvested by whom from Eastern WA, U.S.A. They used lumber in CLT production in Colville, Washington, U.S.A. CLT fabricated by Vaagen uses UF adhesive cured by radio frequency (RF) press.

Smartlam is primary CLT company operating in Montana, U.S.A. since 2012. Its products use generally SPF or DF-L bonded with PUR HBX adhesive system (characterized by better fire performance) pressed cold.

For this research, Vaagen and Smartlam were requested to make CLT of Ponderosa pine from logs harvested in Western forest restoration programs which is not their standard practice. Only Vaagen is involved in the forest restoration programs in Eastern Washington. Smartlam CLT panels were produced from Ponderosa Pine produced by Collins Lumber company involved in the forest restoration programs in Southwestern Oregon and Northern California.

Dimension of lumber used for CLT laminations was 35 mm x 133 mm (1.375 in x 5.25 in) in cross section and 1219 or (4 ft) or 1828 mm (6 ft) long. The location of finger joint was randomly distributed. The grade of lumber to fabricate by Smartlam was visual grade No. 2. while Vaagen used 2 & Btr. A summary of materials used in this study is shown in Table 4.

Instrumentation

Six type K ceramic insulated 0.51 mm (24 gauge) thermocouples were placed on the fire unexposed surface per each panel to measure surface temperature. They were covered with a 152 mm x 152 mm (6 in x 6 in) ceramic fiber pads to prevent interference with the ambient lab temperature affected by heat generated by the furnace.

Type K PFA insulated 1.4 mm x 2.4 mm wire thermocouples were embedded in each CLT panel specimen in six clusters of five at 5 mm, 35 mm, 70 mm, 105 mm , and 140 mm from fire exposed surface to measure temperature gradient during the fire test.

Thermocouples in each cluster were placed in a roughly diagonal line configuration 51 mm (2 inches) apart from each other in plane direction to avoid effect of previous thermocouples to next it (Figure 17). In order to prevent damage to thermocouple wires where CLT is mounted in steel frame, three notches on each of the longer edges of CLT panels were designed. The depth of the notches was 25 mm (1 in), and the width was 254 mm (10 inches). The surface of the notch (Figure 17d) was coated with a fire stop sealant and then covered with mineral wool and plywood (Figure 17 e).

The relationship between the left and right side of distance between clusters of thermocouple holes from fire exposed surface is 180 degrees rotation symmetry as shown in Figure 17c. The side view of general thermocouple clusters installation is shown in Figure 17d.

Thermocouples were embedded in-plane of the panel and with the expected isotherm, in the direction along the minor strength direction, and embedded depth from the long edge of CLT panels was 305 mm (1 ft) to measure temperature gradient across the panel thickness. These thermocouples were planted in the panels through 11 mm (7/16 in) holes drilled from the long edge of panels, and secured in holes on the side close to fire exposed surface by 9.5 mm (3/8 in) aspen dowels to ensure loose fitting ans proper space for thermocouple wires. Aspen dowels were selected because specific gravity of aspen is similar to Ponderosa pine (FPL, Wood Handbook). Tips of thermocouples were placed at the end of the hole. A groove 2 mm deep and 2 mm wide was carved along the length of Aspen dowels to assemble with thermocouples. The sets of thermocouple wires and dowels were secured using 3M paper type. Lengths of dowels were 0.25 to 0.5 inch shorter than depth of holes to prevent damage to thermocouples from bending at sharp angle. Remaining volume of holes was filled with 3M CP 25WB plus or HILTI CP 601S fire stop sealant to prevent from fire spreading through the remaining volume of the holes.

Test procedures

All fire tests were performed at the Western Fire Center's fire testing facility in Kelso, WA. A pair of specimens was tested in parallel at a time, using a custom steel frame. The left CLT panels were named "a", and the right CLT panels were named "b" in the Table 4 It was shown in Figure 16 All assemblies were subjected to a modified procedure of the standard ASTM E119 (2015) test for fire resistance for 150 minutes without external loading to evaluate the fire performance of the custom CLT layup specimens. Two CLT panels with embedded thermocouples were mounted on the insulated steel frame. In the case of the wall fire tests, the gas of the furnace was ignited before the thermocouple embedded CLT and the assembled steel frame were mounted in the furnace. As soon as it was ignited, the steel frame and the furnace were mounted using a forklift. The fire resistance tests were conducted for 150 minutes The fire resistance tests were carried out for 150 minutes based on the time when the side door of the furnace was closed. The furnace temperature curve of this experiment followed the standard temperature curve of ASTM E119. After 150 minutes, the furnace gas injection was stopped and then the furnace and the steel frame were separated. When the furnace and the steel frame were separated, the fire was extinguished by spraying water as soon as the exposed fire surface was exposed to extinguish the fire.

Data analysis

The char rate was calculated using the distance from the fire-exposed surface of the thermocouple installed at each location and the time it reached 300°C. F-test and t-test were performed to to compare the char rates obtained from the panels.
F-Test for char rate between CLT fire test assemblies was conducted to decide t-Test method. Depending on the result of the F-test, an equal or unequal variance t-test was performed.
T-Tests: Two-Sample assuming unequal variances or equal variances were selected to compare CLT fire test assembles depending on the results from F-test results. The critical P value was

0.025 because of two tails condition. If calculated P value in F-test is larger than 0.025, the null hypothesis (all variances are same) cannot be rejected, and t-Test: Two-Sample assuming equal variances is selected. Other cases, which P value in F-test is smaller than 0.025, t-Test: Two-Sample assuming unequal variances is selected.

Results and Discussion

Charring depth as a function of the time for all fire test performed with Ponderosa pine cross-laminated timber panels with two manufacturers in horizontal (floors) and vertical (walls) position is shown in Figure 18. The slope of this graph is the char rate. Thus, the char rates between thermocouples embedment depths were calculated using this value. It is shown in Figure 19.
According to the statistical analysis performed to verify the similarity of the char rate of each condition, there were no statistically significant differences in char rates between panels regardless of the adhesive systems used (UF vs. PUR HEX) or panel position during the test (horizontal vs. vertical) at two tails, 0.95 confidence. These statistical results were shown in This is presumably because the occurrence of char fall off observed in PUR-HEX type adhesive was similar to that of UF in CLT.

Because there was no statistically significant difference in char rate between panels the data obtained for each TC embedment depth could be pooled.
Results pooled for each depth are shown in Figure 5 and Figure 6.
As a result of performing a t-test of the average char rates for the embedding depth of the thermocouples, it was confirmed that the difference between groups in the average char rate by embedding depth was statistically significant. These results were shown in Table 6.
The recorded char rates varied as the char front moved away from the exposed surface. The average measured char rates were higher than those posted for Ponderosa pine in EN 1995-1-2 standard except the first 5 mm layer exposed to the initial low part of the standard temperature curve.

Summary and Conclusions

The mean char rate for Ponderosa pine CLT was determined at … mm/min, which faster than the 0.65 mm/min benchmark published in EN 1995-1-2.
There were no statistically significant differences in char rates between all-Ponderosa panels regardless of the adhesive systems or panel position during the test (horizontal vs. vertical) at two tails, 0.95 confidence. The recorded char rates varied as the char front moved away from the exposed surface. There were statistically significant differences between groups in the average char rate by embedding depth. The average measured char rates for individual layers were higher than those posted for Ponderosa pine in EN 1995-1-2 standard except 0-5 mm.

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Table 4

Table 4. Summary of materials used in this study

Spec. ID	Species	Grade	Adhesives	Manufacturer	Test position	Position in furnace frame
W1a	Ponderosa pine	No. 2	PUR(HEX)	Smartlam	Wall	Left
W1b						Right
W2a		2 & btr	UF	Vaagen Bros.	Wall	Left
W2b						Right
F1a		No. 2	PUR(HEX)	Smartlam	Floor	Left
F1b						Right
F2a		2 & btr	UF	Vaagen Bros.	Floor	Left
F2b						Right

Table 5

Table 5 The statistical comparison about char rates between pair of CLT fire test assemblies depending on charring depth using F-Test and t-Test (two tails, 0.95 confidence)

P-value from t-Test and F-Test		UF-Wall 0-5 mm 5-35 mm 35-70 mm 70-105 mm		PUR(HEX)-Floor 0-5 mm 5-35 mm 35-70 mm 70-105 mm		UF-Floor 0-5 mm 5-35 mm 35-70 mm 70-105 mm	
		t-Test	(F-test)	t-Test	(F-test)	t-Test	(F-test)
PUR(HEX)-	0-5 mm	0.1628*	(0.0017*)	0.3857	(0.1664)	0.629*	(0.004*)
	5-35 mm	0.206	(0.1674)	0.7603	(0.3042)	0.1397	(0.1223)
	35-70 mm	0.7673	(0.3372)	0.4194	(0.1343)	0.2238	(0.3847)
	70-105 mm	0.3725	(0.131)	0.7909	(0.0362)	0.0634	(0.3442)
UF-Wall	0-5 mm			0.0771*	(0.0001*)	0.4248	(0.3664)
	5-35 mm			0.3482	(0.0322)	0.8043	(0.4191)
	35-70 mm			0.2873	(0.0654)	0.1577	(0.4493)
	70-105 mm			0.363	(0.2069)	0.5236	(0.072)
PUR(HEX)-	0-5 mm					0.3571*	(0.0003*)
	5-35 mm					0.2466	(0.2546)
	35-70 mm					0.5225	(0.0824)
	70-105 mm					0.1631*	(0.0191*)

* P value of F-Test Two_Sample for Variances is less than 0.025 (Two tails), and P value of t-Test is calculated by t-Test: Two-Sample assuming unequal variances.

Table 6

Table 6 The statistical comparison about mean of all char rates between charring depth using F-Test and t-Test (two tails, 0.95 confidence)

P-value from t-Test and F-Test	5-35 mm		35-70 mm		70-105 mm	
	t-Test	(F-test)	t-Test	(F-test)	t-Test	(F-test)
0-5 mm	0*	(0.0019*)	0.0095*	(0*)	0.0002*	(0.0035*)
5-35 mm			0*	(0*)	0.0001	(0.4861)
35-70 mm					0.0147*	(0*)

* P value of F-Test Two_Sample for Variances is less than 0.025 (Two tails), and P value of t-Test is calculated by t-Test: Two-Sample assuming unequal variances.

LIST OF FIGURES

Figure 16

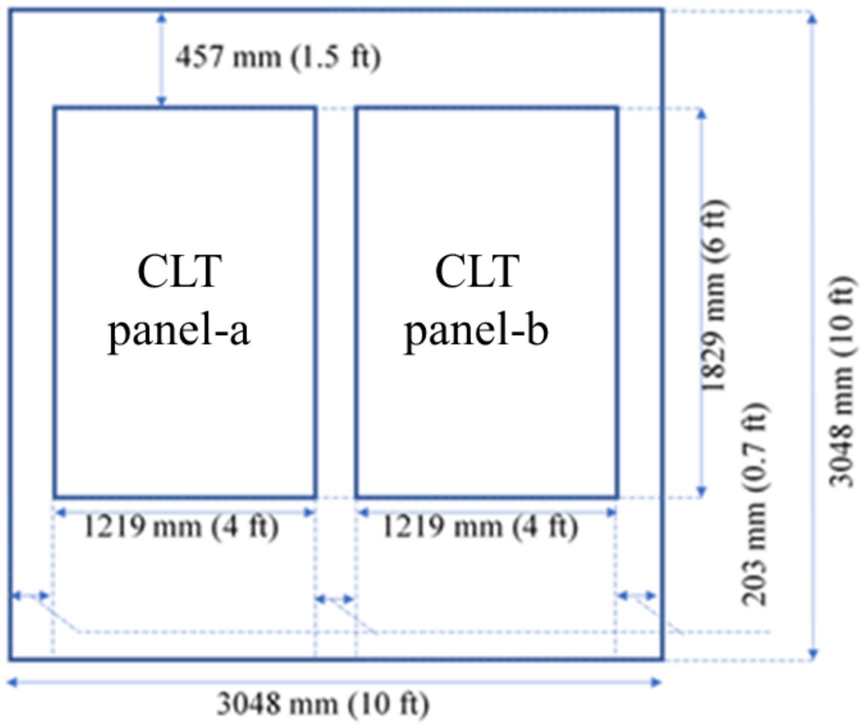

Figure 16 CLT assembly with steel frame dimensions

Figure 17

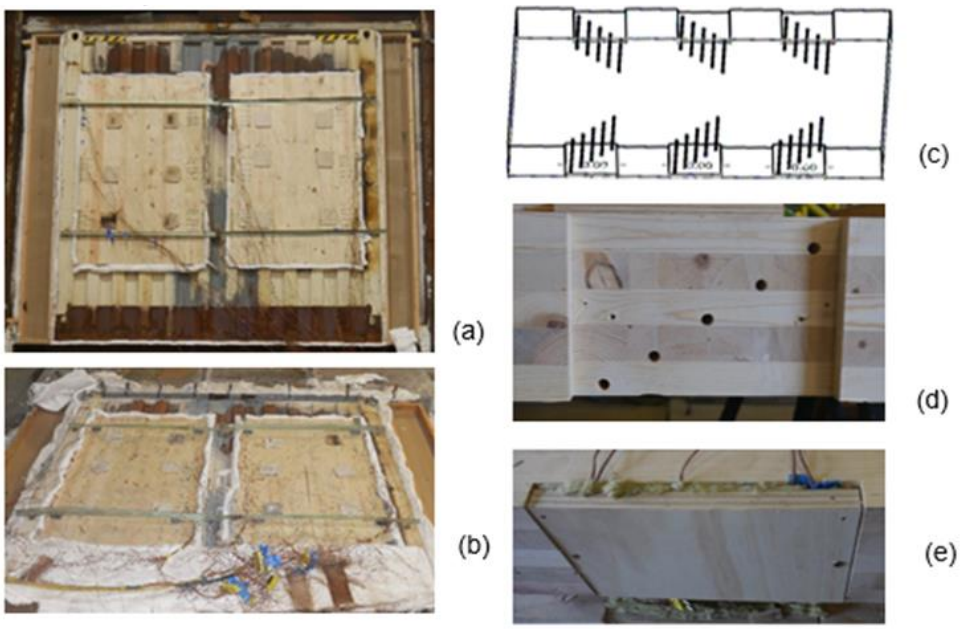

Figure 17 The example of wall assembly (a), and floor assembly (b), rotational symmetry of thermocouples clusters (c), the dimension and position of holes (d), and an example of covering thermocouple cluster by mineral wool and plywood pad (e).

Figure 18

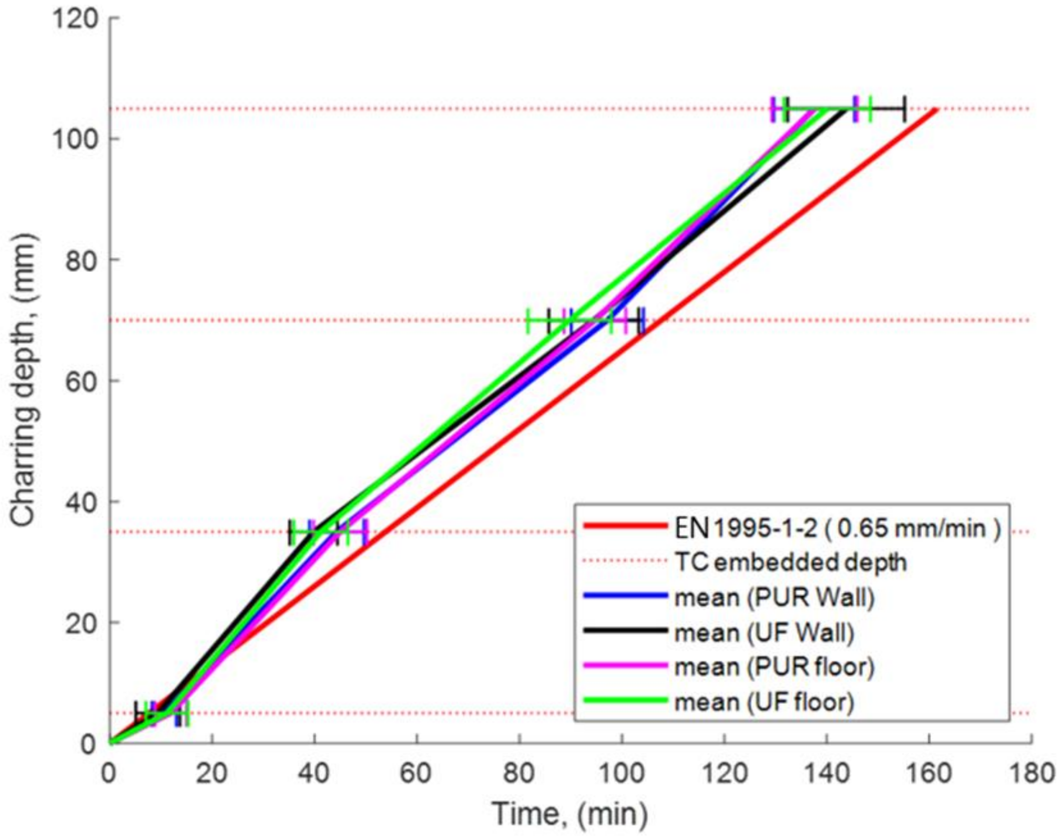

Figure 18 Charring depth as a function of the time for all fire test performed with Ponderosa pine cross-laminated timber panels with two manufacturers in horizontal (floors) and vertical (walls) position. The horizontal red dotted lines mark data of thermocouples embedded depth. The moments when the char limit temperature (300 °C) was measured by individual thermocouples (TC) are marked by yellow circles for TC embedded depth. Detailed lines explained in the legend.

Figure 19

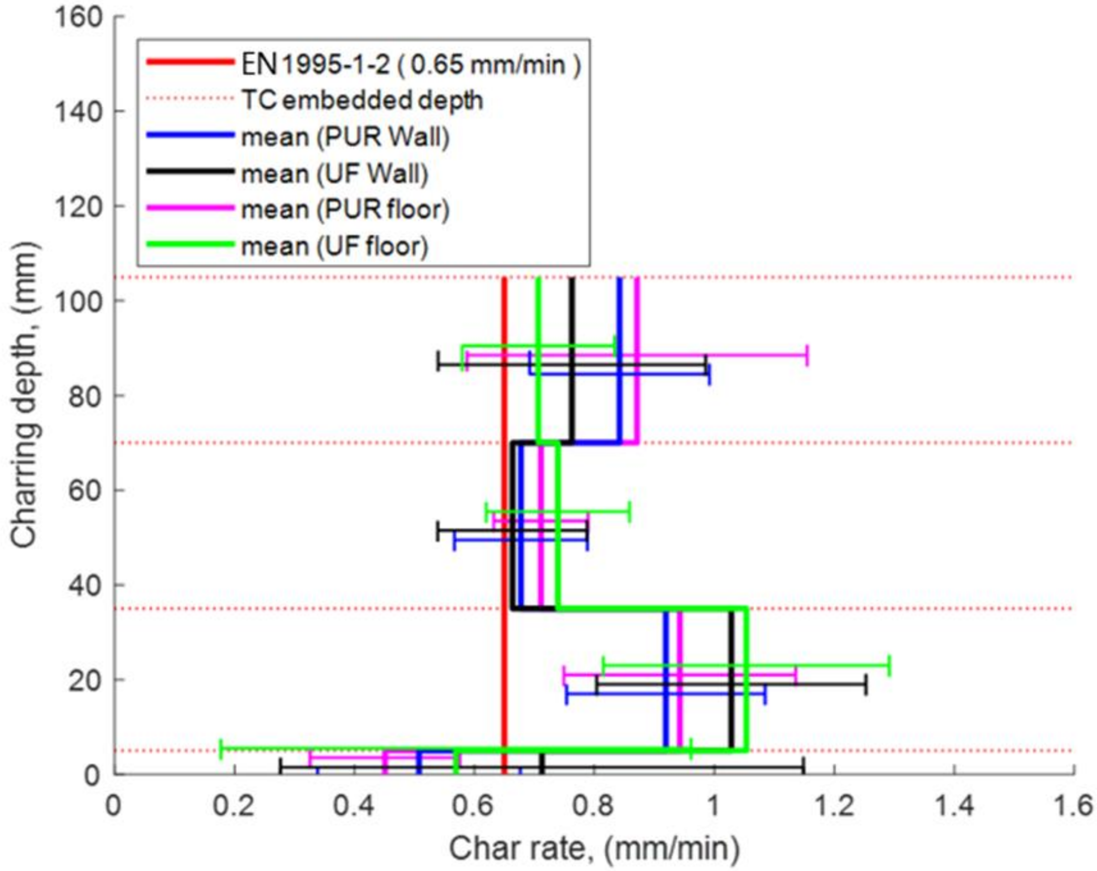

Figure 19 Char rates between thermocouples embedment depths for all fire tests performed with Ponderosa pine cross-laminated timber panels with two manufacturers in horizontal (floors) and vertical (walls) positions.

Figure 20

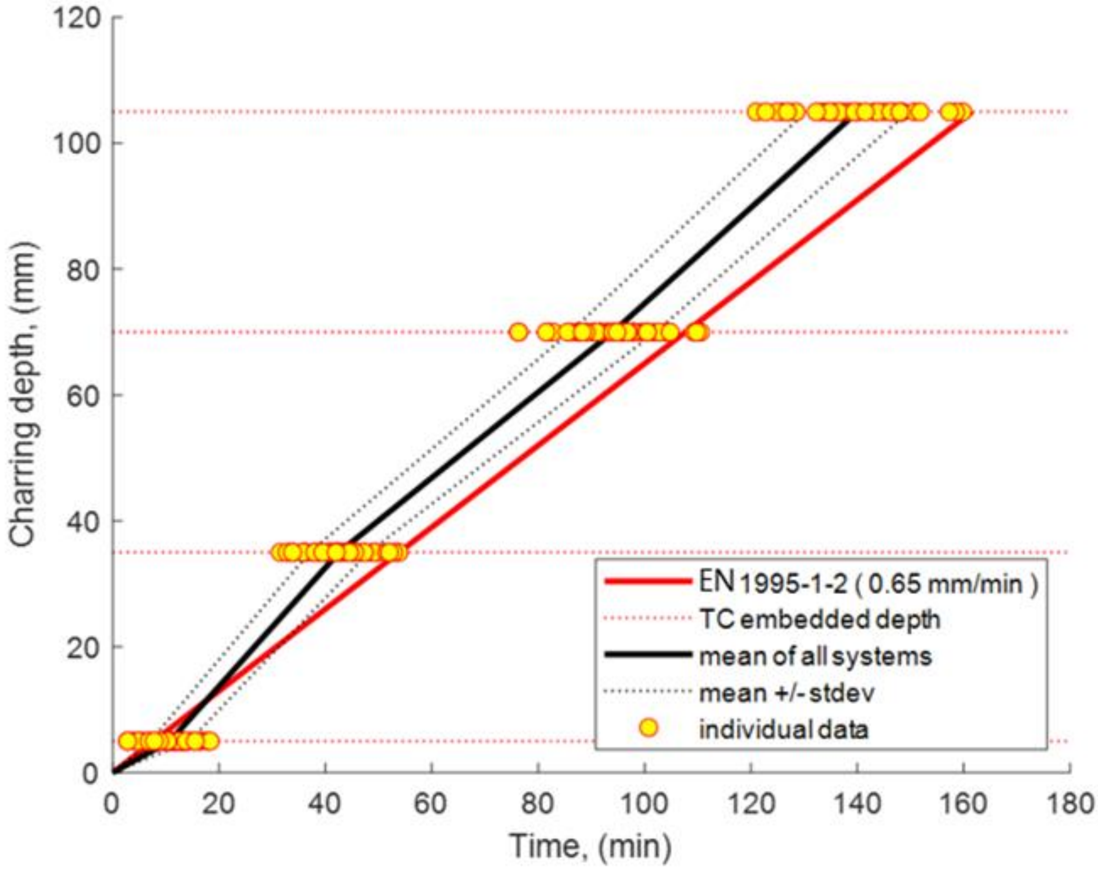

Figure 20 Mean of all charring depth as a function of the time for all fire test performed with Ponderosa pine cross-laminated timber panels with two manufacturers in horizontal (floors) and vertical (walls) position. The horizontal red dotted lines mark data of thermocouples embedded depth. The moments when the char limit temperature (300 °C) was measured by individual thermocouples (TC) are marked by yellow circles for TC embedded depth. Detailed lines explained in the legend.

Figure 21

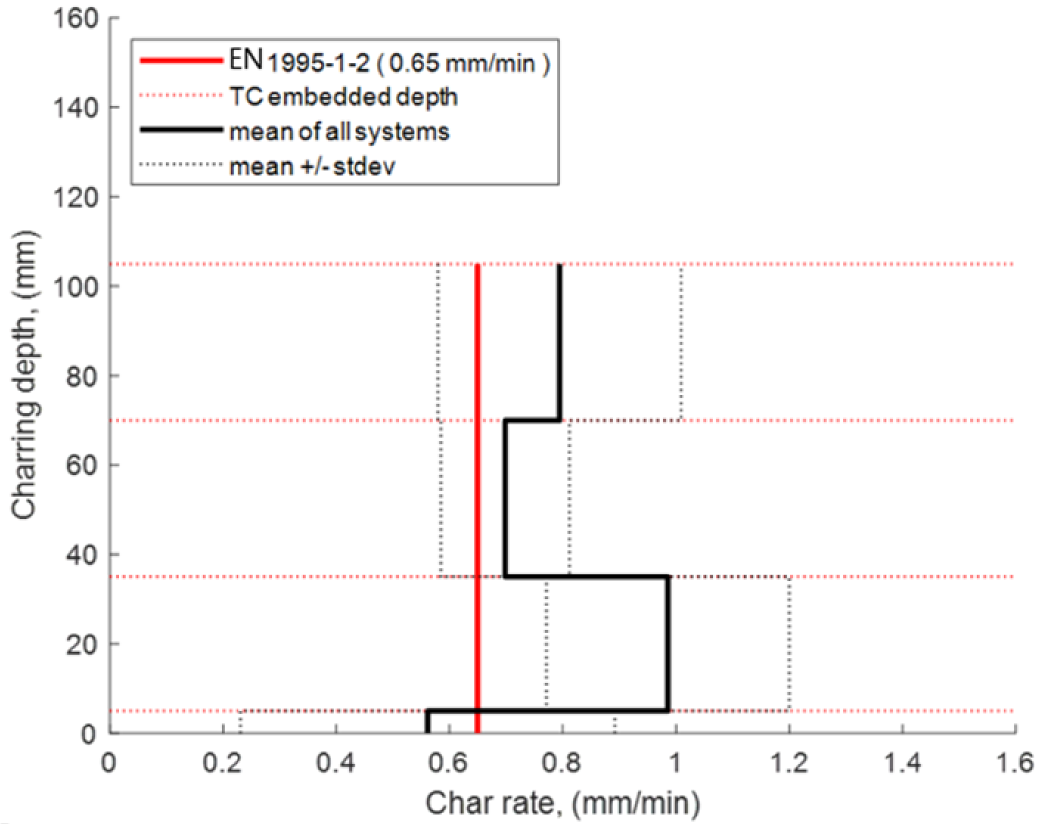

Figure 21 Mean of all char rates between thermocouples embedment depths for all fire tests performed with Ponderosa pine cross-laminated timber panels

A STUDY IN THE MORPHOLOGICAL PROPERTIES OF CNC POWDERS MANUFACTURED BY ULTRASONIC SPRAY DRYER

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Abstract

Many industries such as pharmaceutical, material science, and food utilize ultrasonic spray dryer called nano-spray dryer (B-90) because it allows for the manufacture of nanometer-sized particles with a high production yield. Furthermore, a few milligrams of solids can be sufficiently dried by a nano-spray dryer (B-90) and the outlet temperature of the dryer is very low, ranging from 28 °C to 59 °C. Due to its advantageous properties of the nano-spray dryer (B-90), it is widely used in industries field that require very safe technology such as heat-sensitive products, and in the production of high value-added products. In addition, the mini-spray dryer (B-290), commonly used on laboratory scales in many industries, has difficulty producing particles less than 2 µm and collecting fine particles.
UMaine tried to manufacture less than 1 µm of CNC powders through the nano-spray dryer (B-90) to identify the potential for future use in many industries. In this study, the production yields, particle sizes, and particle shapes of CNC powders were analyzed by moisture analyzer, scanning electron microscope (SEM), particle size distribution (PSD), and morphorlogi-G3 depending on different spray mesh sizes, solid concentrations, and gas flow rates. Lastly, UMaine compared the morphological properties of CNC powders manufactured through the nano-spray dryer (B-90) and mini-spray dryer (B-290).

Keywords: cellulose nanocrystal, nano-spray dryer (B-90), mini-spray dryer (B-290)

Characteristics of Ponderosa Pine Dimension Lumber Obtained from Forest Restoration Programs

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Abstract

Forest restoration programs are performed to reduce the risk of catastrophic wildfires by selectively removing smaller diameter trees from over-crowded forest stands. Every year, these operations generate significant amounts of ponderosa pine (PP) from Northern California and Southern Oregon in national forest system restoration programs. Compared to commercially harvested material, restoration program PP lumber has more juvenile wood, wane, and dead knots. That is why the material is not in demand by the construction industry and why it is considered low-value. Moreover, a substantial portion of the material contains blue-stain reducing its market value even further. USDA Forest Service is seeking a value-added market for PP lumber generated in restoration programs to offset the high costs of these operations. The hypothesis of this project is that the low-demanded PP lumber can be utilized in fabrication of cross-laminated timber (CLT) for construction of low-rise modular buildings. CLT is a prefabricated structural panel made of at least three orthogonally laminated layers of graded dimension lumber bonded with an adhesive.

National design specification (NDS) supplement handbook provides the design values of commercially harvested PP lumber within Western Woods (WW) specie group. These properties could be used to estimate the design values of a custom layup PP CLT, but it is uncertain if the mechanical PP lumber generated in restoration programs thorough selective removal does match values published for WW. The objective of presented study is to determine the characteristics of restoration harvested PP and to compare the measured design values with the published values for commercially harvested material (WW).

We have tested 810 pieces of PP dimension lumber from logs harvested in forest restoration operations, sawn, and kiln dried by Collins Lumber Co. (Lakeview, OR). More than 75% of the material has been visually graded by the company as: No. 1 (3%), No. 2 (48%), and No. 3 (25%), while the rest (24%) was delivered ungraded. Specific gravity and modulus of elasticity (MOE) of

the material was determined using single mode vibration method (Metriguard E-computer Model 340 dynamic tester) and some of the most frequent grade-defining features of the material investigated visually was recorded for each piece. The preliminary results showed that the average specific gravity of the material at 12% moisture content is 0.43 ± 0.04 which is higher than the value published for WW. The results of one sample t-test method showed that the MOE values for restoration harvested PP were statistically different from any of WW grades. This means that WW is not a true representative of restoration harvested PP lumber and that appropriate design values of other mechanical characteristics for restoration harvested PP will have to be determined experimentally. A short-term conservative alternative may be using the design values of WW grade No.3, which has lower mechanical properties compared to the restoration harvested material. The discussion of the outcomes and preliminary conclusions will be presented in the poster.

Potential of Industrial Hemp Towards Environmental Application

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Abstract

Water is an essential resource for life on the planet and for human development. The presence of contaminants like heavy metals, dyes, pesticides, etc. steadily degrades the quality of water and is the major reason for several diseases and damage to human health. The dyes are soluble organic compounds and are produced from pulp and paper industries and textile industries. The release of these colored wastewaters in the ecosystem is a dramatic source of esthetic pollution, causing eutrophication and harming aquatic life. The textile dyes, along with a large number of industrial pollutants, are highly toxic and potentially carcinogenic. Contamination of surface and groundwater by pesticides from agricultural runoff and industrial discharge is one of the main causes of aqueous contaminations the world over. Atrazine is a toxic, non-biodegradable widely used endocrine-disrupting herbicide. Hemp is a multi-purpose crop delivering stalks, seeds, and leaves, which find numerous applications. In this study, hemp hurd derived from hemp (Cannabis sativa L.) is chosen as a raw material to explore its adsorption capacity for methylene blue (MB), Brilliant green dyes, and atrazine herbicide. The effectiveness of the pollutant removal will be conducted using both raw hemp hurd and modified hemp hurd with organic acid/s. Measurement of atrazine and dyes will be carried out in a UV-visible spectrophotometer. The physicochemical properties of the synthesized sample will be studied by scanning electron microscopy (SEM) and Fourier transform infrared (FT-IR).

The effects of contact time and pH on the adsorption will be studied using the batch technique. Thus, low-cost green abundant hemp hurd derived bioadsorbent can exhibit outstanding removal capabilities for herbicide and synthetic dyes.

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A New Generation Apparatus to Automatically Study the Hygroscopicity of Wood

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Abstract
Wood is a unique material, being sustainable, ecological and eye-catching when used properly. However, it has several limitations according to the desired applications. Dimensional stability is a factor that limits wood and wood-based products usage in several aplications. To overcome these issue, new sylvicultural techniques, chemical and thermal treatments, and modified wood-based materials are being developed to produce wood and wood materials that will be stronger, more stable, and more durable. Most of the approaches used to test and evaluate the dimensional stability of wood products are time-consuming and demand excessive labor. The objective of this research was to design and build an apparatus to study wood and wood products' sorption/desorption behavior and the dimensional changes in response to environmental changes in a fully automated process using imaging techniques and transducers. The apparatus was designed and built to be more efficient and tunable than the available environmental chambers and incorporates technological expansion and capabilities from the state-of-art information technology standards. With this new apparatus multiple environmental scenarios can be set, varying by time or based on sample obtained values. Beyond the sensors and actuators, the apparatus has four environmental interconnected chambers to provide self-sanitizing procedures. Namely, a pneumatic panel, a hydraulic panel, a control panel, and an ozone generator. The control panel has two onboard computers to run both embedded robust software and a Linux operating system that runs the data collection software. The apparatus was designed with the main focus on providing precision in wood science, allowing it to control the environment with relative humidity values varying from 20% to 100% and temperatures ranging from 20 °C to 30 °C while operating in standard ambient temperature and pressure. It is still in development and more resources may be required, but it has the potential to also be used for fungal growth experiments and corrosion tests in its current stage of development. By changing the chamber construction material and/or sensors and actuators and the development of new software, the usage of this apparatus can be expanded to other applications.

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Short Term Field Durability Test Of Physical Barriers Against Termites In A CLT Wall Envelope System

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Abstract

The production and use of cross laminated timber (CLT) have been growing rapidly in the United States and Canada during the past few decades after its first introduction in Austria in the early 90s. The structural integrity of wood, however, can be compromised by decay fungi and termites. Internationally acknowledged building codes require external wooden walls to be installed on a raised concrete foundation or use a hybrid construction method. A standard CLT wall envelope system described in the North American CLT handbook consists of several layers such as siding, air cavity, vapor barrier and insulation to control heat, water, and air movement. The inclusion of a physical barrier in the standard envelope system can be an alternative approach to prevent subterranean termite attack of CLT walls. In the present study, the effectiveness of using commercial polyethylene flashing and stainless-steel mesh in CLT wall systems as the termite barriers will be evaluated in a short-term field test. Three wall envelope configurations were constructed with 3-ply 11” (width) x 18” (length) CLT panels, cement board sidings, and aluminum spacers. The control configuration did not have physical barrier other than sidings, while the other two configurations had either the polyethylene flashing or stainless-steel mesh barrier. Ten wall envelope specimens were assembled for each configuration. The CLT envelope specimens were installed at a field site in Mississippi in February 2021. After 15 weeks of exposure, the termite damage on the wall envelope specimens will be visually examined according to the AWPA E21 standard.

Utilization of Secondary Processing Mill Residues in Maine to Produce Raw Materials for Wood-Plastic Composites

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Abstract
Maine, among the most forested states (89% coverage) in the nation has a large number of forest product producers that generate around 1.6 million tons of mill processing residues annually. However, most of the mill residues are not utilized commercially, some being utilized as bedding for livestock, in biomass plants, and in pellets manufacturing. Being home to a wood-plastic composite (WPC) manufacturer, there is no commercial production of wood flour in the state and the company relies on a Canadian firm for sourcing wood flour feedstock. Bulk density study of wood flour (12-14 lbs./ft^3) and wood pellets (41-44 lbs./ft^3) shows a tractor-trailer can carry almost three times more pellets than flour. Flour, constrained by volume is loaded in the trailer without attaining the maximum weight limit. This can exceed its shipping cost than the actual material price, consequently increasing raw material price for WPC manufactures and the price of finished products. Scientific research on wood flour production from mill residues is limited. In addressing the above-mentioned issues, this study focuses on exploring the utilization of mill residues from four wood species in Maine. Laboratory work was performed on wood flour, wood pellets, and WPCs manufacturing and their material properties characterization. Besides wood flour, WPCs were manufactured and tested using wood pellets. Experimental results showed the physical and mechanical properties of WPCs manufactured using these two raw materials were not significantly different. Interviews are going on with industrial producers to understand the processing costs of wood flour and wood pellets. Similarly, works on understanding the transportation costs and life-cycle Assessment (LCA) are continuing for a better comparative study. It is expected this study will ultimately encourage investors to establish an industry in Maine that generates raw materials for WPCs to ensure the efficient outlet of mill residues. Furthermore, WPC manufacturers would benefit from the minimization of their raw material costs that would positively impact subsequent customers.

Keywords: *Secondary processing mill residues, wood flour, wood pellets, wood-plastic composites, transportation costs, processing costs, life-cycle assessment*

Quantifying the Percent Wood Failure in Adhesive Bonded Joints via UV-VIS Spectroscopy

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Abstract

The aim of this project is to automate the determination of percent wood failure in shear-tested structural composite bondlines through the utilization of a UV-VIS spectrometer. Manufacturers of CLT, Glulam, LVL, Mass Plywood, and Softwood Plywood are interested in this nondestructive measurement technique for continuous improvement efforts and compliance to quality and safety standards. A robust and repeatable statistical model to rapidly measure the ratio of wood to adhesive failure will replace traditional methods which are either slower, more expensive, or vary in accuracy.

This method will be calibrated according to ASTM D5266 – *Standard Practice for Estimating the Percentage of Wood Failure in Adhesive Bonded Joints*. Current techniques are laborious and often inefficient at measuring intermediate wood versus adhesive failure. The utilization of Multivariate Data Analytics (MVDA) methods such as Principal Component Analysis (PCA) and Soft Independent Modelling of Class Analogies (SIMCA) will provide for viable differentiations between certain wood species and adhesive spectra.

Implementing this accurate, precise, and relatively affordable technology in the mill environment will provide manufacturers with cost savings through increased efficiency and an ultimate competitive advantage in the marketplace. Additionally, the resulting ergonomic improvements will drive employee satisfaction in the workplace. A spectrometer will be used to quantify the percentage wood failure in these shear-tested laminated composite products. This approach is expected to maintain an accuracy within five percent wood failure (ASTM D5266), repeatability between operators, and to occur faster than traditional methods.

Key words: wood bonding, shear testing, UV-VIS spectroscopy, Multivariate Data Analysis, Engineered Wood Products, adhesive penetration, surface chemistry, automation, wood failure

Production of Dry Nano-Scale Cellulose Nanocrystal Powder via Electrospraying for Sustainable Composites

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Abstract

Electrospray drying (ESD) produces nano-scale dried cellulose nanocrystal (CNC) particles using a high voltage electric field and a low feed rate to produce ultra-fine droplets through electro-hydrodynamic atomization (EHDA). CNC suspensions contain high levels of water and are energy intensive to dry. Hydrogen bonding increases CNC size to micron-scale or greater after processing by conventional spray drying (SD). With ESD, coulomb repulsion breaks the surface tension of the CNC suspension. Gravity pulls the mist through a fixed distance, from the tip to the collector, at atmospheric temperature and pressure while droplet evaporation occurs, leaving nano-scale CNC particulates on a grounded collection substrate. A 3% (wt.) CNC suspension with a 40/60 ethanol water mixture was sprayed at a rate of 6 µL min^{-1} with four syringes in parallel containing 11.5 mL each. Particles were collected and dried at 105°C for 2hr. Dried nano-scale CNC is effective at increasing the tensile strength and modulus of elasticity when compounded into a thermoplastic matrix. A counter rotating twin-screw extruder was used to compound 0.5% CNC into a poly-lactic acid (PLA) matrix. Injection molded (IM) tensile samples were produced and mechanical properties were tested. Particles were observed with scanning electron microscopy (SEM) and digital analysis software was used to measure the CNC particle dimensions. Particle sizes of the ESD CNC powder ranged from approximately 40 – 1200 nm in length and 10 – 500 nm in width. Approximately 80% of CNC from the 3 wt.% suspension was collected and ready for thermoplastic compounding. With the addition of 0.5 wt.% CNC, the modulus of elasticity (MOE) and tensile strength of CNC/PLA composite samples were 3.66 GPa and 62.5 Mpa. When compared to the neat PLA, the strength and stiffness increased 12.5 and 9.6%, respectively.

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Lint Fiber Polyethylene Composites Fabrication

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Abstract

One form of common everyday waste in America is dryer lint fibers, waste short fibers that have been removed from clothing after they have gone through a dryer and been collected in a lint trap. A residential family home will most likely only produce a few pounds of lint a week depending on how often the dryer is used, whereas commercial laundromats may produce as much as over 100 lbs of dryer's lint per shift. The majority of dryer lint produced is a mix of natural fibers (cotton, wool, hair, fur, etc.) and synthetic fibers (polyester, spandex, etc.) and is thrown away as waste where it is disposed of in landfill in trash bags. Dryer lint fiber as a material show potential, however, due to it already being in the form of small fibers, ease of being formed into a fiber mat like in a lint trap, ease of handling, and ease of shaping. It is due to these properties of dryer lint fiber where it shows its potential as a material for composite fabrication. The objective of this study is to look into the processing parameters used to make a composite that uses dryer lint fiber as a reinforcement with polyethylene film recycled from plastic grocery bags as the matrix. Polyethylene was chosen for the matrix because of its prominence in being used in plastic bags, which are a major source of waste and pollution. By using these materials for the composite matrix, the plastic bags can be easily prepared into strips of film, which can then be use to bind the lint fiber layers together. Using a hot press, the lint fiber polyethylene composite panels will be fabricated. The effective processing parameters (temperature, time, and pressure, matrix to fiber ratio, density) for its fabrication and the mechanical properties (tension, bending, internal bond) and interfacial properties of the resulting composites will be investigated. In regards to the hydrophilic and hydrophobic differences between the lint fiber and polyethylene film, the use of a coupling agent will be studied to see the effect it has on the composites compared to the those without a coupling agent. By combining dryer lint fiber, the goal is to develop a value added composite material that is entirely derived from to major sources of every day waste in hope of reducing pollution and environmental damage.

Connection Performance in Decayed Cross Laminated Timber Members

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Abstract

Good connection performance is important for structural integrity throughout the lifespan of mass timber buildings. However, the hygroscopic and biological nature of the material promotes growth of organisms such as insects, bacteria and fungi which could impact the integrity of the building assembly.

To characterize, the resilience of CLT connections to biological degradation, *Postia placenta*, a brown rot fungus known to attack soft wood species was cultivated under controlled conditions in decay chambers containing cross laminated timber (CLT) connection assemblies. The connection assemblies consisted of two blocks of CLT each 13 X 8 X 4 inches held together by metal L-brackets, simulating, a wall-floor connection in actual buildings. Four wood species including Douglas fir, Southern Yellow Pine, Spruce-Pine-Fir and Norway Spruce were inoculated for a period of 10 weeks and 20 weeks, harvested, and tested. A quasi-static cyclic test based on a CUREE protocol was used to evaluate the shear performance of the connections. Dowel bearing strength tests were also performed to evaluate the impacts of the fungus on the different wood species.

The results of this study will assist in describing the susceptibility of each wood species to fungal attack and evaluate the performance of connections in decayed mass timber building elements. Data generated will assist engineers and builders in applying appropriate safety factors when building with CLT in areas prone to biological degradation.

In-Depth Characterization of Bondlines in Cross-Laminated Timber made with Preservative-Treated Lumber

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Abstract

Cross Laminated Timber (CLT) is quickly taking over the construction industry as a sustainable and environmental building material but is susceptible to termite attack making mass timber structures at a higher risk of failure in termite-prone areas. To combat this issue, mass timber elements must be treated in some way with chemicals to prevent termite attack. However there are questions about whether pressure treatment of lumber prior to layup causes a loss in structural properties of CLT and we sought to investigate this problem. Douglas-fir 2 x 6 in lumber were pressure treated with one of three different preservatives (Klear Guard 25, Preserve Tech, Hi-Bor). Treated or untreated lumber was used to manufacture CLT panels using one of two resins (MF, PUR). Panels were then sized into 18 x 30-inch pieces and triplicate untreated samples were pressure treated post-layup with each of the three preservative systems. Triplicate 18 x 30-inch panel sections were sent to Hawaii for exposure to Formosan termites. A sample of each panel type was reserved for testing block shear and delamination testing. In addition, CLT samples from each treatment were sectioned and stained for observation with a fluorescence microscope. Staining protocols were developed to resolve the resin from surrounding wood cell walls and the depth of penetration was measured as a proxy for bondline strength. Data collected will be used to measure the impact of preservative treatments on CLT and will provide fundamental data that will help improve mass timber durability.

A Strong and Highly Light-transmissive Bamboo Composites

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Abstract

Bamboo is one of the most important forest resources, which is widely used in building industry, furniture manufacturing, decoration and packaging. Many bamboo products have been developed, such as laminated bamboo, bamboo curtains, bamboo chipboard and bamboo fabric. Transparent wood product was reported to be successful. However, for the transparent bamboo, there are still many technical issues, such as poor permeability of bamboo, excessive delignification time and vulnerable cellulose scaffold. In this study, bamboo was converted into a transparent material with great optical transmittance and good strength. Bamboo has a much faster regeneration rate than wood, but its high density and high extractive content make it challenging to produce transparent products. This study presents a simple and effective approach that could address this challenge. Pretreatment of bamboo with low concentration sodium hydroxide greatly improved the preparation efficiency of transparent bamboo. The transparent bamboo with a thickness of 1 mm and cellulose volume fraction of 22% made from the pretreated bamboo exhibited an improved total optical transmissivity up to 80%, which was 60% higher than that of untreated bamboo. Compared to transparent wood (TW), although the transmissivity of transparent bamboo was slightly lower, its mechanical strength was almost doubled. Besides, the developed transparent bamboo exhibited a low heat conductivity of 0.203 W m −1 K−1, being about 10% lower than that of TW (0.225 W m −1 K−1) and approximately 80% lower than that of common glass material (0.974 W m −1 K−1). The transparent bamboo would significantly enhance energy-saving performance, being a promising alternative to traditional glass.

Keywords: bamboo composites, cellulose nanomaterials, transmittance, thermal insulation, mechanical strength

Undergraduate Research in Mass Timber and Digital Manufacturing: A Multiple Year Experiential Learning Project

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Abstract

Undergraduate research experience has proven to improve student learning and retention. Since 2018, Dept. of Wood Science and Engineering at Oregon State University is offering Research and Extension Experiences for Undergraduates (REEU) with support from the USDA NIFA AFRI Education and Workforce Development program. Over the last three years, 32 undergraduate students have conducted research and gained experience in extension projects for a period of 12 weeks with 22 different mentors from 4 different departments and 2 different institutions. These students come from many institutions nationwide and have diverse backgrounds and experiences. Efforts are directed towards attracting, recruiting, and retaining, a diverse application pool. This presentation will introduce the framework of the REEU site; selection of students, mentors, and projects; successes and lessons learned from offering these experiences; examples of student projects; and plans for the future. Based on interviews with both REEU mentors and mentees, four advantages are highlighted: obtaining new skills, networking benefits, adapting to new situation, and being independent.

Regular Posters

Hardwood Sawmills Capacity to Produce Structural Grade Hardwood Lumber

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Abstract

In recent years, the structural grade lumber market is continuously growing and cannot meet the domestic demand in the US. The growth of the CLT market helps to increase the consumption and demand for structural grade lumber. Production of structural grade hardwood lumber from potential hardwood species could reduce structural grade lumber imports. A survey study was chosen to understand the hardwood sawmills' current capability to produce structural grade hardwood lumber. The study suggests that less than 10% of the sawmills participated could produce structural grade hardwood lumber without additional investment in additional resources. Other 90% of them required to invest in at least one resource: sawing, drying, grading, sorting, and surfacing technology. Additionally, some of the sawmills needed to invest in inventory capacity to handle additional lumber types. This survey concludes that more than 80% of the sawmills are required to invest in surfacing technology, and 70% of them need to hire a grader to produce structural grade hardwood lumber.

Hydrothermal Liquefaction and Fast Pyrolysis Biochar as Adsorbent for Textile Dye Removal

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Abstract

The potential use of biochar as a low-cost adsorbent for pollutants from water was explored. This work studied the biochar from hydrothermal liquefaction (HTL) and fast pyrolysis (FP) of southern yellow wood (*Pinus spp*) and used the biochar for the removal of dye (Terasil Red) from textile industry effluent. The HTL-biochar and FP-biochar were characterized using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM). The effect of relevant parameters such as function of pH, adsorbent dosage, contact time, and dye concentration were evaluated. The adsorption data of Terasil Red at 300-333 K corresponded with Langmuir and Freundlich isotherms. The results suggested that biochar from HTL and FP processes show a potential use as bioremediation in water quality treatment and present additional value for the utilization of lignocellulosic biomass.

Key words: Biochar, hydrothermal Liquefaction, pyrolysis, Textile dye

Color Enhancement of Ash and Yellow Poplar by Surface Thermal Treatments

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Darker color wood species are aesthetically pleasing and could have a higher value. These deeper wood tones are usually found in tropical wood species, which many of them are classified as endangered and protected, or by application of chemical stains and finishes. Thermal treatments could also produce darker shades of wood and enhance some material properties, such as dimensional stability, acoustic performance, and decay resistance. The advantages of thermal modification are also low toxicity. It can even be considered an alternative environment finish, which could be an essential attribute for healthier products. This work aimed to determine surface color modification responses in selected hardwoods by surface heat treatment and its effect on the material's physical and mechanical properties. Ash and Yellow Poplar, two US popular commercial hardwood species, were thermally treated in the hot press under variable temperatures (225 to 325°C, five levels) and time (15 sec. to 15min., nine levels). This specific thermal treatment is not the traditional heat transfer medium, but it is processed directly by contact heat pressure. The obtained darker shades were tested according to CIE standard method. Lightness value L*, red-green value a*, and yellow-blue value b* were measured. This experiment proved that surface heat treatment could produce attractive darker color shades in selected hardwood species by combining two variables: time and temperature.

Evaluating the Inclusion of Circular Economy Practices in the Furniture Industry

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Abstract

According to the Environmental Protection Agency, Americans throw out around 9 million tons of furniture and furnishings each year. Because of the complexity of furniture structures and the inclusion of multiple materials, recycling them is greatly diminished. Upholstered furniture is especially a problem to recycle when considering hygienic factors. The rapid growth of furniture waste is linked to limited avenues for responsible disposal, fast population growth, and unsustainable consumer practices. In the last decade, furniture became a commodity with low value, cost, and quality. The shift towards fast fashion, wherein trends are pushing the manufacturing of new stylish products quickly and cheaply, has also emerged in the furniture industry and their products. There is a need to address each aspect of a product's life cycle to remedy this growing problem in the furniture sector.

Despite the extraordinary environmental, aesthetic, physical, and mechanical properties of wood and products made, many of these products will end up in the landfill while still having good residual value. Only less than 0.3% of wooden furniture is recycled in the US. Durable wood products have an essential role to play in a future circular economy. However, despite good intentions and circular economy (CE) aspirations, there is very little science-based data to support optimal decision-making for end-of-use (EOU) options. The circular economy framework can produce alternative pathways that will reduce end-of-life options that negatively impact the environment. Not only can alternative pathways be discovered, but products can also be produced in a way that initially prolongs their life span.

A growing number of furniture companies currently incorporate circular economy principles, such as introducing take-back programs, offering repair services, using recycled material, developing innovative products for easy recycling, and extending product lifespan by applying strength design. However, in general, we still have a way to implement correct sustainability practices in the furniture production sector. In this project, we are adapting the value-retention process (VRP) model introduced by the UN International Resource Panel (IRP) (2018). We quantify the selected environmental and economic impacts of various VRPs, including CE practices of repair, reuse, refurbishment, and recycling, as they are undertaken for a durable wood product.

Keywords: fast furniture; circular economy; sharing economy; furniture sector

life cycle to remedy this growing problem in the furniture sector.

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Hardwood CLT Performance Testing, Product Development, and Fabrication

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ABSTRACT

Wood is starting to play a significant role as a sustainable building material. Interesting wooden (CLT) structures are on a growing trajectory worldwide and are gaining popularity in the US. There are efforts to include hardwoods in CLT construction. The intention is to find the best use for abandoned, lower-quality material available throughout the US, mainly in the Central Hardwood Region. Research is underway to evaluate the physical and mechanical properties of HCLT and to develop exciting HCLT products. These complementary products would fit nicely into new sustainable buildings and make them more appealing and uniform with other building materials. Innovative modular furniture designs made from HCLT are being developed. Thinner hardwood CLT panels, intended to be used for products such as wall partitions, columns, complementary elements, and furniture, are proposed. The motivation to use this type of wooden material in building construction is to capture more carbon and avoid the use of nonrenewable resources in the first place.

Zero shot learning of the attributes based on microscopic wood images

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Abstract

The application of Convolutional Neural Network in developing algorithms for machine wood identification has received significant attention recently. These techniques commonly use many correctly identified (labeled) images to train a neural network (CNN). This approach's limiting prerequisite is the cost of acquisition and the limited availability of a sufficient number (typically hundreds or thousands) of images per species, and the verification of species labels. In this study, we apply the concept of zero-shot learning to identify the classes of features that are not present during neural network training. A typical approach in the zero-shot learning method is to learn the attribute vector instead of the categorical label. This approach mimics the traditional way of human identification of wood by its features. This study shows that CNN can learn attributes of microscopic images based on approximately 6,800 species from around the world.

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Computer Vision Identification of North American Ring-Porous Hardwoods

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Abstract
North American ring-porous hardwoods are a critical part of the American forest products industry. For example, the U.S. railway system consists of approximately 620 million in-service cross ties, with 23 million new cross ties installed annually. As most of these cross ties are North American ring-porous hardwoods with different treatment schedules and service properties, obtaining accurate and reliable wood identifications is central to maximizing durability and service life. To increase access to such identification capacity, we developed a convolutional neural network-based computer-vision wood identification model for North American ring-porous hardwood species using the XyloTron platform. The model was trained and evaluated using verified specimens from three xylaria, and then real-world testing was completed using specimens in a fourth xylarium. We present metrics on the performance of the model, comments on where it is weakest, and the influence of deploying the model across multiple hardware instances and operators. With the portability and ease-of-use capabilities, the XyloTron platform allows distributed, decentralized, and customizable field deployment of computer-vision wood identification models. We call for rigorous evaluation and research into practical real-world implementation of computer-vision wood identification as a promising tool for combating illegal logging and wood trade worldwide.

Broadening cellulose-based packaging into plastic packaging markets

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Abstract: The USDA Science Blueprint reports that the world population will likely grow by 20 percent to 9.7 billion people over the next 30 years, and demand for goods and services provided by farm and forest lands will increase by about 40 percent. Food packaging will become increasingly important to preserve food quality and facilitate food distribution to reduce poverty and hunger across the world. Meanwhile, the pressure from climate change and plastic pollution challenges us to develop a bioeconomy - where petroleum-based products are replaced with biobased and biodegradable products. Cellulose emerges as a potential versatile biopolymer to make hydrogels for absorbents, aerogels for insulation, membranes for filters, films for packaging, and fibers for textiles and reinforcement. Wood cellulose is perceived by relevant stakeholders to be renewable, biodegradable, and sustainable. The fiber supply infrastructure is readily available to provide billions of tons of wood as feedstocks. However, challenges need to be overcome for the realization of cellulose-based primary packaging. We discuss the investigations and findings of developing cellulose-based packaging with barrier properties comparable with plastic packaging, including nanocellulose films, nanocellulose polymer laminates, and cellulose nanofibril coated paper; testing gas and vapor barrier properties; understanding composition/structure/barrier property relationships.
Keywords: cellulose, bioeconomy, circular economy, barrier packaging, layered structure, challenges

Introduction

Increased regulations around plastics are leading to a growing demand for non-plastic alternatives, and new opportunities are becoming available for cellulose-based packaging. There are several development trends that inspire scientists in the forest products industry to innovate forest-based biomaterials to replace environmentally unfriendly materials: 1) Increasing world population leads to increasing material demands. All materials including metals, ceramics, and plastics are competing to play an important role in shaping the world for future generations. The performance, cost, and environmental impact of a material are three important metrics. The potential market share of biomaterials is still uncertain and depends on the advancement of technologies, environmental regulations, and governmental carbon policy. 2) Plastics have allowed many products to be made cheaper, smaller, and more efficiently and many services more convenient; the plastic industry strives to innovate plastic technology to increase plastic recyclability, compostability, and circularity, reducing plastic products that are littered to the environment – providing a circular economy solution to plastic pollution. This forms a barrier to hinder biomaterials from diffusion into markets or raises the bar for biomaterials to enter markets. 3) Solar and wind renewable energy will accelerate the electrification of transportation: increasing electrical and hydrogen vehicles but decreasing internal-combustion-engine vehicles. Crude oil for fuel markets will shrink but will remain to compete in material markets. It is challenging to develop high quality and affordable biobased products that perform comparably with their petroleum-based counterparts and also are cost-competitive. 4) The forest products industry has been impacted by digitalization, e-commerce, globalization, and climate change. Digitization is partly responsible for shrinking graphic paper markets and paper mill closures. Globalization is responsible for production being transferred to other countries. Meanwhile, e-commerce also increases the demand for containerboard for secondary packaging and shipping. 5) Many businesses like restaurants and municipalities want to implement sustainable practices and minimize their ecological footprints, but sourcing quality, affordable, and eco-friendly containers can be difficult. These trends require wood scientists to innovate processes and products to meet emerging challenges and needs. Cellulose seems to be in a position for increased and more diversified use.

Cellulose forms and terminology

Cellulose can be in many different forms based on its purity and morphology (Figure 1). Paper and paperboard are made from cellular wood fibers or cellulose fibers. Microcrystalline cellulose is alpha-cellulose broken in size in tens of micrometers. It is used as pharmaceutical excipients for drug delivery. Both colloidal dispersions of cellulose nanoparticles and cellulose dissolutions are viable for filament spinning and film forming. Regenerated cellulose such as cellophane film, rayon, and lyocell fibers has been used for many years. However, the processes of producing regenerated cellulose are not environmentally friendly. In recent years, nanocellulose has emerged as a new versatile material. Nanocellulose can be produced without changing cellulose natural crystalline structure, which may reduce the cost of producing a film- or fiber-forming cellulose.

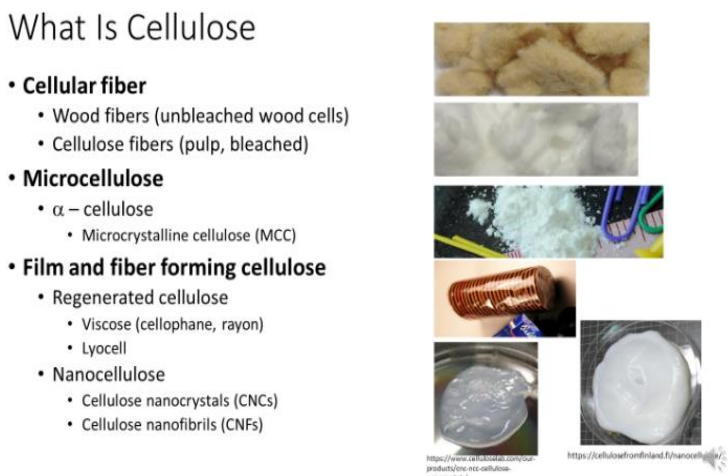

Figure 1 Examples of cellulose forms and compositions.

There are various terms to describe cellulosic materials. Generally, these terms can be classified into four general categories: substances, independent objects, dependent constituents, and qualitities (states) as shown in Table 1. The relationships between an object and the material of which it is made—its matter/substance/material—are ontologically fundamental. Constituentsare components of objects or materials that cannot exist independently; the shape, form, and size are qualities of the object whereas crystallinity and porosity are the qualities of the material. A quality is a property that is inherent in an object or material and also cannot exist independently. A cellulose nanofibril is an object with cellulose as its material. The term microcrystalline cellulose refers to microsized α-cellulose, which is a pharmaceutical excipient. It should be under the category of an object. But its name seems a misnomer because it uses a portmanteau of the size prefix “micro” and adjective “crystalline” describing a structure; in addition, its last item cellulose hints at a substance/material, not an object. Naming it “cellulose microcrystal” may be more appropriateas suggested by *ISO/TS 20477 Nanotechnologies - Standard terms and their definition for cellulose nanomaterial* since the last word does refer to an object. The same is true for the term nanocrystalline cellulose. Cellulose macro-, microfibril, and elementary fibril are terms used by wood anatomists to describe the observed elements in plant cell walls under high-resolution imaging. Their boundaries are not exactly delineated, which differentiates them from isolated technological cellulose such as a cellulose nanofibril. Overall, cellulose domain knowledge is typically expressed using a wealth of similar yet different terms. But faster innovation requires supporting comprehensive and integrated searches and analyses across the growing and increasingly linked data and knowledge sources, such as scientific publications. This, in turn, requires the information to be encoded using a shared and consistent vocabulary for referring to objects, materials, processes, and findings across individual publications. An ontology facilitates this by providing a controlled vocabulary of concepts (e.g. classes of materials) and relationships (e.g. the kind of materials to which a specific class of manufacturing processes can be applied), whose meanings are clarified through semantic relationships such as subsumption (subclass) relations, domain and range restrictions, or permissible numeric ranges for certain properties. It appears there is a need for an ontology of cellulose materials.

Table 1 Cellulose entity classification.

- **Cellulose entity**
  - **Substance/Material/Matter**
    - Cellulose
    - Hemicellulose
    - Lignin
    - Lignocellulose (wood)
  - **Object**
    - Cellulose nanocrystal
    - Cellulose nanofibril
    - Microcrystalline cellulose
    - Microfibrilated cellulose
    - Nanofibrilated cellulose
    - Cellulose filament
    - Nanocrystalline cellulose
    - Cellulose molecule
    - Cellulose film
    - Cellulose membrane
  - **Dependent Constituent**
    - Cellulose microfibril

- **Cellulose entity**
  - **Quality/State/Property**
    - Composition
    - Structure
      - Foam
    - Nanostructure
    - Ultrastructure
    - Morphology
    - Texture
    - Solid-state
      - Crystalline
        - Cellulose I
        - Cellulose II
      - Paracrystalline
      - Amorphous (glassy)
      - Shape/form/size
        - sheet
        - Fiber
        - Granular
        - powder

Cellulose microfibril bundle (macrofibril)	State of mixture
Elementary fibril	Dispersion
Crystallite	Suspension
Crystalline region	Colloidal
Amorphous region	Gel
	Continuous phase
	Dispersed phase
	Composite

Film-forming cellulose comparison

Neat bulk cellulose materials can be fabricated through either nanocellulose or regenerated cellulose. Cellulose can be comminuted into fibrils at the nanoscale, or directly dissolved in solvents and separated into individual cellulose molecules. These isolated cellulose fibrils or macromolecules can be reassembled into various neat cellulosic bulk materials, such as hydrogels, aerogels, foams, membranes, films, fibers. These human-scale cellulosic materials are fabricated by various processes, including drying, vacuum filtration, solution casting, layer-by-layer assembly, coating, forming, extruding, spinning, and drawing. Some processes are more efficient and effective than others in product and process performance; process efficiency and material performance decides their commercial viability.

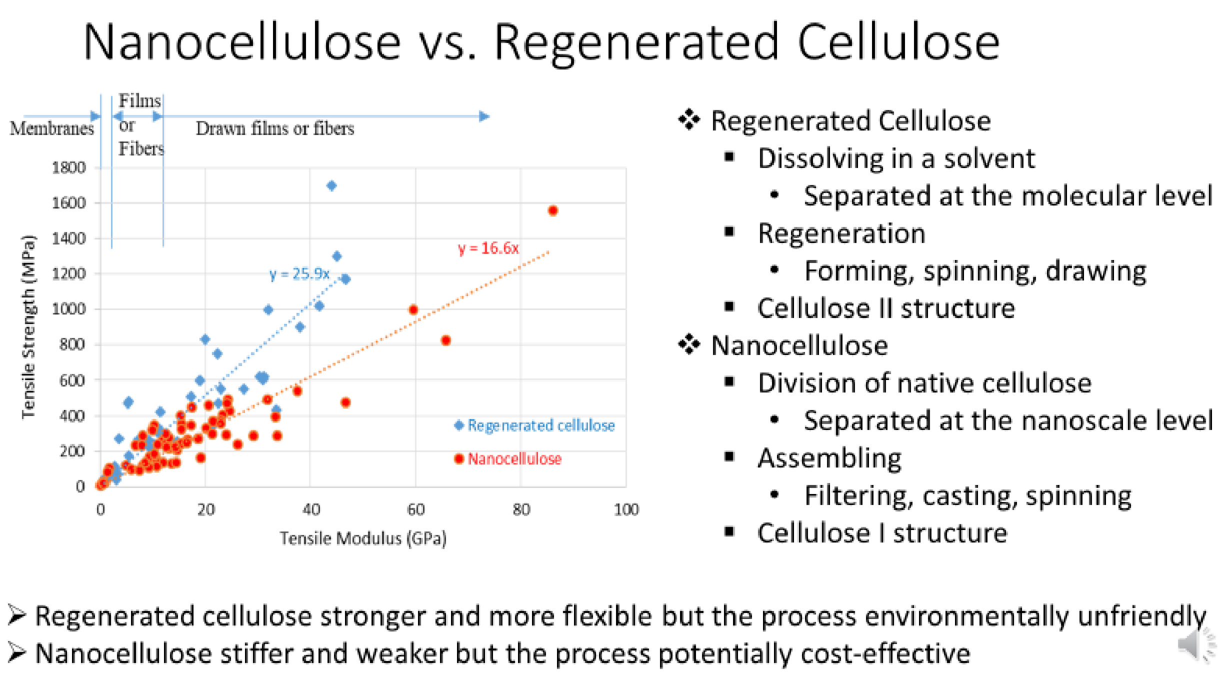

Figure 2 Comparison of tensile properties of film-forming cellulose (Wang et al., 2021).

Figure 2 plots the tensile strength of cellulosic materials against their tensile modulus of elasticity. The graph compares regenerated cellulose and nanocellulose materials from the literature. The red points represent neat nanocelluse materials; the blue points represent regenerated cellulose materials. Hydrogels and aerogels were rarely characterized with tensile properties, so no data are presented here. There are large variations in the tensile properties depending on the type of cellulosic materials. The data generally fall into three regions: membrane, film, and fiber. The tensile properties are dominantly determined by the presence of pores and fibril orientation. They can be finely tuned by processing methods. The difference between membranes and films is that membranes utilize their pores for performance whereas films prefer a dense structure with low porosity. Cellulose membranes are typically formed by immersion precipitation. Their porosity can be controlled at around 40 to 90 percent. Their tensile properties decrease with increasing porosity and are lower than films. Films are often prepared by solution casting, vacuum filtering, and are further consolidated by pressing. Hence, films are denser, stiffer, and stronger. Drawing can orient films and thus improve the tensile properties along the drawing direction. Fibers are wet spun through a small capillary hole resulting in orientation to a certain extent during the spinning process. Post-spinning drawing further orients the fibrils or cellulose chains along the fiber axis. The drawing thus enhances mechanical properties in the drawing direction. It can be seen from the graph that regenerated cellulose-based materials tilt towards the tensile strength y-axis. This indicates they are stronger and more flexible than those fabricated from nanocellulose. Since materials with higher strength stiffness ratios are more versatile in applications, it appears that the properties of regenerated cellulose are more desirable than those of nanocellulose, especially for textile fibers. Indeed, regenerated cellulose such as rayon and cellophane have been used for textiles and food packaging since the 1920s. However, regenerated cellulose processing involves organic solvents, and they are not very green to the environment and workers. Using nanocellulose prepared from a mechanical process or a light chemical process could produce cellulosic materials in a more environmentally friendly way.

Gas, vapor, and grease resistance of cellulose materials

Material barrier properties are typically measured in a chamber separated by the sample into the upper chamber and lower chamber (Figure 3). A partial pressure differential is maintained to drive the permeant transmitted across the sample. The tests typically measure the amount of the permeant that is transmitted under steady-state, the time duration, and the sample area. All other parameters are derived by assuming the transport follows Darcy's law or Fick's first law of diffusion depending on which driving force parameter is known in the situation. When discussing barrier properties, there are several terminologies or parameters to be used as metrics for material barrier performance such as water vapor or oxygen transmission rate, water vapor or oxygen permeability, air permeability or Gurley time, and permeability coefficient. These parameters are calculated with these laws effectively; the transport mechanism is not considered no matter what the permeant flows through the sample, diffuses through the sample, or a combination of both. Practically, the air permeability is measured as Gurley time by forcing the air to flow through the sample. In contrast, during water vapor and oxygen transmission measurements, the permeant might dominantly diffuse through the sample. If the material is homogeneous and does not interact with the permeant, the permeability coefficient, lowercase k, is a material property. Ideally, the permeability coefficient k measured by air should be the same as that by oxygen or water vapor. All other parameters are related to both the material and the permeant. Transmission rates also relate to the dimensions of the material.

Characterization of Permeant Transport across a Material

$$\mathbf{F} = \frac{Q}{tA} = \frac{k}{\mu L}\Delta p = \frac{P}{L}\Delta p \quad \textbf{(Darcy's law)} \qquad \mathbf{F} = \frac{D}{L}\Delta C \quad \textbf{(Fick's first law)}$$

F – flux or transmission rate across material ($m^3/m^2 \cdot s$)
Q – amount of permeant transferred (m^3 or gram)
t – time in which Q occurs, or Gurley time (s)
A – sample surface area (m^2)
L – sample thickness (m)
Δp – environmental pressure drop across material P_1-P_2 (Pa)
C – gas or water vapor concentration in material (m^3/m^3)
µ – dynamic viscosity of gas or water vapor(Pa·s)
k – permeability coefficient (m^2) of material
P – water vapor or gas permeability (m^2/Pa·s), P = k/µ
D – diffusion coefficient in material (m^2/s)
S – gas or water solubility in material (m^3/m^3·Pa), P = D*S

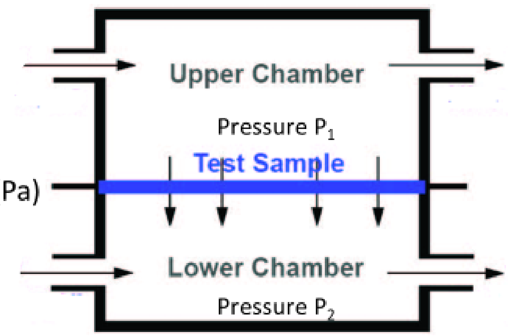

Figure 3 Permeation characterization: laws and parameters. The parameters highlighted in red are usually used to quantify the barrier properties of a material. P, D, and S are affected by both the material and permeant whereas k is decided only by the material.

Dense cellulose films are transparent, strong, stiff and resistant to air, oxygen, and grease. These properties have the potential to be commercialized for packaging applications. For example, cellulose films have the potential to substitute other oxygen barrier materials such as aluminum foils, polyvinyl alcohol, and polyvinylidene chloride. Cellulose films are grease resistant and have commercial values for greaseproof paper products. Their grease resistance results from the relative absence of pores. This is like glassine, a supercalendered paper produced from highly beaten fibers. Another is parchment paper, produced by passing the paper through a bath of concentrated sulfuric acid, followed by rinsing out the acid and drying the paper. Although both Parchment and glassine paper are still in use, they have been substantially displaced by fluorocarbon-treated paper. Fluorochemical agents impart both organophobic and hydrophobic character to paper by reducing the surface energy without the need to form a continuous film on the paper surface. Hence, the fluorochemical treatment is very effective and economical. However, fluorochemicals such as PFAS - per- and polyfluoroalkyl substances have caused environmental and regulatory concerns. The paper industry needs more innovations to provide an economical option to get out of the fluorocarbon treatment business. The challenge is how to solve the effects of moisture on cellulose-based packaging and decrease the production costs.

There are many methods to chemically modify cellulose to make it moisture resistant. However, literature data have pointed out that these modifications do not necessarily decrease water vapor permeation. Acetylation generally decreases cellulose water absorption, but both cellulose esters and ethers have only slightly smaller water vapor permeability than cellulose. They have a larger oxygen permeability than regenerated cellulose or nanocellulose films. Oxygen permeability is positively correlated with carbon chain length. It reflects that the longer branched chain increases the free volume of the resulting modified polymer. Different mechanisms decide liquid water resistance and water vapor permeation. Liquid water transport in materials is largely dictated by surface tension and wetting ability and is thus measured by contact angles. Water vapor does not have surface tension and wetting process, and its adsorption, diffusion, and desorption are largely decided by pores and free volumes as well as the affinity between cellulose and water molecules. Although there are many findings of treatments to improve water resistance (Wang and Piao, 2011), that knowledge and understanding do not necessarily translate into studying water vapor permeation. Water vapor and gas transport is related to materials' porosity, structure, and chemical composition and is usually described by Fick's laws.

In addition, materials that are good oxygen barriers are usually poor barriers to water vapor such as cellulose, and vice versa such as polyethylene. This is because of their opposite polarity: water is a polar molecule, and oxygen is a nonpolar molecule. Oxygen molecules cannot permeate through dense cellulose films whereas water molecules can break hydrogen bonding formed between cellulose and form new hydrogen bonding with hydroxyl groups bridging cellulose molecules. Other gases such as carbon dioxide, liquids, flavors, oil, and grease interact with cellulose in structurally, chemically, and physically different ways. Increasing vapor resistance might cause a decrease in gas resistance. Developing cellulosic materials that can protect against most gases, vapors, and greases is not easy, often requiring composites of several different materials, which in turn decrease facile recyclability.

Layered structures to improve barrier properties

Cellulose film moisture and oxygen barrier. Does cellulose have the potential to substitute plastics for primary packaging? It is a challenge concerning its barrier to gas and vapor permeation. Nanocellulose has a higher moisture absorption than regenerated cellulose and paper products. Both regenerated cellulose and nanocellulose films also have a very high water vapor transmission rate. Polyvinylidene chloride (PVdC) and ethylene-vinyl alcohol copolymer (EVOH) are two excellent commercialized oxygen barriers. Below 60 percent relative humidity, cellulose films have even better oxygen barriers than these two polymers. But the oxygen barrier properties of cellulose films are affected by their moisture content. Above 60 percent relative humidity, cellulose films almost lose their oxygen barrier properties. Regenerated cellulose also behaves similarly (Wang et al., 2017).

Moisture-resistant polymer/cellulose laminates. We hypothesize that laminating cellulose films with polymers can improve their moisture resistance and thus preserving their oxygen barrier properties at high relative humidity. In a study (Wang et al., 2020), the performance of cellulose nanocrystals (CNCs) and cellulose nanofibrils (CNFs) were evaluated and compared as free-standing films and in the form of laminates. Nanocellulose films were prepared by solution casting. The CNC films contained 20 percent D-sorbitol as the plasticizer. The film diameter was 100 millimeters. The neat films had two nominal weights of 20 and 50 grams per square meter. The laminated film is a five-layered structure with two polypropylene skin layers, the core nanocellulose layer, and two polyurethane layers as the tie layer bonding cellulose with polypropylene. They are laminated under 90-degree Celsius roller temperatures. Laminated films contain either CNCs or CNFs at the two casting weights. They were labeled as CNC20L, CNC50L, CNF20L, and CNF50L (Figure 4 Left). PP/PU represents Polypropylene/Polyurethane laminated films without cellulose and served as control samples. Neat cellulose films are indicated without the letter L. This result shows that cellulose films are poor water vapor barriers themselves. Nanocellulose laminates with the polymer have improved the water vapor barrier, but the prepared samples are slightly short of the potato chip packaging requirement. That is less than 0.2 grams per square meter per day. The result also shows that the neat CNF films have slightly better oxygen barrier properties than the neat CNC films, probably because the CNC films contain the 20 percent plasticizer. Lamination with the polymer can preserve the good oxygen barrier properties of cellulose at high relative humidity. However, the laminated CNC films have a better oxygen barrier than the laminated CNF films. It is speculated that the CNC films provide a smoother surface for better lamination than the CNF films. They both can meet the oxygen barrier requirement for potato chip packaging.

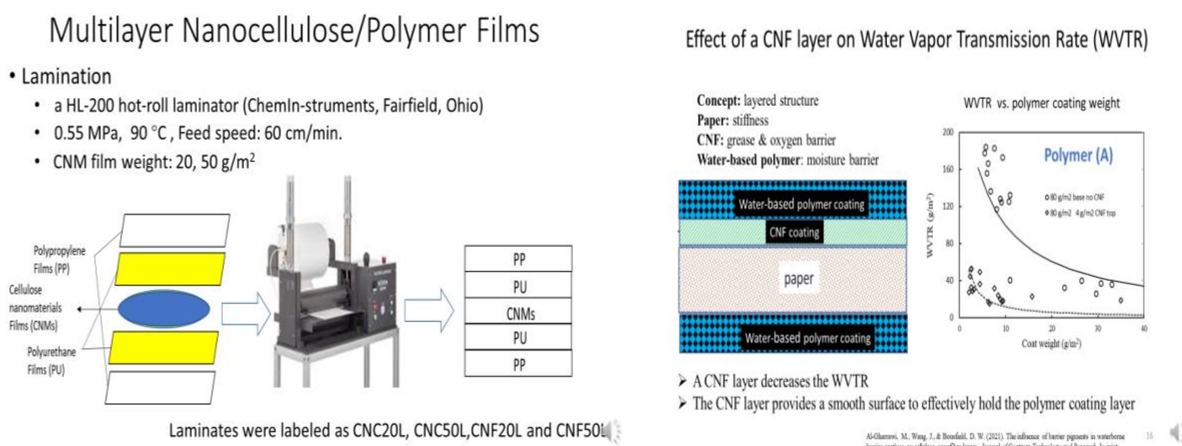

Figure 4 Ways of manipulating cellulose and other material objects to make a layered structure to achieve optimal barriers against gas, vapor, and grease permeation. Left: polymer/cellulose lamination, right: cellulose/water-based barrier coating.

CNF coating on base paper. Coating a dense layer of cellulose nanofibrils on a low-cost base paper can produce a structured sheet of paper (Figure 4 Right). It has a synergy of base paper's stiffness and nanocellulose's oxygen and grease barrier properties. A packaging material should have many functionalities to protect the content against adverse agents. The left diagram in Figure 4 Right represents a concept of a four-layer structure with different layers providing different functions. The paper layer provides bulk and stiffness. The CNF layer provides grease and oxygen resistance as well as a smooth surface for polymer coating. The polymer coatings provide moisture resistance and heat sealability for converting into packaging. The polymer can be biodegradable or compostable. Water-based polymer coatings make product repulping easier than melting laminated polymers. The right graph in Figure 4 Right shows that the CNF layer substantially decreased the water vapor transmission rate for a base paper of 80 grams per square meter (Al-Gharrawi et al., 2021).

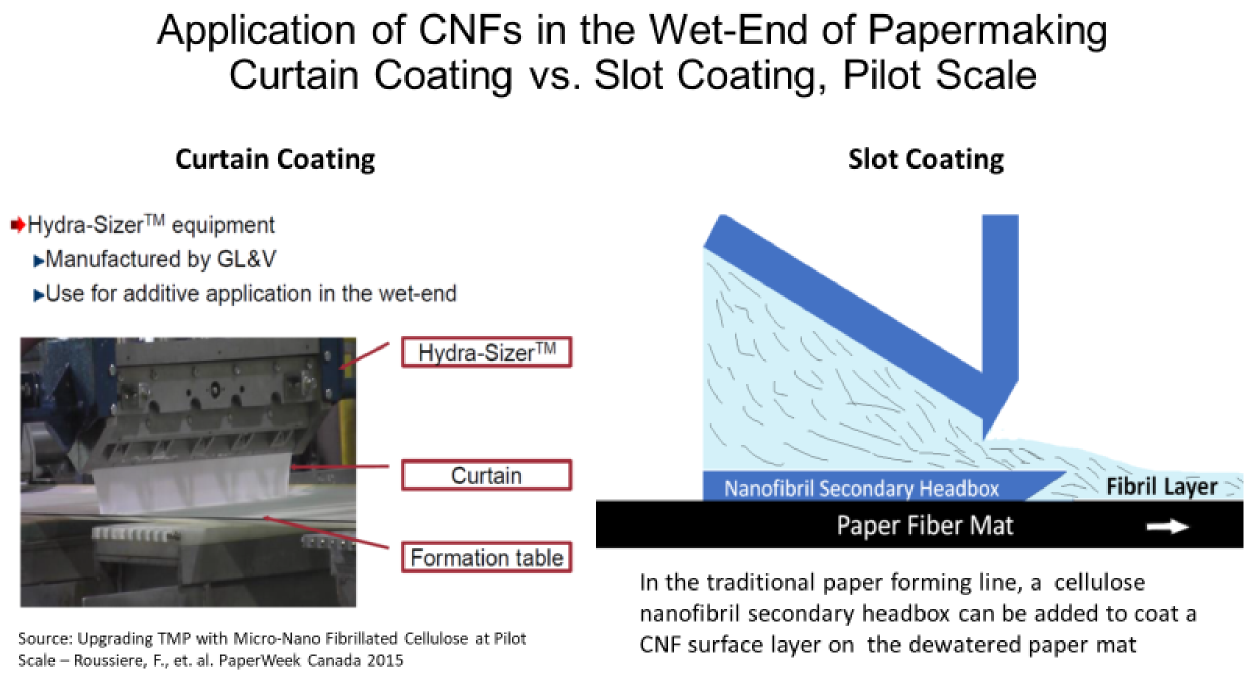

Figure 5 Coating cellulose nanofibrils on base paper at the wet end of the papermaking.
The industrial application of cellulose nanofibrils on base paper is a challenge. The current experimental approach being examined is to add cellulose nanofibrils directly during paper formation. There are two slightly different application methods as shown in Figure 5, which are named curtain coating (Figure 5 Left) and slot coating (Figure 5 Right). The left photograph indicates a curtain coating system named as Hydra-Sizer (Charfeddine et al., 2015). It was developed by GL and V, now part of Valmet. The right diagram indicates a slot coating head like a conventional paper headbox. The difference between curtain coating and slot coating is the distance between the substrate and the coating head. No apparent curtain forms with the slot coating method. The University of Maine Process Development Center has a slot coating head positioned at the forming table of a papermaking pilot line. The web width is around 12 inches. The web speed is around 100 feet per minute. The paper mat is already substantially dewatered before applying the CNF coating. The normal 3 percent CNF suspension is diluted to 1 percent solids for application. It can apply a weight of up to 16 grams per square meter. There are considerable parameters concerning the coating head and CNF suspension rheology to be optimized to enhance the performance of CNF coatings. The coating head position along the formation table should minimize the dewatering limitations. Carboxymethyl cellulose may be added to modify the viscosity and help apply a high concentration of CNFs on the surface. Typically, CNFs form a dense layer on the paper surface and reduce the roughness and porosity of the top side. The surface quality of the coated paperboard depends on the degree of cellulose fibrillation, coating weight, and original paperboard surface features. Compared with neat cellulosic nanofibril films, CNF coated paper is not transparent. Compared to the base paper the mechanical properties of the coated paper are improved in the cross direction and out-of-plane. Gurley time measures the ability of a substrate to resist the flow of air at a given pressure differential. The larger the Gurley time, the higher the resistance, and the smaller the

permeability, which also indicates the smaller porosity. The 5 percent CNF internal sizing increased the Gurley time 4 times. The 5 percent CNF surface coating increased 338 times. Hence, CNF surface sizing is more efficient than internal sizing in decreasing base paper air permeability. We have investigated the grease resistance of CNF coated papers as a function of coat weight, fineness of CNFs, and the presence of the viscosity modifier Carboxymethyl cellulose (CMC). Generally, it needs a coating weight larger than 10 grams per square meter to achieve reasonable grease resistance. A finer cellulose nanofibril coating performs better. Adding the viscosity modifier CMC helps to improve grease resistance at the same coating weight and fineness.

Sustainability and circularity of cellulose-based materials

Paper or plastic? Unfortunately, there's not a simple answer on whether paper or plastic packaging is better for the environment. As shown in Table 2, they both have downsides, but there are a few broad lessons to keep in mind. Plastics have tangible and substantial benefits, but their drawbacks are significant, long-term, and too obvious to ignore. Only a small portion of plastics are ever recycled, and littered plastics have contaminated the marine environment. They are a bad solution for single use. While cellulosic materials are renewable and abundant, there are downsides such as production costs, inferior performance, moisture sensitivity, toxic additives such as fluorocarbons for grease and moisture resistance. Reducing the diversity of polymers and compositions that are widely used for enhancing cellulose functionalities is likely to facilitate the greater recycling of cellulosic materials. Wear and tear are disadvantages of biomaterials as compared with metals, ceramics, and plastics in the circular economy, which reduces the number of times cellulose can be recycled. Cellulose hornification and contamination also hurts recyclability.

Table 2 Competitive comparison of plastics and cellulosic materials.

	Plastic	Cellulosic
Natural abundance	Depletable	Renewable
Carbon Footprint Energy Demand	Smaller* Less	Larger More
Performance	Superior	Inferior
Ecological Impact	Hurt marine life	Tear when wet
Toxicity	Some	None/additives
Affordability	Economical	Premium
Versatility Biodegradability	Versatile/designable No/carbon storing	Moisture sensitive Yes/Carbon Release

* Brad Plumer, Plastic bags, or Paper? Here's What to Consider When You Hit the Grocery Store, 3/29/2019, NY Times.

Traditionally, wood products such as engineered wood and wood-based panels are used for buildings, furniture, and structures. The development of mass timber buildings is a true success story. With e-commerce, the demand for paper and paperboard packaging increases, but its share remains level. Innovations are needed in these areas to keep and increase wood materials market share. The plastics industry is rethinking the current plastic economy concerning biodegradability, littering, and recycling, and wants to transition to a circular economy by developing ways of recycling plastics. The development of cellulosic materials can reduce plastic growth rate. Further technological advances are needed to make the processing of cellulose more efficient and cellulosic products more functional in competing with plastics and facilitate the transition towards a sustainable society.

Currently, biobased materials research is mainly driven by sustainability. The current mentality is that the wide use of fossil fuels and plastics has caused climate change and environmental pollution and is thus not sustainable. Many solutions have been provided to address the current challenges including the bioeconomy, circular economy, and hydrogen economy. Forests and wood products are the main natural resource that can effectively absorb carbon from the atmosphere and store it in consumer products. Broadening cellulosic materials into plastic products should have great potential. However, if conventional energy is used, plastic packaging has lower carbon footprints than biobased packaging as indicated in Table 2. If renewable energy is used to make biobased products, carbon footprints will be different.

It appears that we should advocate the bioeconomy or defossilation. Meanwhile, it appears that a considerable number of scholars prefer the circular economy. Will a plastic circular economy kill a bioeconomy? Do timberland owners prefer selling more virgin wood for revenues to support forest management instead of advocating a circular economy? The circular economy system wants to minimize the leaking and loss, i.e. minimize the input from other systems such as forests into the manufacturing process. Recycling paper is certainly part of the circular economy, but what is beyond that for a forest-based circular economy. Are natural resources such as forests in the circular loop? Or are they out of the loop system to supply the makeup in case of need? Should we maximize the revenue from forests and revitalize the rural economy? It is a challenge task to find the optimal balance between conserving forests for ecological and cultural services and supplying us with raw materials to manufacture a variety of products – from textiles and automotive parts to liquid fuels and packaging. An ideal outcome would be that we will continue enjoying the performance and benefits from plastic-like performance biomaterials. But plastics are recyclable and can be sourced from forests. There are also other emerging concepts and techniques such as carbon capture and storage and carbon utilization that will become important and affect a sustainable path to the future. Many biobased products would most likely be more expensive than their petroleum counterparts in part because they often require more energy to produce. A lot of uncertainties lie ahead. A sustainable society could be biobased, circular of plastics, metals, and everything else, of solar energy-based hydrogen economy, or a combination of three. The future is under construction with many dynamic blueprints. Scientists in the forest products industry are positioned to assist in shaping the path to the future towards a sustainable society: where the amount of raw materials from forests are optimal.

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Thursday, August 5th

Valuable Composites and Adhesives 2

Chair: Douglas Gardner, University of Maine

Characterization of Resin Distribution on Wood Strands

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ABSTRACT

Adhesive applied to wood strands during the manufacture of OSB is present as discontinuous droplets. Typically, less than 20% of the strand is covered with adhesive out of the blender, and there is significant variation of resin coverage between strands. If properly formulated, the resin drops will spread along the strand surface, and some penetration will occur. Once the mat of strands is placed under compression, some additional spreading on the strand surface will occur, thus increasing surface area covered by resin. Resin distribution will be affected by resin loading, resin fluid properties, and atomizer controls. The current project assessed the influence of phenol-formaldehyde resin molecular weight and spinning disk atomizer speed on resin distribution and subsequent bond performance. Aspen and southern pine strands were evaluated. Strand board internal bond strength, single-lap shear testing, and 3D focus variation microscopy were used to assess differences between treatments. Resin distribution on a strand surface as a result of spinning disk atomization is influenced by disk speed and resin viscosity within the range of treatments included in this study. Increasing disk speed reduces resin spot size. Increasing PF resin viscosity decreases spot size. Overall, smaller resin spot size improves adhesive bond performance in the current study. As expected, increasing resin coverage on strand surfaces increases bond performance. Analysis of droplet diameter in a spray is useful for assessing trends, but does not correspond to resin distribution on strand surfaces due to wetting, penetration, overlapping resin spots, and resin transfer from strand to strand.

Keywords: OSB, oriented strand board, adhesive application, atomization

INTRODUCTION

Common commercial practice to manufacture oriented strandboard is to apply resin and wax on dry strands in a rotating blender. The resin is typically phenol-formaldehyde (PF) or pMDI. Sometimes the resin is atomized with a spinning disk atomizer to form small droplets for distribution on the wood strands. Some resin directly impacts the strand surface from the atomizer and some resin is transferred strand to strand as the strands tumble inside the rotating drum. The resin is added to the blender based on a specified weight of resin solids per dry weight of strands. The amount of resin on the strand surface and size of the resin spots influences panel properties (Kamke et al. 1996, Zhang et al. 2008). However, the variability of resin coverage on the strands can be very high (Kamke and Lenth 1995, Kamke et al. 1996).

Conrad et al. (2003) studied the influence of PF resin spot size on fracture toughness of bonded Douglas-fir assemblies. The authors applied a precise resin drop pattern to the substrate using a flexographic printing process to control drop diameter and spacing. Optimum performance was found at 110-140 micron resin spot diameter with spacing of 0.5 mm, and 340-490 micron diameter with spacing of 1 mm between resin spots.

Dai et al. (2007) created a simulation model to predict resin coverage on strands and compared results to laboratory blended strands. At 5% resin loading, predicted coverage was about 40% compared to 30% for measured coverage. At 10% resin loading, predicted and measured coverage was 90% and 60% respectively. The simulation did not account for droplet size distribution or overlapping of resin spots.

The purpose of the current study was to determine if resin viscosity and atomizer spinning disk speed affects resin distribution. In addition, the study compared controlled resin distribution to adhesive bond performance of isolated specimens, as well as strandboard properties.

MATERIALS AND METHODS

Commercially produced aspen and southern pine strands (dry face-layer) were used for fabrication of strandboard samples. Mill strands were to achieve 3% moisture content prior to use. Logs from the mills were collected and used to produce laboratory strands for lap-shear bond testing. Laboratory strands were produced from veneer, which was cut to approximately 1/8-inch thickness using a guillotine veneer slicer. Block orientation was controlled to produce parallel grain. The wet veneer was then placed under restraint and dried. The veneer was surfaced using a hand scrapper to produce a smooth surface for bonding, and then cut to final dimensions for resin application (1/8” x 1” x 2”). Laboratory strands containing defects, such as knots and splits, were discarded.

The three different phenol-formaldehyde (PF) resins were prepared. Starting with a commercial OSB resin, samples were aged to advance polymerization by warming the resin with a temperature-controlled water bath and frequent checks of viscosity. Resin samples were held in sealed containers to avoid water evaporation. Once the target viscosity was achieved, the resins were stored at 5°C until needed. Just prior to use, viscosity was measured. Samples from each resin were analyzed by gel permeation chromatography to obtain molecular weight information. The result was three identical resin samples except for the degree of polymerization.

Lap-shear specimen preparation and testing

A spinning disk atomizer (Coil Manufacturing, Burnaby, BC) was used to apply resin on lap-shear strands in a laboratory blender. Resin was applied to one side of a strand, covering an area of 1 in^2. Strands were introduced to the resin spray using a pneumatically-controlled insertion device (Figure 22). The device contained 4 slots (1 in x 1 in) and a sliding baffle to shield the strands from resin until needed. Three strands and one piece of aluminum foil were mounted in the device. The foil was used to measure the weight of resin applied. Duration of exposure was determined by preliminary experiment. First the atomizer was brought to the desired rotational speed and resin flow was initiated. Resin flow was controlled by a peristaltic pump, which was calibrated to each resin sample, thus delivering a consistent flow of 180 g/min. The blender drum was held stationary for this procedure. Upon removal from the insertion device, the foil was immediately weighed and compared to its initial weight. The weight of the resin on the foil was assumed to be the weight of resin applied to each strand. Two of the strands were assembled for the lap-shear specimen. Resin was applied to both sides of the bondline. The assembly was then pressed at 200°C, 50 psi, for 2 min. Lap-shear specimens were tested to failure in tension loading with loading rate of 0.3 mm/min according to ASTM D-2339. The third strand extracted from the insertion device was placed in a convection oven to cure the resin, then the strand was saved for later resin distribution analysis.

Strandboard manufacture and testing

Each of the three PF resins were used to make laboratory strandboard. Batches of strands were blended at three atomizer disk speeds: 7000 rpm, 10000 rpm, and 13000 rpm with each of the PF resins. Nine blender runs were performed for aspen and southern pine strands. From each blender run strands were randomly selected for resin distribution analysis. There were three replicate panels per treatment. Combined, 54 panels were produced, including aspen and southern pine panels. The panel manufacturing specifications are given in Table 7. Panels were cut into internal bond and bending test specimens as specified by ASTM D1037, then stored at 20°C and 65% relative humidity prior to testing.

Resin distribution analysis

Digital image analysis was used for measurement of resin spots on strands. First strands were observed using a fluorescence microscope with a UV filter set to clearly distinguish PF resin from the wood background (Kamke and Lenth, 1995). In this case the wood fluoresces light blue and the PF resin appears dark brown. The strands were then observed using the focus variation mode, and white light illumination, of a laser scanning microscope (Keyence VK1050, Osaka, Japan). With a 2.5x objective, in combination with a 5.6 MP camera, the field of view was 7.4 x 5.5 mm^2. Focus variation produces a crisp image over the full field of view. The automated x-y stage was used to collect 30 images on the strand surface, which were then stitched together to produce a composite image with total area of approximately 650 mm^2 for blender strands and 760 mm^2 for lap shear strands. Image resolution was 32 μm^2. The composite image area was the entire bonded area of the lap-shear strands. A composite image was prepared for both sides of each blender strand. Comparison between the images captured with white light to the UV fluorescence images confirmed that the PF resin spots could be detected on both aspen and southern pine strands.

Resin distribution measurements included projected 2D area of each resin spot and the percent of surface coverage. Measurements were performed using ImageJ (Ruden et al. 2017). Images were converted to 8-bit gray-scale, then a gray-scale threshold was manually selected that corresponded with a minima in the gray-scale histogram. The resin spots were treated as objects within the selected gray-scale range. Objects less than 25 pixels were omitted because no resin spots smaller than 25 pixels could be found. Observations using higher magnification confirmed the lower size exclusion limit. A circularity criteria (0.001 – 1 accepted) was also set to omit fine cracks from the measurement.

RESULTS AND DISCUSSION

Results for resin viscosity measurements are in Table 7. There was only a slight change of viscosity between the time of lap-shear specimen preparation and strandboard manufacture. The lowest viscosity is the value of the commercially produced resin as received. Although the resin samples were stored at 5°C, the high viscosity resin was less stable than the lower viscosity resin samples. An attempt was made to create a sample at approximately 2000 cP, but the peristatic pump system failed to deliver the desired volume flow rate in the blender.

Resin spot size data was combined for each treatment, and then the data was sorted by size, smallest to largest. Cumulative area of resin spot size was calculated and plotted as a function of spot size. Only the southern pine strand data is reported here. Figure 23 shows the full distribution of spot size for the low and high viscosity resin samples on southern pine blender strands. The medium viscosity resin data was omitted for clarity, but fell between the low and high viscosity resins. No resin spots larger than 2 mm^2 were detected for the low viscosity resin, while the high viscosity resin included a resin spot of almost 10 mm^2. Visual observation of the full distribution reveals little difference between the atomizer disk speeds. Figure 24 shows the lower 50th percentile of resin spot sizes. Fifty percent of the resin detected on the strands blended with the high viscosity resin at 10,000 and 13,000 rpm disk speed had spot size 0.03 mm^2 or smaller. The high viscosity resin applied at 7,000 rpm had the 50th percentile at 0.054 mm^2. The low viscosity resin had a similar trend with respect to disk speed. However, larger spots were detected. Figure 25 shows the distribution for the upper 25th percentile. Clearly, the low viscosity resin had a greater fraction of large resin spots compared to the high viscosity resin. Note that resin spots detected as objects in the image analysis process may be individual resin droplets or multiple droplets that overlap on the surface of the strand. Figure 26 shows an image of a southern pine lap-shear strand with low viscosity resin that was applied at 7,000rpm. Figure 26 (right) shows a 3D projection created by focus variation, with equivalent x-y-z dimension scaling.

Zhang et al (2009) reported droplet size distribution data for PF resin atomization using a spinning disk atomizer. Measurements were made of the spray using a laser diffraction analyzer. Disk speed was 12,900 rpm using the same Coil Manufacturing atomizer as used in the current study. The PF resin viscosity at 25°C was 246 cP, which is similar to the low viscosity resin used in the current study (176 cP). Zhang et al. reported the 50th percentile droplet diameter, based on volume, as 0.012 mm. The spot size of the 50th percentile for the low viscosity resin applied at 13,000 rpm in the current study, based on projected area, was 0.034 mm^2 (Table 10, average for aspen and southern pine). If one assumed a perfect half-sphere of resin on the surface, and no penetration, the resin spot volume would be 0.00236 mm^3, and the equivalent volume sphere diameter would be 0.165 mm. The droplet diameter results from Zhang et al. are more than 10 times smaller than the estimated idealized droplet diameter in the current study. Microscopic observation of resin spot shape on the strand surface revealed the spots are not perfect half-spheres. The spots had a contact angle less than 10 degrees and noticeable elongation along the grain.

Table 9 shows the percent of surface area covered by resin for the blender strands. Disk speed had no affect on surface area coverage. The lowest viscosity resin had greater surface coverage on the aspen strands, approximately 15% compared to the medium and high viscosity resins at about 9%. Analysis of variance indicated a slightly greater surface coverage of the low and medium viscosity resins on southern pine strands at approximately 12% compared to approximately 9% for the high viscosity resin. Difference in coverage is likely due to greater wetting by the low viscosity resin compared to the high viscosity resin.

Table 10 is a list of percentiles (25, 50, 75, and 100%) for all treatments in the blender trial. For percentiles 25, 50, and 75, the slowest disk speed had the largest spot sizes. 100th percentile has little value as this only represents the single largest resin spot observed for each treatment. Lower resin viscosity produced a distribution of greater spot sizes than either the medium or high viscosity resins. This trend was consistent for all disk speed and for both species. Although not measured, the low viscosity resin appeared to wet the surface of the strand to a greater extent than the high viscosity resin. Wetting of the droplets on the strand surface will promote larger spots as viewed in a 2D projection. Perhaps the lower viscosity resin also penetrates into the wood more than the higher viscosity resins, but this was not measured.

Lap-shear test results are shown in Figure 22Figure 27 for aspen and southern pine strands, respectively. Depending on the treatment, the lap-shear strands did not receive the same amount of resin. In general, increasing disk speed reduced the weight of resin applied. This may be the result of variation of spray direction from the spinning disk when disk speed is changed. Since the specimens used for lap-shear tests were stationary inside the blender, a change of resin spray direction would affect the amount of resin applied to the specimen. Consequently, the lap-shear test results are presented as specific failure stress, where the failure stress is divided by the amount of resin applied in milligrams. Analysis of variance, at $\alpha = 0.05$, indicated that both resin viscosity and disk speed had a significant effect on lap-shear specific failure stress. In general, increasing disk speed increased the specific failure stress for aspen and southern pine lap-shear specimens, except for the case of high viscosity resin on southern pine, where there is no difference. The low viscosity resin had the lowest specific failure stress for aspen lap-shear specimens. However, the high viscosity resin had the lowest specific failure stress for the southern pine lap-shear specimens.

Comparing with resin distribution data, strands with a greater proportion of large resin spots, which were obtained from the low viscosity resin, had the lowest specific failure stress. The highest atomizer disk speed (13,000 rpm) had the greatest proportion of small resin spots and the largest specific failure stress. These results support the hypothesis that smaller resin spot size, for equal resin loading, produces better bond strength.

Results for internal bond testing are shown in Figure 28. Analysis of variance, at $\alpha = 0.05$, indicated that IB was significantly affected by disk speed for aspen and southern pine strand board. IB increased with increasing disk speed. Resin viscosity had no effect on IB. Strands randomly tumbling inside the rotating blender completely filled the volume of the drum. Therefore, all strands had equal chance for resin application. Contact between strands likely caused transfer of resin between strands.

The effect of disk speed on IB and lap-shear performance were consistent – increasing disk speed improved performance. Whereas the high viscosity resin improved lap-shear performance for aspen, it reduced performance for southern pine, and resin viscosity had no effect on IB. Comparison with resin distribution results indicate that smaller resin droplets produced better overall results. This observation is consistent with previous work using PF resin on aspen strandboard (Kamke et al. (1996).

Some differences were detected between species, which may be due to the resin spot size relative to cell lumen size. Aspen has vessels that have larger lumens than the lumens of longitudinal tracheids in southern pine. However, the smallest resin spots were similar in size to the width of aspen vessels. A more likely effect of species on IB performance was density of the wood, since panels were produced to the same density. Strand dimension may also have been a factor with IB, since strands were produced at different mills.

CONCLUSIONS

Resin distribution on a strand surface as a result of spinning disk atomization is influenced by disk speed and resin viscosity within the range of treatments included in this study. Increasing disk speed reduces resin spot size. Increasing PF resin viscosity decreases spot size. Overall, smaller resin spot size improves adhesive bond performance in the current study. As expected, increasing resin coverage on strand surfaces increases bond performance. Analysis of droplet diameter in a spray is useful for assessing trends, but does not correspond to resin distribution on strand surfaces due to wetting, penetration, overlapping resin spots, and resin transfer from strand to strand.

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Table 7. Strandboard manufacturing specifications.

Target density (lb/ft^3)	40.6
Thickness (in)	0.51
Length (in)	16
Width (in)	16
Wood MC %	3
Resin solids loading %	6.5
Wax solids loading %	0
Mat MC %	10
Platen temperature (°C)	200
Closing time (s)	30
Vent time (s)	30
Total press time (s)	420

Table 8. Phenol-formaldehyde resin viscosity at 25°C and number average molecular weight (Mn).

PF Resin	Viscosity During Lap-Shear Preparation (cP)	Viscosity During Panel Manufacture (cP)	Mn (g/mol)
Low Viscosity (LV)	176	176	2045
Medium Viscosity (MV)	548	524	2940
High Viscosity (HV)	1215	1086	4075

Table 9. Percent surface area coverage for blender strands.

Wood Species	Resin Viscosity	7,000 RPM		10,000 RPM		13,000 RPM	
		Avg	*SD*	*Avg*	*SD*	*Avg*	*SD*
Aspen	**Low**	13.0	2.6	16.2	2.1	14.9	2.8
	Medium	9.6	2.7	10.2	6.4	10.3	6.2
	High	9.4	4.0	9.4	2.2	6.8	3.1
S. Pine	**Low**	11.7	4.4	13.7	5.7	10.9	4.7
	Medium	10.3	3.6	11.7	5.2	10.8	5.4
	High	7.0	2.8	8.6	5.6	11.6	4.3

Table 10. Resin spot size at 25%, 50%, 75%, and 100% of the cumulative fraction of area coverage for PF resin for each population of aspen and southern pine blender strands (mm^2).

Wood Species	Resin Viscosity	Disk RPM	Cumulative Fraction of Area Coverage			
			0.25	**0.50**	**0.75**	**1.00**
Aspen	**Low**	7,000	0.014	0.052	0.153	13.19
		10,000	0.012	0.043	0.120	4.59
		13,000	0.009	0.030	0.101	5.06
	Medium	7,000	0.011	0.037	0.096	2.09
		10,000	0.009	0.028	0.083	9.50
		13,000	0.006	0.019	0.066	8.25
	High	7,000	0.010	0.037	0.107	2.46
		10,000	0.006	0.021	0.061	5.04
		13,000	0.004	0.014	0.041	3.19
S. Pine	**Low**	7,000	0.030	0.110	0.333	6.03
		10,000	0.018	0.065	0.233	9.71
		13,000	0.010	0.038	0.166	6.58
	Medium	7,000	0.023	0.074	0.194	4.22
		10,000	0.012	0.039	0.139	14.26
		13,000	0.008	0.027	0.120	12.89
	High	7,000	0.015	0.054	0.153	2.21
		10,000	0.010	0.031	0.100	1.89
		13,000	0.010	0.031	0.091	1.95

LIST OF FIGURES

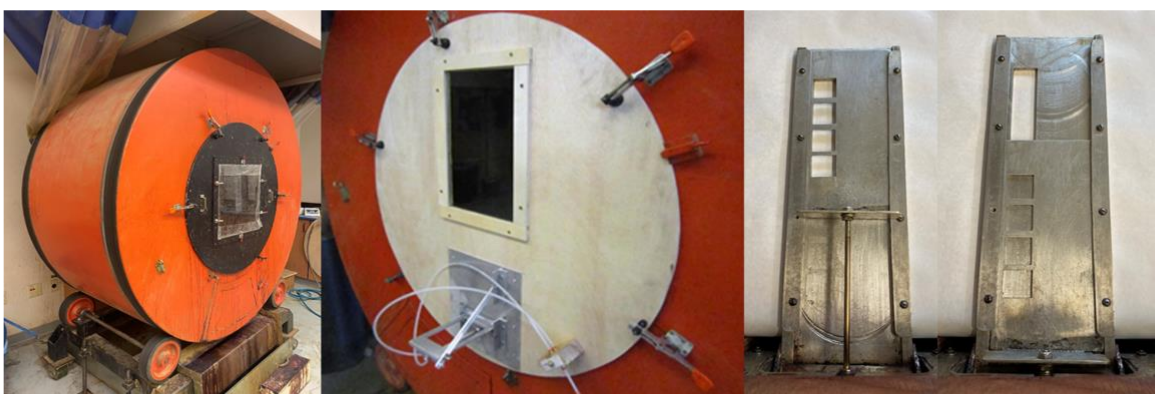

Figure 22. Rotary blender (left), (center-left) outside of blender door with pneumatic insertion device, (center-right) shown inside of door from below with 4 slots open, and (right) shown with 4 slots closed.

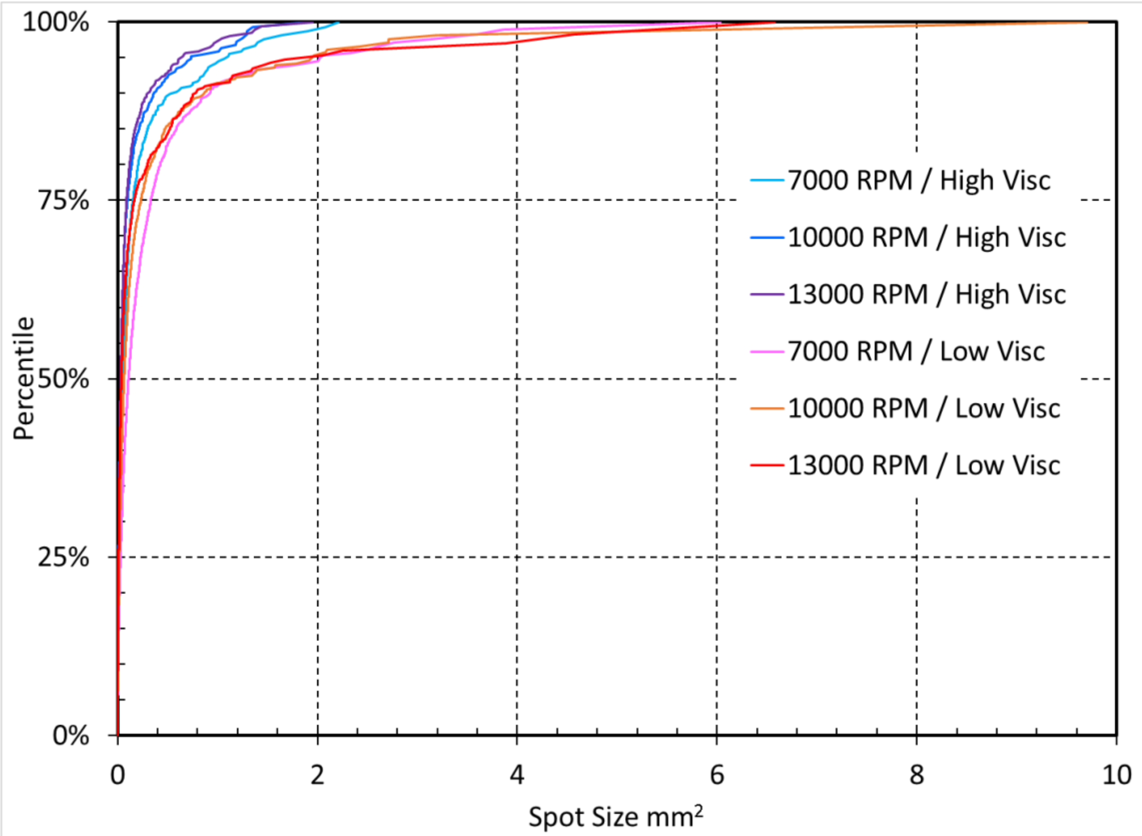

Figure 23. Full distribution of resin spot size, by percentile of cumulative resin detected, on southern pine blender strands for low and high viscosity phenol-formaldehyde resin.

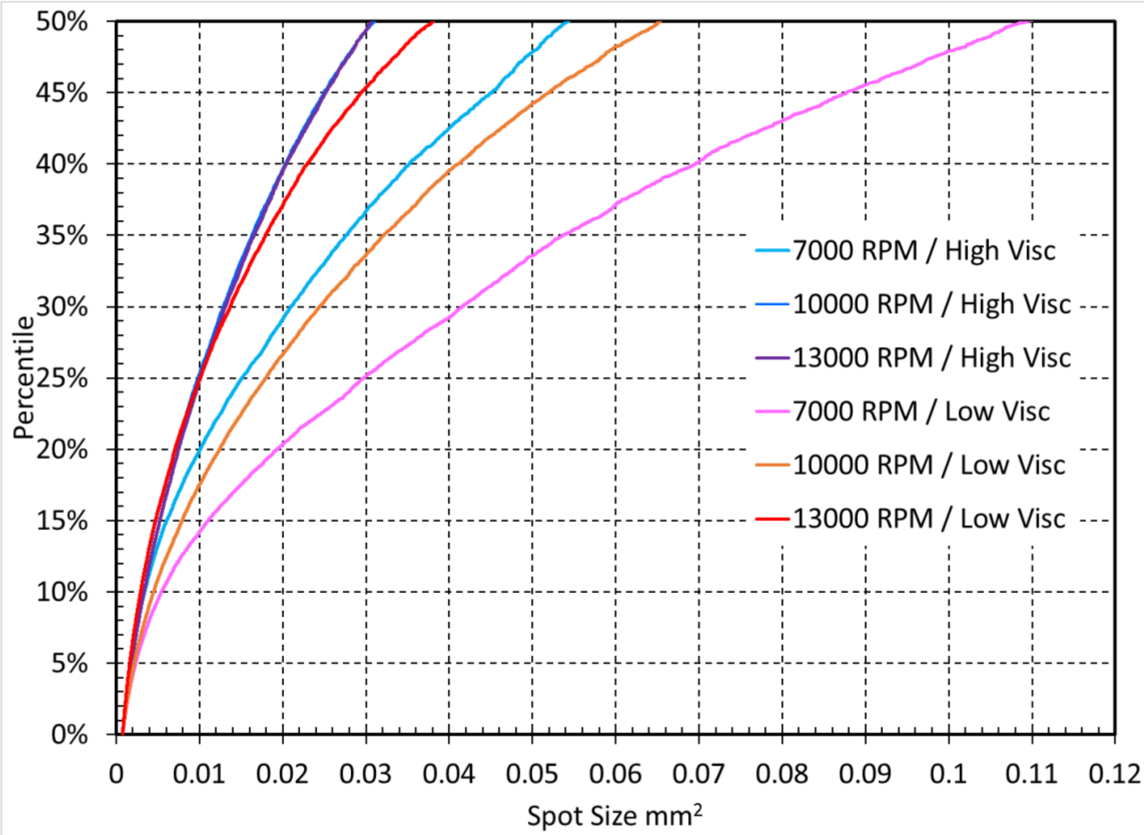

Figure 24. Lower 50th percentile distribution of resin spot size, by percentile of cumulative resin detected, on southern pine blender strands for low and high viscosity phenol-formaldehyde resin.

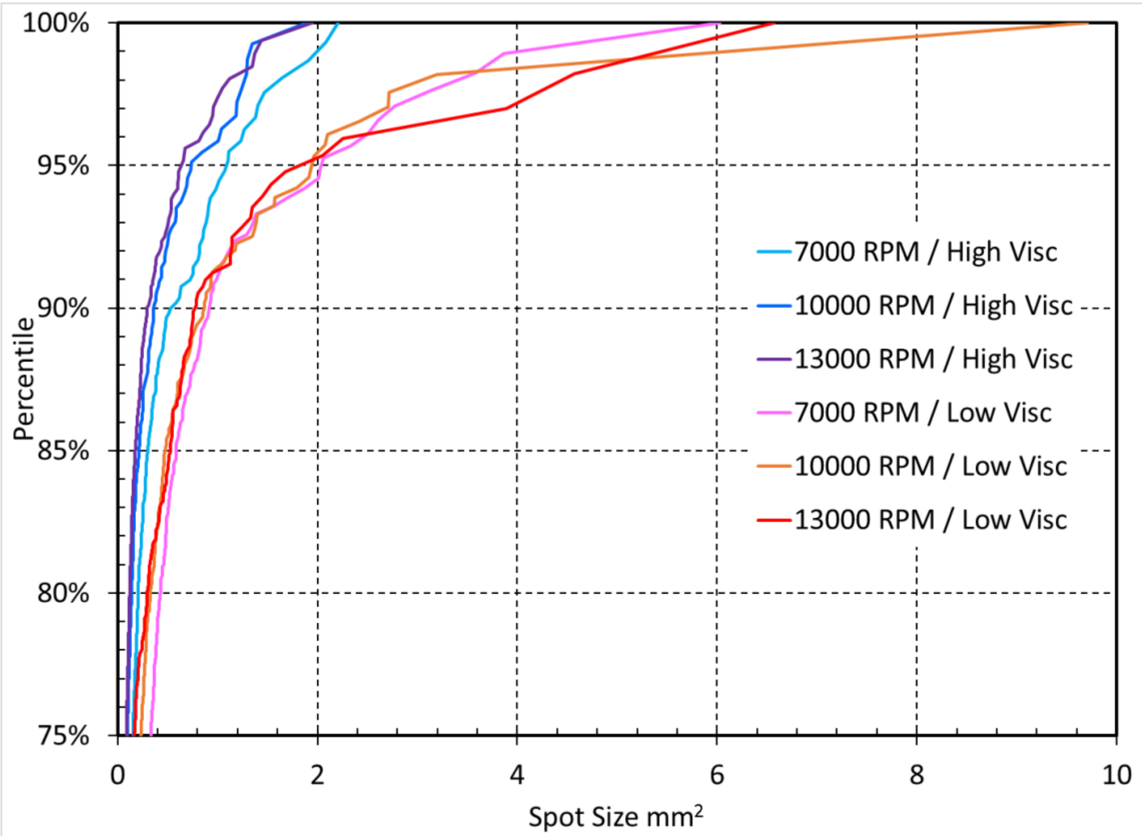

Figure 25. Upper 25th percentile distribution of resin spot size, by percentile of cumulative resin detected, on southern pine blender strands for low and high viscosity phenol-formaldehyde resin.

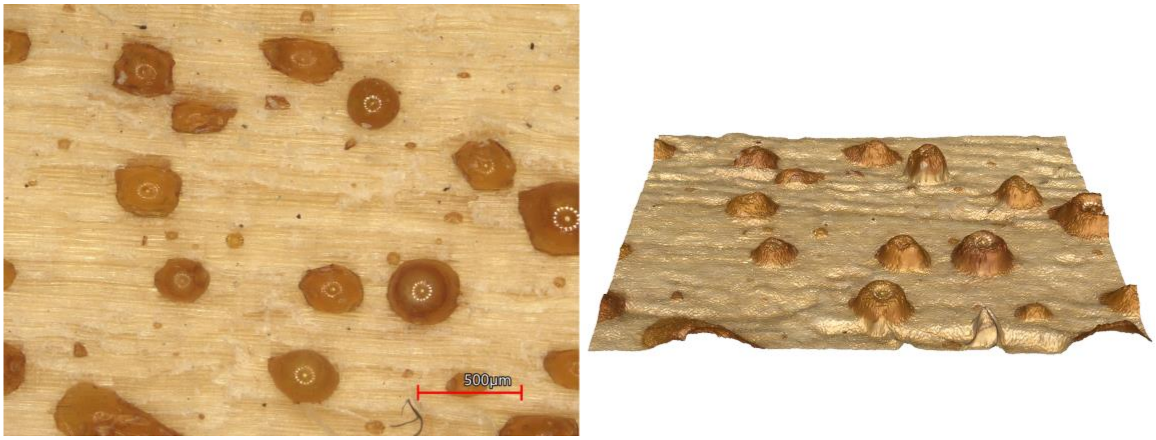

Figure 26. Southern pine lap-shear strand with low viscosity resin added at 7,000 rpm; (left) scaled image, (right) 3D projection of same region.

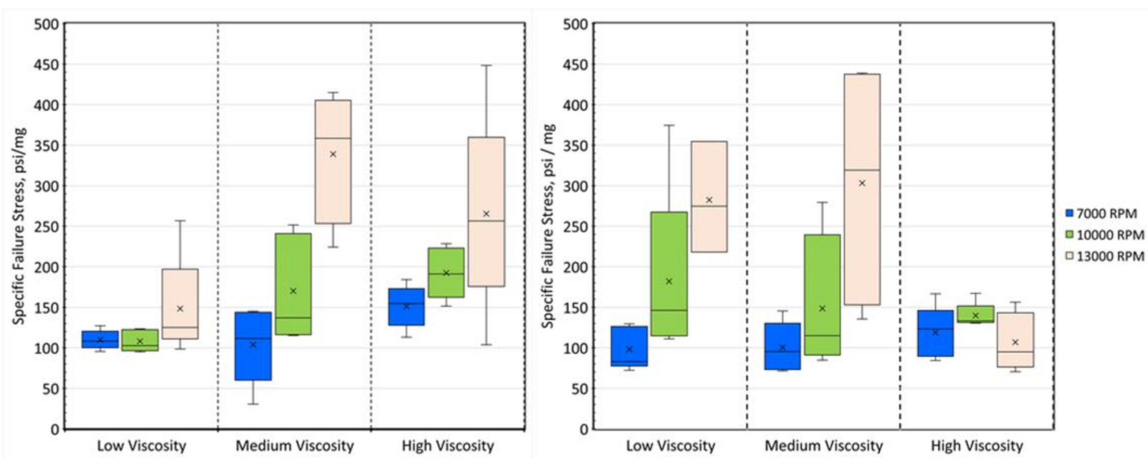

Figure 27. Specific failure stress, per mg of resin applied, for (left) aspen and (right) southern pine lap-shear specimens for low, medium, and high viscosity phenol-formaldehyde and three atomizer disk speeds.

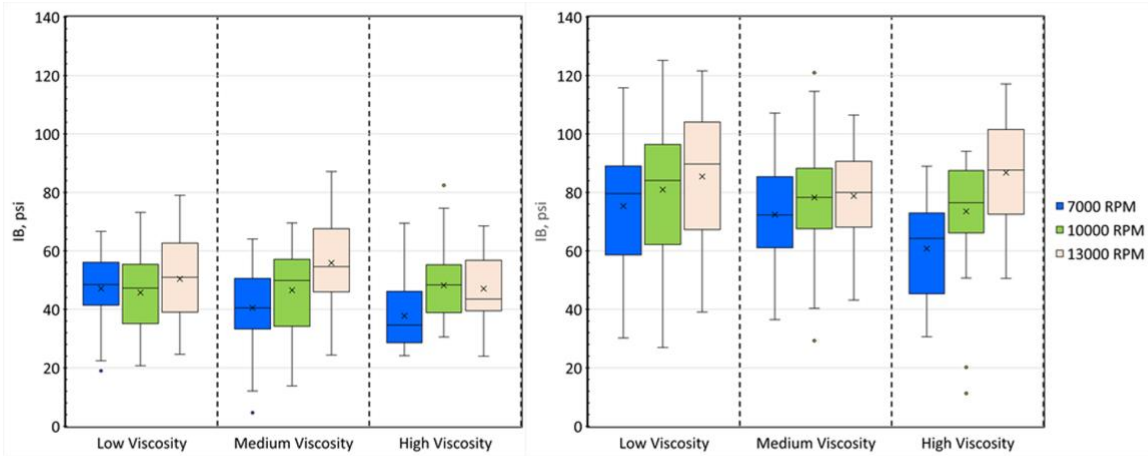

Figure 28. Internal bond strength for (left) aspen and (right) southern pine strandboard with low, medium, and high viscosity phenol-formaldehyde resin, and three atomizer disk speeds.

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Cellulose Nanocrystal Coatings on Poly(lactic acid) Film for Food Packaging Applications

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Abstract
Cellulose nanocrystals (CNCs) are among the most promising next-generation materials in the food packaging field. However, the moisture sensitivity of CNCs has a negative effect on barrier, mechanical, and other essential properties of pure CNCs films as a packaging material. Based on this, CNC films laminated with plastic films as an outside layer is a reasonable approach that has been explored. In this research, poly (vinyl alcohol) (PVA) and kappa-carrageenan (K-C) were added into 6% CNC suspensions to overcome the compatibility issue between cellulose nanocrystals (CNCs) and the poly (lactic acid) (PLA) film. This mixed CNCs composite system was used for PLA coating. After drying, another layer of PLA film was laminated onto the coated films to obtain the final sandwich composite structure. Meanwhile, the properties of the CNCs composite system and coating performance of different formulations were evaluated. Although there was a huge difference in viscosity between PVA and K-P mixed systems, both of them could significantly improve the coating quality only at 15wt% addition based on CNCs mass. The laminated PLA/CNC films showed great barrier properties, water vapor transmission rates were around 24 g/(m^2·d), compared with pure CNCs films (444 g/(m^2·d)).

Lignin-Polyesteramide Based Thermoplastics

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Abstract

Lignin-polyesteramide copolymers were synthesized using a single pot, solvent free, melt condensation reaction. The synthesis occurred in two stages. In the first stage a prepolymer consisting of a diol and diacid with varying amounts diamine was heated under vacuum. In the second stage, prepolymer was mixed with kraft lignin and further reacted under vacuum at elevated temperature. Progression of polymerization was monitored using FTIR spectroscopy and electrospray ionization-mass spectrometry. Polymer properties were characterized using dynamic mechanical analysis, differential scanning calorimetry and thermogravimetric analysis techniques. The morphology was analyzed using polarized optical microscopy. Polymer mechanical properties were found to be influenced by the type of diacid, lignin and diamine contents. The lignin-copolymers were shown to have thermoplastic behavior. Additionally, above 30 wt% lignin the lignin-copolymers did not exhibit melt behavior.

Biofilter based Nanofibrilated Cellulose and Polylactic Acid for Personal Protective Equipment

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Abstract

Currently, personal protective equipment (PPE) is highly demanded not only by the medical community, but the population at large. Most importantly, there is an important increase of healthcare associated infections in hospitals due to the increased load of diseased patients, and the lack in proper and effective protection for the medical community. Various emerging infectious diseases caused by viruses, including severe acute respiratory syndrome coronavirus (SARS-CoV), Ebola virus, norovirus, and dengue virus have prompted the discovery and development of antimicrobial reagents and personal protection equipment (PPE) to guard against infectious agents. Common PPE are disposable, non-degradable, single use items that not only incur a high cost but are vulnerable to penetration by microorganisms. The N95 medical mask is the most common type of particulate filtering facepiece respirators. This product is made of non-degradable non-woven polypropylene fiber and removes 95% of airborne particles. We have been developing a reusable nanoporous biofilter that protects against microorganisms that have a diameter greater than 50nm, including COVID-19, which has an approximate 125nm diameter. This initiative considers the feasibility of using nanomaterials from renewable sources in combination with other biopolymers in the production of a novel biofilter for an improved facial mask performance against COVID-19.

Measurements of Cellulose Nanocrystal Suspension Viscosity Using a Rotational Viscometer

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Abstract

The interest in the material of cellulose nanocrystal (CNC) from academia and industry has been growing significantly since the beginning of this century. Many applications have been developed for the CNC material and appropriate procedures used to handle the CNC suspensions are critical for all these applications. In this study, a quality control method evaluating the consistency of the CNC suspensions was explored. A rotational viscometer was used to characterize the CNC suspensions at the concentrations of 3, 4, 5, and 6 wt.%. The primary readings from the rotational viscometer, including spindle rotation speed and torque were collected to generate the apparent viscosity and shear rate data for the CNC suspensions. Three different methods summarized from the literature were applied to calculate the apparent viscosity and real shear rate from the primary readings of the rotational viscometer. The differences among the calculation results from the three methods were critically analyzed. Shearing thinning behaviors obeying the power law flow model were observed for all the CNC suspensions in the shear rate tested in this study. At different concentrations, the consistency and flow behavior indices in the power law model were different in the measured shear rate range. This study indicated that a rotational viscometer can be used as a quality control tool for characterizing the rheological properties of the CNC suspensions. Recommendations for calculating the real shear rate and the apparent viscosity of the CNC suspensions using the primary readings of a rotational viscometer were made.

Experimental Investigation of Shear and Flexural Properties of Mass Plywood Panel and Concrete Composite Floor System

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Abstract

Timber-concrete composite (TCC) floors offer increased stiffness, greater load-carrying capacity and improved vibrational and acoustic properties when compared to timber floors. The critical design feature in TCC floors are the connections between the timber and the reinforced concrete. Connections need to be cost-effective and facilitate composite action. This presentation will focus on the results of an experimental program that investigates the structural performance of floor slab assemblies that combine Mass Plywood Panel (MPP), reinforced concrete, and screws or expanded steel mesh plates as shear connectors between concrete and timber. MPP is a veneer-based timber product that can be manufactured with thicknesses and lengths of up to 0.30m and 18.3m, respectively. In addition, to improve the acoustical performance of the floor assemblies tested, solutions with acoustic mats installed between the reinforced concrete and MPP are also tested. Results of push-out tests of two thicknesses of the acoustic mats (5mm and 19mm), various screw embedment angles, and various mesh plate embedment depths are presented. In addition, results of three-point bending tests are also presented, characterizing flexural stiffness and strength of the composite floor solutions. The results indicate that structurally, the solutions are effective and robust, and the impact of the acoustic mat is also predictable. However, additional testing on full-scale bending tests and creep tests are necessary to gain a full understanding of the behavior.

Lint Fiber polyethylene Composites Fabrication

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Abstract
One form of common everyday waste in America is dryer lint fibers, waste short fibers that have been removed from clothing after they have gone through a dryer and been collected in a lint trap. A residential family home will most likely only produce a few pounds of lint a week depending on how often the dryer is used, whereas commercial laundromats may produce as much as over 100 lbs of dryer's lint per shift. The majority of dryer lint produced is a mix of natural fibers (cotton, wool, hair, fur, etc.) and synthetic fibers (polyester, spandex, etc.) and is thrown away as waste where it is disposed of in landfill in trash bags. Dryer lint fiber as a material show potential, however, due to it already being in the form of small fibers, ease of being formed into a fiber mat like in a lint trap, ease of handling, and ease of shaping. It is due to these properties of dryer lint fiber where it shows its potential as a material for composite fabrication. The objective of this study is to look into the processing parameters used to make a composite that uses dryer lint fiber as a reinforcement with polyethylene film recycled from plastic grocery bags as the matrix. Polyethylene was chosen for the matrix because of its prominence in being used in plastic bags, which are a major source of waste and pollution. By using these materials for the composite matrix, the plastic bags can be easily prepared into strips of film, which can then be use to bind the lint fiber layers together. Using a hot press, the lint fiber polyethylene composite panels will be fabricated. The effective processing parameters (temperature, time, and pressure, matrix to fiber ratio, density) for its fabrication and the mechanical properties (tension, bending, internal bond) and interfacial properties of the resulting composites will be investigated. In regards to the hydrophilic and hydrophobic differences between the lint fiber and polyethylene film, the use of a coupling agent will be studied to see the effect it has on the composites compared to the those without a coupling agent. By combining dryer lint fiber, the goal is to develop a value added composite material that is entirely derived from to major sources of every day waste in hope of reducing pollution and environmental damage.

Resilient Wood Resources (Revisiting Wood Quality)

Chairs: Dave Auty, Northern Arizona University, USA; Laurence Schimleck, Oregon State University, USA

Modeling Specific Gravity and Diameter Inside Bark of Western Hemlock and Sitka Spruce Growing in Southeast Alaska

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Abstract

Western hemlock and Sitka spruce are two commercially important species in Alaska with harvests beginning to focus on naturally regenerated young-growth. We developed within-tree models of ring specific gravity (SG) and diameter inside bark (DIB) for young-growth western hemlock and Sitka spruce. Eight even-aged stands (age < 75 years) in southeast Alaska were felled and disks collected from multiple height levels; 128 trees and 451 disks were collected for western hemlock, and 217 trees and 952 disks were collected for Sitka spruce. Radial strips were prepared and scanned using X-ray densitometry. We fitted non-linear mixed-effects models to the data, with cambial age, height within tree, and dominance class used as explanatory variables. The R^2 values (fixed effects only) for the SG models were 0.48 and 0.42 for western hemlock and Sitka spruce, respectively. The corresponding fit indices for the DIB models were 0.86 and 0.85 percent for western hemlock and Sitka spruce, respectively. Tree maps depicting the within tree variation in SG showed more variability in Sitka spruce than in western hemlock. The wood and growth properties of young-growth trees in Alaska will continue to become more important as the U.S. Forest Service transitions away from harvesting old-growth trees.

Brown Rot Decay Development on Coated Southern Pine CLT and Dimensional Southern Pine Lumber

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Abstract

Film forming paints, water-repellents and stains are widely used in buildings and construction. The performance of these finishes and their response to biotic and abiotic environmental stressors is dependent on the substrate characteristics. The use of mass timber structures is increasing throughout North America and concerns about its durability have become an important topic. Because of the structural design of cross laminated timber panels, they may absorb water through exposed end-grain, which can impact mechanical properties and facilitate the development of decay. Although coatings such as paints, water repellants and stains are not designed to permanently protect wood elements against decay, when containing biocide ingredients, they may inhibit or slow down the development process. The objective of this work was to investigate the attack of one brown rot (*Postia placenta*) decay fungus on both coated and uncoated mass timber and lumber specimens. Three commercial coatings (C = transparent, water based, high durability; F =semi-solid, water-based; I = transparent, oil-based) were selected to be tested on three-ply cross laminated timber (southern yellow pine) and grade No. 2 pine lumber samples in a modified version of AWPA E-10 (2016). Both the CLT material and dimensional lumber sections were of the same dimensions, 110 mm × 50 mm × 25mm (length, width and height). Weight losses were recorded after 20 weeks' exposure to the brown rot decay fungus. There was significant interaction between substrate material type and coating in the mass loss of samples exposed to the brown rot fungus (α=0.05). Coating I applied on CLT offered the lowest protection against *P. placenta*. However, CLT samples coated with the water repellent C coating inhibited brown rot development. Overall, CLT samples achieved greater weight loss compared with lumber of the same size and wood species. *P. placenta*caused more weight loss in CLT samples coated with I, even when compared to control samples.

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Image Analysis to Assess Wood Variability in Longleaf Pine

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Abstract

Image analysis as a non-destructive tool is increasingly used by forestry and forest products industries to assess wood properties and determine specific end uses of raw materials and finished products. Our objective for this study was to show that imaging can be a suitable alternative to reference measurements of wood and bark volumes and diameter, and to show the advantages that imaging has in better describing other features of the disks such as the shape. We used a total of 1120 cross-sectional disks collected from 104 longleaf pine trees grown in 16 different stands across Georgia. Forty-eight trees were straight defect-free trees and 56 of them had at least one visible stem defect including significant sweep, forks, or ramicorn branches. One side of each disk was machined using a computer numeric controlled router prior to imaging. Three images were taken for each disk under various lighting conditions, the first image was collected using white light, and the second using blue light. The third image was taken using blue light with an optical longpass filter (>525 nm, blocks blue wavelengths); this image was used to isolate the wood from the bark. To calculate volume from area measured by images, we measured the disk thickness using an acoustic sensor. Overall our results show that the wood and bark volume and diameter measurements from images were in close agreement with reference methods and all models fit had high R^2 values and low root mean square errors (RMSE). Specific models fit were: 1) wood volume ($R^2 > 0.99$, RMSE = 26.5 cm^3), 2) bark volume (R2 = 0.96, RMSE = 3.9 cm^3), 3) outside bark diameter ($R^2 > 0.99$, RMSE = 3.2 mm), and 4) inside bark diameter ($R^2 > 0.99$, RMSE = 0.9 mm). Out of round (%) was calculated using the four inside bark radii with pith as the starting point, and a threshold of 40% was used to classify disks as 'round' and 'not round'. An algorithm to check for compression wood occurrence was applied on images of both 'round' and 'not round' disks. The algorithm succeeded in identifying severe compression wood but it was not able to classify mild compression wood. A larger number of 'not round' disks came from trees that had stem defects. Specifically, trees having excessive sweep yielded the most out of round disks and had the most severe occurrence of compression wood. Imaging allows for the digital record of disks which is an added advantage because the images could be used to generate more information in future studies.

Keywords: bark, diameter inside bark, diameter outside bark, nondestructive evaluation, southern pine, wood and bark volume, wood imaging, wood and fiber quality

Comparison of Two Methods for Evaluating Percentage of Latewood of Southern Pine Structural Lumber

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Abstract

The evaluation of percentage of latewood in structural lumber is relevant due to its relation to other wood properties such as density and strength. The goal of this study was to compare the usual method for estimating percentage of latewood using dot counting (dot grid) with a pixel estimation in a binary image, obtained by processing pictures with a software. A total of 913 southern pine (*Pinus* sp.) No.2 kiln dried structural lumber pieces of different nominal sizes were examined. The overall mean for percent of latewood (dot grid) was 45.20 whereas mean percent of latewood using image processing was 38.45. Density was calculated and added to enhance comparisons. The overall density value was 560 kg·m^{-3}. Statistically significant differences using the two-sample t-test (α=0.05) were found between both latewood estimation methods. Significant difference was also found for density estimation per both latewood methods. Investigating the relationship between density and latewood, higher r^2 values were obtained with the dot grid procedure. For 2 × 4, the r^2 were 0.35 and 0.16 (dot grid and image processing respectively). For 2 × 6, the r^2 were 0.22 and 0.19. For 2 × 8, 0.29 and 0.17. The r^2 values for 2 × 10 were 0.32 and 0.26. The results suggest that dot grid technique is still the recommended method. Nevertheless, further exploration with additional sample preparation is recommended.

keywords: latewood; southern pine; wood quality; image analysis; wood density

Introduction

Latewood and earlywood are recognizable regions that form part of the growth rings in trees. Latewood is a dark colored region formed generally during the latter part of the growing season. Latewood anatomical features include tracheids with thick cell walls and small cavities or lumen. Earlywood is formed in early growing season and can be identified for its light color and tracheids with thin cells walls and relatively large cavities.

The combination of one band of earlywood and one band of latewood produces an annual ring. Studying proportion of latewood is important because it contributes to broaden the knowledge about wood quality and the physical and mechanical properties of wood. (Senft et al. 1985; Begum *et al.* 2012; Irby *et al.* 2020).

Although annual growth rate and wood quality is not well understood (Koga & Zhang 2001), it is known that latewood evaluation provides information about density of wood (Lindström 1997). Density is one of the most important properties of wood because it correlates well with other properties such as stiffness and strength. For this reason, density is commonly associated with wood quality (Zhang 2003). However, density is not the only attribute that impacts the quality of wood.

Begum *et al.* (2012) stated that "the amount of latewood formed in conifers controls wood quality through changes in wood density" (p.875). Nevertheless, when using the proportion of latewood as an attribute to assess wood quality, it is important to consider that earlywood and latewood proportion can vary between trees and within the tree due to environmental and or internal conditions.

Currently, in the wood research field, latewood estimation is done manually. Doing this work, although very useful, can be tedious and time consuming. A common method to estimate proportion of latewood in lumber consists in aligning a small plastic dot grid (1×1 in) over the visible latewood rings in the cross section and count the dots that fall under the latewood region.

Ideally, studying tree rings would require sanding and polishing the ends to better distinguish the earlywood and latewood regions (Vaz *et al*. 2004). However, preparing samples manually for a large data set is not feasible for the industry nor researchers.

It has been previously stated that tree cross section analysis should be automated. (Österberg *et al*. 2006; Vaz *et al.,* 2004). Even though some electronic devises are being developed for tree ring identification and measurements, few studies have evaluated the proportion of latewood using computers or electronic devices.

In a study, Österberg *et al*. (2006) evaluated in a prototype version, the images obtained from prepared and unprepared board ends and logs. The authors used a "moving window" and images processed with a digital binary technique (black and white images) to estimate latewood proportion.

This study aimed to evaluate latewood proportion of southern yellow pine (*Pinus* sp.) structural lumber. To accomplish this, the authors were looking to compare the percentage of latewood (LW) estimation using the traditional technique (dot grid) with the percentage of LW obtained with the digital image processing technique. Also, to enhance comparison, calculated density was added to study its relationship with the proportion of latewood.

Materials and Methods

A total of 913 southern pine (*Pinus* sp.) No.2 kiln dried structural lumber pieces of different sizes (206 pieces of 2 × 4, 282 pieces of 2 × 6, 287 pieces of 2 × 8, and 138 pieces of 2 × 10) were evaluated to estimate percentage of LW using two methods: a dot grid (1×1 in) and pixel estimation in a binary image (black and white) processed in an image processing software (Image J).

Table 1. Number of lumber pieces of southern pine (*Pinus* sp.) evaluated by size.

Lumber Size	No. Pieces
2×4	206
2×6	282
2×8	287
2×10	138
Total	913

Apparent density

The lumber pieces were kept under a breezeway until the moisture content (MC%) of the pieces reached around 12 percent. Density was calculated after weighting and measuring thickness and width of each lumber piece.

$$\rho = \frac{m}{v} \qquad \text{Eq. (1)}$$

where ρ is density; m is mass (kg), and v is volume (m^3).

Percentage of latewood – Dot Grid

The Dot Grid method was used to calculate the percentage of LW. It uses a small plastic dot grid (1 × 1 in). The dot grid was placed at both ends of the lumber piece, aligning the dotted rows to the growth rings. The dots that touched the latewood zone were counted and recorded. Then the total of dots counted, was divided by the total amount of dots of the dotted grid (64 dots).

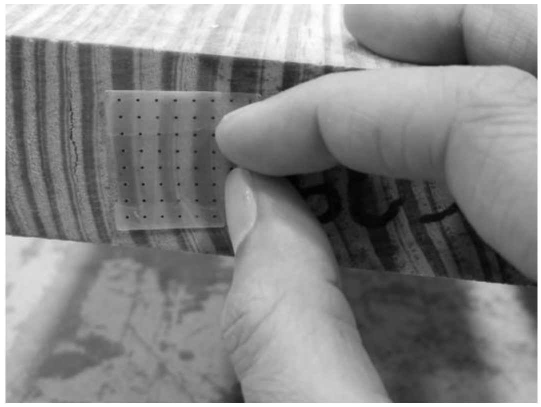

Figure 1. Latewood evaluation using a plastic dot grid of 1 by 1 in.

Percentage of latewood - Image processing

The surfaces of the cross section of the lumber pieces were analyzed. No prior preparation was done to visualize the rings in the images. No water was added, nor surfaces were sanded. After a curating process, a total of 1826 binary images obtained from the ends (cross section) of each lumber piece were studied. Photos were taken using a phone with a front camera of 8 megapixels (Samsung Galaxy Note 8).

Figure 2. Example of photo taken to the ends of 2×10 lumber pieces. Notice the abrupt transition between earlywood and latewood.

To process each image, a small crop was made from the original photo. The size of the crop on each photo was randomly assigned to better fit the area where the rings were more distinct. Despite the curating process done before processing the images, many images still showed some noise generated for the poor ring definition and the rough texture of the cross section.

Each of the cropped images was processed to construct a binary image (black and white image). After that, LW (%) was estimated for both ends of each lumber piece by identifying in a histogram, the total amount of black or white pixels contained in the image. Notice that in each binary image, latewood regions were represented in white or black depending on the quality of the image and the color variation between earlywood and latewood. Then, that value was divided by the total amount of pixels from the binary image.

RESULTS AND DISCUSSION

Percentage of latewood was estimated using both methods. Small sections were cropped from an original picture to visualize the earlywood and latewood regions. The image processing method was able to distinguish the latewood in visible and distinct images (Figure 3). Poor quality cross section surfaces affected the image processing method. The dot grid method was more capable to distinguish the latewood.

Figure 3. Small section cropped from an original picture to visualize the earlywood and latewood regions. (A) An example of an image where LW rings are distinct. (B) An example of an image with noise generated by the rough surfaces in the cross section. (C) Histogram generated after converting the image in black and white. LW (%) was estimated by counting the pixels in the histogram.

Table 2 summarizes the results obtained for density from southern pine structural lumber of different sizes. With a 10.82% COV, the overall density mean, min and max (for all sizes) were 560.17 $Kg{\cdot}m^{-3}$, 410.29 $Kg{\cdot}m^{-3}$ and 787.81 $Kg{\cdot}m^{-3}$, respectively.

Table 2. Overall results for density ($kg{\cdot}m^{-3}$) of southern pine (*Pinus* sp.) structural lumber.

Lumber Size	Mean	Median	Min	Max	COV (%) *
2×4	550	548	417	788	11.79
2×6	572	568	429	763	10.18
2×8	558	550	410	784	10.98
2×10	556	549	436	707	9.69
All sizes	560	555	410	788	10.82

* Coefficient of variation

Table 3 summarizes the results of LW (%) obtained after using the dot grid method. Overall, the mean value for LW (%) (all sized combined) was 45.20. The min was 44.53 and the maximum was 78.13 with a coefficient of variation of 22.82%. Table 4 shows the results of LW

(%) using image processing. For all sizes, LW (%) mean was 38.45; min was 11.97 and max was 79.89 with a coefficient of variation of 26.02%.

Results displayed in both tables show that mean values for LW (%) were higher for all lumber sizes using the traditional method. Also, variation was less for all size categories when compared to the variation generated by image processing.

Table 3. Overall results for percentage of latewood (%) of southern pine (*Pinus* sp.) lumber estimation using the dot grid method.

Lumber Size	Mean	Median	Min	Max	COV (%) *
2×4	44.10	43.75	19.53	76.56	24.61
2×6	47.27	46.88	25.00	78.13	21.29
2×8	43.52	43.75	21.09	68.75	22.84
2×10	46.13	45.31	21.09	76.56	21.77
All sizes	45.20	44.53	19.53	78.13	22.82

* Coefficient of variation

Table 4. Overall results for percentage of latewood of southern pine (*Pinus* sp.) lumber estimation using image processing.

Lumber Size	Mean	Median	Min	Max	COV (%) *
2×4	39.23	39.72	16.20	70.29	26.26
2×6	39.31	38.92	14.10	79.89	27.34
2×8	36.73	36.16	11.97	67.43	23.29
2×10	39.11	40.55	18.55	66.25	26.66
All sizes	38.45	38.21	11.97	79.89	26.02

* Coefficient of variation

Mean comparisons

Two-sample t-tests were performed to determine if there were significant mean differences between LW (%) obtained with the dot grid and the image processing. Additionally, t-tests were performed to examine difference between density and LW (%) obtained from both methods. Table 5 shows p-values obtained from t-tests at a 0.05 significance level.

The two-sample t-tests revealed significant differences between the two means for LW (%) obtained from the two methods evaluated at the 0.05 level ($p < 0.0001$). As shown in table 3 and table 4, mean values for LW (%) obtained with the dot grid method were higher, results from the t-test revealed that these values are significantly different from the ones obtained using image processing for all lumber sizes. T-tests also revealed significant difference between density per both methods for all lumber sizes.

Table 5. Two-sample t test for percentage of latewood (LW) and density.

t-test	Size	df	p-value
LW (%): Dot grid method vs Image processing	2×4	410	<0.0001
	2×6	562	<0.0001
	2×8	560	<0.0001
	2×10	274	<0.0001
Density vs LW (%) $_{\text{dot grid.}}$	2×4	261	<0.0001
	2×6	353	<0.0001
	2×8	369	<0.0001
	2×10	167	<0.0001
Density vs LW (%) $_{\text{Image processing}}$	2×4	267	<0.0001
	2×6	344	<0.0001
	2×8	396	<0.0001
	2×10	165	<0.0001

α = 0.05, 2-tailed

The two-sample t-tests revealed significant differences between the two means for LW (%) obtained from the two methods evaluated at the 0.05 level (p <0.0001). As shown in table 3 and table 4, mean values for LW (%) obtained with the dot grid method were higher, results from the t-test revealed that these values are significantly different from the ones obtained using image processing for all lumber sizes. T-tests also revealed significant difference between density per both methods for all lumber sizes.

Analysis for density and percentage of latewood

The relationship between density and LW (%) for 2×4 and 2×6 southern pine using the dot grid and the image processing methods are shown in Fig. 4A and Fig. 4B. With an r^2=0.35, the correlation between density and LW (%) for 2×4 (dot grid) is moderate. With an r^2=0.16, the correlation between both variables using the image processing is negligible.

For 2×6, The relationship between density and LW (%) (dot grid method) was weak (r^2=0.22), whereas the relationship between both variables using image processing was negligible (r^2=0.19).

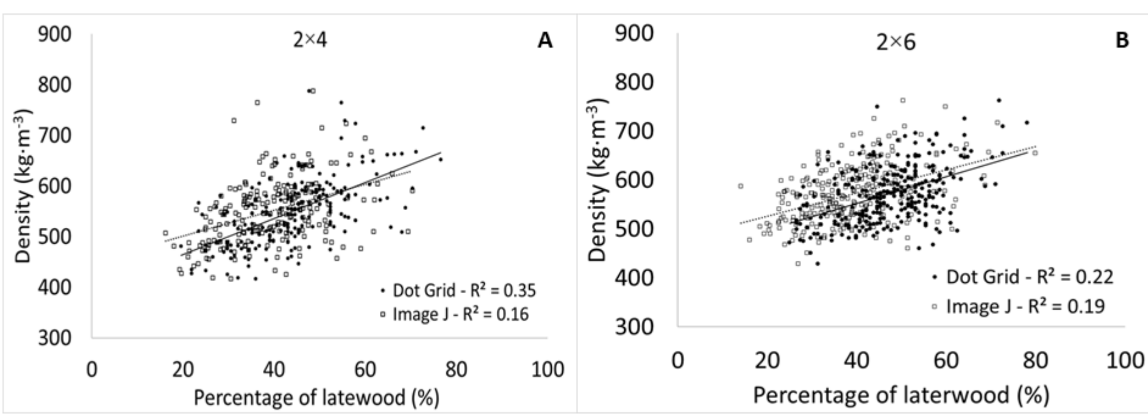

Figure 4. Fig. A and B shows linear regression plots between density and percentage of latewood (LW) obtained from the dot grid and image processing methods for 2×4 and 2×6 southern pine lumber.

In Fig. 5, it can be seen the relationship between density and LW (%) for 2×8 and 2×10. For 2×8, the relationship between density and LW (%) (dot grid) was weak (r^2=0.29) whereas the relationship between both variables using image processing was negligible (r^2=0.17). For 2×10, correlations between density and LW (%) were weak or negligible for both methods.

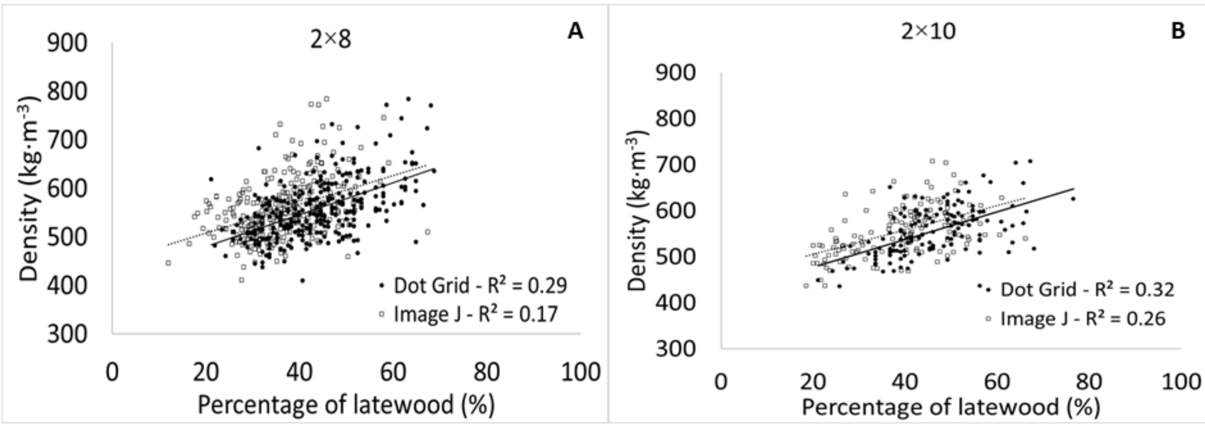

Figure 5. Fig. A and B shows linear regression plots between density and percentage of latewood (LW) obtained from the dot grid and image processing method for 2×8 and 2×10 southern pine lumber.

CONCLUSIONS

This study evaluated the percentage of latewood (LW) of 913 southern pine No.2 kiln dried structural lumber pieces of different sizes using two methods: a dot grid (1x1 in) and processed binary images. The evaluation of LW (%) using image processing method was not straightforward due to the irregularities presented in each binary image. The analysis itself presented challenges due to shadows and poor definition of the rings caused by the rough texture in the cross section of many pieces.

The mean values for LW (%) obtained with the dot grid method were higher and significantly different than the ones obtained after processing the binary images (for all lumber sizes). Significant difference was also found between density and LW (%) obtained from both methods.

From the dot grid method, it was found that density is a moderate predictor of LW (%) for 2×4 and 2×10, and a weak predictor of LW (%) for 2×6 and 2×8. Our results suggest that dot grid technique is still the recommended method. However, further exploration with additional sample preparation is recommended.

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Quantifying the Percent Wood Failure in Adhesive Bonded Joints via UV-VIS Spectroscopy

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Abstract

The aim of this project is to automate the determination of percent wood failure in shear-tested structural composite bondlines through the utilization of a UV-VIS spectrometer. Manufacturers of CLT, Glulam, LVL, Mass Plywood, and Softwood Plywood are interested in this nondestructive measurement technique for continuous improvement efforts and compliance to quality and safety standards. A robust and repeatable statistical model to rapidly measure the ratio of wood to adhesive failure will replace traditional methods which are either slower, more expensive, or vary in accuracy.

This method will be calibrated according to ASTM D5266 – *Standard Practice for Estimating the Percentage of Wood Failure in Adhesive Bonded Joints*. Current techniques are laborious and often inefficient at measuring intermediate wood versus adhesive failure. The utilization of Multivariate Data Analytics (MVDA) methods such as Principal Component Analysis (PCA) and Soft Independent Modelling of Class Analogies (SIMCA) will provide for viable differentiations between certain wood species and adhesive spectra.

Implementing this accurate, precise, and relatively affordable technology in the mill environment will provide manufacturers with cost savings through increased efficiency and an ultimate competitive advantage in the marketplace. Additionally, the resulting ergonomic improvements will drive employee satisfaction in the workplace. A spectrometer will be used to quantify the percentage wood failure in these shear-tested laminated composite products. This approach is expected to maintain an accuracy within five percent wood failure (ASTM D5266), repeatability between operators, and to occur faster than traditional methods.

Key words: wood bonding, shear testing, UV-VIS spectroscopy, Multivariate Data Analysis, Engineered Wood Products, adhesive penetration, surface chemistry, automation, wood failure

Wood Physics and Properties 1

Chair: Gloria Oporto, West Virginia University, USA

Relating Within-Tree Variability in Ultrasonic Velocity to Microfibril Angle in Loblolly Pine

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Abstract

Roundwood is increasingly sourced from highly productive plantations that yield excellent growth. Information is needed on the wood properties from plantation trees because these trees contain a higher proportion of low stiffness corewood compared to naturally regenerated trees of the same size. For the corewood of loblolly pine, the low stiffness is a function of its low specific gravity (SG) and its high microfibril angle (MFA). Increasingly, acoustic velocity is being measured at multiple scales (tree, log, lumber) because longitudinal stiffness is a function of the velocity squared times the density. Advancement in ultrasonic velocity (USV) measurements (>20 kHz) are now enabling acoustics to be used for measuring pith to bark variability in samples collected from wood disks. The objective of this study was to examine the within-tree variation in USV in loblolly pine, and to relate the USV measurements to microfibril angle measuring using X-ray diffraction. Approximately 400 pith-to-bark radial strips collected from multiple height levels were processed. Ring-by-ring SG was measured using x-ray densitometry. Time-of-flight USV was measured in the longitudinal direction at 10 mm radial resolution using two 1-MHz delay line transducers with the distance between the two transducers measured at each radial location using a LVDT sensor. From a subset of samples, microfibril angle was measured using SilviScan's X-ray diffraction system. Non-linear mixed effects models were developed to predict the variability in SG, USV, and dynamic modulus of elasticity (MOE) calculated from SG and USV. Patterns of USV followed the asymptotic patterns similar to the inverse of microfibril angle both radially and by height level. Microfibril angle had a strong linear relationship with USV. This study shows that measuring USV from pith to bark in disk samples is a highly accurate alternative to X-ray diffraction measurement of microfibril angle.

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A New Generation Apparatus to Automatically Study the Hygroscopicity of Wood

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Abstract

Wood is a unique material, being sustainable, ecological and eye-catching when used properly. However, it has several limitations according to the desired applications. Dimensional stability is a factor that limits wood and wood-based products usage in several aplications. To overcome these issue, new sylvicultural techniques, chemical and thermal treatments, and modified wood-based materials are being developed to produce wood and wood materials that will be stronger, more stable, and more durable. Most of the approaches used to test and evaluate the dimensional stability of wood products are time-consuming and demand excessive labor. The objective of this research was to design and build an apparatus to study wood and wood products' sorption/desorption behavior and the dimensional changes in response to environmental changes in a fully automated process using imaging techniques and transducers. The apparatus was designed and built to be more efficient and tunable than the available environmental chambers and incorporates technological expansion and capabilities from the state-of-art information technology standards. With this new apparatus multiple environmental scenarios can be set, varying by time or based on sample obtained values. Beyond the sensors and actuators, the apparatus has four environmental interconnected chambers to provide self-sanitizing procedures. Namely, a pneumatic panel, a hydraulic panel, a control panel, and an ozone generator. The control panel has two onboard computers to run both embedded robust software and a Linux operating system that runs the data collection software. The apparatus was designed with the main focus on providing precision in wood science, allowing it to control the environment with relative humidity values varying from 20% to 100% and temperatures ranging from 20 °C to 30 °C while operating in standard ambient temperature and pressure. It is still in development and more resources may be required, but it has the potential to also be used for fungal growth experiments and corrosion tests in its current stage of development. By changing the chamber construction material and/or sensors and actuators and the development of new software, the usage of this apparatus can be expanded to other applications.

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High-Performance Sustainable Tissue Paper from Residue of Decorticated Nonwood Fique Fibers

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Abstract

Global megatrends towards sustainability are leading to an increased utilization of sustainably perceived fibers such as recycled and agricultural residue fibers, in hygiene tissue applications. An important gap to address is that products advertised as sustainable have substantially higher prices and inferior performance compared to conventional products manufactured from virgin fibers. Through this work, the feasibility of using residues from fique fiber processing as an alternative substitute to Northern Bleached Softwood Fibers (NBSK) in high-performance hygiene tissue applications was demonstrated. Fique is a natural non-wood fiber original from the Colombian Andes region that is primarily utilized for the fabrication of coffee sacks. Fique residues are a by-product of the decortication process. These residues are left on the field without any market value. For our study, fiber residues from the field were cleaned and upgraded using Soda pulping and a three-stage elemental chlorine-free (ECF) bleaching sequence, resulting in a pulp suitable for premium tissue paper. The pulp obtained was characterized in terms of yield, kappa number, and viscosity. Handsheets of 30 g/m^2 were prepared using a modified Tappi Standard to mimic tissue paper properties. A complete characterization of fiber morphology and evaluation of tissue paper properties (bulk, softness, water absorbency, tensile strength) were performed and compared against NBSK market pulp. Additionally, pulp from fique residues were blended with Bleached Eucalyptus Kraft (BEK) in different ratios and at varying freeness level to match the target product performance of a selected benchmark consisting of 70% BEK and 30% NBSK. Results obtained using a fiber quality analyser (FQA – OpTest Equipment Inc.) showed that bleached soda pulp from fique residue has a similar fiber length and width as NBSK market pulp. Tissue handsheets prepared using fique residue displayed comparable tensile strength as NBSK market pulp but superior bulk, water absorbency, and softness. When used in combination with BEK, our findings demonstrate that fibers from fique residue can be used to replace NBSK in several hygiene tissue applications such as toilet paper, kitchen towels, and flushable cleaning wipes. Upgrading residues from fique fibers as raw materials for the hygiene tissue industry has the potential to bridge the gap between sustainability and product performance, while providing cost-saving opportunities in the formulation of furnishes and the possibility of opening new revenue streams for millions of small indigenous farmers in the producing countries.

Bacterial Degradation of the Cell Wall of Transgenic Poplar with Modified Lignin Content and Composition

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Abstract

Biotechnology has the potential for making significant genetic improvements to wood properties in a matter of years instead of decades. Recent progress in genetic engineering has been focused on tailor-made trees for specific purposes, such as altered lignin content and structure for more efficient pulping and biofuel production. In this study, the bacterial degradation of genetically modified *Populus trichocarpa* wood with reduced lignin content was investigated.

Caldicellulosiruptor is a genus of thermophilic anaerobic bacteria known to degrade and ferment cellulose and hemicelluloses of plant cell wall. One of the species of this genus, *Caldicellusiruptor bescii,* has been identified as a potential bacterium for biofuel production. Since lignin is a major barrier to plant biomass solubilization, transgenics with modified lignin content and composition could be the solution to the recalcitrance of lignocelluloses to microbial degradation.

Six-month-old stems of two transgenic poplar lines with modified lignin content and composition and their wild-type for control were investigated. Line #54 was generated by down-regulating the coumarate 3-hydroxylase 3 (*PtrC3H3*) gene resulting in transgenic wood with a lignin content of 10% and a lignin S/G ratio of 9.9. Line #80 targeted the down-regulation of two cinnamyl alcohol dehydrogenases (*PtrCAD1*, *PtrCAD2)* that reduce cinnamaldehydes to their corresponding alcohols for lignin biosynthesis and with a lignin content of 13.8% and a lignin S/G ratio of 3.0. For comparison, the wild-type had a lignin content of 22% and lignin S/G ratio of 2.1.

Scanning electron microscopy was used to explore cell wall degradation of stem segments that were incubated for seven days at 25ºC (25ºC control), at 65ºC without *C. bescii* (abiotic control), or at 65ºC with *C. bescii*. From the treated stem segments, 1 mm thick disks and longitudinal cuts of approximately 3 mm with duplicates were prepared for examination with FEI Verios 460L field-emission scanning electron microscope (FESEM). The results of this investigation will be discussed in this presentation.

Do Resin Canals Help Prevent Tree Mortality from Southern Pine Dieback?

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Abstract

Loblolly pine plantations in the southeastern United States are experiencing periodic local dieback referred to as southern pine dieback (SPD). The exact causes of SPD are unknown but are likely due to the interaction between abiotic and biotic factors. Obtaining information on SPD has been difficult because trees deteriorate quickly and thus stands having SPD are harvested rapidly to minimize financial losses. A primarily defense mechanism for pine trees is through resin production from resin canals, and here we hypothesize that longitudinal resin canals (both frequency and size) are contributing to vulnerability of trees to SPD. We sampled seven symptomatic stands experiencing SPD just prior to them being clearcut, and we sampled seven asymptomatic stands from the same region. Bark-to-bark core samples were collected from 10 'healthy' trees from all stands, and 10 'unhealthy' trees from symptomatic stands. Specific gravity and ring width information was first measured on pith to bark samples using X-ray densitometry. Following which samples were polished and then imaged from pith to bark using a 4X objective lens using near-infrared sidelights. A total of 24,153 images were collected from the 210 samples. The images were processed to identify the size and location of the longitudinal resin canals using algorithms developed in Python and OpenCV. Resin canal location from the concatenated images was then linked with the X-ray densitometry data for positioning resin canals within each cambial age. Non-linear mixed models with trees nested in stand is being used to compare the resin canals size and frequency at ring levels. The results from this study will provide novel information on the frequency of resin canals in loblolly pine, and it will provide insight into the role resin canals have on SPD. The result of this study will serve as a reference to landowners and forest product companies in understanding the impact SPD has on wood properties.

Keywords: *forest health; image analysis; loblolly pine; wood anatomy; wood and fiber quality*

Plant-Based Materials Selection

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Abstract

Increasing environmental concerns have resulted in a growing interest in replacing non-renewable materials with plant-based materials. To facilitate product design and development involving plant-based materials, their properties have to be compared with metals, ceramics, and polymers. In this presentation, comparisons are made by using material property charts. In such charts, relevant property or property combinations are plotted such that performance indices are maximized or minimized. This allows the designer or engineer to identify the application in which materials will perform particularly well. Mechanical and physical property charts are presented for a variety of plant-based materials to allow for the design of products of different configurations (tie, beam, plate), subject to certain contraints, while optimizing for features such as weight, cost and ecological impact. Case studies will be presented to highlight the relevance of property charts in materials selection and to show that many plant-based materials can compete successfully in various applications against man-made materials of engineering.

Friday, August 6

Wood Physics and Properties 2

Chair: Gloria Oporto, West Virginia University, USA

Analysis of Wood and Biomaterials by Dynamic Vapor Sorption Technique

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Abstract
The interaction of water vapor (i.e. humidity) with solid surfaces is important for the proper performance, storage, processing, and formulation of materials across numerous industries and applications. Wood products are usually exposed to humid air, and the changes in relative humidity and temperature are responsible for causing dimensional variation as well as mechanical stress. To assess the behavior of wood in an environment where moisture is present, reliable data are needed to predict the behavior of wood materials. This study summarises several examples of using Dynamic Vapour Sorption (DVS) to study wood materials.

Assessing Southern Pine Tension Properties Using Nondestructive Evaluation

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Abstract

Efficient use of the available wood resources is necessary to sustainably meet the long-term demand for wood products. The objective of this study is to evaluate the mechanical properties of 176 pieces of No.2 grade 2×10 southern pine lumber using nondestructive testing (NDT) techniques. Nondestructive tests were conducted on each specimen to obtain the dynamic modulus of elasticity (dMOE) through longitudinal vibration (Director HM 200) and transverse vibration (Metriguard E-computer). Longitudinal vibration dMOE was equal to 10,195 MPa, and dMOE from transverse vibration was 10,602 MPa. The tension modulus of elasticity was equal to 9,492 MPa and the ultimate tension stress (UTS) was equivalent to 23.51 MPa. The preliminary results show that NDT techniques can assess tension properties of SYP lumber.

Keywords: mechanical properties, tensile properties, nondestructive testing, southern pine, structural lumber

Introduction

Tension parallel to the grain is one of the fundamental properties of wood (Doyle & Markwardt 1967). When a piece of lumber is pulled away from the ends, a tension stress is generated resulting in an elongation of the material in direction of the applied force. The high strength exhibited by a piece of wood when exposed to a tension force is related to its anatomical features such as fibers orientation, fiber arrangement and thickness of cell walls (Record 1914).

The work done by Doyle & Markwardt in 1967 is considered one of the most extensive compilations of tensile properties of full-size dimensional lumber southern pine. For this study, the authors evaluated properties from 496 specimens (2×4, 2×6 and 2×8 sizes) and correlated the results with the ones obtained from flatwise nondestructive bending tests. A more recent study was conducted by Senalik *et al.* (2020) to understand how wood's natural occurring effects and the acoustic properties of wood can be of help in the estimation of ultimate tension stress (UTS).

Nondestructive testing provides meaningful information that helps in the decision making to properly assign the use of wood. With wood being a biological material, the influence of anatomical structure and natural occurring defects such as knots, slope of grain, reaction wood, decay among others, can cause a reduction in the strength properties of wood. This, in combination with the possible processing defects, represent challenges for manufacturers and end users (Ross, 2015). Nondestructive testing helps broaden the knowledge of the structural potential of wood despite the variability inherent in the material.

The purpose of this study was to assess southern pine No. 2 2×10 lumber tension properties using nondestructive (longitudinal and transverse vibration) techniques by analyzing the relationships between visual characteristics (rings per inch, percentage of latewood), density and the properties MOE and MOR obtained from tension tests and nondestructive evaluation.

Materials and Methods

The sample size for the study consisted in 176 pieces of No. 2 – 2×10, kiln dried southern pine (*Pinus* sp.) structural lumber with two length sizes (4.27 and 4.88 m). Lumber was obtained from the 18 original regions of southern pine growth regions in the United States. All material was conditioned to 12% moisture content prior to testing. From each specimen the following variables were recorded: specimen dimensions, moisture content (MC), density, percentage of latewood (LW) and rings per inch (RPI).

Rings per Inch and Percentage of Latewood

To evaluate RPI, the visible rings at the ends of each piece of lumber were counted according to the procedures from SPIB grading rules (SPIB 2014). Then, the total rings counted were divided by the thickness or the width depending on the grain direction of the piece (radial or tangential direction).

Percentage of LW was measured using a small plastic dot grid (2.54 cm × 2.54 cm). The grid was placed at both ends of the lumber piece, aligning the dotted rows to the growth rings. The dots that matched with the latewood zone were counted and recorded. Then the total of dots counted, was divided by the total amount of dots of the dotted grid (64 dots).

Longitudinal vibration

All pieces were evaluated using the longitudinal vibration technique with the Director HM 200 (Fibre-gen, Christchurch, New Zealand) tool. This technique consists of putting the lumber specimen in a support, touching one of the ends of the piece with the director tool, and immediately hitting it with a hammer.

This impact produces an acoustic longitudinal vibration that travels through the whole length of the piece. The director tool records the wave velocity. The procedure was done following the ASTM E 1876 (ASTM 2015) standard. Calculation of the dynamic modulus of elasticity ($dMOE_{long}$) in longitudinal direction is given by Equation (1).

$$dMOE_{long} = \rho v^2 \qquad \text{Eq. (1)}$$

Where $dMOE_{long}$ is the longitudinal vibration dynamic MOE (MPa), ρ is the density of the lumber piece ($kg \cdot m^{-3}$), and v is the longitudinal wave velocity ($m \cdot s^{-1}$).

Transverse vibration

All pieces were evaluated using the transverse vibration technique with the E-computer equipment (Metriguard Model 340 Transverse Vibration E-Computer). The technique consists of putting the lumber piece in flatwise direction over two supports, and then tapping in the center of the span to generate an oscillation wave. Test followed ASTM E 1876 (2015). The equation used to calculate the transverse vibration dynamic modulus of elasticity ($dMOE_{tr}$) is given in the Equation (2).

$$dMOE_{tr} = \frac{f^2 W s^3}{2.46 I} \qquad \text{Eq. (2)}$$

Where $dMOE_{tr}$ is the transverse vibration dynamic MOE (MPa), f is the resonant frequency (Hz), W is the mass of the lumber piece (kg), s is the span (m), and I is the moment of inertia (m^4).

Tension test

After nondestructive tests were performed, all pieces were destructively tested in tension parallel to the grain using a Metriguard 412 Tension Proof Loader. Before starting the test, each specimen was placed horizontally in the tension machine. Metal grips held both ends of the specimen while the test was performed.

Over time, these grips pull the specimen apart until it fails. The span of testing was 96 in for the shorter lumber (14ft) and 117 in for the longer pieces (16ft). Testing allowed the measurement of tension stress and strain. The calculation of UTS is the maximum tension stress for each piece. Tension tests were conducted according to the standard D198-15 (ASTM 2015).

RESULTS AND DISCUSSION

Table 1 summarizes the results obtained for moisture content (MC), density, rings per inch (RPI) and percentage of latewood (LW %) from 2×10 structural lumber. The mean MC when specimens were tested was 12.41%. With a 10.23 % COV, the density mean, min and max were 547.59 Kg·m^{-3}, 435.90 Kg·m^{-3} and 753.64 Kg·m^{-3}, respectively.

The mean, min, and max for RPI was 3.94, 1.66 and 14.33, respectively. The coefficient of variation for RPI was 47.88%. For LW (%), the mean was 46.04; the min was 25.78, max was 75.78 and the coefficient of variation was 20.08%.

Table 1. Overall results for moisture content, density, rings per inch (RPI), and percentage of latewood (LW) %.

	Mean	Median	Min	Max	COV (%)*
Moisture Content	12.41	12.3	7.6	20.7	18.65
Density	547.59	540.09	435.90	753.64	10.23
RPI	3.94	3.36	1.66	14.33	47.88
LW (%)	46.04	48.43	25.78	75.78	20.08

Density (Kg·m^{-3});
* Coefficient of variation

Analysis for density and tension properties

The relationship between density and tension modulus of elasticity (E_t) is shown in Figure 1A. With an r^2=0.27, the correlation between both variables is weak. Figure 1B shows the relationship between density and ultimate tension stress (UTS). With an r^2=0.40, the correlation between both variables is moderate.

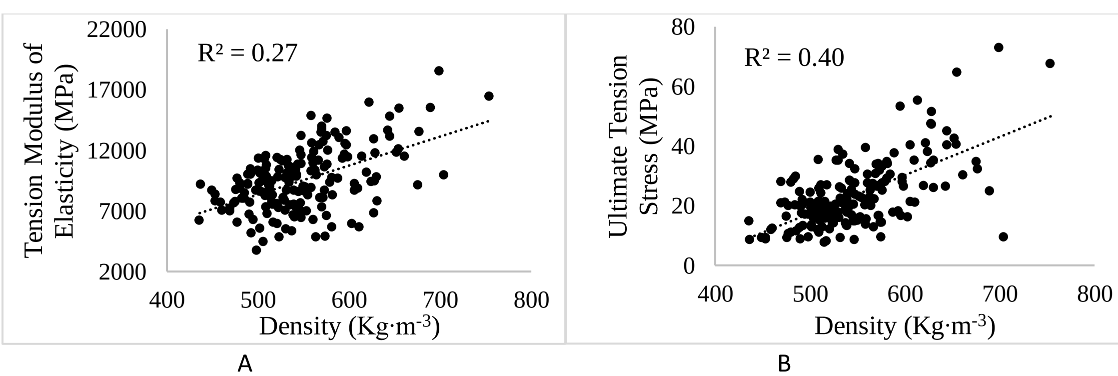
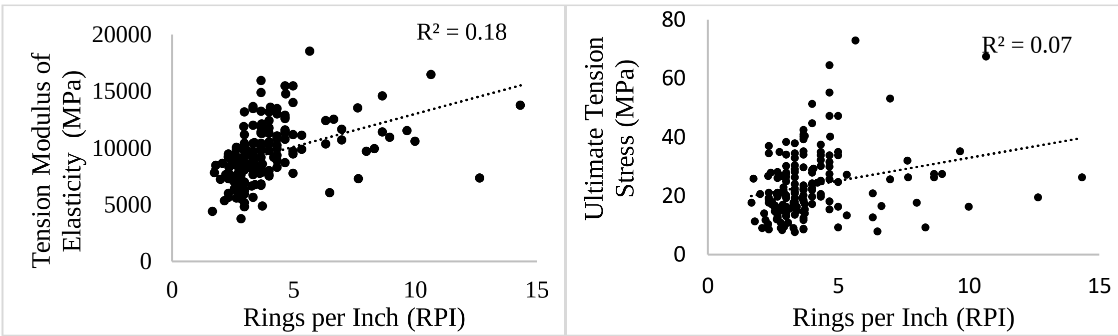


Figure 1. A. Linear regression plot between density and tension modulus of elasticity (E_t). B. Linear regression plot between density and ultimate tension stress (UTS).

Analysis for rings per inch tension properties

Figure 2A shows the linear regression between RPI and (E_t). A correlation coefficient of 0.18 indicates a weak correlation between both variables. Figure 2B shows a linear regression between RPI and UTS. A correlation coefficient of 0.07 indicates a negligible correlation between both variables.

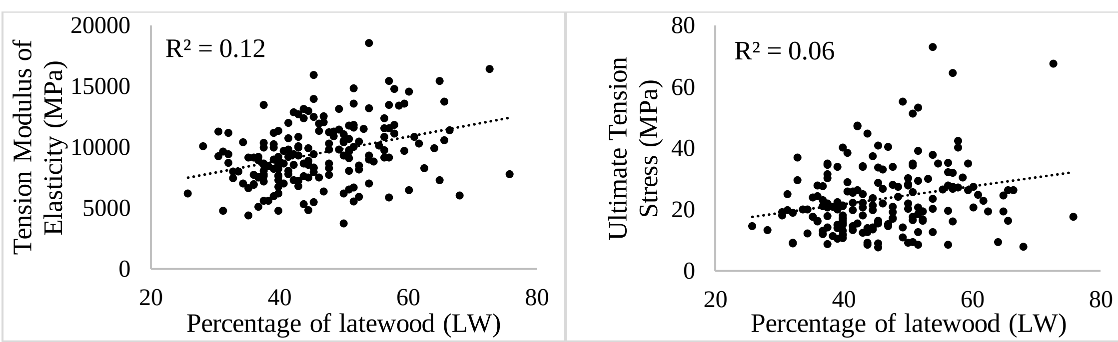


A B

Figure 2 – A. Linear regression plot between rings per inch (RPI) and tension modulus of elastic (E_t). B. Linear regression plot between rings per inch (RPI) and ultimate tension stress (UTS).

Analysis for percentage of latewood and tension properties

Figures 3A and 3B show the plots of percentage of LW versus Et and UTS. The correlation coefficient for LW (%) versus Et was 0.12. The relationship between LW (%) and UTS exhibited a correlation coefficient equal to 0.06. The results indicate a low relation between LW (%), Et and UTS.



A B

Figure 3 – A. Linear regression plot between percentage of latewood (% LW) and tension modulus of elasticity (E_t). B. Linear regression plot between percentage of latewood (% LW) and ultimate tension stress (UTS).

Analysis for dMOE and tension properties

Table 2 shows the overall results obtained from the nondestructive tests using the longitudinal and the transverse vibration technique. For the 2×10 pieces evaluated in this study, $dMOE_{tr}$ mean value was slightly higher than $dMOE_{long}$ mean value.

For $dMOE_{long}$, the mean, min, and max were 10,195 MPa, 4,614 and 19,635 respectively, with a coefficient of variation of 25.85%. The mean, min, and max for $dMOE_{tr}$ was 10,602 MPa, 4,850 and 19,658 with a coefficient of variation of 25.62%.

Table 2. Dynamic modulus of elasticity ($dMOE_{long}$ and $dMOE_{tr}$) on 2×10 southern pine dimensional lumber.

	Dynamic Modulus of Elasticity (MPa)				
	Mean	Median	Min	Max	COV (%)*
Longitudinal vibration	10,195	9,881	4,614	19,635	25.85
Transverse vibration	10,602	10,166	4,850	19,658	25.62

*Coefficient of variation

Analysis for tensile strength properties parallel to grain

Table 3 shows the overall results obtained for E_t and UTS. The mean for E_t was 9,492 with a coefficient of variation of 27.20%. The mean for UTS was 23.51 with a coefficient of variation of 48.34%.

Table 3. Tension modulus of elasticity and ultimate tension stress values obtained from test conducted in tension parallel to grain on 2×10 southern pine dimensional lumber.

	Tension Parallel to grain (MPa)				
	Mean	Median	Min	Max	COV (%)*
Tension MOE	9,492	9,224	3,737	18,547	27.20
UTS	23.51	20.86	7.67	72.97	48.34

* Coefficient of variation

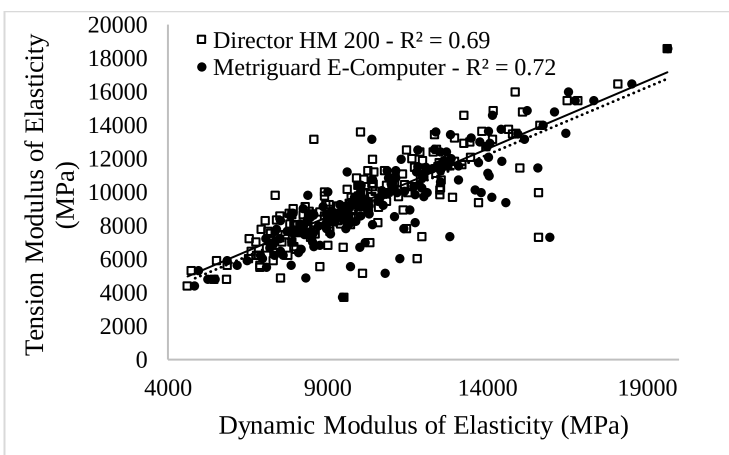


Figure 4 – Linear regression plots between dynamic modulus of elasticity ($dMOE_{long}$ and $dMOE_{tr}$) and tension modulus of elasticity (E_t).

The correlation between dMOE and E_t is shown in Figure 4. Results indicate a moderate correlation (r^2 =0.69) between $dMOE_{long}$ and E_t. The same figure shows a strong correlation (r^2 =0.72) between $dMOE_{tr}$ and E_t. The correlation between dMOE and UTS is shown in Figure 5. Results indicate a weak correlation (r^2 =0.26 & r^2 =0.29) between dMOE ($dMOE_{long}$ and $dMOE_{tr}$) and UTS.

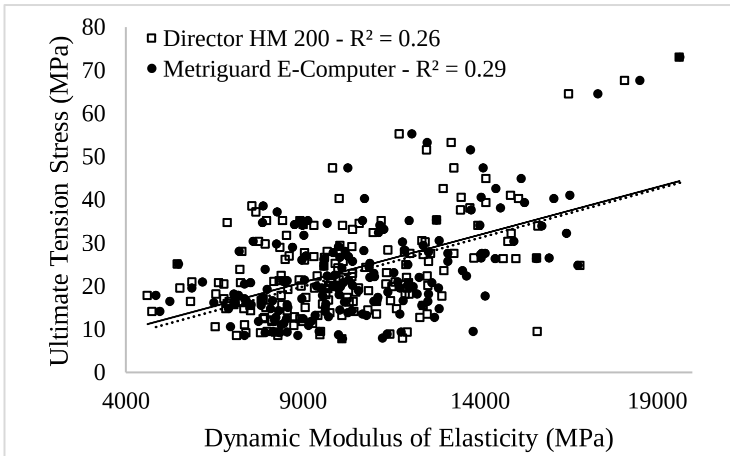


Figure 5 – Linear regression plots between dynamic modulus of elasticity ($dMOE_{long}$ and $dMOE_{tr}$) ultimate tension stress (UTS).

CONCLUSIONS

Tension properties of 176 specimens of 2x10 southern pine No.2 kiln dried structural lumber were evaluated. Material studied represent the 18 regions of southern pine growth in US. The moisture content mean before tests was 12.40%. Density mean was 547.59 Kg·m-3, rings per inch (RPI) mean was 3.94 and mean percentage of latewood (LW %) was 46.04.

Nondestructive testing was performed using longitudinal and transverse vibration technique. The mean $dMOE_{long}$ was 10,195 (MPa). The mean $dMOE_{tr}$ was 10,602 (MPa). Destructive testing was performed to assess tension properties parallel to the grain. The mean for tension modulus of elasticity (E_t) was 9,492 (MPa) and the ultimate tension stress (UTS) was 23.51 (MPa).

This study evaluated the relationship between density, RPI and LW (%) with tensile properties. Additionally, the study explored the possible relationships between E_t, UTS and dMOE. From these analyses, we found that:

- RPI and LW (%) are weak or negligible predictors of tensile properties.
- Density is a moderate predictor of UTS).
- $dMOE_{long}$ is a moderate predictor of E_t.

- $dMOE_{tr}$ is a strong predictor of E_t.
- $dMOE_{long}$ and $dMOE_{tr}$ are weak predictors of UTS.

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Evaluation of Decay Effect on Tension Perpendicular To Grain Properties of Wood

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Abstract

Most wood designs attempt to reduce the use of perpendicular to the grain stresses because of the reduced strength compared to parallel to the grain connections. Despite these attempts there are times avoiding this type of stress is not possible. Much research has been done to create a baseline for parallel to the grain properties it is important to broaden the existing research on perpendicular to the grain properties. The objective of this study is to describe the effect of brown-rot decay on tension perpendicular to the grain of southern yellow pine wood exposed over different periods of time and to determine the effect of wood brow-rot fungi in wood tension perpendicular to the grain. The results of this research are beneficial for connections within mass paneling and other wood connections. Knowledge of the effect decay has on perpendicular to the grain properties can allow for in service member to be replaced before structure failure.

Keywords: brown rot; mechanical properties; mass timber products; perpendicular to the grain; tensile strength

Workshop Review on Wood Education

Chairs: Bob Smith, Virginia Tech, USA

Sustainable Materials Science and Technology, A Defining Discipline of our Time

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Abstract

Materials have always been linked to human society's progress such that periods of our history are named after the dominant material of the time – stone age, bronze age, etc. The demand for raw materials has grown explosively since the Industrial Revolution. The environmental impact of material consumption is proportional to population, per capita consumption (affluence), and technology deployment. Western society's techno-economic approach to development is strongly correlated with environmental degradation and that affluence is not distributed evenly. In contrast, the concept of sustainability balances the competing demands of the environmental, social, and economic sectors. North Carolina State University's Department of Forest Biomaterials has successfully instituted a Sustainable Materials and Technology undergraduate program since 2013. The curriculum includes courses that cover the three pillars of sustainability while providing the students the needed STEM, materials science, and material processing background. Through technical and advised electives, the program also gives the students the flexibility to tailor the curriculum to their own career goals, and to expand their sustainability portfolio. This presentation will describe the curriculum revision process, go into details of the curriculum content, and give examples of topics covered in several courses. The NCSU approach can serve as a model in making changes to undergraduate programs. Together we can produce graduates grounded on sustainability and are ready to tackle transformative issues on which our own species' and planet's future depends.

Biographies

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Osei is a Post-Doctoral Fellow at Auburn University. He graduated from Auburn University with a PhD in Sustainable Biomaterials and Masters in Polymer and Fiber Engineering. Also, Osei received MPhil in Wood Science and Technology and a BSc in Natural Resources management at the University of Science and Technology Ghana. Currently, he is developing cold-setting bio-based adhesives for CLT and glulam

Expertise: Wood Science (wood anatomy, mechanics, physics and wood chemistry), Wood composites and wood-based plastic composites, Wood Adhesives, wood energy and biofuels, water remediation

Auty, David

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David Auty is an associate professor of wood science at Northern Arizona University. After gaining his doctorate at the University of Aberdeen, Scotland in 2011, he worked as a postdoctoral scholar at Laval University, Quebec, Canada, before joining
Northern Arizona University in 2014. His research is focused on wood quality and modeling variation in wood properties at multiple scales, and has published models for several commercial tree species, including Scots pine and Sitka spruce in the UK, black spruce, white spruce, and northern hardwoods in Canada, and ponderosa pine, loblolly pine, and western hemlock in the US.

Expertise: Links between management and wood quality; Wood properties modeling; Linking wood properties models to growth and yield systems

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Sujit Bhandari is a Ph.D. student at Oregon State University with a dual degree in Wood Science and Civil Engineering. He is advised by Dr. Mariapaola Riggio, Dr. Lech Muszynski, and Dr. Erica Fischer, and is working with another Ph.D. student, Sina Jahedi on a project to use Ponderosa pine from restoration forests into CLT modular structures. Sujit has a Master's degree in Structural Engineering and a Bachelor's degree in Civil Engineering.
Sujit has worked in the industry for about seven years in different capacities. He has worked as a Civil Engineer, in the construction sector in the United Arab Emirates. He was engaged in reconstruction after the disastrous 2015 Gorkha earthquake in Nepal and has served in the capacity of a project engineer for the government of Nepal and for a project funded by the United Nations World Food Program.
Sujit is passionate about providing shelter to those in need. Sujit is fond of music, books, and food. In his free time, he likes to write and watch short documentaries.
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Expertise: Wood Science, Structural Engineering

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Gabi Bobadilha is a postdoctoral associate at Mississippi State University in the Department of Sustainable Bioproducts. As a scientist she wants to promote the forest products industry by improving traditional testing procedures by applying machine learning frameworks to integrate disciplines, approaches, information, and knowledge into stakeholders-engaged solutions. Gabi started researching since her undergraduate program and proved to be flexible and adaptable to different research areas. She has published several papers in the areas of soil science, wood quality, wood protection and durability, and use of artificial intelligence in wood products. In her free time, Gabi likes to cook authentic Brazilian dishes for her friends and family members.

Expertise: Wood Preservation

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Dr. Daniel J. Burnett is the Vice President for Surface Measurement Systems, NA, located at the North American headquarters in Allentown, PA. His team works on research studies and science applications for many prominent companies. He received his bachelor's degree in Professional Chemistry from Eastern Michigan University in 1997 and Ph.D. degree in Chemical Engineering from the University of Michigan in 2001. Dr. Burnett has authored and co-authored over 25 papers in peer-reviewed journals and presented at numerous national and international conferences

Expertise: Vice President, Sorption science

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Candra Burns built her foundation by volunteering in her local community as a child. She started applying for scholarships and grants in high school to go to college because she was raised low-income and first-generation. Candra took advantage of the support programs on both of her college campuses. Within five years, she earned 25 scholarships and grants claiming her a debt-free education. Since 2015, she has been the social media communications chair for Washington State Society of American Foresters and held that chair while she lived in Germany with her Air Force husband. She realized her passion for media marketing through these efforts which gave her the idea to start Talking Forests, a social media-based communication business in 2016. Candra's business wishes to help others have a voice and build an online presence. Her inspiration comes from the people who gave her hope and the people who give her hope for the future. These are the generous people who work every day to grow and help each other equally. In 2018, she gave a refreshing social media speech at the International Forest Business Conference in Poland, documented the #forestproud conference in Atlanta, and taught military spouses how to use social media at a regional conference with her "Building the Future with Social Media" speech at the American's Working Around the Globe Conference at Ramstein Air Base. In 2019 & 2020, she taught social media seminar classes in Edelweiss Resort at the

American's Working Around the Globe Annual Conference to inspire spouses with "A Future with Social Media" and "LinkedIn 101" to show them how to leverage social media to achieve any goal they have. In 2020, Candra was the project digital marketer for the Institute of Chartered Foresters Virtual Conference called Trees, People and the Built Environment 4 where we sold over 600 tickets and had successful social media campaigns working for the delegates. She was a speaker in the Fall of 2019 at the Society of Wood Science and Technology's International Convention in Yosemite National Park and to the Society of American Forester's National Conference in Kentucky. She holds two associate degrees from Grays Harbor College and a Bachelor of Science from The Evergreen State College. She is a proud military spouse with the ability to work from anywhere in the world. She is based in North Carolina now.

Expertise: Social Media Communications and Marketing

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Marly Gabriela Carmona Uzcategui is a Graduate Research Assistant at Mississippi State University, USA. Originally from Venezuela, she is currently pursuing a PhD in Forest Resources at Mississippi State University, she holds a Master's degree in Sustainable Bioproducts (2020) from Mississippi State University and a Bachelor's degree in Forestry (2017) from the University of Los Andes, Venezuela. Her areas of interest are physical and mechanical properties of wood, nondestructive evaluation of wood (NDT) and Sustainability. Currently, she is conducting a research to assess southern pine tension properties using nondestructive evaluation in agreement with the USDA Forest Products Laboratory.

Expertise: Wood Properties, Non Destructive Testing, Wood Physics, Wood Mechanics, Wood Quality

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Cong Chen obtained her Bachelor's and Master's degree in Wood Science and Technology from Beijing Forestry University in China. Cong is currently a Ph.D student at the University of Maine working with Drs. Jinwu Wang and Douglas Gardner. Her research is focused on food packaging films utilizing cellulose nanomaterials

Expertise: Cellulose nanomaterials, food packaging, wood protection and modification

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Graduate Research Assistant at Mississippi State University.

Expertise: Wood, Wood Properties, Wood Degradation, Wood Presentation

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Dr. Mike Eckhoff is a public policy expert with over 15 years of experience in the forest products industry. He has worked for both the Colorado State Forest Service and the USDA Forest Service where he shaped policy for the natural environment in response to the mountain pine beetle epidemic. Since 2017, he has been a Codes & Education Specialist for Hoover Treated Wood Products, providing technical expertise on fire-retardant-treated wood (FRTW) to architects (AIA-approved seminars; HSW credit), building/fire officials (ICC Preferred Education Provider), engineers, and designers. He has given hundreds of invited presentations, lectures, and interviews on sustainable wood products, including FRTW, to firms, municipalities, agencies, universities, and media throughout the United States. He completed his Ph.D. in Forest Science at Colorado State University in Fort Collins, CO.

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Expertise: Wood identification, population genetics, phylogenetics, genomics

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Expertise: Wood Science, Wood Technology, Wood Degradation, Wood Presentation, Wood Properties, Wood Qualities

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Expertise: Wood Properties, Wood Physics, Wood Mechanics, Wood Quality, Non Destructive Testing, Drying

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Douglas J. Gardner is Professor and Program Leader of Forest Operations, Bioproducts & Bioenergy in the School of Forest Resources at the University of Maine. He is also member of the Advanced Structures and Composites Center and Forest Bioproducts Research Institute. Gardner's research, teaching, and service activities focus on polymer and interfacial science aspects of wood-polymer composite materials. He has co-authored over 250 technical publications and 150 research presentations, and 6 patents. Gardner is a Fellow of the Society of Wood Science and Technology (SWST). He was awarded the SWST Distinguished Service Award in 2014 and the SWST Distinguished Educator Award in 2018.

Expertise: Wood Science and Technology

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Expertise: Sales Engineer

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Working at USDA Forest Service Forest Products Laboratory, the Research Unit of Economics, Statistics and Life Cycle Analysis, Dr Gu has been engaged in advancing forest biomass utilization and greenhouse gas emission reduction applying the life cycle assessment tool and economic analysis tool, bolstering innovation of wood use in green building products development and nanocellulose applications. Recent years, Dr Gu has been focusing on Mass Timber Building sustainability development with whole building life cycle assessment and life cycle cost analysis studies to support US Forest Service policies in resource management and utilization.

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Expertise: Responsible and legal wood sourcing

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Expertise: Forest Operations and Biomass

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Expertise: Forest Products Marketing

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Dr. Eva Haviarova is a Wood Products Engineering and Strength Design professor in The Department of Forestry and Natural Resources, Purdue University. She is responsible for the teaching of World Forest and Society, Global Sustainability Issues, Wood ID, and several Wood Products Development courses. She is researching Strength Design, Sustainable Product Development, Value Added for Hardwoods, Design and Development of Low-Cost Furniture for Underprivileged, Circular Economy, Product Lifecycle and Sustainability, and advanced Wood ID. She has published over 70 peer-reviewed publications and delivered over 200 professional presentations. Through her outreach activities, she is working mainly with the forest products industry. She is an active member of several professional associations and currently serves as the Past President of the Society of Wood Science and Technology.

Expertise: Wood Science, Sustainable Products Development, Value-added to Hardwoods

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Expertise: Executive Director, Statistics

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Seung hyun Hong is pursuing a master’s degree in Oregon States dual degree program after finishing his degree in Wood Science & Engineering from Chungnam National University in Korea. He will be presenting on Char rates and residual char depths in unprotected CLT floor and wall assemblies after 2-hour ASTM E119 fire tests.

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Expertise: Bioproducts, Nanocellulose

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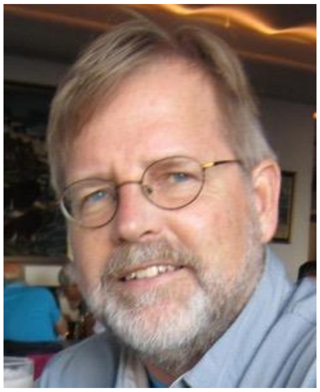
Sina Jahedi is a Ph.D. student at Oregon State University, who is pursuing his dual degree in Wood Science and Engineering, and Computer Science. He is passionate about software development and the use of technology in the mass timber industry.

Kamke, Fred 
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Dr. Kamke is the Site Director for the NSF Center for Wood-Based Composites at Oregon State University, and JELD-WEN Professor in the Department of Wood Science & Engineering since 2005. He is a past-president of SWST and an SWST Fellow. Kamke's research and teaching focus is the design, manufacture, and performance of wood-based composites.

Expertise: Wood-based composites

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Expertise: Chemistry

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Mr. Rajnish Kumar is a second year PhD student in the Forest Biomaterials Department at NC State University. His research interests involve evaluating and studying alternative non-wood natural fibers to discover their application potential in paper and nonwoven applications. He holds a BSc degree in Pulp and Paper Engineering from IIT Roorkee and MBA in finance from IIM Udaipur, India. Before joining, graduate program at NC State, Rajnish has worked in the industry for almost five years (Voith Paper, Suryoday Small Finance Bank).

Expertise: Paper-making, Pulping and Bleaching, Non-wood fibers, Hygiene Tissue Products, Specialty Papers

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Expertise: As a certified wildlife forensic scientist from the Society for Wildlife Forensic Science I specialize in timber identification and complex matrix analysis using morphology and chemical fingerprinting.

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Expertise: Editor of Wood and Fiber Science

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Joseph Loferski earned his B.Sc. degree in Wood Science and Technology from Colorado State University in 1977. He earned his M.S. degree in 1980 from Oregon State University with a major in wood engineering and a minor in statistics. In 1985 he completed his Ph.D. degree in Wood Engineering in the Department of Wood Science and Forest Products at VPI&SU. His dissertation title was "A Reliability-Based Design Procedure for Wood Pallets." Dr. Loferski was employed as a Research Associate at VPI&SU from 1980 to 1985. He worked for a consulting wood technology firm in Colorado and Minnesota, and as a laboratory assistant in Colorado State University.

Expertise: Timber Engineering

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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 36 years' experience in bioproducts and biomaterials research and development and has presented and published numerous articles. Armando came to UI in 2001 from New Zealand Forest Research, where he was a Group Leader of the Materials Discovery group. His time at UI is devoted to mainly research and teaching with some extension/service activities. He teaches classes in Biocomposites, Biomass chemistry, and Bioproducts and Bioprocess Development. Dr. McDonald has graduated nine Ph.D. students and 17 M.S. students, currently has 5 Ph.D. and 4 M.S. graduate students and hosted 16 International visiting scholars in his laboratory. Dr. McDonalds' group is currently investigating: (i) bioplastics from lignin and other waste streams, (ii) biofuels from pyrolysis of biomass, municipal solid waste and waste plastics, (iii) development of nanostructured Fischer-Tropsch catalysts for production of fuels, (iv) biocomposites, (v) algae conversion to fuels, (vi) biomass conversion into chemicals, (vii) torrefaction of biomass and plastic waste, (viii) natural products chemistry, (ix) characterization of sorghum and maize stalks, and (x) lipid production in yeasts. Furthermore, Dr. McDonald also works with industry from service work to product development projects.

Expertise: Wood Materials Chemistry; Biomass conversion; Biofuels; Biopolymers; Biocomposites

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David is a Graduate Research Assistant and a Ph.D. candidate at the Department of Sustainable Bioproducts of Mississippi State University. He has a B.Eng. in Timber Industrial Engineering (2017). His research focuses on wood modification, wood preservation, and the development of instruments for wood science.

Expertise: Dimensional Stability of Wood, Biodegradation of Wood, and Instruments Development for Wood Science

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Takuya Morii is a doctoral student in the Laboratory of Environmental Materials Design, the University of Tokyo
He has been conducting research on the input-output structure of the Japanese timber industry in order to assess in more detail the economic effects generated by wood use.

Expertise: I-O analysis, Economic ripple effect

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Lech Muszyński is a Professor in the Department of Wood Science and Engineering at the Oregon State University. A native of Poland, he received his M.S. in Wood Technology and Ph.D. in Forestry and Wood Technology from the University of Life Sciences in Poznań, Poland. In 1998-2004 he worked in the Advanced Engineered Wood Composites Center at the University of Maine. Lech joined OSU in 2004. His research area includes mechanical performance of solid wood, engineered wood-based composites, with stress on interface performance, adhesive bond, durability, fire resistance, damage assessment, and hygro-mechanical behavior. Since 2010 one of the focus areas of his research has been the cross laminated timber (CLT) technology and other mass-timber panel (MTP) products. Lech has toured MTP manufacturing plants, construction sites, MTP-focused research centers, and related businesses around the globe.

Expertise: Structure-property relations in wood and wood-based composites: multi-scale mechanics, optical measurement techniques, integration of modeling and experimentation
Mechanics of wood and wood composites: wood-water relations, mechano-sorption, bonding

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Expertise: Woody biomass, wood based biocarbon/bio char, wood composites

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Expertise: Civil engineering, Building Construction, Mass Timber Buildings, Building Envelope, Cross Laminated Timber, Bio-deterioration, Structural Engineering, Numerical Modeling

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Dr. Gloria S. Oporto-Velasquez is a faculty member in the School of Forestry and Natural Resources at West Virginia University. She received her bachelor's degree in Chemical Engineering at the University of Concepcion in Chile, and her PhD in Forest Resources at the University of Maine. Her main research interests are in the field of biomaterials from lignocellulosic sources, novel composites, nano-biocomposites, and in engineered wood-based composites.

Expertise: Biomaterials

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Since 2001, Frank Owens has been involved in the global marketing and sourcing of wood products. Fluent in Japanese, he has lived abroad for eight years in East Asia and the Middle East. He holds a bachelor's degree in international relations from the University of Minnesota, a master's degree in East Asian languages from UCLA, and a doctoral degree in forest resources from Mississippi State University, where he currently serves as an Assistant Professor in the Department of Sustainable Bioproducts. He teaches courses in wood anatomy and forest products marketing and conducts research on lumber properties, nondestructive testing, and computer vision applications for wood identification. He currently serves on the Council of the International Association of Wood Anatomists (IAWA) and the Board of Directors of the National Association of Floor Covering Technicians (NAFCT).

Expertise: Wood identification

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Dr. Yucheng Peng is an Assistant Professor in the school of Forestry and Wildlife Sciences at Auburn University. He received his PhD from the University of Maine in Forest Resources and has extensive experience working on paper and plastic based packaging for packaging converters and consumer packaged goods brand owner. His main research areas include polymer composites, nanocellulose coatings for functional materials, sustainable packaging, packaging recycling, and bioproducts.

Expertise: Wood composites Polymer composites nanocellulose

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Expertise: Sustainable Materials and Technology

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Ilona Peszlen is an Associate Professor at the Department of Forest Biomaterials, North Carolina University. Previously, she was a faculty member at the Department of Forestry, Iowa State University and at the Institute of Wood Sciences, University of West Hungary. She teaches wood property related courses. Her research emphasis is on juvenile and reaction wood, effects of environment on wood properties, genetic improvement of wood quality, and on properties and utilization of plantation wood.
Ilona received her B.S. Wood Technology (1978), her M.S. in Wood Engineering (1979) from the University of Sopron, and her M.S. in Higher Education (1984) from the University of Gödöllő, Hungary. She was the recipient of a Fulbright Scholarship and completed her Ph.D in Wood Science & Forest Products (1993) at the Virginia Polytechnic Institute and State University, Blacksburg, Virginia. She did post-doctoral research at the North Carolina State University, Raleigh and at the University of Canterbury, Christchurch, New Zealand.

Expertise: Wood and fiber science

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Currently, Geeta Pokhrel is a graduate research assistant at Advanced Structures and Composites Center, University of Maine, Orono, USA pursuing Masters in Bioproducts Engineering. She is originally from Pokhara, Nepal. She did her undergraduate studies at the Institute of Forestry, Nepal. Prior to coming to the USA, she did some internships and jobs in forest resources-based industries in Nepal.

Expertise: My research works are focused on working with wood fillers for the manufacturing of wood-plastic composites. Wood flour, pellets, plastic composite, engineered products, cellulose nanomaterials, etc. are my main focus.

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Nawa Pokhrel (MS, Wood Quality) is a Graduate Research Assistant at the University of Georgia, Warnell School of Forestry and Natural Resources. He received his undergraduate degree from Agriculture and Forestry University, Faculty of Forestry, Nepal. In his undergrad, he worked on various dendroclimatology projects, where he sampled, processed, and analyzed tree cores to study climate change impacts on tree growth. In his master's research, he has processed and examined tree cores from loblolly pine to establish a relationship between Southern Pine Dieback and the tree's defensive mechanism. In his Ph.D., he will work on modeling wood and fiber properties of southeastern pine species.

Expertise: Wood Biometrics, Wood Anatomy, Wood and fiber properties, Image analysis

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Expertise: Professor

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Sameen Raut is a PhD student at the University of Georgia Warnell School of Forestry and Natural Resources. His major professor is Dr. Joe Dahlen. He graduated in 2020 with an MS degree from University of Georgia where his research focused on planted longleaf pine stem and wood quality assessment by means of image analysis as well as traditional measures of wood quality assessment which include specific gravity and moisture content. His PhD research will focus on advancing the use of hyperspectral imaging to build machine learning based modeling framework that will be able to correlate the biomass chemical compositions of Southern Pine Forest Residues (SPFR) to their bioenergy yield. SPFR includes juvenile wood, bark, needles, branch wood, and foreign materials. After PhD, he plans to work in academia or industry where there is an opportunity to work at the intersections of wood science, bioenergy, forest biometrics, statistics, machine learning, and computer vision. You can reach him at sameen.raut@uga.edu.

Expertise: Wood properties, computer vision, image analysis, statistics, forest biometrics. I am interested to learn about spectral analysis, wood chemistry, bioenergy, machine learning, and deep learning.

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Talbot Rueppel is a graduate research assistant and MS student in the Department of Wood Science & Engineering at Oregon State University since 2020. He has a BS degree from the University of Idaho in Renewable Materials Engineering, with a minor in Business. Rueppel's research interests are wood-based composite materials, adhesive bonding, and all things lignocellulose. He has previous work experience with Packaging Corporation of America, Norbord, Inc., and Universal Forest Products.

Expertise: Process flow, quality control, strategic communications, engineered wood products, viscoelasticity, particle size analysis, adhesives, thermodynamics, biochemistry, physics and mechanics of materials, spectroscopy, manufacturing parameters, statistical analysis

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Expertise: Ecological restoration, Forest biometrics, Spatial and temporal analysis, Forest pattern-process interactions, Vegetation dynamics, Remote sensing, Computer Science

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Originally from Pocatello, ID, Elliott first attended college at the University of Idaho. Before graduating, he participated in a University of Maine internship through the National Science Foundation's - Research Experience for Undergraduates - Explore It! that was hosted through the Forest Bioproducts Research Institute in Orono, ME. During this internship he worked closely with Dr. Gardner's research group on nanocellulose spray drying at the lab scale. The following year he returned to Idaho and graduated with a B.S. in Renewable Materials. Soon afterwards, he set off to Maine and began studying for his M.S. Forest Resources with an emphasis in Bioproducts Engineering. After graduating in the Spring of 2017, he continued to study for his Ph.D. and now works with electrospraying/spinning biomaterials. He expects to graduate in December of 2021.

Expertise: Ph.D. Candidate Forest Resources - Bioproducts Engineering

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Dr. Matthew Schwarzkopf is a researcher at the InnoRenew CoE an 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 focuses on agricultural biomass utilization, the wood-adhesive/polymer interphase, optical measurement techniques, wood-plastic composites and wood modification techniques. He is currently involved in a variety of international projects with topics including utilization of olive processing by-products from the local Slovenian olive industry and modification of under-utilized wood species.

Expertise: Agricultural biomass utilization, the wood-adhesive/polymer interphase, optical measurement techniques, wood-plastic composites, and wood modification techniques

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Expertise: Biocomposites, Biomass to carbon conversion

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Bob is a professor in Forest Products Marketing and Management in the Department of Sustainable Biomaterials at Virginia Tech and the Associate Dean for Engagement for the College of Natural Resources and Environment. Bob holds a Ph.D. from Virginia Tech (1994) in Forest Products Marketing, an MBA from the University of Wisconsin at Oshkosh (1989), and a B.S. in Wood and Fiber Utilization from Michigan Tech (1977). Bob taught undergraduate, graduate and continuing education courses in the areas of wood science, business management, international marketing and forest products marketing. As an extension specialist for 14 years his work focused on assisting companies in forest products with business and marketing issues to help increase their competitiveness. His research efforts focus upon industrial marketing and new opportunities for wood in international markets. Prior to completing his Ph.D., he worked for a major U.S. manufacturer of wood products for 14 years as quality control director, production manager, and sales representative in the Midwest.

Expertise: Forest Products Business and Marketing International Marketing Wood Products Business management

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Lee Smith is a PhD. Candidate in the department of Mechanical Engineering at the University of North Texas in Denton, Texas where he is currently getting his degree in Mechanical and Energy Engineering. He has been studying under his research advisor Dr. Sheldon Q. Shi whom he met during his undergraduate when working on his senior design project for which Dr. Shi was the advisor. Lee's primary research focus initially was on natural fiber composite processing but as he developed his topic for his dissertation the focus changed to developing a model of the self activation process that is used to create activated carbon from raw biomass.

Expertise: Bio-composite Activated Carbon Pyrolysis

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Mohit Raja Srivastava (M.S., Civil Engineering and Wood Science, 2021) Oregon State University, is from India. Mohit research focuses on Wood Structures. Mohit is also a graduate research assistant at Oregon State University and currently working on Timber-Concrete Composite. After completion of the program, Mohit aspires to design Mass Timber Projects.

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Expertise: Wood Products Extension

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Dr. Brian Via is Regions Bank Professor of Forest Products and is currently the Director of the Forest Products Development Center in the School of Forestry and Wildlife Sciences (SFWS) at Auburn University. He recently took on the challenge of Editor in Chief of the Forest Products Journal and is also on the Editorial Board for the Journal of Analytical Methods in Chemistry and Forests. Recently, Dr. Via worked with the faculty and Dean to start a new undergraduate curriculum Sustainable Biomaterials and Packaging. This curriculum is a unique model in which we have participation from 5 Colleges/Schools and is housed in SFWS. Dr. Via has worked at International Paper and Louisiana Pacific Corporations in the area of wood quality and wood composites respectively. As Director, he works closely with industry for economic development and commercialization and has a current patent that is now in the early stages of approval.

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A PhD student in the Department of Sustainable Bioproducts at Mississippi State University, Adam Wade has been studying forestry and forest products since 2016. During his time as an undergraduate, he conducted research on the effect prescribed burning had on bark moisture retention of upland tree species and worked as a teaching assistant for the Summer Field Program in forestry. His credentials include certified American Tree Farm Inspector, Mississippi Professional Logging Manager, and Registered Forester. Adam currently conducts wood anatomy research in the area of computer-vision wood identification and enjoys woodworking in his spare time.

Expertise: Wood identification

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Cody Wainscott is a PhD researcher at Oregon State University. Originally from Texas, he first got his B.A. from Texas A&M University where he grew his interest in renewable energy and composites from renewable materials. He got his Masters from Mississippi State University in 2019 with research in pyrolysis technology and continues to pursue his interests to better himself and his career aspects. A few hobbies he enjoys are history, reading books, geography, videogames, randomly looking up renewable technologies and space.

Expertise: Wood Composites and Energy

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Dr. Jinwu Wang is a Research Forest Products Technologist at the Forest Products Laboratory, USDA Forest Service and a faculty associate at the University of Maine School of Forest Resources and Advanced Structures.

Expertise: Wood fiber utilization for paper, composites, and packagin

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Dr. Wang is currently an Assistant Research Professor at the School of Forest Resources in the University of Maine, with an affiliation with the Advanced Structures and Composites Center. Dr. Wang obtained his BS degree in Wood Science and Engineering from Central South University of Forestry & Technology, his MS degree in Bamboo Engineering Materials from Nanjing Forestry University and his Ph.D. degree in Forest Resources under the supervision of Professor Doug Gardner from University of Maine, USA. Dr. Wang's research interest include large-scale 3D printing, cellulose nanomaterials production, packaging materials, adhesion, interface and material recycling. He has so far published nearly 30 peer-reviewed articles.
Expertise: Cellulose nanomaterials, composites, 3D printing, packaging, recycling

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Xuan Wang holds a B.S. degree in Wood Science and Engineering in 2016 and an M.S. in Wood Science and Technology in 2019 from Nanjing Forestry University. From 2019 Aug. to the present, he is studying at University of North Texas (UNT) as a Ph.D. student. His research interests are wood modification and bioproducts.
Expertise: Wood Modification; Biocomposites, Transparent Wood

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Expertise: Biobased fuels, chemicals, and materials

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Kathy Young is a second year undergraduate student in Oregon State University, majoring in Forest Engineering with a minor in Forestry. She has always been interested in environmental issues, which is her main reason choosing the major, with the hopes of being able to make a significant change with her job after she graduates. Currently, she is working with Dr. Pipiet Larasatie and Dr. Eric Hansen as a research assistant in the university.

Expertise: I am majoring in Forest Engineering, and have an interest in pursuing GIS. Other than that, I have also been enjoying classes that are related to Microsoft Excel and plant identification

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