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In Situ CT-Scanning of Checking and Collapse Behaviour of *Eucalyptus nitens* During Drying

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Abstract

Eucalyptus nitens has become a commercially important species in Chile and it is representing one of the fastest growing wood-stock in the country. Today, it is widely used for pulp and paper production, but the interest in using the solid wood has increased in recent years. Before the sawn timber can be utilized, its moisture content must be reduced. Often during drying, hydrostatic tension forces within the cell exceed the compressive strength of the thin cell wall of *Eucalyptus nitens* and the cell collapses. This phenomenon usually leads to severe surface deformation and both surface and internal cracks (honeycombing). Yield and quality of the final product, and thereby sawmills' profitability, are decreased by these cracks and deformations. The aim of this study was to investigate, by CT-scanning samples throughout the drying process, if it is possible to detect when and how cracking and deformation occurs and develops in specimens of *Eucalyptus nitens* from Chile. Based on this knowledge, better drying schedules can hopefully be developed to improve the yield and provide a higher end-quality of the sawn timber.

Keywords: CT-scanning, *Eucalyptus nitens*, wood drying, image processing, cell collapse

Introduction

The volume of eucalypt wood planted and used in the southern hemisphere has increased very much during the last decades. The major use of eucalypt wood is for the pulp and paper industry, to the point that it is the most widely used source of short wood fibers in the world (Hart and Santos 2015). According to the Chilean Statistical Yearbook of Forestry 2015 (INFOR Area of Information and Forest Economics 2015), in Chile *Eucalyptus globulus* and *Eucalyptus nitens* combined represent 33,1% of the surface of forest plantations. It also shows that the production of Eucalypt wood in the country has been increasing since the 80's but the volume used as sawn timber has decreased dramatically throughout the years. The data for 2014 shows that nearly 12 M m^3 of eucalypt wood was consumed in Chile out of which only 12 000 m^3 were used for producing sawn timber.

Even though the use of eucalypt for high quality solid wood products is minor, some research is taking part regarding how to improve the properties of the sawn timber. Blackburn (2012) focuses on *Eucalyptus nitens*, the wood species that is used in this study as well, and provides a wide picture of the existing knowledge at different levels: material science, genetics, forest management and final products.

One of the reasons why the use of eucalypt for solid wood applications is so limited is that it is extremely prone to internal checking and collapse during drying (McKinley et al. 2002, Shelbourne et al. 2002, Lausberg et al. 1995) which results in defects that are unacceptable for the industry. The literature provides some record of research that addresses checking and collapse of different Eucalyptus species from various points of view. For instance: anatomical (Wilkes and Wilkins 1987, Chauhan and Walker 2004, Valenzuela 2012); material science (McKinley et al. 2002, McKenzie et al. 2003, Ilic 1999) or genetics (Hamilton et al. 2009, Kube and Raymond 2002). Some use of scanning technologies has been made in the research of this phenomenon. Lausberg et al. (1995) applied X-ray scanning technology to study densiometry of *Eucalyptus nitens* wood strips. Wentzel-Vietheer et al. (2013) tried to identify collapse zones in *Eucalyptus globulus* with near infrared spectroscopy (NIR). Ananías et al. (2014) used a Quintek X-ray Ring Tree Analyzer to measure width and density of annual rings while studying how the cell location within the stem influences collapse.

This work is a first approach to the study of internal checking and collapse in real time with aid of computer tomography (CT)-scanner, by using a unique piece of equipment that combines a drying chamber and a medical CT-scanner. The main goal is to explore the opportunities that these techniques provide to study internal checking and collapse of *Eucalyptus nitens* during the drying process. As there are on-going projects developing new algorithms for MC measurements from CT-scanning images (Watanabe et al. 2012, Hansson and Fjellner 2013, Couceiro and Elustondo 2015), this parameter could be included as well in future work and help drawing a wide picture of the drying process and wood's behaviour. In the long term, this could provide new ways for the development of better drying schedules and therefore improve the yield and quality of *Eucalyptus nitens*' sawn timber.

Materials & Methods

Three specimens, one specimen in each drying run, of *Eucalyptus nitens* were used for the tests. Their cross-sectional dimensions, prior to the drying, were 105 x 23 mm^2 and their length was roughly 70 cm. A specially designed laboratory drying kiln that fits within the void of a Siemens Somatom Emotion medical CT-scanner was used (Fig. 1). With this equipment it is possible to scan the inside of the kiln without interrupting the drying process. The dryer works as a regular heat and vent kiln and the drying takes place in atmospheric pressure. Prior to drying, the specimens were soaked in water for 24 hours and the ends were sealed with a heat resistant silicone. In the three drying runs, the dry bulb temperatures were set at around 50, 82 and 103 °C respectively while the wet bulb depression was varying as the drying went on (Fig. 2). The warming-up process was done with saturated atmosphere and at a rate of 30 degrees per hour. The specimens were scanned periodically and at different spans. Three thermocouples, type T, connected to a PC-logger (Intab AAC-2), and placed in holes drilled in the specimens, were used to achieve complementary data. Two of the thermocouples were placed in the center of the specimens' cross section and one at approximately 3 mm depth from the surface. The data provided was used to make videos of the process following the changes in the specimens with the CT-images and a temperature graph (Fig. 3).

Figure 1: Drying kiln and CT-scanner. The specimen is located in the metal tube that fits within the void of the scanner.

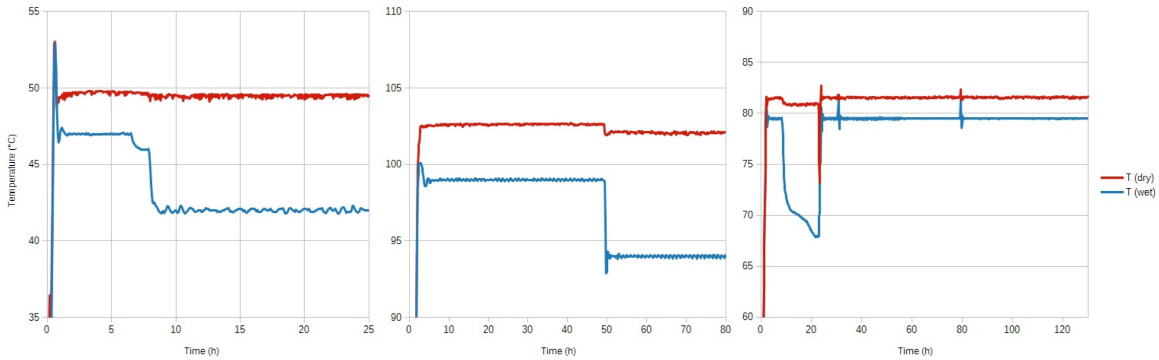

Figure 2: Wet bulb and dry bulb temperatures of the drying runs.

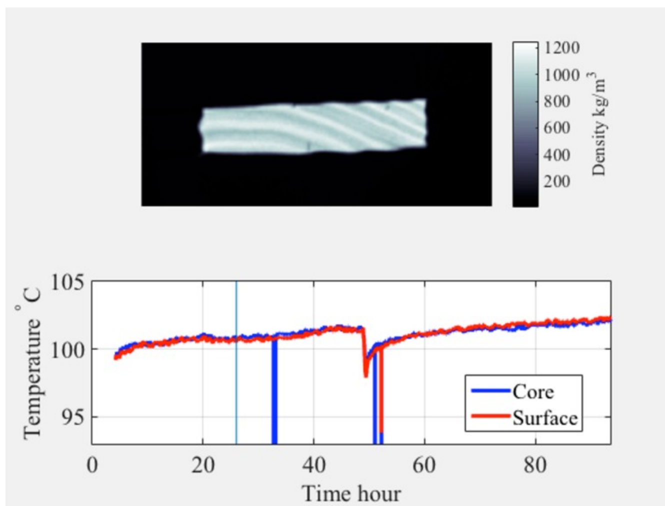

Figure 3: Frame of one of the videos of the process. It shows how the specimen changes as the drying process goes on and the temperature inside the specimen varies (shown in the graph by the vertical stroke that in this case is at around 25 hours).

Results and Discussion

The method allows to clearly see changes in the cross section of the specimens at given intervals during the drying process. The pixel size of the images corresponds to 0.98 x 0.98 mm^2 in the specimens. The depth of the voxel was 10 mm, meaning that the data given for each pixel corresponds to an average value of such a volume. It is possible to see a good level of detail with such parameters, but it could be possible as well to adjust the settings in order to achieve even higher spatial resolution.

The settings of the experiments were not optimal for the goal pursued. A higher resolution can be achieved thus having higher level of detail in the images. The drying process had a too fast warming up phase, driving to collapse and cracks in early stages and also big changes between scans. Two actions need to be taken in future tests in order to avoid this: raising the temperature slowly and scanning the boards more frequently in the early stage of the drying process.

Collapse seems to become noticeable before any internal crack is visible. In early stages of the drying process a wavy deformation in the otherwise flat surface is clearly noticeable. (Fig. 4)

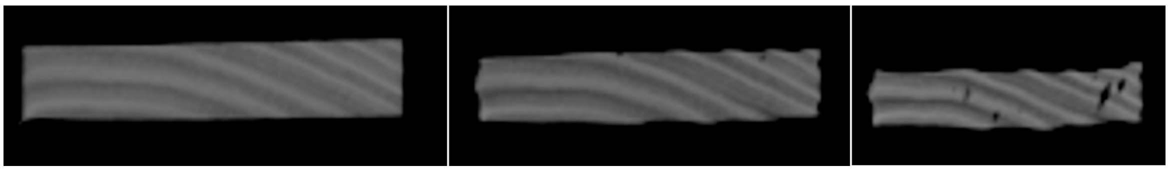

Figure 4: Sequence of the same specimens. Left: beginning of the drying. Center: collapse is visible at the surface of the specimens before any checking. Right: internal checking is visible well after the collapse.

As these experiments were a test for future research, some malfunctions and mistakes were expected. Nevertheless, these mistakes are just a matter of fine tuning in the experiment setup and can easily be corrected for future experiments.

Conclusions

The method enables the opportunity to see how internal cracks start and develops throughout the drying process. In this case, the setting of the experiments resulted in a bad record of the crack occurrence, but the expectations are high for future research. It is reasonable to think that the procedures can easily be adjusted for future experiments and other parameters, as density and moisture content, could be included in order to get a wider picture of the process. Therefore, the equipment provides the means to develop a method to study this phenomenon at a high level of accuracy, giving the chance to a better understanding of the internal cracking and collapse behaviour of *Eucalyptus nitens* or any other wood specie.

Acknowledgments

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Influence of Processing Parameters on the Piezoresistivity of Bio-based Carbon Sensor Material

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Abstract

Carbon materials from woody biomass have been gaining some attention for use in electrical storage and composite applications. Bio-based carbon from wood is traditionally used in lower value applications such as soil amendments. Our prior research produced piezoresistive based sensors using commercially produced, mixed hardwood biochar as the conductive material. The objective of this research was to evaluate the conductive properties of three woody biomass species that were carbonized at a variety of temperatures and to evaluate their piezoresistive properties. Specifically, red oak, yellow-poplar, and short rotation shrub willow were carbonized in a specially designed tube furnace. The conductivity and structure of the carbon materials were evaluated. The carbonized material was then processed to a variety of micro and nano-sized particles and used in the preparation of piezoresistive sensor materials. The sensors were produced through the addition of carbonized particles into a 10% polyvinyl alcohol (PVA) solution, followed by film casting and degassing. The resulting sensors were evaluated for piezoresistive properties when subjected to dynamical mechanical thermal loading. Results will be presented on the influence of carbonization temperature on the properties (e.g., conductivity, pore structure, elemental analysis) of the bio-based carbon and the effect of particle size and bio-carbon loading levels on the piezoresistive properties of the composite sensor materials.

DEVELOPMENT OF A CONTINUOUS WOOD SURFACE DENSIFICATION PROCESS – THE ROLLER PRESSING TECHNIQUE

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Abstract

The hardness of the outer areas of solid wood can be improved by surface densification, and this opens up new fields of application for low-density species. So far, surface densification relies on time- and energy-consuming batch processes, and this means that potential advantages over more expensive hardwood species or non-renewable materials are lost. Using fossil-based plastics or applying wood densification processes with a high energy consumption has adverse effects on the environment.

The purpose of this project has been to study the viability of a high-speed continuous wood surface densification process on Scots pine boards using roller-pressing equipment. Based on the process parameters used in existing research into the surface densification of wood, an experiment was conducted to study the potentials and limitations of the roller pressing approach.

Densification with a roller pressing technique resulted in a densified surface at feed speeds up to 80 m/min, but there is a complex relation between the roller pressing process parameters and the properties of the densified wood surface. Even though immediate springback was observed, the peak density increase reached up to 40%. The data indicate that a short heating time at a high temperature to soften the wood yields the best results.

Future work will continue on optimization of the densification process, and also on improving the process from an economic and an environmental perspective.

Key words**:** wood modification, compression, thermo hydro mechanical processing

Introduction

Increasing the hardness of wood by densification is not a new approach. Sixty years ago, Seborg et al. (1956) presented a heat-stabilized compressed wood product, called Staypak. The increase in hardness opens up new fields of application for low-density species, e.g. highly durable wood flooring or kitchen counters.

Staypak and other compressed wood products have in common that the level of densification is more or less constant throughout the thickness of the piece of wood, indicated by the term *'through densification'*.

Densifying only the area close to the surface of a piece of wood has several advantages over through densification: it has a higher material input efficiency from a strength perspective, similar to that of an I-beam. For some applications it can be advantageous that the undensified core has better dampening characteristics than a densified core, e.g. in flooring.

In contrast to through densification, surface densification of wood became a research topic only more recently. Even though some experiments were reported already in 1968 (Tarkow & Seborg), research on surface densification became more popular only about ten years ago (Navi & Sandberg 2012). One can say that the majority of recent research into the surface densification of solid wood originates from Aalto University in Finland. In his doctoral thesis, Rautkari (2012) explored various approaches to surface densification of solid wood. Laine (2014) focused on surface densification in a hot press, examining the effects of the process parameters on the resulting properties of the surface-densified wood.

Rautkari et al. (2010) investigated one of the crucial obstacles that prevent surface-densified wood from being a marketable product: set-recovery, the moisture- or heat-induced "swelling" of the densified wood back to its original thickness. Without additional treatment, set recovery reaches almost 100%. Gong et al. (2010) and Laine et al. (2013) showed that set-recovery can be reduced by a thermal post-treatment stage.

Even though past research offers solutions for most of the problems encountered, the major obstacle that remains is how to improve the economic viability of the surface densification process. So far, surface densification relies on time- and energy-consuming batch processes. Post-treatment stages to eliminate set-recovery work in principle, but consume a lot of time and energy. This eliminates the potential advantages over more expensive species or non-renewable materials with a higher inherent hardness, for both economic and environmental reasons. So far, continuous processes have only been investigated in other contexts, for example for a novel impregnation process (Inoue et al. 2008).

The aim of this research project is to develop a continuous wood surface densification process, which fulfills the requirements of being fast and economic, together with a low environmental impact.

This paper covers the first experimental study of the roller-pressing technique, and the influence of the process parameters on the resulting density and density profile of the densified wood samples.

Materials and Methods

The study was conducted in collaboration with the Swerea Mefos in Luleå, Sweden, who provided the roller pressing equipment and expertise regarding the roller pressing of steel and other metals.

The densification process

19 Scots pine (*Pinus sylvestris*) samples with a length of 1000 mm, a width of 40 mm and a thickness of 20 mm were compressed in the radial direction. The samples were cut from boards so that the densified surface would consist only of sapwood, and the samples were conditioned to a moisture content of 13% before the treatment started. The mean density of the samples before densification was 470 ± 100 kg/m^3.

The densification process consisted of two stages: 1) softening of the wood samples under heat, and 2) densification of the wood samples between two rollers (Fig. 1). The samples were softened between two steel plates of which one was heated in an oven to a constant temperature, in order to soften only one of the surfaces. The densification of the samples was achieved by feeding them through a pair of rollers of which one was heated (Fig. 2). The diameter of the rollers was 160 mm. The roller pressing equipment is usually used in the steel industry, which means that the forces developed during wood densification are much below the limit of the capabilities of the equipment.

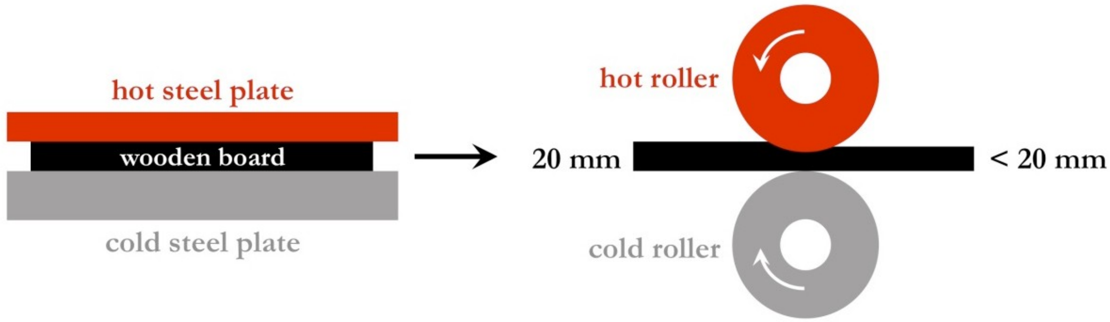

Figure 1: The roller pressing process: a) softening of one surface of the wood between one hot and one cold steel plate (left), and b) densification between one heated and one cold roller (right).

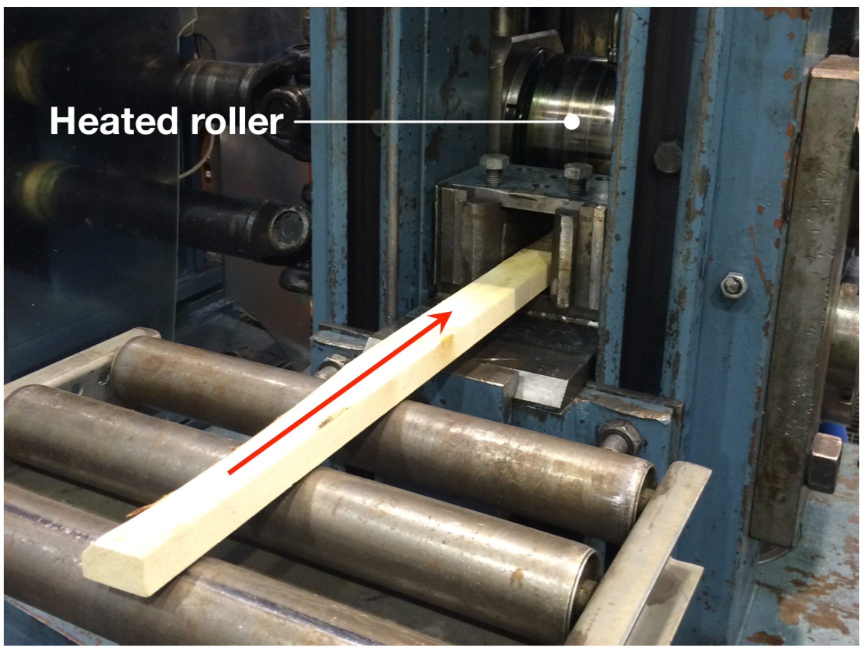

Figure 2: The roller pressing equipment. The upper roller was heated. The lower roller is not visible in the photograph.

Table 1 shows the process parameters used in the test. The temperatures of the heated steel plate and the heated roller were determined with a pyrometer.

The heating time and temperature of the steel plate, and the targeted thickness reduction under compression were based on the results reported by Rautkari et al. (2011). For the first sample, a low feed speed was chosen, and the feed speed was thereafter increased stepwise in order to test the limits of the process.

Table 1: Sample overview and process parameters.

Pre-heating	Densification process

Sample No.	$T_{steel\ plate}$ [°C]	Heating time [s]	$T_{heated\ roller}$ [°C]	Feed speed [m/min]	Target thickness reduction [mm]
1	180	90	140	0.083	5
2	180	90	140	0.8	5
3	180	90	140	8	5
4	180	90	140	80	5
5	180	90	140	80	5
6	130	90	140	80	5
7	130	90	150	20	5
8	130	90	150	20	5
9	140	90	150	20	5
10	150	180	50	20	5
11	190	180	50	20	5
12	180	90	45	20	5
13	170	90	45	20	5
14	180	90	130	20	5
15	175	90	130	20	1
16	170	90	170	20	2
17	160	90	145	20	3
18	20	0	140	20	3
19	20	0	130	20	3

Determination of the sample thickness, density and density profile

The density and density profile of all samples were measured before and after densification with an X-ray computer-tomography (CT) scanner. Cross-sectional CT images were taken every 100 mm in the length direction of the samples, evenly distributed over the length of each sample. The image processing software ImageJ was used to extract density values and density profiles from the CT images. The density profiles were measured through the center of the cross-sectional images (Fig. 3).

The grey scale data were calibrated and expressed in kg/m^3 in the range from 0 to 1000 kg/m^3. The density calibration was achieved with the aid of the known density of air and water (Kalender 2011). Light grey areas indicate high-density values, and dark grey areas indicate low-density values.

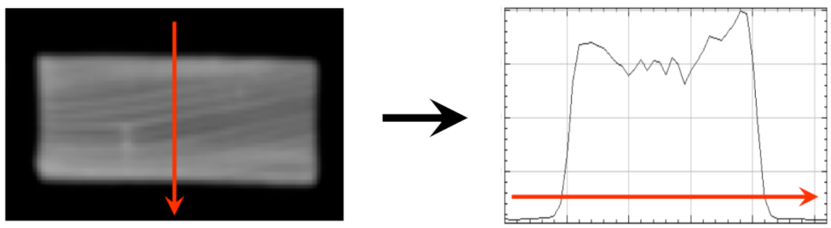

Figure 1: Principle of measurement of the density profile. The density profile is measured through the centre of the cross-sectional CT images. The lighter areas in the CT image indicate a higher density than the darker areas.

Results and Discussion

To explore the possibilities of a continuous wood surface densification process, various process parameters were tested with regard to their influence on the resulting sample density and density profile. The goal was to obtain density profiles with a pronounced peak close to the heated surface.

It was not possible to detect significant interactions between the heating temperatures during softening and densification and the resulting density profile. For example, the data do not show whether a pre-heating temperature of 180°C and a roller temperature of 140°C provided a better result than a pre-heating temperature of 130°C and a roller temperature of 150°C. The data do show however that if heat is not applied in either the softening or the densification stage, an undesired density profile is obtained.

Figure 4 shows that the feed speed has only a small influence on the density profile, with a slightly less pronounced density peak at a feed speed of 80 m/min. A feed speed of 20 m/min was found to be a good compromise between process speed and resulting density profile.

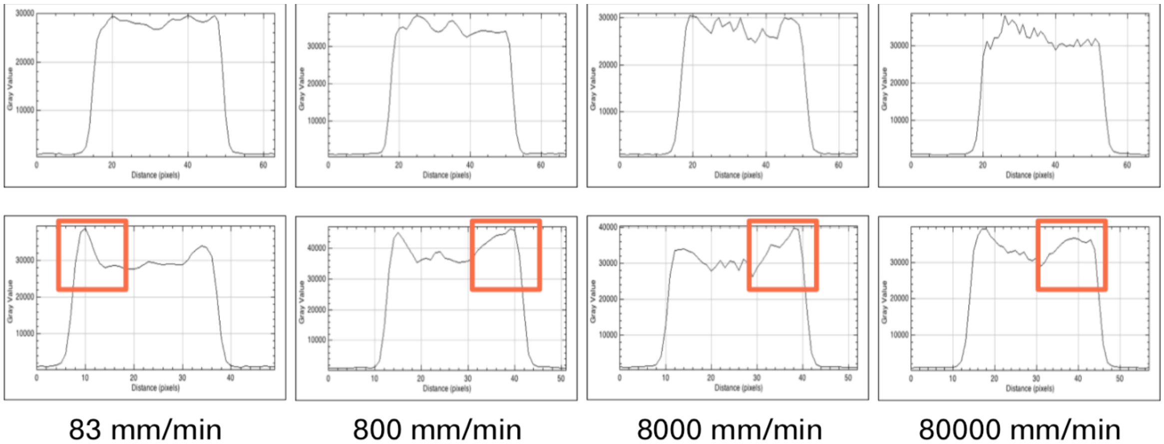

Figure 2: Influence of feed speed on the density profiles. Sample numbers from left to right are 1, 2, 3, and 4. The upper row of images shows the density profile before densification. The lower row of images shows the same samples after densification. The values on the axes in each graph are not meant to be read. The squares show the increased density of the softened wood cells of the samples.

A heating time of 180 s led to density profiles with less pronounced peaks than a heating time of 90 s. With a longer heating time, the samples were probably softened too deep into the core, resulting in a flatter density profile. This result is in agreement with the findings of Rautkari et al. (2011). The results suggest that a short but intense softening stage will yield the best results.

Calculating the densities from the CT images at various locations within each cross-sectional image revealed that the core of the samples with a pronounced density peak was not compressed at all. The average peak density increase in these samples was between 25% and 40%. Taking into consideration an immediate spring-back of approximately 50%, which can probably be avoided by an additional cooling stage, the potential for a strong increase in density is high.

Conclusions

The purpose of this project was to study the viability of a high-speed continuous wood surface densification process on Scots pine boards using roller-pressing equipment. It was shown that the roller-pressing approach works, even though it was not possible to clearly relate the outcome to the heating temperatures. However, the results suggest that the softening/heating time should be rather short, with a high heating temperature rather than a low heating temperature.

The feed speed only has a small influence on the resulting density profile. Even at high speeds, which are required to achieve an economically viable process, the roller pressing approach resulted in a clear density increase close to the surface and an undensified core.

Now that the promising potential of densifying the surface of solid wood with roller pressing equipment has been shown, further tests will focus on introducing a more controlled softening stage and on introducing a subsequent cooling stage. Perhaps the most crucial issue to tackle in the future will however be the elimination of the set-recovery in as fast a way as the actual densification process.

Acknowledgement

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Nanofibrillated cellulose from Appalachian Hardwoods Red Oak *(Quercus rubra)* and Yellow Poplar (*Liriodendron tulipifera*) as template for copper nanoparticles

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Abstract

TEMPO oxidized cellulose nanofibrils (TOCN) were prepared from two underutilized Appalachian hardwoods to evaluate their potential to synthesize copper nanoparticles. The woody biomass composed by Northern Red oak (*Quercus rubra*) and Yellow poplar (*Liriodendron tulipifera*) were provided in the form of logging residue from Preston County, WV. The general steps to prepare TOCN consisted of kraft pulping, bleaching (five stages), TEMPO oxidation process and a final homogenization step. The material produced was characterized in terms of its functional groups, morphology, degree of polymerization and carboxylic group's content. For both species the final TOCN presented similar morphology and carboxyl content. Bleached and TOC samples from yellow poplar displayed lower viscosity, lower degree of polymerization and lower crystallinity compared to TOC from red oak. Based on these results no differences are expected in terms of the capability of both hardwood species to synthesize copper nanoparticles, but improved mechanical properties of the hybrid material might be expected when using TOC from red oak.

Key words: *Nanofibrillated cellulose, TEMPO oxidation, red oak, yellow poplar.*

Notation:
TEMPO: 2,2,6,6-Tetramethylpiperidin-1-yl)oxyl
TOC: TEMPO-oxidized cellulose (produced after the TEMPO-oxidation process).
TOCN: TEMPO-oxidized cellulose nanofibrils (produced after the final homogenization step).

Introduction

In the last decade the interest to produce and utilize nanofibrillated cellulose (NFC) from woody biomass has increased exponentially. This material, usually obtained as a viscous gel, was firstly produced in the eighties after passing a wood fiber suspension several times through a homogenizer under high pressure (Gamelas et al. 2015). Several approaches have been performed so far to reduce the required energy to obtain nanofibrils from cellulose and to exploit their inherent properties. These processes include mechanical, enzymatic, and chemical pre-treatments. TEMPO mediated oxidation has been applied successfully to facilitate the fibrillation of cellulosic fibers, by introducing carboxylic acid groups in the C6 position of the glucose unit.

The purpose of the present study was to compare the final properties of TEMPO oxidized cellulose (TOC) and TEMPO oxidized cellulose nanofibrils (TOCN) from two highly available hardwood species in the Appalachian region (red oak and yellow poplar), in order to determine their feasibility to synthesize copper nanoparticles.

Materials & Methods

Materials

Northern red oak (*Quercus rubra*) and yellow poplar (*Liriodendron tulipifera*) were used in the form of logging residue. The samples were chipped and screened. The fraction retained between 1/2 inch opening and 3/8 inch was used for pulping.

TEMPO oxidized cellulose nanofibrils (TOCN) production

The TOCN production that included kraft pulping, bleaching, TEMPO-oxidation and mechanical treatment (homogenization) was performed at the Forest Product Laboratory, Madison, Wisconsin. A five-stage bleaching sequence (DEpDEpD) was performed in order to remove the residual lignin. The conditions for pulping and bleaching process are presented in Table 1 and Table 2, respectively.

The process of TEMPO-mediated oxidation was performed according to Saito et al. 2007 using TEMPO/NaBr/NaClO system, under alkaline conditions. A final step consisted of a mechanical fibrillation performed by passing the oxidized material twice through an M-110EH-30 Microfluidizer (Microfluidics, Newton, MA).

Table 1: Pulping conditions

Variables	
Maximum temperature	165 °C
Time at maximum temperature	50 min
Liquor to solid ratio	4
Sulfidity	25
H−factor	750

Table 2: Conditions of bleaching process

Stage	D(First Chlorine Dioxide)	Ep (Alkaline Extraction Stage 1)	D (Second Chlorine Dioxide)	Ep	D
Chemical charge	ClO_2 (1.7%) H_2SO_4 (0.2%)	NaOH(2%) H_2O_2 (0.38%)	ClO_2 (0.8%)	H_2O_2 (0.197 %) NaOH (1%)	ClO_2 (0.3%)
Pulp consistency	10%	10%	10%	10%	10%
End pH	2.5	11	3.5	11	
Temperature	70 ℃	70 ℃	70 ℃	70 ℃	70 ℃
Time	45 min	60 min	80 min	130 min	60 min

Notation:
TOC: TEMPO-oxidized cellulose (produced after the TEMPO-oxidation process).
TOCN: TEMPO-oxidized cellulose nanofibrils (produced after the final homogenization step).

Characterization methods

- Viscosity of the bleached and TEMPO-oxidized cellulose (TOC) was measured according to TAPPI Standard Method T230 om-99. The degree of polymerization (DP) of both materials was estimated according to Sihtola et al. 1963.
- The determination of carboxyl content of the bleached and TEMPO-oxidized cellulose (TOC) was performed according to T 237 om-88.
- Functional groups on the bleached, TOC and TOCN samples were determined using Fourier transform infrared spectroscopy (FT-IR) (Perkin-Elmer Spectrum 2000 FTIR spectrometer). The spectra were analyzed in the range 600 to 4,000 cm^{-1}.
- The degree of crystallinity was determined using an X-ray diffractometer (PANalytical X'Pert Pro, Almelo, Netherlands) with a Cu Kα X-ray source. The X-ray diffractograms were recorded over a 2θ scan in the range 10-40°. The crystallinity index was calculated according to following formula:
  Crystallinity Index = $(I_{crystalline} - I_{amorphous}) \times 100\% / I_{crystalline}$
  Where $I_{crystalline}$ was identified with the intensity at 22.5°, and $I_{amorphous}$ was the intensity at 18.6°. (Qin et al. 2011).
- The morphology of the final TOCN was determined using transmission electron microscopy (TEM). A droplet of a diluted suspension of TOCN was deposited to a glow-discharged copper grid with formvar and carbon film (400 mesh) and the sample was imaged using a Philips CM-100 TEM (Philips/FEI Corporation, Eindhoven, Holland) operated at 100 kv, spot 3,200-Im condenser aperture, and 70-Im objective aperture.

Results and Discussion

In Table 3 are presented the viscosity, estimated degree of polymerization (DP) and carboxylic acid group content of the bleached and TEMPO-oxidized cellulose (TOC) samples of red oak and yellow poplar. The viscosity and degree of polymerization were higher for red oak in both, bleached and TOC samples compared to yellow poplar. After one and a half hours of oxidation the DP of bleached red oak was reduced 89 %, and the DP of bleached yellow poplar was reduced 96%.

As reported by Saito and Isogai (2004), TEMPO oxidation leads to a considerable reduction of the DP when the oxidation is performed under alkaline conditions. So, even though the reduction in viscosity and (DP) after the oxidation process was expected, the differences in the two specie is surprising. This preliminary results indicated that the final degree of polymerization (DP) of bleached red oak was 40% higher than bleached yellow poplar, and the final DP of TEMPO-oxidized cellulose (TOC) for red oak was 273% higher than the DP of TOC yellow poplar. Normally, we expect a viscosity around 20-30 mPa-s for a bleached pulp. This preliminary results must suggest either a problem earlier in the experiment or intrinsic differences in the nature of the species. To verify this preliminary results, experiments to measure the length of the fibers and fibrils are currently being performed.

In terms of carboxyl group content, a clear increase is appreciated for both species after the TEMPO-oxidation process (Table 3). No differences between species regarding the final carboxyl of TOC samples was found.

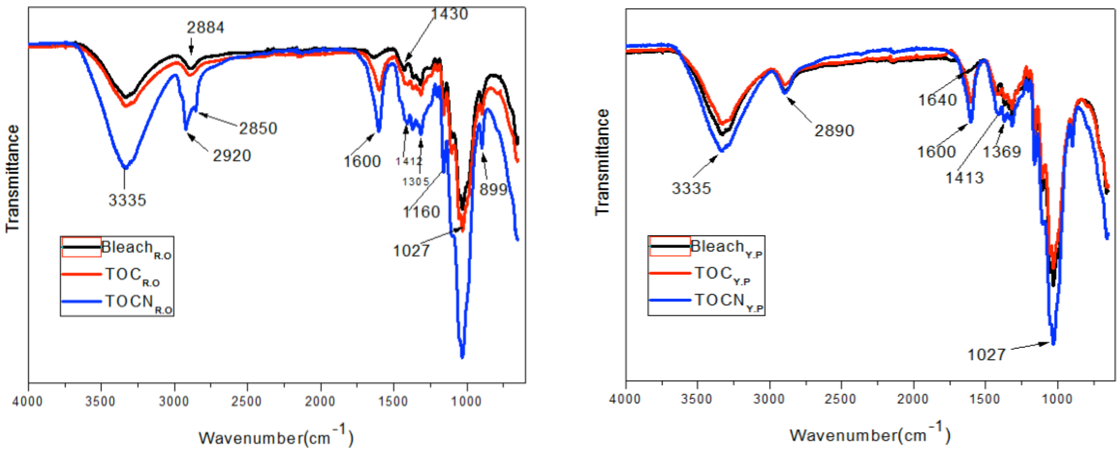
Table 3: Viscosity, degree of polymerization (DP), and carboxylic content (COOH) of bleached, and TEMPO-oxidized cellulose (TOC) of red oak (RO) and yellow poplar (YP).

Sample(s)	Viscosity(mPa s)	DP	COOH (mmol/g)
$TOC_{(R.O)}$	2.9	141	0.82
$TOC_{(Y.P)}$	2.4	38	0.80
$Bleached_{(R.O)}$	19.4	1342	0.05
$Bleached_{(Y.P)}$	10.9	957	0.07

In Figure 1 are presented the FTIR spectra for a) red oak and b) yellow poplar after bleaching, TEMPO-oxidizing process (TOC), and after their final mechanical treatment (TOCN).

Bleached samples of yellow poplar showed an intense OH peak at 3330 cm^{-1}, corresponding to intra- and inter-molecular hydrogen bonds (Chirayil et al. 2014), and at 1027 cm^{-1} (the stretching of C-O and O-H) (Nacos et al. 2006), compared to bleached red oak. The correspondent intensities of these peaks for TOC and TOCN of red oak and yellow poplar are quite similar.

The spectra of all samples showed the characteristic C–H stretching absorption around 2920–2800 cm-1 (Le Troedec et al. 2008). This bond was more intensive in TOCN compared to TOC, and bleached samples for red oak.



a) Red oak b) Yellow poplar

Figure 1: FT-IR spectra of Bleached, Tempo-oxidized cellulose (TOC) and Tempo-oxidized cellulose nanofibers (TOCN) for (a) red oak and b) yellow poplar.

Two strong absorption bands at around 1638-1600 and 1412-1402cm^{-1} derived from the carbonyl groups −C=O are present in both TOCN red oak and yellow poplar samples, and they confirm the oxidation effect after the TEMPO-mediated oxidation process. That is, the hydroxyl groups at the C6 position of cellulose chains are converted to sodium carboxylate (Ifuku et al. 2009). These two ranges were higher after TEMPO mediated oxidation in the order of TOCN≈TOC>bleached samples for both, red oak and yellow poplar.

In Table 4 are presented the results for degree of crystallinity of untreated species (raw material) and TEMPO-oxidized cellulose (TOC) samples. The degree of crystallinity increased almost 50% for both red oak and yellow poplar after the TEMPO-oxidation process.

Table 4: Degree of crystallinity of bleached, and TEMPO-oxidized samples (TOC) of red oak (RO) and yellow poplar (YP).

Sample(s)	Degree of crystallinity (%)
TOC $_{(R.O)}$	58.4
TOC $_{(Y.P)}$	53.7
Raw material $_{(R.O)}$	39.3
Raw material $_{(Y.P)}$	35.7

Transmission electron microscopy images (examples in Figure 2) and their correspondent analysis using imagej (Ferreira 2012 reveal that red oak and yellow poplar have an average diameter of 3.8 ± 0.74 nm, and 3.6 ± 0.85 nm, respectively.

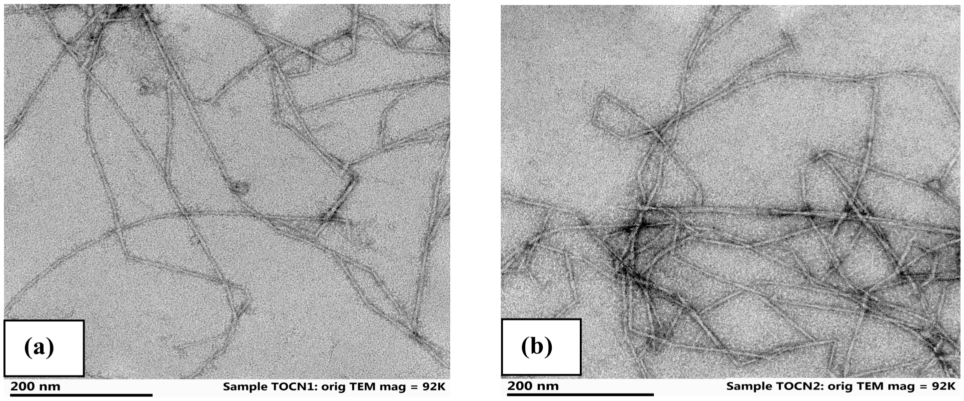


Figure 2: TEM images of TEMPO oxidized cellulose nanofibrils (TOCN) of (a) red oak, and (b) yellow poplar.

Conclusions

Nanofibrillated cellulose from Northern red oak (*Quercus rubra*) and yellow poplar (*Liriodendron tulipifera*) were produced successfully using a TEMPO-mediated oxidation process. Both species presented similar morphology, functional groups and carboxyl content after the TEMPO oxidation process. However, interesting differences in terms of their viscosity, degree of polymerization and crystallinity were observed. Based on these results no differences are expected in terms of the capability of both hardwood species to synthesize copper nanoparticles, but improved mechanical properties of the hybrid material might be expected when using NFC from red oak.

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Two-stage Fungal Pretreatment of Genetically Modified *Populus trichocarpa* with White-rot Fungus, Ceriporiopsis Subvermispora, and Brown-rot Fungus, Postia Placenta

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Abstract

Pretreatment steps are required for lignocellulosic biomass in order to increase surface area, remove lignin, and reduce its recalcitrance prior further processing such as pulping or biofuel/biochemical applications. Fungal pretreatment has the potential to displace current pretreatment methods which utilize high temperatures, harsh chemical, and high energy input, hence resulting in a low cost and environmentally friendly method of biomass pretreatment. Utilized in this study were genetically altered Populus trichocarpa clones which are deficient in several genes controlling lignin synthesis and wood with altered lignin content and/or lignin structure. Wood cell wall composition was measured using standard wet chemistry techniques. Wood was treated for 30 days with white-rot fungus, Ceriporiopsis subvermisopora; then a subset of specimens were treated for an additional 30 days with brown-rot fungus, Postia placenta. After the fungal treatment, weight loss was measured to assess the degradation. In addition, focus was placed on understanding how the topochemical deposition of lignin in the cell wall affects degradation by wood-rot fungi through the use of microscopic imaging techniques. The goal of this study is to assess the utility of using wood from genetically modified P. trichocarpa with fungal pretreatment of white and brown-rot fungi. These results will contribute to the understanding of how lignin content and structure influence fungal degradation on solid wood.

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Mild Thermal Modification to Add Value to UK Grown Larch: Monitoring Quality, Physical Properties and Benefits

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Abstract

Many timber species in British forestry were selected for fast growth rate and imported from other regions within the temperate zone of the Northern Hemisphere. As these stands of trees have matured, the difference between UK grown and timber grown within the original provenance of the species has become apparent. One such example is Japanese larch (*Larix kaempferi*). The use of these home grown timbers presents challenges relating to growth rate and density. Japanese larch is a species of interest for diversifying softwood timber consumption in the UK, but sharply defined earlywood and latewood leads to several problems in machining and utilizing the timber. One option for enhancing timber quality is mild thermal modification. This paper presents a broad range of results from projects undertaken within Wales to develop and scale up the mild thermal modification process. The principal aims were to improve machinability and working properties of the timber in joinery applications.

By comparing timber from treatment runs with residence times in the treatment zone which ranged from 1½ hours to 5 hours, an optimized protocol for furniture and joinery products was developed. Surface quality observations, bulk density and weight change were used to initially screen the efficacy of the treatment. The influence of the different thermal regimes on the level of modification are discussed. The efficacy of the treatment on regions of juvenile wood versus mature wood was also considered, as the difference in physical properties between juvenile and mature wood in untreated timber is significant and contributes to machining and working variability. The stability and machinability of large planks from the scale up were evaluated. The mild thermal modification shows

potential for interior applications, and eradicates many issues commonly associated with fast grown larch such as resin pockets and springback of the latewood after machining.

Key words: *Larix decidua*, thermal modification, machining, adding value, growth rate

Introduction

Forest cover in the United Kingdom is dominated by commercial softwood species: Sitka spruce (*Picea sitchensis*, 50.84% of conifer area), Scots pine (*Pinus sylvestris*, 16.67%), Douglas fir (*Pseudotsuga menziesii*, 3.52%) and three larch species (*Larix* spp., 9.63%); while in hardwood forest 16.38% of the area is oak woodlands (*Quercus robur* and *Q. petrea*),which are the main commercial activity (Forestry Commission, 2014). The spruce, Douglas fir and larch, and other minor conifer species were introduced to the UK in the 19th century, and were widely planted by the Forestry Commission during the 20th Century to fulfil the need to rapidly establish a reserve of timber. Seed provenances with fast growth rates were frequently favoured, and the maritime climate of the UK further increased the growth rate, leading to low numbers of rings per inch and low density. While the timber industry within the UK is well adapted to using home grown spruce and pine, the growth rate and machining issues (Figure 1) mean that larch remains a less favoured timber, despite favourable mechanical properties. Larch for construction and joinery is frequently imported from Europe or Scandinavia, due to the slower growth rate in these regions and greater suitability for cladding.

Figure 1. a) Fast grown untreated larch can be prone to difficulties in planing, such as the broken grain shown in this window frame. b) Difference in strength of the low density earlywood and high density latewood of larch can result in delamination at the growth ring boundary in planing.

The western regions of the UK, including Wales, tend to have stands of Japanese larch (*Larix kaempferi*), while the drier Eastern regions were planted with European larch (*L. decidua*) and the hybrid larch (*L.* x. *eurolepis*) may also be planted for its greater vigour. Within the past ten years the Japanese larch stands of the Southwest of England, Wales and Scotland have come under attack by *Phytopthera ramoram*, a fungal pathogen to which this species of larch shows poor resistance. The availability of a large volume of larch timber on the market has coincided with the period of this project, and driven interest in adding value to this timber. Thermal modification was identified as a suitable technology for the Welsh timber industry, and trials by small companies had favoured a lower temperature high steam process, with great variability of the method between locations and operators. During the project many of the key players in this area worked together to conduct a series of experiments and trials which led to a clearer definition of the protocol, a more unified approach and greater replicability between batches. Additional joinery and wood using companies were engaged to evaluate the timber produced, and to work on demonstration projects.

Thermal modification is a well developed technology within Europe (Hill 2006, Ormondroyd *et al.* 2015), with an increasing market in exterior joinery such as cladding and decking products. The mild thermal treatment investigated within this project operates at a lower temperature than the current market leading technologies (Spear *et al.* 2014, 2015a). The mild thermal modifications were conducted in three stages: drying, treatment and reconditioning. Stages that were a single working day in duration were chosen to allow small businesses to operate kilns on a single shift working pattern, unlike the continuous treatment schedules and high treatment temperatures used in the Thermowood process and other treatments conforming to DD CEN/TS 15679, for which a larger workforce is required. Fuller details of the treatment, including the definition of treatment phase (set temperature of the kiln) and treatment zone (duration above a specified threshold temperature) have been reported in Spear *et al.* (2015a). The mild thermal treatment has also been demonstrated to have a beneficial effect in controlling problems relating to the exudation of oleoresin (Spear *et al.* 2015b), by a drying process.

Materials & Methods

Thermal modification

Planks of Japanese larch were sourced from three sawmills within Wales using Welsh grown timber. Plank cross sections were 110 x 30mm and 155 x 38mm for the small (pilot scale) kiln and 155 x 25mm for full scale production. Planks were supplied at lengths of 3m for the full scale kiln, and cross cut to lengths of 90cm for use in the pilot scale kiln. Within the full scale kiln the planks were stacked with stickers aligned with the four threaded bar supports of the trolley. Downward force was applied at these four locations, throughout the thermal treatment, using a broad crosspiece held by a nut and spring restraint, which was tightened to a pre-defined level for a set volume of timber.

Thermal modifications were conducted in three stages: a drying day (120°C), a treatment day and a conditioning day (80°C). The conditions for the drying day and the conditioning day were consistent throughout the study, and all steps were conducted under continuous supply of steam to maintain elevated humidity. During the kiln trials the maximum temperature and resulting treatment phase parameters were varied to achieve 1.5 to 5 hours within the treatment zone.

After treatment, planks from selected locations within the stack were cut to provide moisture content samples to evaluate uniformity through the pack. Timber taken from between the cuts made for moisture content samples was available for testing mechanical and physical properties. The remainder of the pack was used for workshop trials and demonstrator projects.

Properties evaluation

The moisture content samples were weighed and measured when cut; after drying in an oven at 105°C and allowing to cool in a desiccator above silica gel; and after conditioning for two weeks at 20°C and 65% relative humidity. The moisture content was determined using the difference between weight when cut and the oven dry weight, related to the oven dry weight.

The bulk density of the planks was calculated using the mass and dimensions of the moisture content samples, both in the oven dry state and in the conditioned state. Moisture content sample data (weight and volume in the oven dry state) was also used to estimate the dry weight of the planks prior to treatment, and after treatment. This estimation is necessary to estimate the weight change due to the mild thermal modification.

Company trials and demonstrators

During the project four small businesses who use wood, and one timber merchant, were engaged with the consortium to discuss and work with the timber during the development stages. Small parcels of timber from the pilot scale and the full scale kiln were provided for use in operations routinely undertaken by the companies, such as window frame manufacture, furniture manufacture, production of regularized or moulded timber and painting and staining. The objective was for these companies to observe the handling and quality of the product, and feedback any issues encountered. As the project progressed, several of these prototypes and furniture items were used in showcasing the treated timber to new contacts, for example at trade fairs (Timber Expo, The Royal Welsh Show).

Results and Discussion

Properties evaluation

Variability of moisture content within the stack was monitored, and used to guide adjustments to air flow within the kiln and kiln schedule adjustments. The moisture content of timber sampled prior to kilning (18% ±0.2%) was reduced by the kiln schedule (to 4.6% ±0.3% for this example). The moisture content of samples was re-evaluated after conditioning for 2 weeks at 20°C and 65% r.h., and the untreated samples had attained a moisture content of 9.6% ±0.1%, while the treated samples had a conditioned moisture content of 7.34% ±0.2%. This indicates that equilibrium moisture content is slightly reduced for the mild thermally treated timber.

The bulk density of treated and untreated samples conditioned at 20°C and 65% r.h. is shown in Figure 2. It is clear that there is very little difference in the bulk density after treatment, and although a small reduction was observed, this was not statistically significant. This small density change corresponded to a small change in the estimated dry weight of the plank. For example in Run regular 4 (on the pilot scale kiln) the estimated dry weight was calculated based on moisture content samples as average 1.49kg untreated and 1.42kg treated, correlating to a weight loss per plank ranging from -0.48% to 8.53%. Within the full scale kiln this sampling method was not appropriate due to timber dimensions, however the similarities in density difference reported indicate that a similar weight change due to thermal treatment can be expected.

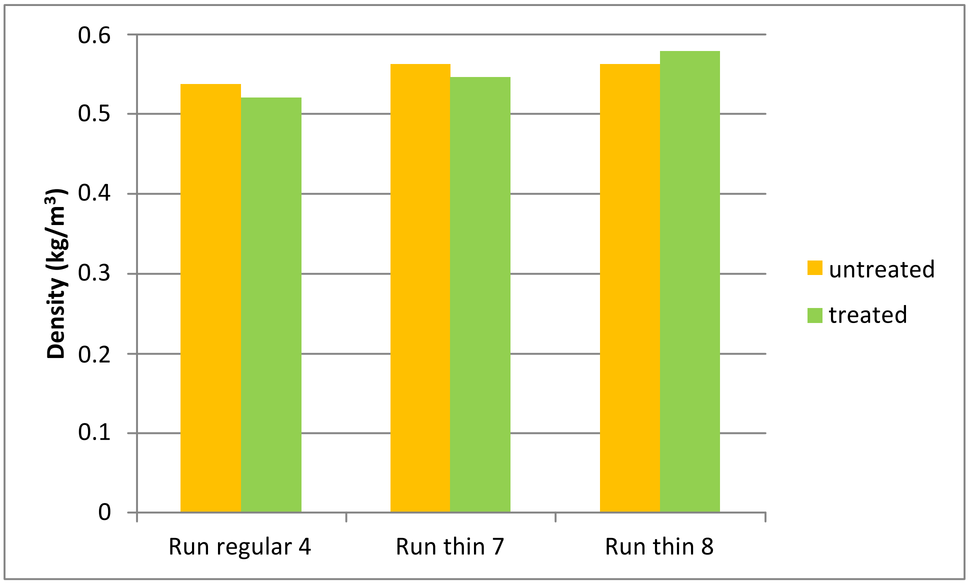

Figure 2. Bulk density of larch in the air dry state, untreated and after mild thermal modification treatment.

The density variation between planks was relatively large, and this related to the variation in levels of juvenile wood within the sampled planks. The timber had been sawn through and through, resulting in boards with either high mature wood or high juvenile wood content. The number of growth rings per inch (rpi) of the planks also showed wide variation. In the first study, values of 2.8 to 9.0 rpi were reported for timber from one supplier (Spear et al. 2015a). This data correlates to Run regular 4 in Figure 2. In later work with timber from a second sawmill, values ranged from 5.08 to 17.78 rpi, for timber which contained a greater proportion of mature wood, and had been sourced from a slower grown stand. In a third study on the timber used in the full scale production, which ws sourced from a different sawmill and another region of Wales, values between 5.08 and 26.67 rpi were observed (this correlates with Runs 7 and 8 in Figure 2). In producing batches of mild thermally treated timber for some applications, segregation of mature wood planks could be beneficial. However, the rpi values for the majority of the timbers sampled, even those containing mature wood, were lower than would typically be expected for Alpine grown European larch (*Larix decidua*) or Scandinavian grown Siberian larch (*Larix siberica*).

A large number of parameters were used in evaluating the timber quality from each treatment run, and observing variability within the stack of timber relating to hot and cold spots within the oven, especially during early runs on the pilot scale oven. For example distinct regions of high colour change and low moisture content were seen on the side from which the hot air was circulating. Thermocouple data for each plank confirmed that rate of temperature increase and duration in the treatment zone was higher for these timbers. Mechanical and physical properties were assessed on a plank by plank basis across the kiln an ideal 'mild' thermal treatment and 'moderate' thermal treatment were defined. Further adjustments to the kiln schedule and air flow allowed the mild thermal treatment to be achieved in a uniform manner across the whole stack of timber.

Company trials and demonstrators

After selection of the optimum treatment conditions, the parameters were transferred to the full scale kiln, and temperature within the stack and within the air was monitored to allow comparison with the pilot scale experimental work. The rate of heating and the air flow (controlling distribution of heat within the stack) were adjusted to suit the larger volumes of timber within the kiln. The product was a moderate not mild treatment, however this also remained below the treatment bracket of DD CEN/TS 15679.

Figure 3. a) Unloading mild thermally treated larch from the scale up treatment kiln. d) Planks were successfully laminated together and machined in a 4-head cutter. Photo credit Morwenna Spear.

A range of joinery and furniture items was made using both the mild and the moderate treated timbers, by companies within the project consortium. A laminated moulding for a window frame, using mild treated larch, is shown in Figure 3b. The ability to laminate thermally modified planks together to form a suitable cross section work piece for mouldings was seen as high priority by the project consortium, to allow the timber to be used in a wider range of products. Surface quality of the mouldings, and the routed profiles made by different companies, was good, with relatively little breaking of the grain.

A range of different products were manufactured (Figure 4), utilizing many different bonding and jointing techniques. Both PVA and isocyanate based glues worked well in the workshop. Occasional problems were reported for nailed or screwed joints if located close to the edge of the piece. This appeared to relate to weakness at the early-wood-latewood interface. The products took paints and varnishes well, and the relatively light colour of the treated product was seen as a benefit, and meant that varnishes and stains were often chosen to finish products.

Figure 4. The thermally treated larch was used to make various interior joinery products, demonstrating the smooth machined surface and natural colour of the timber. Photo credits: Phil Jones.

Dissemination was an important aspect of the project, and the timber was shown at several events to gain comments from additional companies and the general public. Working with two of the project partners further demonstration activities were undertaken, with full scale production continuing to supply timber for a new build factoray and visitor centre at a local tourist attraction (Figure 5b).

Figure 5. a) Display stand in Coed Cymru's Ty Unnos Pavilion at the Royal Welsh Show, Builth Wells, Powys. b) Cladding installed at a visitor attraction on Anglesey as a demonstration project. Photo credits: Morwenna Spear.

Summary and Conclusions

The project worked with small businesses within Wales, to develop a protocol for mild thermal modification of larch timber. The timber retains a natural appearance, which was widely accepted in demonstrator events and discussion with the timber industry. The mild modification does not alter durability, but does significantly reduce machining defects relating to the wide growth rings and large difference in density between earlywood and latewood within each growth ring. The benefits are a smooth, easily worked timber suitable for interior joinery. The process was designed to best suit small enterprises, and to be suitable for enterprises with a very small work force. The next steps are to enagage with sufficient companies to increase product throughput and develop a market within the UK.

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Properties of Southern Pine Modified with Melamine Formaldehyde Resin[1]

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ABSTRACT

The objective of this preliminary study was to evaluate the influence of different levels of melamine formaldehyde (MF) and curing cycle on mechanical properties of southern pine. Thirty samples for each combination of treatment and curing regimen plus untreated controls and controls subjected to the same curing regimen were tested. Samples were than tested in bending using an ASTM D143 (2012) standard. ANOVA was performed to analyze the main effects and the interaction between concentration and curing cycle using a generalized linear model and Tukey's test (〈 = 0.05) for mean separation. There was a significant interaction between levels of melamine formaldehyde and curing cycle for modulus of elasticity (MOE) and modulus of rupture (MOR). The 15% and 20% MF cured at 120°C for 48 hours were statistically higher in MOE. For the 120°C curing temperature, MOR was significantly better or equal to the controls. The 15% and 20% MF cured at 103°C for 24 h were significant lower either for MOE and MOR.

Keywords: modulus of elasticity, modulus of rupture, chemical modification, melamine formaldehyde resin, southern pine

INTRODUCTION

Wood is a biological material that has been used for buildings, construction and furniture because of its properties such as appearance, strength and thermal properties. However, some properties such as dimensional instability and low natural durability of some species are perceived as a negative characteristic of this material. Chemical modification is a promising way to improve wood properties (Gindl et al, 2003). Rowell (2006) defines chemical modification of wood as a reaction of a reactive part of wood with a reactive chemical, with or without catalyst, to form a covalent bond between the two.

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Melamine-formaldehyde (MF) are resins synthesized from formaldehyde and melamine through a condensation reaction (Park et al. 2009). Because of its properties, i.e. high hardness and stiffness, and low flammability MF it is widely used in decorative laminates, molding compounds, adhesives, coatings and other products resins have potential to improve properties of solid wood (Inoue et al., 1993; Deka et al, 2002).

Deka et al (2002) studied the influence of urea formaldehyde (UF), melamine formaldehyde (MF) and phenol formaldehyde (PF) in mechanical properties of Anthocephalus cadamba (Roxb) Miq., and there was no significant improvement in strength and stiffness after treatment with these resins. Lopes et al. (2015) studied the mechanical properties of Pinus pinaster chemically modified with N-methylol melamine formaldehyde and found a reduction in MOE and MOR after treatment. Leng and Barnes (2012) showed a significant increase in MOE and MOR for steam-pressed pine scrim panels treated with 5% MF resin.

The objective of this study is to examine the influence of melamine-formaldehyde (MF) impregnation on the strength and stiffness of southern yellow pine in static bending.

MATERIALS & METHODS

Materials

For this study southern pine samples measuring 25 x 25 x 40 mm (tangential x radial x longitudinal) were treated with two levels (15%, 20%) of melamine formaldehyde resin (MW=840) with 4% proprietary additives and cured at two temperatures for different time periods (103°C for 24 h, 120°C for 48 h). A total of five groups with different treatment and curing regimens plus two untreated controls groups undergoing the same curing regimen were tested. A third untreated control group without undergoing any curing regimen was included. Thirty samples for each combination were tested. Samples we assigned to treatment groups such that all seven groups had the same density distribution. Treatment and curing cycles are given in Table 1.

Treatment and testing

Samples were placed in a small pressure retort and covered with treating solution. A 30-min vacuum (4 kPa) followed by a one-hour pressure cycle at 1034 kPa was used to treat the samples. Samples were wiped free of excess treating solution and weighed to determine solution uptake. Retention of active ingredient was calculated based on solution strength and uptake. The curing cycle (Table 1) was then applied to the treated samples. Following conditioning to ambient conditions, samples were tested in bending following the ASTM D143 (2015) standard with one exception. The speed of testing was doubled to 2.5 mm/min. SAS 9.4 was used to conduct the ANOVA and treatment means were compared using a Least Squares analysis (〈 = 0.05).

Table 1. Study design

Treatment[1]	Curing Temperature (°C)	Curing time (h)
15% Melamine	103	24
20% Melamine	103	24
Untreated control	103	24
15% Melamine	120	48
20% Melamine	120	48
Untreated control	120	48
Untreated control	None	None

RESULTS AND DISCUSSION

The results of bending test are shown in Table 2. The interaction between treatment and curing cycle was significant for MOE ($p < 0.0001$) and MOR ($p < 0.0001$). The influence of temperature and curing cycle was significant for MOE ($p < 0.0001$).

Table 2. Bending test of southern pine modified with melamine formaldehyde

Treatment[1]	Curing Cycle	MOE (GPa)[2]		CoV[3]	MOR (MPa)[2]		CoV[3]
15% Melamine	103°C, 24 h	8.0	C	10.8	70.4	D	13.0
15% Melamine	120°C, 48 h	10.8	A	10.2	94.4	A	15.3
20% Melamine	120°C, 48 h	10.8	A	7.8	88.6	BC	16.7
20% Melamine	103°C, 24 h	8.0	C	11.0	74.2	D	12.6
Untreated control	120°C, 48 h	9.8	B	11.1	92.2	ABC	12.3
Untreated control	103°C, 24 h	9.8	B	10.7	94.3	AB	11.0
Untreated control	None	9.3	B	11.0	87.3	C	12.1

[1] Melamine treatments include 4% additives; [2] Values followed by a different letter within a column are statistically different according to ANOVA and Least Squares comparison ((= 0.05); [3] Coefficient of Variation

There was a significant difference between treatments for both parameters evaluated. The groups of 15% and 20% MF cured at 120°C for 48 h were significantly higher for MOE, with an average of 10.8 MPa for both groups, while the 15% and 20% MF cured at 103°C for 24 h had a significantly lower value for MOE (8.0 MPa for both groups). There was a significant improvement for 15% and 20% MF cured at 120°C for 48 h on MOE after treatment. The average value of MOE of groups two and three was 11 % higher than untreated control groups (untreated control subjected to the same curing regimen). And compared to groups one and four, the difference was even higher, up to 25%.

For MOR, 15% MF (70.4 GPa) and 20% MF (74.2 GPa), both cured at 103C for 24 h, were also significantly lower compared to the other groups. However, there was no significant difference between the other combinations of concentration and curing cycle and control groups. The average of MOR for groups one and three is 21% lower than average of the other groups.

The samples cured at 103 °C for 24 h for both MF concentrations showed no improvement in MOE and MOR. Both groups were statistically in MOE and MOR, even lower than the control groups.

No and Kim (2004) studied the effect of resin formulation, catalyst, and curing temperature on particleboard binder type urea-formaldehyde (UF) and melamine-modified urea-melamine-formaldehyde (UMF) resins using dynamic mechanical analysis method at 120 -170°C. The results showed that curing temperature of 120 - 170°C were able to optimize resin formulation, catalyst level and mix time, and curing temperature and time. Lukowsky and Rapp (1998) found that a sufficient curing for melamine formaldehyde resin requires temperatures in the range between 120 - 140 °C for a period of several hours.

SUMMARY AND CONCLUSIONS

There was a significant interaction between levels of melamine formaldehyde and curing cycle. The 15% and 20% MF cured at 120°C for 48 h had a positive effect on MOE, which both groups presented a significantly higher value of MOE compared to the other groups. The modification made on southern pine had no significant improvement for MOR. The 15% and 20% MF cured at 103°C for 24 h were significant lower for MOE and MOR. This suggests that the curing-time and curing-temperature was insufficient to cure the resin properly.

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Session

Bio-Composites

Moderators:
Jerry Winandy, University of Minnesota, USA
Rupert Wimmer, BOKU, Vienna, Austria

Multi-scale Investigation of Adhesive Bond Durability

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Abstract

Moisture durability is essential for wood composite products, especially those used in building construction, where products are prone to weathering. The main focus of this research is to determine if adhesive penetration into the cell wall has a positive influence on bond durability. This study uses bonded Douglas-fir test specimens varying in bonded surface cell type (earlywood vs. latewood), bonded surface orientation (longitudinal vs. tangential), and adhesive type (low and high molecular weight phenol-formaldehyde, and a polymeric diphenylmethane diiscoyanate). Half of each type of test specimen undergoes accelerated weathering and the rest remain dry. All samples are mechanically tested in lap shear. The stress and strain around the bondline are measured using Digital Image Correlation (DIC). Smaller samples (2mmx2mmx10mm) are cut from the previously tested samples and scanned at the Advanced Photon Source (APS) using micro X-ray Computed Tomography (XCT). Samples are then sectioned down to a 50 micron by 50 micron area where we identify adhesive penetration into the cell wall from the micro-XCT data. These samples are scanned a second time on a higher resolution beamline at the APS. This technique gives high resolution (1.3µm3/voxel and better), 3D images where cell wall penetration can be analyzed at the nanometer scale. The mechanical test results, DIC results, and XCT images will be compared and used to quantitatively measure effects of moisture on the bondline.

Recycling Wood Waste from Construction Sites: Part 1: Manufacture and Characterization of Blockboard

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Abstract

The aim of this work was the production and characterization of blockboard using wood wastes from construction sites. The collection of discarded used wood pieces was made during and after the completion of building construction sites defined by CEPLAN (Planning Center at the University of Brasilia-UnB). Wood pieces were cut from the waste woods in dimensions of 30x12 mm (width and thickness) and varying lengths of 200, 300, 400 and 600 mm and glued laterally and longitudinally for producing panels of 600x600mm. Subsequently, these panels were laminated with two wood veneers on each side of the panel into blockboards. The physical and mechanical properties of the panels were evaluated. The blockboard produced in this study showed satisfactory results and proved to be a good alternative for the reuse of waste timber from building construction, but it is recommended that a study be done on the economic viability of production.

Key words: civil construction; waste timber; blockboard.

Introduction

The publication Outlook of the Solids Wastes in Brazil (Abrelpe 2014) reports that 78.6 million tons of Municipal Solid Wastes (MSW) were generated nationwide in 2014. On the other hand, the research shows that municipalities collected 45 million tons of construction and demolition wastes (CDW), a 4.1% increase over 2013.

Wood is used in various ways in the construction and demolition sites and can be used temporarily as concrete forms, scaffolding and load bearing columns, or incorporated in the final construction, as wood trusses and others, ceilings and flooring and in framing structures (doors and windows). According Zordan (2015), the wastes generated in construction places is formed in larger fraction of mass by non-mineral materials (wood, paper, plastics, metals and others).

The CDWs originate from construction of new houses/buildings, renovation and demolition processes and according to Angulo (2001), recycling of these wastes are still in small amounts in Brazil, except for the recycling accomplished by the cement and steel industries.

Studies on the use of solid wood waste for the production of reconstituted panels such as MDP has been published (Iwakiri et al. 2012; Weber 2011; Weber and Iwakiri 2015), however, published articles on plywood type blockboard are infrequent. The production of blockboard consists on forming the central part of the panel (core) with lumber (strips, battens) glued laterally into panels, and then finish coating the panel by bonding veneers (one or more) on both faces (Iwakiri 2005).

Studies that assessed the recycling of wood wastes from construction and demolition are still very rare in the literature. In the case of wood wastes, the production of blockboard becomes a good option, especially for smaller pieces, which are usually discarded into landfills. According to the report 39 of UFLA Edition (Mendes 2015), the use of such waste for making blockboard add value by utilizing this material as strips or battens in the core of the panel, but one should take into account that not all pieces can be used since it would increase the cost of preparing the joints, due to the increase in planning operations and joints of the battens.

According to Chamma (2004), board production with application of wastes from different sources can contribute to meeting the demand for wood based panels and to promote the proper final disposal of the wastes and, yet, generate materials that preserve the natural resources, and indirectly contribute to the objectives of the National Policy on Solid Wastes.

Considering the significant volume of wood and wood-based products generated as CDW and aiming their use into final products, the objective of this research was the production and characterization of blockboard using wood residues discarded from construction sites.

Materials & Methods

Wood residues processing:
The discarded pieces of wood wastes were collected during and after completion of civil construction works defined by the Planning Center at the University of Brasilia-CEPLAN/UnB. The wood pieces were those that would be destined for recycling within the University's Solid Wastes Management Program in Construction Sites. The wood was collected by sampling the different forms and dimensions used temporarily in the construction, such as strips, lumber and small diameter logs (Figure 1). The residues selected were processed and allocated to this work.

Strips of the following wood species were identified and used in the blockboard production:

- Açoita-Cavalo - *Lueheopsis duckeana*; Amapá Doce - *Brosimum potabile*; Angelim-vermelho - *Dinizia excelsa*; Cabelouro-da-caatinga - *Lonchocarpus sericeus*; Cedrinho - *Erisma uncinatum*; Copaíba - *Copaifera* sp.; Jequitibá-Rosa - *Cariniana* sp.; Louro-Amarelo - *Licaria rigida*; Melancieira - *Alexa grandiflora*; Tauari - *Couratari* spp.; Taxi - *Tachigali* spp.ou *Sclerolobium* spp.

Figure 1. Various types of wood wastes collected (left) and visual aspect of wood strips for blockboard production (center); and after planning (right). Photos: author.

The residues were processed according to the assembled product. Nails, wires and the like were removed manually and then the pieces contaminated with cement were machine processed. They were first sanded to remove impurities, then processed in a wood thickness planer and graded according to quality (defect, knots, holes, etc.) and then sawn aiming at creating standard sizes and dimensions according to the type of waste.

A total of 281 wood strips were processed, being 33 with density up to 0.60 g/cm³ and 248 with densities greater than 0.60 g/cm³. The material was stored in a conditioning room under controlled conditions of temperature (20±3)°C and relative humidity (65±5)%, up to constant mass. The objective was to achieve a moisture content of approximately 12%, ideal for bonding. Wood strips of 30x12 mm (width and thickness) and lengths of 200, 300, 400 and 600 mm were then cut. For the manufacture of the blockboard it was established a standard size according to the dimensions and wood waste sections available as shown in Figure 2.

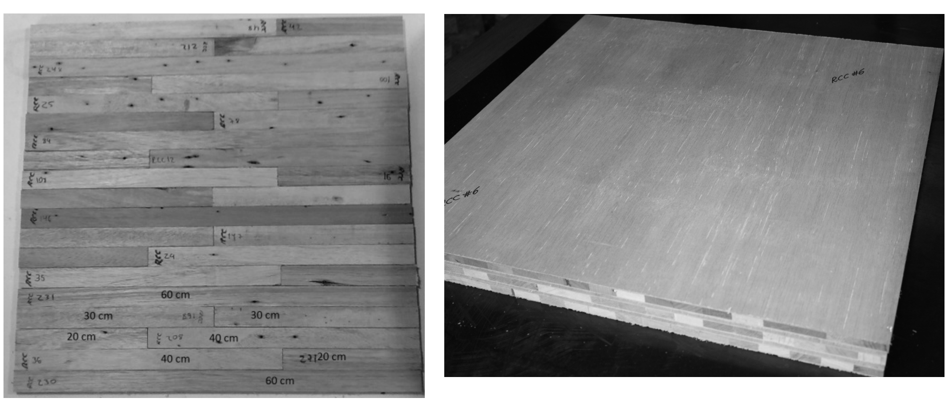

Figure 2. Core panel of 600x600 mm with 600, 400, 300 and 200 mm long wood strips (left) and blockboard assembled (right). Photos: author.

Blockboard manufacturing
Two different adhesives were used for bonding:

Polyurethane (PU): Cascola PU adhesive from Henkel Co. is an adhesive based on polyurethane prepolymer, especially suitable for structural and waterproof applications, classified as D-4 according to the standards EN 204 and EN 205. With pH between 4.0 and 5.0, density 1.12 g/cm³ at 20°C, Brookfield viscosity between 7000 and 9000 cP at 20°C and solids content of 100%, and;
Polyvinyl acetate (PVA): Emulsion of polyvinyl acetate (PVA) from Pidilite Co., Solids content of 56% to 60%, pH (at 25°C) between 6.0 and 8.0, Brookfield viscosity (Sp6/20rpm/25°C) between 10,000 and 14,000 mPa.s.

The procedure for both adhesives was the same, with respect to the manufacturer's instructions as to the way of use and gramature. The gramature used for PU adhesive was 150 g/m², minimum weight according to the manufacturer, for all bonds of the process. The gramature used for the PVA was 200 g/m².

The selection of wood strips for each panel and position within the panel was taken randomly. The adhesive was first spread on the top of the strips, pressed with clamps until the adhesive curing time, and then glued laterally following the same procedure. After the curing time of the adhesives the panels were sanded to remove the excess of adhesive for subsequent bonding of the face veneers.

The panels were face veneered with two veneers of amapá (*Brosimum parinarioides*) on each side with nominal dimensions of 600x600x0.55 mm. The first veneer was glued with the grain direction perpendicular to the grain of the core panel and the second parallel. The core panel and veneers were then pressed at room temperature and pressure of 1.5 MPa and the final blockboard conditioned in a controlled condition room. The final average thickness of the blockboard was 12.6 mm. The pressing time varied according to the adhesive manufacturer specifications.

Blockboard testing
The evaluated physical properties of the blockboards were moisture content (TU), apparent specific mass (MEA), water absorption (AA) and the thickness recovery (RE), and swelling plus thickness recovery (RT). The mechanical properties evaluated were static bending (modulus of rupture-MOR and modulus of elasticity-MOE) and shear strength in the glue line (RLC) and percentage of wood failure.

The specimens were conditioned under controlled conditions of temperature (20±3)°C and relative humidity of (65±5)% to reach equilibrium moisture content of approximately 12%.

Evaluation of the physical properties of blockboards
Determination of the moisture content
The specimen moisture content was conducted according to the NBR 9484 standard (ABNT 2011) for plywood. Six specimens were used per panel.

Determination of the apparent specific mass
The panels were tested according to the NBR 9485 standard (ABNT 2011) for plywood.

Determination of water absorption
The panels were tested according to the NBR 9486 standard (ABNT 2011) for plywood. It was used 48 specimens with dimensions of 75x25x9 mm in length, width and thickness of the panel, being 24 specimens with PU adhesive and 24 with PVA adhesive, 12 parallel and 12 perpendicular to the grain of the battens.

The samples were subjected to the following procedures:

1) Drying in oven for 24 hours at (50±2)°C; 2) Cooling in desiccator; 3) Weighting in a scale; 4) Immersed in distilled water at constant temperature (25±2)°C for 24 hours; 5) Quickly wiped dry on paper towels; and 6) Weighting again.

Recovering in thickness (RE) and swelling plus recovery in thickness (IR)
The specimens were tested according to the NBR 9535 standard (ABNT 2011). Twelve specimens of 86 x 22 mm per panel were tested, totaling 48 specimens, 24 with adhesive PU and 24 with PVA adhesive. These specimens were separated into two series of six per panel, one series used as control. The samples were placed in room conditioning under controlled conditions of temperature (20±3)°C and relative humidity of (65±5)% to reach constant mass.

After the first measurement of thickness in the central part of each specimen, control samples were dried in an oven at (103±2)°C for 24 hours, removed and cooled in a desiccator and measured again. The other series of test specimens were immersed in distilled water at (20±2)°C for 24 hours. After this time, the thickness of the specimens were measured, and, soon after, the samples were dried in an oven at (103±2)°C for 24 hours, removed and cooled in a desiccator and measured again.

Evaluation of mechanical properties of the blockboards
Static bending
The Static bending testing was conducted in accordance with European standard EN 310 (1993) for wood-based panels. A total of 12 specimens per panel, six in each grain direction, were cut with dimensions of 50 x 12.65 x 290 mm (WxTxL) and tested. The tests were executed on an Instron testing machine with a span of 255 mm and speed of 9.0 mm/min.

Shear test in the glueline
The blockboards were cut into specimens as illustrated in Figure 3 and tested in accordance with European standards EN 314-1 (2004) and EN 314-2 (1993) for plywood, since the Brazilian standard does not have provisions for the shear test in the glue line for blockboard. Sixty four specimens with the dimensions of 100 x 25 x 25 mm were tested. Of these, 36 tested samples were taken from panels glued with PU adhesive and 28 with PVA. For the specimens with the PU adhesive, 16 were assigned to the dry test (12%

moisture content) and 20 for the water boiling test (boiling and drying cycle), and for those with PVA adhesive 16 were allocated to dry test and 12 to the wet test (24 hours immersed in cold water).

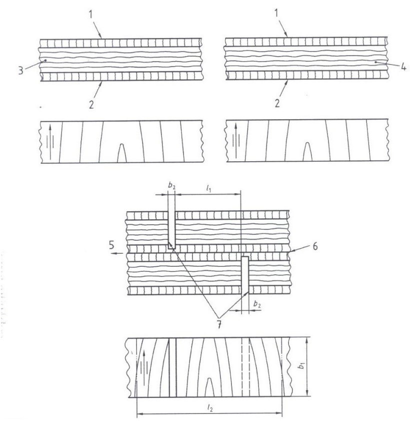

Figure 3. Specimen of quality bonding test. Standard EN 314-1.

Legend:

1) Face; 2) Counterface; 3) Part 1; 4) Part 2; 5) Faces of Part 1 and Part 2; 6) Glue Line, not subject to shear stress; 7) Saw cuts throughout the face layers; b_1 = shear width (25±0.5) mm; b_2 = saw cut width (2.5 to 4 mm); l_1 = shear length (25±0.5) mm; l_2 = minimum distance between clamps (50 mm).

The specimens for testing were glued under room temperature at pressure of 12 kgf/cm² (1.18 MPa) and gramature of 150 g/m². The tests were performed in an Instron testing machine at a speed of 6.0 mm/min.

Statistical analysis
The average values of physical and mechanical properties of the panels were compared with the literature. The properties of the panels were compared taking into account the following factors: type of adhesive and position into the panel relative to the grain of the wood strips, depending on the test. It was calculated the average and the standard deviation of the panels manufactured for each position in the panel and separated by adhesive type. Subsequently, the averages were submitted to analysis of variance *t* test to establish whether there were statistically significant differences among the factors studied

Results and Discussion

Evaluation of the physical properties of the blockboards
The mean values of physical properties of the blockboards for both adhesives are presented in Table 1

Table 1: Physical properties of blockboards with PU and PVA adhesives.

Adhesives	MEA* (g/cm³)	TU*	AA24h*	IR*	RE*
		---- (%) ----			
PU	0,762 (0,040)	12,3 (0,26)	14,75 (7,51)	2,02 (1,75)	4,67 (1,38)
PVA	0,733 (0,028)	13,3 (0,38)	25,01 (8,77)	5,42 (1,29)	6,88 (1,43)

(*) statistically significant at the 0.05 level, in the test; TU = moisture content; MEA = Apparent specific mass (12%); AA = water absorption; IR = Swelling plus recovery in thickness; RE = Recovery in thickness; number in parenthesis is the standard deviation.

Moisture content

The moisture content values were close to 12%. Cabral (2011) obtained moisture content values (TU) of 11.53% for veneer plywood panels of *Pinus taeda* and Bortoletto Jr. (2003) reported values for phenolic bonded 10-mm-thick panels, made with 11 *Eucalyptus* species, ranging from 9.21% for *Eucalyptus maculata* to 10.24% for *Eucalyptus saligna*. According to the National Program of Wood Quality (PNQM) the results are within the maximum value of 18% required for moisture content.

Determination of apparent specific mass

The values of apparent specific mass (MEA) presented in Table 1 show a significant difference between the means. The PU bonded panels had the higher MEA. This result was expected, since this adhesive has higher solids content than the PVA. Bortoletto Junior (2003) obtained higher mean values for 10-mm-thick phenolic bonded veneer plywood of 11 species of eucalyptus, ranging from 0.783 (*E. saligna*) to 0.999 g/cm³ (*E. citriodora*).

Water absorption

According to the mean values, the panels with PVA adhesive, which is not water resistant, presented the higher water absorption (AA) after 24 hours. Bortoletto Jr. (2003) reported values ranging from 17.51% (*E. tereticornis*) to 36.79% (*E. torelliana*), with phenolic adhesive, that is non-hygroscopic.

Recovering in thickness (RE) and swelling plus recovery in thickness (IR)

According Cabral (2011), the thickness swelling of the plywood panel is the result of two components: the swelling due to water absorption and release of stress caused by pressing. Factors affecting swelling are pressing time, pressing temperature and type, proportion and adhesive formulation used.

It can be observed from Table 1 that there is a significant difference of IR for the two adhesives. The panels with the PVA adhesive showed an IR higher than the panels with PU. Cabral (2011) observed for 4- and 5 mm thickness veneer plywood bonded with urea-formaldehyde values of 6.75%, higher than those found in this study.

There was a significant difference between the means of RE for the two adhesives. The panels with the PVA adhesive showed a higher RE than panels with PU. The results show that the panels had good dimensional stability

Evaluation of mechanical properties of the blockboards

Static bending

The average values of MOR and MOE parallel and perpendicular to the fiber direction in static bending are shown in Table 2.

Table 2: Modulus of rupture (MOR) and modulus of elasticity of the blockboards with PVA and PU adhesives in the parallel and perpendicular to the grain directions.

Adhesives	MOR // ^{ns}	MOR ⊥*	MOE //*	MOE ⊥*
	(MPa)			
PU	89,51 (24,57)	35,32 (6,29)	10.047 (1857)	3.436 (224)
PVA	75,21 (14,73)	27,23 (6,95)	8.358 (1080)	2.402 (662)
ABIMCI**	37,4	24,8	6.761	2.782

(^{ns}) not statistically significant at the 0.05 level, in the test; (*) statistically significant at the 0.05 level, in the test; (**) Average standard value for pinus veneer plywood, 5 layers, thickness of 12mm, external use (ABIMCI 2002); MOR/MOE = Modulus of rupture and elasticity, parallel e perpendicular to grain of the battens; number in parenthesis is the standard deviation.

The MOE and MOR values parallel to the fibers direction were higher than those perpendicular. The ratios of MOR in parallel/perpendicular direction are respectively 2.5 and 2.8 for the PU and PVA adhesives and 2.9 and 3.5, respectively, for the MOE. There was no significant difference between the adhesives, for MOR parallel to the fibers direction. For the other properties it was observed statistically significant difference between the adhesives, with higher average values for panels bonded with PU adhesive.

Laufenberg et al. (2006) produced blockboard similar to this study, with faces veneered with ekaba (*Tetraberlinia bifoliolata* Harms.) treated with fire retardant products and core battens of fir (*Abies bornmulleriana* M.) without treatment. The battens were bonded with PVA and the veneers with phenol formaldehyde. The results of MOR ranged between 45.69 and 48.16 MPa for the condition parallel to the fibers and between 35.54 and 37.52 MPa for the perpendicular. The MOE values ranged between 3,114 and 3,928 MPa for the parallel and between 2,303 and 2,779 to the perpendicular direction. Compared to the results obtained in this work, all results obtained by Laufenberg et al. (2006) were lower, exception only for the perpendicular MOE.

Cabral (2011) informed values for *Pinus taeda* 5-mm-thick veneer plywood of 47.40 and 5,765 MPa for MOR and MOE parallel to the fibers, respectively, and 18.56 and 957

MPa for MOR and MOE perpendicular, values that are lower than those found in this study.

Bortoletto Junior (2003) obtained values for veneer plywood ranging from 84 MPa (*E. saligna*) to 130 MPa (*E. pilularis*) and 12,336 MPa (*E. saligna*) to 19,331 (*E. urophylla*) to MOR and MOE parallel to the fibers, respectively. MOR and MOE perpendicular to the fibers found by the same author ranged from 46 MPa (*E. saligna* and *E. microcorys*) to 64 MPa (*E. citriodora*) for the MOR and 3,419 MPa (*E. torelliana*) to 5,487 MPa (*E. citriodora*) to the MOE. This means are higher than those found in this study. In another article Trianoski et al. (2015) produced 10-mm-thick plywood with 5 layers of *Melia azedarach* and attained MOR values ranging from 30.61 to 76.7 MPa and the MOE between 2,266 and 8,071 MPa, in both directions

Comparing the results obtained in static bending tests to the DIN 68705-3 standard (1981), which establishes only the parallel and perpendicular MOR of 40 MPa and 15 MPa, respectively, we conclude that the blockboard can be recommended for structural use. As for the DIN 68792 standard (1979), both blockboard meet the requirements for use as concrete form.

Shear in the glueline

The mean values obtained in the test of resistance to shear in the glue line (RLC) in the dry, wet and after water boiling tests and the average values of wood failure (%) for the PU and PVA adhesives are shown Table 3.

Table 3: Means of the bonding quality in the glue line and wood failure in the dry, wet and boiling test of PU and PVA adhesives.

	Dry[1]		Wet (PVA)[2] e Boiling (PU)[3]	
Adhesives	RLC (MPa)	FM (%)	RLC (MPa)	FM (%)
PU	8,01 ns (2,01)	21 ns	0,20 ns (0,045)	64*
PVA	7,98 ns (1,29)	28 ns	0,19 ns (0,073)	20*

([1]) at 12% moisture content; ([2]) after 24h water immersion (only PVA bonded panels); ([3]) after 24h water immersion, 6h water boiling plus 1h in cold water (only PU bonded panels); (ns) not statistically significant at the 0.05 level, in the test; (*) statistically significant at the 0.05 level, in the test; RLC = resistance to shear in the glueline; FM = wood failure; number in parenthesis is the standard deviation.

The values of RLC test in the dry condition were well above the average standard of 28 kgf/cm² (2.74 MPa) specified in the plywood Technical Catalog (ABIMCI 2002) for panels of pinus with 5 layers and 12 mm thickness.

Ferreira et al. (2012) tested three PVA adhesive formulations for producing plywood panels of *Eucalyptus* sp. and obtained values between 2.61 and 3.58 MPa in the dry test, well below those achieved in this study.

The wet tests with PVA adhesive and water boiling with PU specimens follow the methodology of EN standards depending on the type of use and resistance to moisture.

The values of the wet test were inferior to the minimum standard presented by the plywood Technical Catalog (ABIMCI 2002) for panels of pinus with 5 layers and 12 mm thickness that is 10 kgf/cm² (0.98 MPa).

Silva (2010), cited by Cabral (2011) found 17.61 kg/cm² (1.73 MPa) of RLC for *Pinus* sp. phenol-formaldehyde bonded panels. Bortoletto Junior (2003) found RLC values ranging from 23.5 (2.3 MPa) (*E. torelliana*) to 27.4 kg/cm² (2.7 MPa) (*E. citriodora*). For both studies, values are lower than those found in this study. Cabral (2011) also reported a mean of 0.2 MPa for average RLC values of the wet test for different positions in the urea-formaldehyde bonded veneer plywood. Panels bonded with phenol-formaldehyde presented average of 0.4 MPa.

The purpose of the shear test is to evaluate the glue line quality and define the plywood according to the condition of use, or whether it may be recommended for dry interior use (estimated in the dry test), intermediate (estimated in the wet test) or covered exterior (estimated by the water boiling test). Thus, the average value of the combined stress at rupture with the average percentage of rupture (failure in the wood) should not be less than the limit specified in Table 4 according to EN 314-2 (1993).

Table 4: Requirements of bonding resistance and wood failure for veneer plywood.

Resistance to shear in the glueline	
Mean shear strength (TR) kgf/cm² e (MPa)	Mean apparent cohesive wood failure (%)
2,0 (0,2) ≤ TR < 4,1 (0,4)	≥ 80
4,1 (0,4) ≤ TR < 6,1 (0,6)	≥ 60
6,1 (0,6) ≤ TR < 10,2 (1,0)	≥ 40
10,2 (1,0) ≤ TR	No requirement

Source: EN 314-2 (1993)

Comparing the mean values of rupture and the percentage of wood failure obtained in this study with the minimum values shown in Table 4, it is observed that the blockboards studied with the two evaluated adhesives largely meet the criteria established for the dry testing, including wide safety margin and may be suitable for interior use. As for the intermediate and outdoors use (more severe condition of use) the panels tested did not meet the established criteria, since they should have FM equal or higher than 80%.

Relating the values obtained in this study with the plywood Technical Catalog (ABIMCI 2002), it appears that dry test was below the minimum requirement of 33% failure and comparing with the values obtained in the wet test, it turns out that they were above the reference of 9% wood failure. Adhesive PU base despite not meeting the requirement in the post-boil test (Outdoor use) probably will meet the criteria for intermediate use.

Summary and Conclusions

Based on the results of this study, the following conclusions can be made:
The higher average absorption was observed in panels with PVA adhesive, which is not water-resistant. The panels bonded with PVA adhesive showed higher RE than panels with PU. According to the results obtained in resistance to shear in the glueline, the blockboard may be used only indoors, since they did not meet the established conditions for intermediate and exterior use. The panels presented high strength by the MOR and MOE, superior to several other studies of plywood and can be recommended for structural use. The blockboard produced in this study showed satisfactory results and proved to be a good alternative to reusing wood waste from civil construction, however it is recommended that the economic viability of production be assessed.

Acknowledgements

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Connecting Wood and 3D Printing

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Abstract

3D printing is an emerging technology, with interest greatly increased since 2013. With 3D printing high part complexity at no additional costs are possible, beside of being ressource efficinet and „green". This contibution reviews recent developments in 3D printing with respect to possible applications with wood. Examples are given on how wood could come to 3D printing, i.e. development of bio-based filaments, printing of wood-like 3D objects, and perform „self-replication" of wood by a combination of 3D printing and microtomography. Bio-based printing filaments require extremely fine wood powder, to ensure homogenious printing processes without nozzle-blocking. Wood-like appearance seems to be of higher priority than the wood-based content itself. The idea of „wood self-replication" is introduced, fostering bio-inspired materials research and biomimetics. Wood-related 3D will have a future, but will also occupy most likely „niche market" only, with e.g. complex-shaped wood products

Session

Marketing, Policy and Strategy

Moderators:
Henry Quesada-Pineda, Virginia Tech USA
Marcelo Wiecheteck, STCP Engenharia de Prejetos, Ltda, Brasil

The Environment for Innovation within the New Zealand Forest Sector

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Abstract

New Zealand's export-oriented forest sector generates 3% of New Zealand's GDP. Structural changes over the past three decades have created separation between growing and processing. The resource mix is changing as new, smaller woodlots come on stream and more established forests are reverting back to agricultural use. The properties and characteristics of the new resource is unknown, creating a market need for tools that establish the properties of the emerging timber resource, and can assign the resource to optimum processing pathways. Tools development requires industry market demand, which is presently very limited, and will not eventuate without the awareness that the quality of the resource matters to utilisation potential. When demand occurs, the system must already be structured to enable smooth and swift implementation and uptake. The nature of structures and functions that support tools development and adoption is still largely unknown. Our traditional technology transfer approach was largely based on a series of research cooperatives. Lately, research efforts have taken a co-innovation approach to involve a network of actors from across the value chain, and enable closer interaction between growers and processors. This paper outlines preliminary findings into a study of the nature of the forest sector innovation system in New Zealand in terms of structures and functions at work that inhibit or enable networking for co-innovation between growers and processors.

Roadblocks, Hurdles, and Glass Ceilings: The Female Executive Perspective

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Abstract

The North American forest sector is well-known for its lack of diversity. In most operations, middle-aged white males are the majority of employees. Given this setting, we investigate the experiences of female executives working in North American forest sector firms. We take a qualitative approach with in-person and Skype interviews of female executives in both large and small forest sector operations. We attempt to assure representation from various specialties and geographies. Interview questions will cover the atmosphere of the interviewee's company and sector, the advantages and disadvantages of being a female manager, what the interviewee thinks would be benefits to the forest sector of having more female executives, and what they think might make the forest sector a more attractive place to work for female managers. Data will be collected in fall 2015 and early 2016. Qualitative data analysis will be used to identify commonalities among respondents. We hope to develop insights that can help improve the sector by eliminating roadblocks and hurdles for female managers as well as provide advice for young females entering the industry.

Lingering Impacts of the Global Financial Crisis: Innovativeness of the US Forest Sector

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Abstract

Wood products manufacturing companies in the US recently experienced a combination of the Global Financial Crisis and severe housing downturn (recession). Although the sector is cyclical with high reliance on housing demand, the turmoil caused by the recession is unprecedented and represents a unique situation within which to study firm response to decline. The literature provides two competing theories explaining firm response to decline, either by centralizing authority, focusing on efficiencies, and increasing formalization, a response akin to a turtle taking refuge within its shell or becoming more innovative and introducing changes in the organization and/or its products in order to counteract decline. Innovative companies are those that are more likely to create and/or adopt new products, processes, and business systems in their operations. Using an online questionnaire, data was sought from US wood products (SIC 24) manufacturers that had previously responded to a survey in 2013 focusing on innovativeness in response to the recession. The primary goal of this new study was to determine if firms that increased innovativeness during the recession experienced increased financial performance as a result. In addition, did firms maintain or reduce their innovativeness as markets improved?

Public Perceptions of Wood as Building Material

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Abstract

To better understand the general public's perceptions of wood as building material, a questionnaire was developed to determine how familiar the general public is with the possibilities that wood as a building material offers. A questionnaire examining user perspectives on the suitability of wood for various building types (single and multi-family residences, non-residential buildings, and bridges), along with the importance of a variety of building material characteristics, and the estimated performance of wood for each of these characteristics. Furthermore, preferred communication channels for learning about building with wood assessed, in addition to general demographic information about the respondents. The survey was available in Slovene, English, German, and Finnish, and was hosted online by the University of Primorska using the LimeSurvey online survey software (LimeSurvey Project Team, 2015).

Collected responses were compared based on demographic differences in addition to involvement in the forest sector with special emphasize on the information if the participant is involved in forest sector. The results revealed distinct differences between respondents with and without involvement in the forest sector. Differences between countries were less pronounced, except for the importance of different communication channels when learning about building with wood. These differences along with respondent segmentation results will be presented.

Measuring Effectiveness of Kaizen Events within the Wood Products Industry

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Abstract

Kaizen events can be used by companies to lower manufacturing cost and increase product value. Being able to measure the effectiveness of Kaizen events is critical to understand the factors that contribute to Kaizen's effectiveness as well as to identifying the success of Kaizen implementation. However, little research has focused on the implementation of Kaizen events within the wood products industry.

The goal of this research is to develop a tool to measure the effectiveness of Kaizen and to apply this tool to companies within the wood products industry. A case study approach was conducted based on interviews, survey of employees, and observation of the manufacturing process. This approach included a detailed examination of how the case study companies implemented Kaizen and how employees perceived such implementation.

Results show statistically significant differences in how production employees across companies viewed motivators related to cost and quality outcomes, as well as the success of other companies. It was found also there are implementation barriers related to middle management, time, money, technology, and poor past experiences. Poor past experience with Kaizen were also viewed significantly differently by production and non-production employees in one of the case study companies. The results also show that perceptions of productivity improvements were the most significant predictor of the perceived effectiveness of Kaizen implementation.

Session

Chemistry and Forest Products Utilization

Moderators:
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Potential for Biobased Adhesives in Wood Bonding

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Abstract

There has been a resurgence of interest and research on using bio-based materials as wood adhesives; however, they have achieved only limited market acceptance. To better understand this low level of replacement, it is important to understand why adhesives work or fail in moisture durability tests. A holistic model for wood adhesives has been developed that clarifies many issues of wood bond durability. This model addresses performance challenges that bio-based adhesives must overcome to compete with synthetic adhesives. Additionally, bio-based adhesives face challenges on economic and process requirements in order to fit into current wood products manufacturing environments. Despite these challenges, bio-based adhesives continue to show great potential for wider acceptance in wood bonding.

Key words: *wood, adhesives, protein, lignin, tannin, durability, moisture*

Introduction

Wood is a renewable resource, but environmental concerns exist about the use of adhesives made from fossil fuels lowering the bio-content of the bonded wood products. Most wood products are adhesively bonded composites and laminates, and there is a strong desire to use more renewable resources in the adhesives. With so many biological materials available, it can be difficult to select the right chemistry for making suitable adhesives. Some biopolymers have proven less useful as wood adhesives; for example, carbohydrate adhesives usually absorb so much water that the adhesive is weakened and the wet bond strength is poor. Though there are a variety of cellulose derivatives that may have enhanced wet strength, it is not clear if any of these are currently used or could be used in wood adhesives. Several routes have been investigated, but none of these systems has been commercialized (Pizzi 2013). If this problem could be solved in a cost effective manner, it could provide an outlet for the abundant carbohydrates, which are low in cost and relatively consistent in composition. Nanocellulose provides a new opportunity for using carbohydrates in adhesives, but this is in its early stages.

Interestingly, biopolymer adhesives have been used as wood adhesives for centuries long before the introduction fossil fuel-based adhesives in the 20th century. Mainly these were proteins from a variety of animal or plant sources.

Before individual biomaterials are discussed in further detail, it is important to understand what properties make a suitable wood adhesive. Wood is typically used for its strength, requiring that the adhesive needs to have strength that is equal to or preferably greater than that of the wood, thus, minimizing failure within the adhesive. Wood products need to bear loads for a long time; therefore an adhesive needs creep resistance so the wood product doesn't distort with time. The typical way to meet both the strength and creep requirements is for the adhesive to be a thermoset that forms a strong interlocking network during the bonding process. The roles of adhesion (adhesive to wood) and cohesion (within to itself) are very important, but determining these aspects is complex given the porous nature of wood. The proper rheology of the adhesive is important for getting the right degree of penetration. If the adhesive does not flow into the wood enough, there is not enough mechanical interlock via the lumens and in some cases infiltration of the wood cell walls for stabilizing the wood surface (Frihart 2009, Kamke 2007). However, too much penetration will leave too little adhesive in the glueline and insufficient cohesive adhesive strength between the wood surfaces.

Durable Wood Bonds

Most adhesives will bond wood and give high wood failure if the sample is kept at a constant moisture content and temperature as when initially bonded. However, this is an unrealistic expectation because wood bonds need to perform for decades if not for centuries under a wide variety of moisture and temperature conditions.

Temperature effects are straightforward in that wood is fairly stable until above 200° C before wood starts to degrade. Structural wood products must not deform or collapse too quickly in a fire, and so the adhesive should not soften or degrade until well above 200C. Therefore an adhesive like an uncrosslinked poly(vinyl acetate) is not good for structural applications due to its thermal softening. Polymers such as those made from isocyanates, can often depolymerize at higher temperatures; thus they may not resist fires as well as phenolic adhesives.

Moisture changes are a far bigger problem for bonded wood products because while wood swells and shrinks with changing moisture levels, most thermoset adhesives tend to have a very small change in dimensions with moisture changes. Thus the adhesive needs to accommodate this increased strain from the differential volume change so that the internal stress at the interface does not exceed the adhesive's strength (case a in Figure 1). There are two ways to minimize the localization of the strain. Case b has adhesive components enter the cell wall to minimize the amount of swelling and shrinking due to bulking of the wall, reacting with the cell wall components, or forming an interpenetrating polymer network in the cell wall (Frihart 2009). Monomeric or oligomeric adhesives that complete their network formation during the bonding step are referred to as *in situ* polymerized. These adhesives often have components that enter into and stabilize the cell wall. This cell wall stabilization is critical for these polymers in that they are inflexible due to their rigid monomers and highly crosslinked structure, and cannot accommodate the wood swelling by movement in the adhesive layer. Thus, amino resins and phenolics, which are known to enter cell wood walls and reduce their swelling, typically survive wet conditions, while epoxies that are also rigid are less able to enter and reinforce cell walls, and are not able to withstand the wood swelling unless a primer is used with them (Frihart 2006).

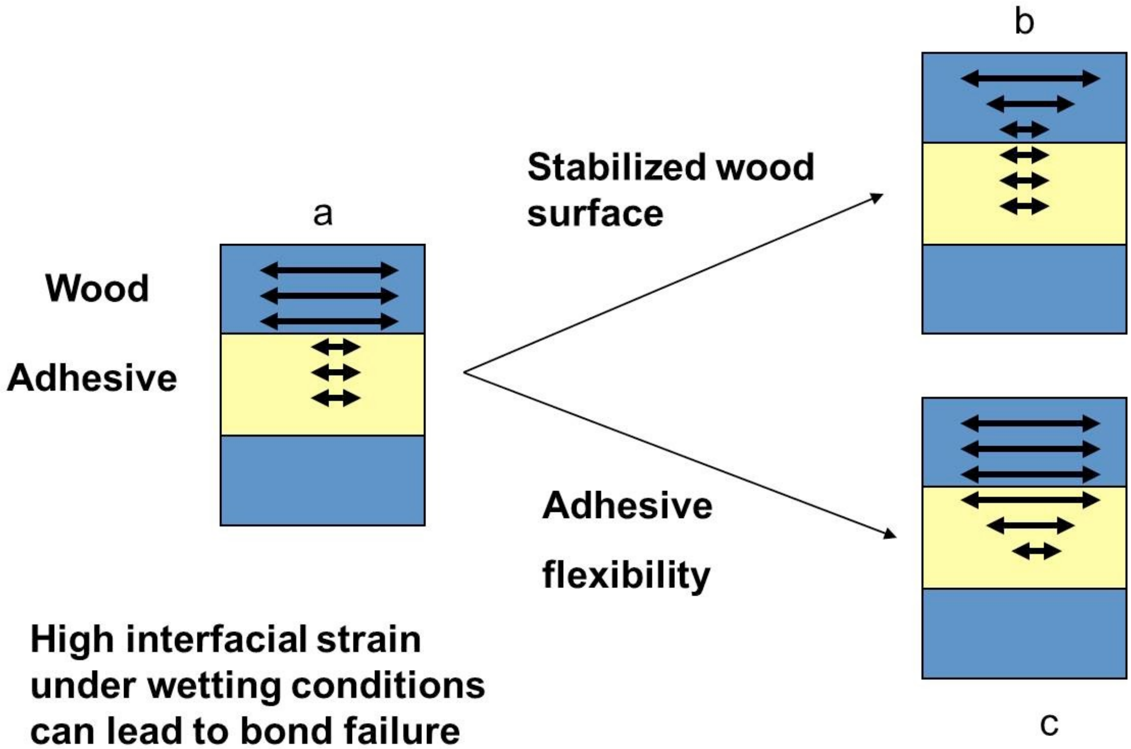

Figure 1. Models for how the adhesives can minimize interfacial strain in a by either stabilizing the cell wall (b), or being able to distort themselves near the interface (c)

In contrast, the other group (case c) of adhesives is the prepolymerized adhesives that undergo light crosslinking, such as polyurethanes, during the adhesive curing. These adhesives are too high in molecular weight to enter and stabilize the wood cell wall, but have a flexible backbone that allows the adhesive to deform, minimizing the bondline stress bondline caused by wood swelling. Because of their high molecular weights, biopolymers usually fit in this case.

Biopolymer Adhesives

Proteins

Although proteins were the dominant choice in wood adhesives for centuries, the previously used technology is for the most part not competitive in today's manufacturing environment. In many cases, the formulations were sensitive to the specific source of the protein requiring a lot of time consuming adjustments and low production rates in the bonding process. Also, the sourcing from various locations as well as long term storage were additional problems; this was especially true for adhesives using blood and fish scales.

Although casein adhesives used in glulam construction have not had a problem with durability during use, including one building at the Forest Products Laboratory that stood for 75 years before deconstruction (Rammer 2014), these adhesives are unlikely to pass the current adhesive standards for glulam durability. Currently casein is more expensive because it is isolated from milk in New Zealand for example, where milk production exceeds what is needed for food applications. The casein is still used for products like fire-resistant wood doors, which is probably made using casein-soy combinations.

Many of the protein glues once widely used now have very limited application for wood bonding Animal glues from the hydrolysis of collagen from hooves and hides were used for paper products more than wood products. The animal glues are currently used in only a small quantities for historic restoration because poly(vinyl acetate) and other synthetic polymer adhesives are easier to use and lower in cost while providing superior performance. Likewise, glues from fish scales are used in small amounts for restoration and artistic products. Blood glues were often used to fortify other protein glues and give tack to phenol-formaldehyde adhesives, but they are probably not used now in wood adhesive applications.

Recently, the main research for using bio-polymers in the wood adhesive field has been on the use of vegetable proteins because they can be produced in sufficient volume for wood adhesive applications and are reasonable in cost. Although most of the research has been on proteins from soybeans, some work has also been done on other sources, such as canola (rapeseed), wheat gluten, lupin flour, and zein using similar types of chemistry to that being used with soy adhesives.

Soy has been the most studied protein adhesive (Frihart and Birkeland 2014), especially in the United States due to its low cost, wide availability, and research support from the United Soybean Board. Although soy was used in large volumes for making interior plywood until the 1960's, this highly alkaline adhesive is no longer competitive with other adhesives in performance or cost. Of the many soy products that have been examined for wood bonding in the literature, most commercial applications use soy flours due their low cost relative other soy products (Frihart et al. 2014). However, there is some commercial exploration of soy protein isolates as binders for magnesium oxide adhesives. The largest commercial market currently employing soy adhesives is decorative (interior) plywood, although soy adhesives are also used for engineered wood flooring and particleboard using the polyamidoamine-epichlorohydrin coreactant technology (Li 2007). A major appeal of these adhesives is that they are in the category of no added formaldehyde, so the bonded wood products are well below the California Air Resources Board standards for formaldehyde emissions. A wide variety of other approaches have been developed for soy adhesives (Frihart and Birkeland 2014), but none of these are used commercially. In the protein adhesive literature, some of the data interpretation on the role of the protein is incorrect due to an unclear understanding of terminology, such as solubility, dispersibility, and uncoiling of the protein, and how the proteins have been altered in making a variety of commercial products (Frihart and Birkeland 2016). It is important to know that soy proteins are colloids so protein-protein interaction is critical for forming strong bonds.

There is still a tremendous opportunity for soy and other vegetable adhesives since they give good dry adhesive strength, are low cost, and can be significantly modified by a variety of means. Some chemists, such as Prof. Kaichang Li, have been examining some innovative ways to improve the wet strength of soy adhesives. The other challenge with vegetable adhesives is that, being prepolymerized adhesives, they need the strength and flexibility to accommodate wood swelling and shrinking, and produce wood failure. This challenge has largely been unmet for making low cost soy adhesives with sufficient cohesive strength.

Lignins

Lignins are the second most abundant renewable resource and in their crude form are low in cost. It has been estimated that there are 78 million tons/year available from Kraft pulping of wood and 60 million tons/year from cellulosic ethanol production (Lake and Scouten 2014). It is important to realize that the lignins are a family of materials instead of a single material. The ratios of the lignin monomers used in nature to construct the lignin polymers is very dependent upon whether the lignocellulosics are from softwoods, hardwoods, and other plants. The lignin polymerizes in many different ways leading to a distribution on the types of linkages between the monomeric units (i.e., lignin precursors). Additionally in the separation of the lignins from the cellulosic plant materials (as well as other non-cellulosics, such as ash), the lignins undergo a variety of reactions that can alter their functionality, depolymerize the lignin and repolymerize the degraded units. Thus, the lignin is characterized by its molecular weight, spectroscopic methods and its chemical reactivity rather than specific structures since its native structure remains a mystery (Stark et al. 2015). Major problems in using lignin as wood adhesives include its high molecular weight, limited number of reactive sites that are often sterically hindered, and a significantly higher cost for purer lignins.

The most often considered approach is to use lignin as a partial replacement for phenol in phenol-formaldehyde (PF) adhesives. Although PF adhesives are a very large market, the high viscosity of the lignin precludes any significant use of it in many applications, such as with oriented strandboard, where the adhesive needs to have a low viscosity for spray or spinning disc atomizer application methods. This still leaves the exterior plywood industry and some other laminating applications for lignin-phenol-formaldehyde (LPF) adhesives. There has been a lot of research touting that lignins can be used up to a 40% replacement of phenol while making products that meet the performance specifications (Nimz 1983, Pizzi 2003a, Pizzi 2013). Problems are that on an industrial scale a fast cure rate and a low cure temperature are economically important. Unfortunately, addition of lignin diminishes the PF adhesive performance in both of these properties. The slow curing of the LPF compared to the PF is a negative for the industry because when too much lignin is added, the lignin becomes more of a filler than a coreactant in the formulation due to lignin's slow cure rate. The addition of cure accelerators allows PF adhesives to cure quicker and at lower temperatures, but more powerful accelerators would need to be used with the lignin. Lignin can be used in the adhesive formulation by either adding it from the beginning of the PF reaction, or by blending in methyolated lignin (product of reacting formaldehyde with lignin) (Gardner and Sellers 1986). Furthermore, if the PF adhesive needs oligomers to stabilize the cell wall and repair surface damage (Frihart 2009), then adding lignin, which has too high of a molecular weight to enter the cell wall, will require that the formulation be readjusted to have more low molecular weight PF components and require the lignin to bridge the two surfaces.

Given the large amount of isolated lignin available in the future, more research should be done to find uses for the lignins in adhesives. However, in order to be successful, this research is likely going to need dedicated development, not just a few experiments here and there as is evident in most of the literature. Furthermore, it will need more market pull because currently there is little incentive for adhesive companies to add the lignin to the PF resins. The development cost and manufacturing risk will outweigh any raw materials saving unless the price spread between phenol and the lignin source is large, limiting how much purification or modification can be done to the lignin.

Tannins

Tannins are very different from lignins in supply, cost, and reactivity, although both are aromatics. Of the two types of tannins, most of the research has been done on the one most commercially available, the condensed tannins. The tannin availability is about 200,000 tons per year from a variety of different plant species, including bushes and trees. Tannins are very reactive due the high content of phenolic groups, and can be compared more to resorcinol in reactivity than to phenol (Pizzi 2003b, Pizzi 2013). Like lignin, condensed tannins are higher in molecular weight so the PF formulation needs to be adjusted to obtain the proper flow and cell wall infiltration characteristics. The high reactivity of tannins has allowed them to be cured without the use of formaldehyde (Pizzi 2013). Another key difference is that commercial lignin is a by-product of other processes (pulping for papermaking and cellulosic ethanol), while tannins are the main product of extraction of plant materials. Thus, the tannin has to bear more of the production costs than does lignin. Consequently tannins are higher in price and more of a localized product compared to PF resins. In the right circumstance, they have been used commercially with good success (Pizzi 2013, Pizzi 2014).

Unsaturated Oils

Many plants make unsaturated oils that are processed for human food applications, but their reactive unsaturated bonds make them useful for wood products. Traditionally they have been used as coatings, such as the catalyzed oxidative curing of linseed oil finishes. However, the unsaturated carbon bond is available for many transformations into other functional groups. One that has been vigorously pursued is the conversion into polyols that can then be converted into polyurethanes (Li 2015). Polyurethanes are widely used as adhesives because they can cure at moderate temperatures using the moisture from the wood and are able to bond wood with higher moisture contents than are phenolic and amino resins adhesives. The research into using this route for wood adhesives has been limited so far, but it would not be surprising if this was more actively pursued in the future. Fatty oils for non-polyurethane routes are also being pursued for making adhesives (Pizzi 2013). It is not clear if this research has led to commercial products because it is important for industry to maintain trade secrets on formulations.

Summary and Conclusions

Bonded wood products have been around for thousands of years, and the original adhesives were biobased. The renewed interest in biobased materials have led to the exploration of incorporating cellulose, proteins, lignin, tannins, and fatty oils. into many innovative adhesives. There is plenty of opportunity to develop new chemistries to make these even better adhesives. The biggest challenge is providing high reactivity and/or wet bond strength while keeping costs low. Currently proteins and tannins are used in wood bonding, but continued research on improved products should expand the wood adhesive market for biobased adhesives.

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Relating Wood Chemistry and Strength: Part I. Wood Structure and Chemistry

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Abstract

The structure of wood is often described as a system of tubular elements collectively known as wood cells. Each of the three major types of wood cells serves a different function. The source of strength in solid wood is this system of interconnected, multi-functional wood cells. The cell wall of each cell type has a unique laminated structure, composed of varying quantities and arrangements of three polymer types: cellulose, hemicelluloses, and lignin. The objective of this Part I paper is to review the fundamental relationships between the structure of wood materials and the chemical components of wood. Part II (Winandy 2016) will later present a universal theory for the chemical process of desequencing woody material under biological-, chemical- or thermal-agents capable of causing wood deterioration.

Key words: Wood Chemistry, Strength, Composition, Cellular Structure

Introduction

The structure of wood is often best comprehended as a system of multi-functional tubular elements. These tubular elements or cells are bound together by a phenolic polymer known as lignin. The source of strength in solid wood is this system of interconnected wood cells. Each cell wall is comprised of layers, each having varying orientations and quantities of three polymer types: cellulose, hemicelluloses, and lignin. Cellulose reinforces the walls of the wood cell because of its high degree of polymerization (DP) and linear orientation. The hemicelluloses because of their lower DP and highly branched structure, act as a packing material supporting the cellulose matrix, increasing the cell wall density. Lignin and hemicellulose are often associated. Obst (1982) suggested a primary role of hemicelluloses was to act as highly specific coupling agents capable of associating both with the more random-areas (i.e., non-crystalline) of hydrophilic cellulose and the more amorphous hydrophobic lignin. The actual role of these hemicelluloses in wood strength was later shown to be far more critical toward the overall engineering performance of wood than had previously been assumed (Winandy & Lebow 2001).

Chemical Composition & Structure Relationships

The chemical components of wood that are responsible for mechanical properties can be viewed from three levels: macroscopic (cellular), microscopic (cell wall), and molecular (polymeric) (Winandy & Rowell 2013). Mechanical properties change with changes in the thermal, chemical and/or biochemical environment. Changes in temperature, pressure, humidity, pH, chemical adsorption from the environment, UV radiation, fire, or biological degradation can have significant effects on the strength of wood (USDA 2010).

Cellulose has long thought to be primarily responsible for strength in the wood fiber because of its high degree of polymerization and linear orientation. Hemicellulose may act as a link between the less-highly orientated cellulose and the amorphous lignin. Hemicellulose definitely acts as a matrix for the amorphous cellulose. Thus, increasing the packing density of the cell wall. Lignin, a phenolic compound, not only holds the fibers together, but also acts as a stiffening agent for the cellulose molecules within the fiber cell wall. All three cell wall components contribute in different degrees to the strength of wood. Together the tubular structure and the polymeric construction are responsible for most of the physical and chemical properties exhibited by wood.

The strength of wood can be altered by environmental agents and the adsorption of chemicals from the environment can have a significant effect on strength properties. Environmentally induced changes must be considered in any discussion on the strength of treated or untreated wood. This susceptibility of wood to strength loss, and the magnitude of that degrade, is related to the severity of its thermal/chemical/biochemical exposure. Because changes in wood chemistry affect wood strength, the strength of wood can also be altered by acids and bases. For example, preservative and fire-retardant compounds are often used to prevent environmental degradation, but in some cases, the strength losses caused by these treatments may affect structural performance and become problematic.

A series of fundamental studies of this chemistry-strength relationship using a cumulative-damage approach first postulated by Gerhards (1985) have now helped account for these potential alterations from untreated wood in the structural design process (Lebow & Winandy 1999, Winandy & Lebow 2001). As a practical understanding of the thermochemical issues that primarily control chemical-treatment related strength loss, it was shown treatment-processing effects could mitigated by modifying in standards, especially initial kiln-drying and post-treatment kiln-drying temperatures to avoid temperature- and/or treatment-related strength loss (Koch 1977, Winandy 1996). With fire-retardant-treated (FRT) wood, a another large amount of work addressed FRT-related strength loss using a kinetics-based approach to model problems with in-service thermal-degradation of FRT wood exposed to elevated in-service temperatures (Lebow & Winandy 1999, Winandy 2001). Winandy & Lebow (2001) then related a unified theory for a fundamental relationship between the mechanical properties and the chemical desequencing of individual components of wood. Such theories are evolving and will eventually lead to a comprehensive understanding of the chemistry of wood strength.

Wood is a natural, anisotropic material. Mechanical properties vary with respect to the three mutually perpendicular axes of the material (radial, tangential, and longitudinal). Even wood without discernible defects has variable properties as a result of its heterogeneous composition and natural growth patterns. This natural variability is further compounded by the environmental influences encountered during the growth of the living tree. Yet wood is a viable construction material because workable estimates of the mechanical properties have been developed through practical experience and a systematic system of national/international standards and building codes.

Relationship of Structure to Chemical Composition

The chemical associations of the individual components responsible for the strength properties of wood can be theoretically viewed from three distinct levels: the macroscopic (cellular) level, the microscopic (cell wall) level, and the molecular (polymeric) level.

Macroscopic Level

The macroscopic level of consideration takes into account the cell type and structure such as earlywood, latewood, or reaction wood, the differences in cell function such as sapwood or heartwood, and the non-woody components such as mineral content, extractive chemicals, resin content, etc. Differences in cellular anatomy, environmental-controlled growth patterns, and chemistry can cause significant differences in the strength of wood.

Wood with its inherent strength is a product of growing trees. Two primary functions of the woody trunk of the living tree are to provide support for the leaves or needles that serve as the tree's phototropic-energy factory and to provide a conduit for moving water and nutrients moving up to those leaves or needles. The phototropic sugars produced by the leaves or needles move down the stem via the bark tissues. Woody tissues, interior to the bark, exist as concentric bands of cells oriented for specific functions (Figure 1). Thin-walled earlywood cells act both as conductive tissue and add some support; but the thick-walled latewood cells provide the primary means of support.

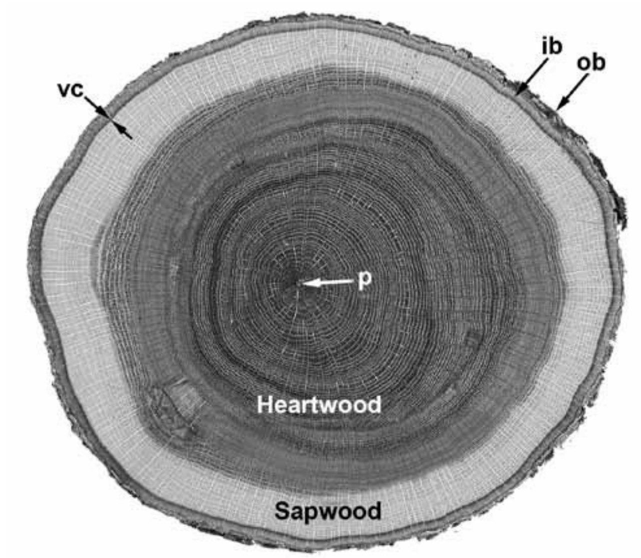

Figure 1. View of a transverse section of a *Quercus alba* log indicating: outer bark (ob), inner bark (ib) and vascular cambium (vc). Interior of vascular cambium is the sapwood and heartwood, and pith (p). (photo from USDA 2010).

The earlywood and latewood cells in softwoods are arranged in concentric bands composed of wood fibers and longitudinal parenchyma and ray parenchyma cells. Hardwoods also have specialized cells for longitudinal conductions called vessels. Each of these cells is a single fiber. Softwood fibers average about 3.5 mm in length and 0.035 mm in diameter. Hardwood fibers are generally shorter (1–1.5 mm) and smaller in diameter (0.015 mm). The earlywood and latewood fibers comprise large composite bands, bonded together by a phenolic adhesive, lignin. Each band, or growth ring, is different because each year's weather is different. Each growth ring in softwood is anisotropic in character and reinforced in two of the three axial directions by longitudinal parenchyma or ray parenchyma cells. In hardwoods, the vessels provide additional longitudinal reinforcement. These parenchyma cells and/or vessel cells function as a means of either radial or longitudinal nutrient conduction and as a means of providing additional support (Figure 2). Because wood is a reinforced composite material, its structural performance at the cellular level has formerly been likened to reinforced concrete (Freudenberg 1932) or recently to fiberglass- or graphite-composites (Mark 1967).

Microscopic Level

At the microscopic or cell wall level, wood has been compared to concentric filament-wound fiber systems (Mark 1967). Each component complements the other in such a manner that, when considering the overall range of physical performance, the components together outperform the components separately. But before discussing how and why the cell wall operates as a highly efficient structural system, we must understand some specifics of the cell wall composition.

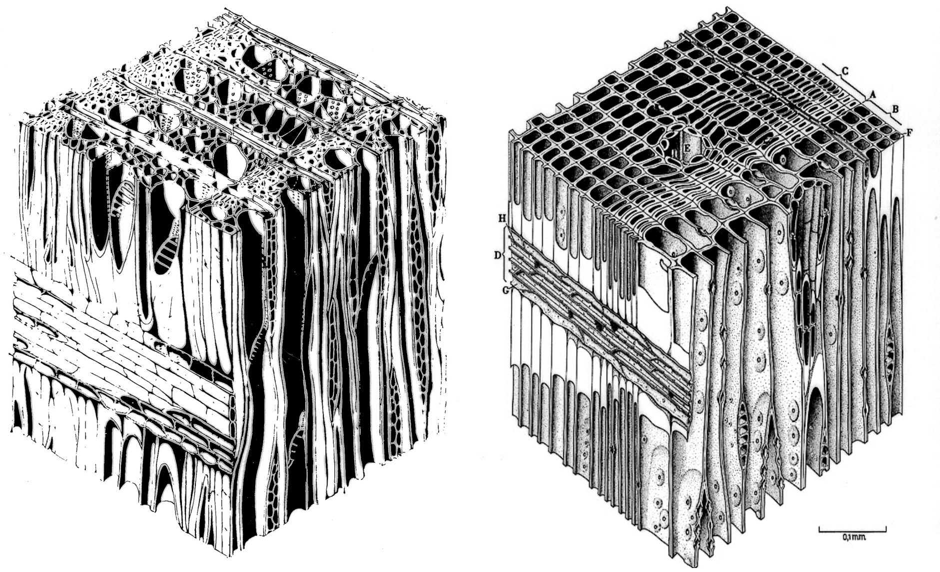

Figure 2. Close-up of the three-dimensional structure of a hardwood (left) and softwood (right) with scale on right indicates 0.1mm (photos from USDA Forest Products Laboratory).

Composition

Within each cell wall are distinct regions or layers (Figure 3). Each layer has a distinct composition and orientation. For a typical softwood, the middle lamella and primary wall are mostly lignin (8.4% of the total weight) and hemicellulose (1.4%), with very little cellulose (0.7%). Next, the S_1 layer consists of cellulose (6.1% of the total weight), hemicellulose (3.7%), and lignin (10.5%). The S_2 layer is the thickest layer and has the highest carbohydrate content; it is mostly cellulose (32.7% of the total weight) with lesser quantities of hemicelluloses (18.4%) and lignin (9.1%). The inner most layer is the S_3 layer. It consists of cellulose (0.8% of the total weight), hemicelluloses (5.2%), and very little lignin.

Cell Wall Structure and Performance

The cell wall has 3 layers around a hollow core (i.e., the lumen) with a fourth layer the binds these many cells together. That fourth layer is known as the compound middle lamella. The 3 actual cell wall layers are known as S_1, S_2 and S_3. It may seem “out of order” but start by considering the S_2 layer. It is by far the largest layer and is structural orientation is between 0-20^o off parallel to the primary orientation of each cell. This nearly vertical orientation makes it primarily responsible for the resistance of pure tensile or compressive stress on the tree trunk (i.e., wood). But it is the fact that the S_1 and S_3 layers are wound in a nearly perpendicular orientation around the critical S_2 layer that makes this cell wall system one of the most efficient strength-to-weight biomaterials in the natural world. The S_1 layer is perpendicularly wound around the exterior of the S_2 layer between S_2 and compound middle lamella.

The S_3 layer is also perpendicularly wound around the insider of the S_2 layer between the S_2 and the lumen.

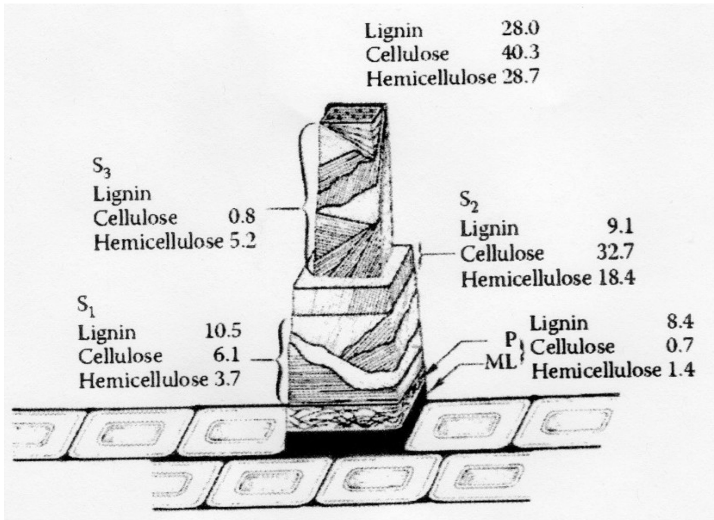

Figure 3. Schematic of the multi-layered, filament wound structure of the wood cell wall. (from Winandy & Rowell 2013).

As an example of how the S_2 layer would operate without these S_1 and S_3 reinforcements consider the famous "Chinese Finger Trap" (Figure 4).

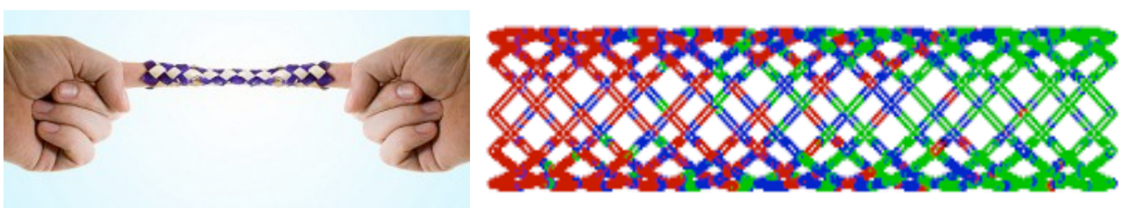

Figure 4. Example of the famous child's toy the "Chinese Finger Trap" (left) and a schematic (right).

When the "Finger Trap" is placed in tension the layered bands of the tubular structure rotate inward causing the whole system to constrict, thereby trapping the user's fingers. Conversely, when longitudinal compression is applied the bands rotate outward and release the user's fingers.

Next consider the benefits of the reinforced concentrically wound, wood cell having these S_1 and S_3 layers. Now when the S_2 experiences pure tensile or compressive stress under load it eventually wants to flex and twist. It then collapse toward the lumen when exposed to pure tensile or distort (i.e., bulge outward) toward the S_1 under pure compressive stress. Herein, lies the simple beauty of the wood cell. When this inward or outward buckling of the S_2 begins to occur, the S_3 or S_1-layers reinforce the S_2 layer and enable it to carrying more and more load in nearly pure compression or pure tension. Thus, while the thick S_2 layer carries the majority of the axial and/or flexural stresses imposed on the tree or wood, that S_2 layer could not perform nearly as efficiently or perform to the limits that it does without the significant reinforcement contributions of the S_1 and/or S_3 layers. Wood is truly nature's preeminent compound filament-wound biocomposite.

Microfibril Orientation

The large number of hydrogen bonds existing between cellulose molecules results in such strong lateral associations that certain areas of the cellulose chains are considered crystalline. More than 60% of the cellulose (Stamm 1964) exists in this crystalline form, which is stiffer and stronger than the less crystalline or amorphous regions of cellulose. These crystalline areas, also known as microfibrils, are approximately 60 nm long (Thomas 1981) and are distributed in varying degrees throughout the cell wall in each S_i layer. Microfibrils are highly ordered groupings of cellulose that may also contain small quantities of hemicellulose and lignin. The exact composition of the microfibril and its relative niche between the polymeric chain and the layered cell wall are subjects of great discussion (Mark 1967). The microfibril orientation (fibril angle) is different and distinct for each cell wall layer (Figure 3). The entire microfibril system is a grouping of rigid cellulose chains analogous to the glass or graphite fibers in filament-wound reinforced plastics or the steel reinforcing bars in reinforced concrete (Winandy & Rowell 2013). Nanocrystalline cellulose is derived from these crystalline regions of cellulose (USDA 2010).

Molecular Level

At the molecular level the relationship of strength and chemical composition deals with the individual polymeric components that make up the cell wall. The physical structure and chemical properties of cellulose, hemicelluloses, and lignin play a major role in the chemistry of strength. Up to recently, our perceptions of wood polymeric properties are based on isolated polymers that have been removed from the wood system and, therefore, possibly altered. The three individual polymeric components (cellulose, hemicelluloses, and lignin) may be far more closely associated and interspersed with one another than was once believed (Obst 1982, Attalla 2002).

Lignin

Most composite materials use an adhesive of some type to bond the entire material into a system. In wood, lignin in many ways fulfills this function of binding together the matrix and matrix-packing materials. Lignin is a hydrophobic phenolic material that surrounds and encrusts the carbohydrate complexes. Lignin is not truly or solely an adhesive and by itself adds little to strength (Lagergren et al. 1957). Yet, lignin due to its complex three-dimensional structure also seems to be responsible for part of the stiffness of wood (Prentice 1949) and is primarily responsible for the exclusion of water from the moisture-sensitive carbohydrates. One little recognized fact is that while the relative lignin ratio is low within the S_2 layer, the largest quantity of lignin in wood as a whole exists within the S_2 layer because of this layer's large overall mass.

While, lignin is often considered nature's adhesive, it is the least understood and most chemically complex polymer of the wood-structure triad. The composition of lignin is organized in highly ordered, three-dimensional phenolic polymers rather than linear or branched carbohydrate chains. Lignin is the most hydrophobic (water-repelling) component of the wood cell. It acts as an encrusting agent on and around the carbohydrate fraction. It limits water's influence on that carbohydrate fraction and is the cornerstone of wood's ability to retain its strength and stiffness as moisture is introduced to the system. Dry delignified wood has nearly the same strength as normal dry wood, but wet delignified wood has only approximately 10% of the strength of wet normal wood (Lagergren et al. 1957). In summary, wood strength is due in part to lignin's ability to limit the access of water to wood's hydrogen-bonded carbohydrate structure.

Cellulose

Cellulose is composed of anhydro-D-glucopyranose ring units bonded together by (®-1-4-glycosidic linkages giving it a relatively linear structure. The greater the length of the polymeric chain, the higher the degree of polymerization, the greater the strength of the unit cell (Mark 1967, Ifju 1964), and the greater the strength of the wood. The cellulose chain may be 5000–10,000 units long. Cellulose is extremely resistant to tensile stress because of the covalent bonding within the pyranose ring and between the individual units and its linear structure. Hydrogen bonds within the cellulose provide rigidity to the cellulose molecule via stress transfer and allow the molecule to absorb shock by subsequently breaking and reforming.

Hemicellulose

The hemicelluloses exist as multi-polymer carbohydrate molecules that consist of differing types of basic sugar units, primarily the six-carbon sugars, D-glucose, D-galactose, and D-mannose, and the five-carbon sugars, L-arabinose and D-xylose. Hemicelluloses have linear chain backbones (primarily glucomannans and xylan chains) that are highly branched and have a far lower DP than cellulose. The sugars in the hemicellulose structure exhibit hydrogen bonding both within the hemicellulose chain as well as between other hemicellulose and amorphous cellulose regions.

Most hemicellulose is found in interspersed within or on the boundaries of the amorphous regions of the cellulose chains and in close association with the lignin (Atalla 2002). Hemicellulose may be the connecting material between cellulose and lignin (Obst 1982). The precise role of hemicellulose as a contributor to strength has long been a subject of conjecture. Past theories have speculated that the cellulose is the predominate factor in wood strength, but recent work has clearly shown the hydrolytic or enzymatic action upon the hemicelluloses seems to always manifest itself as the primary measurable event during the earliest levels of strength loss in woody materials. Recent work strength-loss relationships when softwoods are exposed to hydrolytic chemical agents, extended exposure to elevated temperatures, or enzymatic decay have consistently indicated that early degradation of hemicellulose(s), especially degradation of the branched monomers off the hemicellulose main chains (i.e, D–galactose and L-arabinose), seem primarily responsible for the earliest portions of strength loss in wood exposed to severe thermal, chemical or biological exposures (Winandy & Lebow 2001). In the chemistry of wood pulping, these relationships of early hemicellulose degradation have been known for years (Sjostrom 1981). He states, *"Hemicelluloses are attached more easily than cellulose mainly because of their amorphous state and low degree of polymerization. … their glycosidic bonds are more labile toward acid hydrolysis than … cellulose. … Galactose residues are easily hydrolyzed … Arabinofuranose … are extremely labile toward acid hydrolysis."*

Summary

In Part I, the relationship between physical properties and chemistry and anatomy of wood has been reviewed. The implications of changes in cellular anatomy, and particularly in the chemical composition of the various levels of cellular anatomy, must be understood to relate changes in engineering properties. Such an explanation was presented to provide a means to visualize a fundamental understanding of the relationship between wood chemistry, structural anatomy, and the mechanical properties of wood. Part II will individually detail strength-loss relationships when softwoods are exposed to hydrolytic chemical agents, extended exposure to elevated temperatures, or enzymatic decay. An array of studies in the last 25-years have repeatedly indicated that earliest events related to strength loss in softwood lumber related almost exclusively to degradation of hemicellulose(s), especially degradation of the branched monomers such as D–galactose and L-arabinose along the hemicellulose main chains. When these studies are viewed as a series, they provide evidence of systematic relationship supporting the hypothesis of an unified model for strength loss in softwood lumber exposed to severe thermal, chemical or biological exposures.

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Chip Formation Studied by High Speed Photography during Log Fragmentation by a Chipper-canter

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Abstract

Videos of wood chip formation were taken with a high-speed camera during the fragmentation of black spruce logs with a chipper-canter. The effects of the cutter head diameter and attack angle on the mechanism of chip formation were evaluated. Two cutter head diameters (661.5, and 448.7 mm) combined with three infeed positions were tested. The mean attack angle (or cutting orientation) of the chipping knife was calculated for each infeed position. The nominal cutting speed was fixed at 23.5 m/s. The rotation and feed speeds were adjusted to obtain a nominal chip length of 25.4 mm. The fragmentation of two logs (under frozen and unfrozen wood condition) per each infeed position was recorded. The images captured the fragmentation sequence along the cutting path of each knife. They showed that the chip thickness depend strongly on the temperature condition (frozen and unfrozen wood) and on the attack angle of the chipping knife as it varies with the log infeed position and through the cutting path. The high-speed images also show that the chip thickness is determined by two types of ruptures: tangential (just at the beginning of the cut) and by radial ruptures.

Proposal of visual grading rules for Uruguayan loblolly and slash pine timber

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Abstract

This paper presents a proposal for visual grading of loblolly and slash pine lumber from Uruguayan plantations. A previous database with bending and density data was used to characterize the material according to European Standards (EN). The database, with material being representative of currently produced lumber, became from a 25-year-old west and 15-year- old southern-west plantations, and consisted of test results from two samples of 261 total specimens (50x150x3300 mm). Testing methods differed from EN guidelines, so a partial objective was to compare the data parameters with those of EN, and when necessary, to propose adjustment coefficients to comply with EN requirements. Density and mechanical properties of each tested beam were calculated following the requirements of EN 408 and characteristic values were computed according to EN 384. Typical visual parameters of each specimen (i.e., knots, fissures, deformations, etc) were evaluated and the relationship between their presence and the characteristic value of the corresponding sample was statistically analyzed using MATLAB software. As a result, all specimens were grouped in one visual grade, named “EC7” for Uruguayan pine lumber, with engineered properties similar to those of the C14 strength class established in EN 338. Longitudinal MOE and characteristic bending strength were the defining properties for class assignation. Knot diameter and warp were the visual parameters with more influence on bending properties.

Key words: Lumber, Visual grading, Uruguayan pine, Pinus elliottii, Pinus taeda

Introduction

In the last thirty years, Uruguay, a country with no tradition in timber construction significantly increased the availability of local produced wood due to a governmental policy to promote forest plantations. A quarter of a total of 1 million planted areas corresponds to *Pinus* sp. intended for sawn lumber and engineered wood products. Lack of strength graded timber in the market along with the fact that no design specification or building code for wood construction is available are the main reasons that prevent contractors, architects and engineers from using timber in structural applications. With the aim of promoting the use of timber for structural applications, the government commissioned to the timber research group (Forest Project Department LATU, School of Engineering Universidad de la República and School of Architecture Universidad ORT Uruguay) to set up a comprehensive project (DNI 2014) to determine, and when was possible, to propose the technical documents needed to generate or to adopt a design specification for timber construction in Uruguay. After reviewing the state of the art and the amount of work needed to write a local specification, it was decided to adopt the European standards package, including from testing methods, to design specifications (EN 1995-1-1, 2004/AC:2006 and EN 1995-1-2 2004/AC:2009). This decision implied to make a series of adjustments and considerations on previous research works, to determine and to propose specific basic documents (i.e. grading rules, design properties for locally produce timber, national annexes, etc) and to identify research needs.

One of the most important issues to boost the use of structural timber, is availability of strength graded material. Visual grading is still a method commonly used by producers, and does not required complicated equipment or labor. Visual grading of structural lumber imposes limits on the singularities or visual parameters shown on the piece to be graded. The visual parameters frequently considered in strength grading of timber are: knots, slope of grain, pith, fissures and warp, among others. Most visual grading standards establish these parameters and their allowable limits, which are generally based on the associated strength reduction of a piece of timber. A logical initial step to generate new grading rules involved makes use of an available standard (e.g., foreign standard) to grade home-grown material, and to evaluate its application. Since timber is very variable in strength and appearance depending on species and provenance, a literal adoption of a grading rule would be unrealistic, and a local grading rule must be written for each species, provenance and cross section. Therefore, the European standard prEN 1912 (2015) establishes the relationships between visual grading for different species and origins and the strength class assigned.

The aim of this study was to propose a visual grading rule for Uruguayan loblolly/slash pine lumber and the correspondent limits for the visual parameters, and to assign a strength class in accordance to prEN 338 (2012).

Materials & Methods

Material

A previous database from a timber strength grading project (FMV, 2012) comprised of bending properties and density data was used to characterize pine lumber in accordance to European standards (EN). The database with material being representative of currently produced loblolly and slash pine lumber became from two commercial plantations in Uruguay, a 25-year-old west and 15-year- old south-west plantations, and consisted of test results from two samples totaling 261 structural size specimens of 3300 mm-long. Table 1 shows number of specimens and dimensions according to origin and age.

Table 1. Number of specimens according to origin and age

Sample	Provenance	Age (yr-old)	Nominal section (mm)	Number of pieces
1	West	25	49 x 147	115
2	Southwest	15	49 x 147	146
			Total	261

The database comprised of results from stiffness and strength determined in 4-point bending test, density and moisture content values. Specimens were conditioned at 65% relative humidity and 20ºC temperature. In addition, the database included a description of typical visual parameters for each specimen: knots, slope of grain, wane, fissures, pith and warp.

Due to the fact that testing and initial analyses were performed following typical ASTM procedures (ASTM D 198, ASTM D 2395, ASTM D2915), bending and density data were reviewed in accordance with European guidelines. Relevant property values, mostly related to modulus of elasticity were adjusted to comply with EN 408 (2011) requirements. Coefficients of 0.9950 and 0.9882, previously determined as reported elsewhere, were applied on specimen modulus of elasticity values in order to correct the MOE values below the 10% and 20% below the rupture load, respectively. Global modulus of elasticity was adjusted in accordance to EN 408 (2011). Mean modulus of elasticity, characteristic bending strength and characteristic density values were determined in accordance to EN 384 (2014).

Methodology for analysis of visual parameters and strength class assignment

A method to statistically analyze the visual parameters using MATLAB (Mathworks, 2012) was proposed in accordance with the procedure as follows, and presented in Figure 1:

1) A preliminary analysis involved selection of the most influential parameters on mean stiffness, characteristic strength and characteristic density, with the aim to establish allowable limits for each parameter;

2) A first script (a function in Matlab environment) was written to compute mean stiffness, characteristic strength and characteristic density, with test data and allowable limits defined in 1);

3) A second script (order-processing file) was developed in order to evaluate different allowable limit combinations and to return, for each combination, values of mean stiffness, characteristic strength, and characteristic density, plus the number of rejected specimens;

4) Selection of the limit combination that returned the less amount of rejected specimens, on a minimum basis of C14 strength class.

The limits were then compared with those established on the Spanish standard UNE 56544 (2011) and Argentinean IRAM 9662-1 (2005) and IRAM 9662-3 (2005) for coniferous lumber.

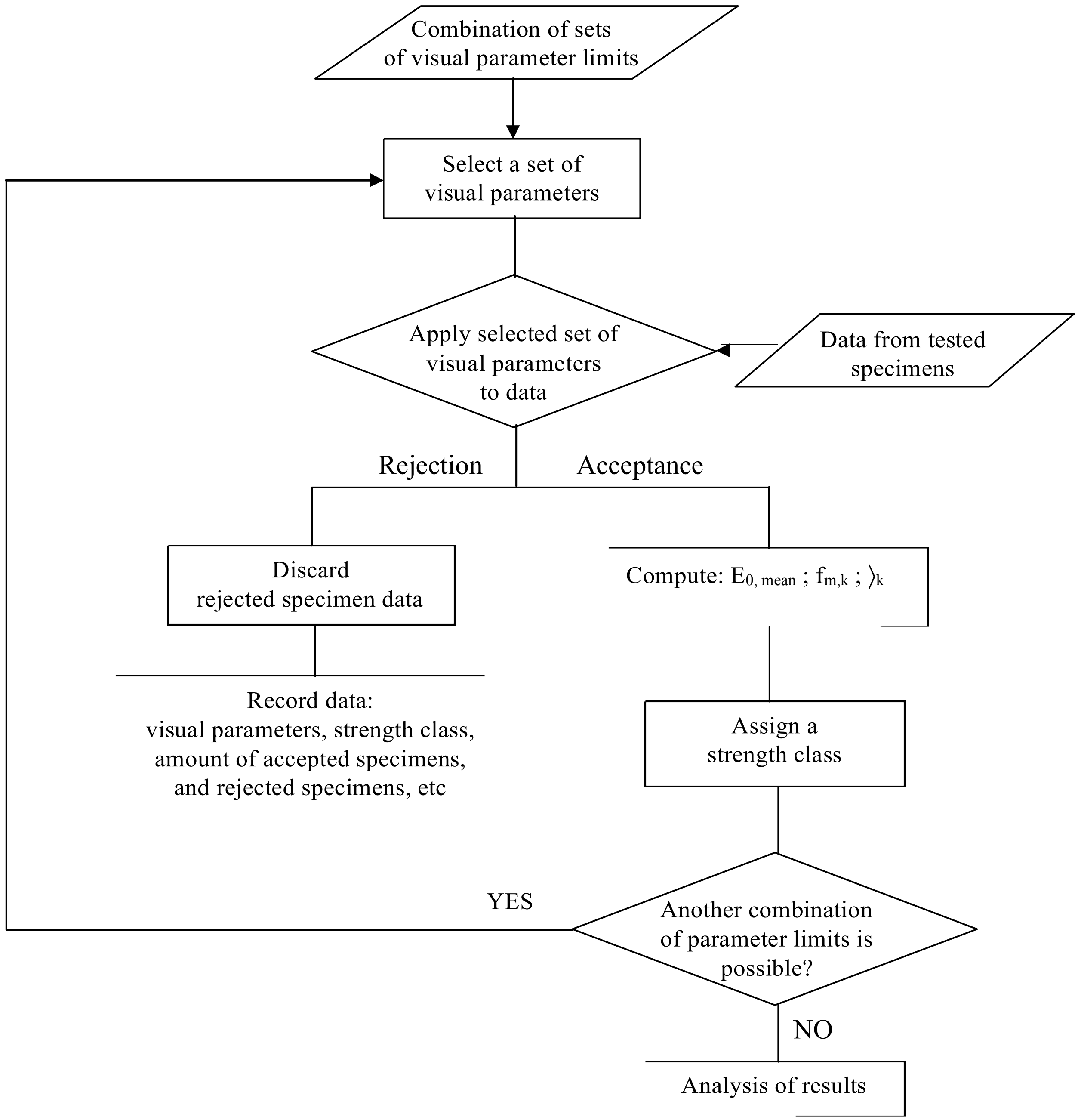

Figure 1. Flowchart of the analysis process

Results and Discussion

Table 2 shows the proposed specifications for visual grading of nominal 2 by 6 Uruguayan pine (*Pinus taeda*/*P. elliottii*) boards, based on data from two representative samples. Actual cross section dimensions of tested specimens were 49 mm x 147 mm. Visual grading was performed under dry conditions (boards moisture content ranged 14-18%) .

Table 2. Specifications for visual grading[1] of Uruguayan loblolly/slash pine 2 by 6 boards[2]

Parameter	**Visual EC7**
Face knot diameter (d)	d ″ 2/5 h
Edge knot diameter (d)	d ″ 2/5 b
Pith	Allowed
Slope of grain	″ 1:6
Maximum width of annual ring	-
Fissures	
- Seasoning checks	″1.0 m ó ″ ¼ l
- Seasoning splits	″1.5 m ó ″ ½ l
Wane	″1/5h
Resin pockets	″ 2 h
Reaction: compression wood	-
Biological damage	
- Blue stain	Allowed
- Fungi decay	Not allowed
- Insect´s galleries	Holes diameter <2 mm
Warp	
- Bow	″ 12 mm
- Crook	″ 9 mm
- Twist	″1.5 mm per 25 mm of h
- Cup	-

[1] Dry condition (MC= 14-18%)
[2] Referred to mean cross section of 49 x 147 mm

Specimens complying with Table 2 specifications were grouped in a single visual grade named as "EC7" (coniferous structural lumber).

Table 3 presents results of the visual grading. Percentages of pieces rejected in both samples are high, being knot size and warp the main reasons. To explain this poor outcome it is necessary to point out that the present specification resulted from analysis of two samples comprised of mature wood, and juvenile wood with low physical and mechanical properties. It is widely accepted that warp due to the drying process is more severe in juvenile wood, whereas annual ring usually is wider than in mature wood. Measurement of annual ring width is not frequently included in visual grading rules for coniferous timber; few grading standards (UNE 56544, 2011) include measurement of annual ring width but only for grading in wet condition, to account for warping due to the drying process. Annual ring width is also an indicator of growth rate and age, which in turn is associated with density, stiffness and strength. Therefore, inclusion of measurement of annual ring and its allowable maximum limit may improve this rule.

Table 3. Visual strength grading results. Percentage of specimens complying with EC7 visual grade and rejections

Sample	Provenance	Age (yr-old)	Mean section (mm)	EC7 (%)	Rejected (%)
1	West	25	49 x 146	50	50
2	South-west	15	49 x 148	29	71
All				38	62

Values of mechanical and physical properties of specimens graded as EC7 ($E_{0,men}$=7.04 kN/mm^2, $f_{m,k}$= 14.63 N/mm^2 and ρ_k=348 kg/m^3) correspond to the strength class C14 established in prEN 338 (2012). Longitudinal MOE and characteristic bending strength were the defining properties for class assignment.

Summary and Conclusions

With the aim of establishing the basis for a future grading rule for Uruguayan pines, a previous database was analyzed and used to define the allowable limits for the visual parameters. A method to obtain the better correlation between the limit values of visual parameters and the strength class was developed. The limits were then compared with those established on the Spanish standard UNE 56544 and Argentinean IRAM 9662-1 and IRAM 9662-3 for coniferous timber.

Specimens were grouped in one visual grade, named "EC7" for Uruguayan pine lumber, with engineered properties similar to those of the C14 strength class established in prEN 338. Knot size and warp were the main visual parameters that defined the strength class. Modulus of elasticity and characteristic bending strength were the defining properties for class assignment.

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Advances on structural design with timber in Uruguay: towards a proposal for a National Annex to Eurocode 5

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Abstract

In Uruguay there is not a national document for design specifications for timber construction, so engineers and architects must employ foreign codes based on the available formats, i.e. Load Resistance Factor Design (LRFD), or Allowable Stress Design (ASD). Some codes, such as the dual format NDS 2012 edition, allow the designer to select the calculation method. Usually, this selection involves information about material properties, such as characteristic or mean values, and the methodology to determine those values. In such context, seems to be appropriate the adoption of an existing code for Uruguay, and the development of specific Annex containing information regarding locally wood materials, adjustment factors, etc. After the analysis of various foreign codes, the European Standard Eurocode 5 was selected. To adopt this code, a Uruguayan National Annex (NA) to Eurocode 5 (EC-5), part 1-1 and part 1-2, is proposed and presented in this work. The proposed Uruguayan NA to EC-5 contains information about Nationally Determined Parameters (NDP), as load duration classes, service classes, local partial factors for materials depending on accepted risk level in buildings, deflection limit values and partial factor for material properties under fire, among others. Furthermore, this NA contains Non-contradictory Complementary Information regarding to the relationship between Uruguayan and European Standards about actions in structures, load combinations, limits for fire resistance, etc.

Key words: Timber structures, Design Codes, Eurocode 5, National Annex, Nationally Determined Parameters, Non-contradictory Complementary Information, Uruguay

Introduction

The Uruguayan forestry sector has had a significant increase in wood volume during the last thirty years as a result of a government policy to promote forest plantations. In the 80´s, according to estimations by the General National Boureau of Forestry (*Dirección General Forestal, DNI)* of the Ministry of Agriculture, Cattle and Fishery (*Ministerio de Ganadería Agricultura y Pesca, MGAP*), there were between 120,000 and 137,000 hectares of cultivated species. Currently, forest plantations cover close to 1 million hectares of fast-growing exotic species, mainly pine (*Pinus* sp.) and eucalyptus (*Eucalyptus* sp). The main industrial use of eucalyptus species is the production of pulp, while the pine and part of the eucalyptus (*Eucalyptus grandis*) are used for construction products (Dieste 2012). The main products are eucalyptus logs, plywood (eucalyptus and pine) and glued laminated timber (*E. grandis*). 1.7 million m^3 of pine logs (mainly *P. elliottii* and *P. taeda*) and 0.4 million m^3 of eucalyptus (mainly *E. grandis*) have no current industrial destination (Dieste 2014). The Uruguayan government has proposed the incorporation of timber for structural use, which implies the need for a national system of standards for timber products and the development of codes and rules for design and construction with timber.

The design process of any structure mainly involves three aspects: i) characterization of the mechanical properties of the materials (steel, timber, concrete, etc.); ii) definition of loads and load combinations applied to the structures; and iii) the definition of the safety requirements of the structure. The definition of these aspects depends on the structural design philosophy employed: Allowable Stress or Limit States. Internationally, both approaches co-exist, but the trend is towards the replacement of the first method by the second one.

In the United States, the method of the Allowable Stress, known by its acronym ASD (Allowable Stress Design), has been gradually replaced by the method of Limit States, commonly called LRFD (Load and Resistance Factor Design). It was introduced in the 70's for reinforced concrete (ACI 318 1970), in 1986 for steel structures (AISC 360 1986) and in 2005 for wood construction (NDS 2005). The most recent editions of the United States timber constructions code propose both approaches for timber and steel. Argentina and Chile have their own timber code, CIRSOC 601 (CIRSOC 601 2013) and NCh 1198 (NCh 1198 2006), respectively, which employ the ASD method, while Brazil (NBR 7190, 1997 and NBR 7190 2010) and the European Community (Eurocode 5: EN 1995-1-1 2004/AC: 2006 and EN 1995-1-2, 2004/AC: 2009), adopted the LRFD method.

The Eurocodes are a set of European rules aimed at removing the technical barriers to trade and the harmonization of the technical specifications in the areas of design, calculation and sizing of structures, developed by the European Committee for Standardization (CEN). These generic documents are adapted to local conditions in each country through the National Annexes to the Eurocodes. They are technical documents of national implementation whose objective is the definition of the Nationally Determined Parameters (NDP) and, optionally, Non-contradictory Complementary Information (NCCI) to Eurocodes.

In Uruguay, the Uruguayan Institute of Technical Standards (UNIT) regulates the national standards. UNIT 33:1991 (UNIT 33 1991) and UNIT 50:1984 (UNIT 50 1984) regulate the actions on structures; the first is related to self-weight and imposed loads for buildings and the second to wind actions. However these standards are not up to date. UNIT 33:1991 does not provide accidental actions (e.g. impacts, fire, etc.), earth or water pressure and actions on other structures, such as bridges or silos. UNIT 50:1984 does not include aspects such as dynamic and aeroelastic effects or design of structures different than buildings. There is a standard for reinforced and mass concrete (UNIT 1050 2005), based on the old Spanish Instruction (EH-91 1991), which uses the LRFD method for the design. However, it does not include the design of prestressed concrete structures and the design in case of fire or the variability of the partial factors depending on the action, among others. There is not a UNIT standard for steel and timber structures. However, there are two documents that define structural design criteria for both materials, IE3-53 (IE3, 1953) and IE4-50 (IE4, 1950) respectively. They were elaborated by the Institute of Structures and Transport, Faculty of Engineering, Universidad de la República, in the 50´s and both of them are based on the ASD method. IE4-50 includes bending strength allowable values of different wood species.

Therefore, in Uruguay there is no a national code for the design of timber structures, which includes from the characterization of materials and manufacturing specifications of engineered wood products to the design, calculation and building construction. This could cause inconsistencies between the mechanical properties of the material and the design code used for engineers or architects, besides the uncertainties in the reduction factors to be applied to the mechanical properties. Also, there is not a common criterion for all materials regarding deflection limits of structural elements, acceptable vibration frequencies depending on the use or time required of mechanical resistance in fire situation of the elements for different uses, among others.

The objective of the this paper, therefore, is to present a proposal to of the National Annex to Eurocode 5 (Part 1-1 and Part 1-2) that includes the Nationally Determined Parameters and Non-contradictory Complementary Information that assist the implementation and interpretation of the Eurocode 5 in Uruguay.

Methodology

The results of this paper were obtained under the research project entitled "Technical Documents for standardization of timber structures and buildings", funded by the National Direction of Industry (*Dirección Nacional de Industrias, DNI*) of the Ministry of Agriculture, Cattle and Fishery (*Ministerio de Ganadería Agricultura y Pesca, MGAP*). The project included two lines of work: i) determining the physical and mechanical properties of timber in Uruguay and ii) design a code for timber structures, being the results of this second line presented in this paper. The tasks performed in the project are described below.

Analysis of international Codes for the design of timber structures

Workshops and technical seminars, with participants from Argentina, Brazil, Chile and Spain, were made with the aim of sharing experiences in the process of development the codes for the design of timber structures. The reasons that influenced the choice of the format of calculation in each country and the most important aspects of the process of developing of the codes were discussed. Topics included: i) characterization of sawn timber and visual grading; ii) background about characterization of timber and design codes in Uruguay; iii) minimum production requirements and quality control for glued laminated timber (glulam); iv) serviceability limit states: limiting values for deflections of beams and vibrations in residential floors; v) structural fire design; vi) analysis of the wind standard UNIT 50-84 and relationship with Eurocodes; and vii) analysis of the different codes for the design of timber structures.

Development of the Uruguayan Code for the design of timber structures

The considerations taken into account in the proposal for the Uruguayan Code for the design of timber structures were, among others, coordinating requirements with other structural materials, with the standards of actions on structures and testing and grading of timber, taking into account existing international standards.

Adoption of an existing Code

An existing Code for the design of timber structures (Eurocode 5) was adopted instead of generating an own Code and the corresponding European Standards (EN) for the characterization of timber, testing, processing requirements for the engineered wood products, etc. The use of the EN presents several advantages for Uruguay, such as consistency between the material characterization and the design code, regular updates, internationally recognized and save much work for generating own standards and codes, already developed.

The proposal for the National Annexes to Eurocode 5 for buildings (EN 1995-1-1 2004 and EN 1995-1-2 2004) were developed. EN related to the characterization of sawn timber and glulam (prEN 408 2015; prEN 384 2014; prEN 338 2012; EN 14080 2013, etc.) were adopted to obtain values of the physical and mechanical properties of national wood.

Drafting of a proposal for the Uruguayan National Annex to Eurocode 5

A proposal for the National Annex to Eurocode 5, in the part 1-1 related to common rules for building and in the part 1-2 of design in case of fire, is drafted for Uruguay. Spanish National Annex (AN_UNE EN 1995-1-1 2014 and AN_UNE EN 1995-1-2 2014) and British National Annex (BS NA EN 1995-1-1 2008) are considered as background. Uruguayan National Annexes include the Nationally Determined Parameters (NDP) and Non-contradictory Complementary Information (NCCI) to the Eurocode 5 for the design of timber structures in Uruguay.

1. Results and Discussion

Uruguayan National Annex to Eurocode 5: Part 1-1

The proposal of the National Annex intends to define the conditions of implementation in Uruguay of the Eurocode 5 and, in case of not having enough information, define the necessary lines of research. NDP and NCCI are defined for Uruguay.

Nationally Determined Parameters

Load Duration classes and Service Classes

Eurocode 5 enables the assignment of classes of duration to the loads and the service classes to the structures. In both cases the classes defined in the Spanish National Annex were proposed with minor modifications, such as the assignation of the wood used for formwork to Service Class 3.

Design values of the material properties

Timber in Uruguay is not graded or structurally certified and there is not experience in timber construction, so other design values of the material properties (Table 1) than the ones proposed by Eurocode 5 are suggested. The values were defined as a function of the quality control of timber and of the quality control of the construction process in order to obtain the same probabilities of failure of the structures. They were obtained from the recommendations presented on the Eurocode 0 in its Annex 3 (EN 1990 2002) and the mechanical properties of about 200 specimens of Uruguayan *Pinus elliottii/taeda*.

Table 1: Proposal of the design values of the material properties in Uruguay

Quality control of the timber	Quality control of the construction	Design value of the timber properties
Normal	Normal	1,60
	Intense	1,45
Intense	Normal	1,45
	Intense	1,30

Serviceability Limit States: limiting values for defections of beams, horizontal displacement and limit values for the vibrations in floors

Limit values for deflections of beams and for horizontal displacement of the structure and limit values for the vibrations of floors were included as an alternative to the proposed values presented in the Eurocode 5. They are taken of the Spanish National Annex to Eurocode 5 and from the Spanish Technical Building Code - Basic Document - Structural Safety: Timber (CTE-DB-SE:M 2009). Three criteria are considered for the limiting values of deflections of beams: a) integrity of the construction components: b) the user comfort and c) the appearance of the structure. The limits for the active deflection in the case a) varies between l/200 and l/500; the limit of the instantaneous deflection for the case b) is l/350 and the limit of the final deflection for the case c) is l/300.

Non-Contradictory Complementary Information

Relationship between the UNIT Actions Standards and the Actions on Structures of the Eurocode 1

The use of the standard UNIT 33 (UNIT 33 1991) is presented as an alternative to Eurocode 1 about self-weight and imposed loads for buildings (EN 1991-1-1 2002). The use of the standard UNIT 50 (UNIT 50 1984), about wind on structures, is recommended to determine the characteristic wind velocity (v_k) and use one of the following methods: i) to convert the characteristic wind velocity (v_k) defined by UNIT 50 in the basic velocity defined by Eurocode 1 (v_b) and define the wind actions on the structure according to Eurocode 1 or; ii) to define the wind actions on the structures according to UNIT 50. Equation 1 is used to convert v_k to v_b (Páez and Morquio 2014), where the coefficients define the orography, the sampling interval and the return period.

$$v_b = 0{,}858 \cdot 0{,}676 \cdot 1{,}149 \cdot v_k = 0{,}667 \cdot v_k \qquad (1)$$

Other parameters

Based on Eurocode 0 and the Spanish Technical Building Code - Basic Document - Structural Safety (CTE-DB-SE 2009), the actions on structures and actions combinations were defined. Regarding the definitions for the calculation of the Serviceability Limit States, active, instantaneous and final deflections of beams are defined, as well as the active and final horizontal displacement of a building and the procedure for the verification vibrations on floors. Other parameters were taken from the recommendations of the Eurocode 5 and the Spanish Technical Building Code because in Uruguay does not exist specific information about these topics. The need for research on the sensitivity to splitting of the *Pinus taeda, Pinus elliottii* and *Eucalyptus grandis* from Uruguay is highlighted.

Uruguayan National Annex to Eurocode 5: Part 1-2

Nationally Determined Parameters

Due to in Uruguay does not exist information about the mechanical resistance in fire situation the recommended values by Eurocode 5, part 1-2 are adopted. The partial factor for material properties ($\heartsuit_{M,fi}$) takes a value equal to 1.0 and the reduction factor for combination of actions ($|_{fi}$) takes a value of 0.6, except for storage areas where $|_{fi}$=0,7. Reduced cross-section method and reduced properties method for the procedure design of mechanical resistance in case of fire are admitted.

Non-contradictory Complementary Information

Mechanical resistance in fire situation of the main members of a structure Due to fact that Uruguay does not have a regulation for resistance of structural members in fire situation, the values of R were adopted from Spanish Technical Building Code - Basic Document – Security in case of fire (CTE-DB-SI 2009).

Summary and Conclusions

Eurocode 5 part 1-1 (General rules for building projects) and part 1-2 (Timber structures in fire situation) was proposed to be used in Uruguay for the design of timber structures, after the workshop held with the participants in the development of structural codes for the design of timber structures in Brazil, Argentina, Chile and Spain. The adoption of the Eurocode for the design of timber structures in Uruguay establishes a precedent for the design codes to be followed in Uruguay for other construction materials.

A National Annex to Eurocode 5 was proposed. It contains the Nationally Determined Parameters and containing Non-contradictory Complementary Information to Eurocode 5 for the Uruguayan conditions of timber design.

NDP for Uruguay are, among others, the definition of load duration classes and service classes, also the assigning of design values of the material properties for the Uruguayan conditions and the limiting values for the serviceability limit states. NCCI contemplates the relationship between the UNIT standard and Eurocode 1 for wind on structures, a summary of the loads combinations according to Eurocode 0, 1 and 5 and the definitions of deflections on beams, horizontal displacement on buildings and limit values for vibrations on floors.

The following topics are recommended to be researched in order to complete the National Annex to Eurocode 5 with information about the local cultivated species (*Pinus taeda, Pinus elliottii* and *Eucalyptus grandis)* and local conditions: i) study of the design values of the material properties; ii) determination of the sensitivity to splitting*;* iii) study of the embedment strength; iv) study of the charring rates; v) determination of the physical and mechanical properties of sawn timber and engineered wood products from Uruguay and
vi) development of an UNIT standard for visual grading and establish the correlation with the strength classes according to EN 338 to that refers the Eurocode 5.

Acknowledgements

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Visual and Mechanical Properties of Southern Pine No.2 Lumber[1]

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Abstract

The objective of this study was to evaluate the influence of certain visual characteristics on the mechanical properties of in-grade southern yellow pine lumber. A total of 138 samples with two different lengths (four and five meters long) were used. The visual characteristics (presence of pith, percentage of latewood and rings per inch) were collected on both ends of each piece which were subsequently mechanically tested by static bending (modulus of elasticity and modulus of rupture). Around 50.7% of the boards exhibited pith on at least one end of the boards. An average of 40.9% of latewood and 4.3 rings per inch were determined. The average modulus of rupture (MOR) was 43.7 MPa and modulus of elasticity (MOE) of 10.9 GPa. A t-test was performed to compare means between lengths, rings per inch and MOR showed a significant difference. No significant correlations were found between visual and mechanical properties indicating that percentage of latewood and rings per inch alone are not good predictors of mechanical properties for this sample of southern yellow pine lumber. The results reported here are not representative of the global population of southern pine lumber on the market.

Key words: presence of pith, percentage of latewood, rings per inch, modulus of elasticity, modulus of rupture.

Introduction

Southern yellow pine is the most important source of softwood in the United States. The species in the southern yellow pine group are well known for their high utility, strength and stiffness properties and as well as preservative treatability. Because of the variation in wood material, it is necessary to beneficial to minimize differences wherever possible (Gaby, 1985).

Grading rules are used to maintain a standard material and guarantee a minimum uniform quality independent of the variation between sawmills and species. Visual grading, and machine grading are the two major methods used to evaluate lumber.

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The visual grading method is the most frequently technique to valuate structural lumber, and it is used to predict the mechanical properties and sort the material into different classes. Visual grading is based on measurement of knots, slope of grain, checks and splits, shake, density, decay, heartwood and sapwood, pitch pockets, wane, and other characteristics (Iniguez et al, 2007).

The objective of this research was to look at a subset of the visual characteristics exhibited by southern yellow pine No. 2 – 2x8 lumber and correlate it to bending properties. Each specimen was examined for presence of pith, percentage of latewood and rings per inch and to determine if correlations exist with the mechanical properties of MOE and MOR and the observed visual characteristics.

Materials & Methods

A total of 138 commercially kiln dried southern pine No. 2 - 2x8 lumber with two lengths (four and five meters) obtained from mills via commerce in Southern United States. Each board was visually characterized and mechanically assessed. The boards were characterized by presence of pith, percentage of latewood and rings per inch based on standard practices used by the Southern Pine Inspection Bureau (SPIB, 2014). After the visual characterization, the setup of bending tests was conducted according to ASTM 198 (2012) with a testing speed specified by ASTM D4761 (ASTM, 2012).

Analysis of values of rings per inch, percentage of latewood, MOR and MOE was made using t-test to evaluate difference between lumber lengths ($p < 0.05$), and Pearson's correlation was performed between visual and mechanical properties.

Results and Discussion

Table 1 shows the results of rings per inch, percentage of latewood and presence of pith. Averages were 4.3 for rings per inch and 40.9% for latewood. The presence of pith in at least one end occurred in 50.7% of the samples. The southern pine No. 2 – 2x8 met the visual requirements of Lumber Standards.

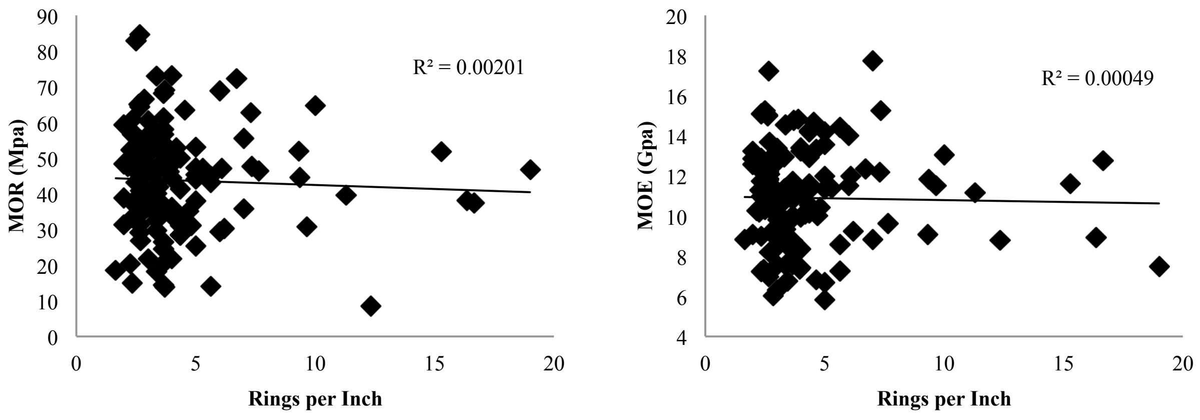
For samples with 4 m length the average for MOR and MOR was 42.5 MPa and 10.8 GPa, respectively. For samples with 5 m length the average for MOR was 46.8 MPa and MOE 11.3 GPa. The overall average for MOR was 43.7 MPa and MOE of 10.9 GPa. There was a significant difference between lengths for rings per inch and MOR. These results are consistent with the current published design strength values for in-grade southern yellow pine lumber. Doyle and Markwardt (1966) studied the properties of southern pine lumber and found MOR of 41.5 MPa and 10.8 GPa for MOE, which are similar to the results found in this study.

Table 1 – Results of visual characterization of Southern Pine 2x8 No. 2 lumber

Size (m)	Rings Per Inch	Latewood (%)	Pith (%)	MOR (MPa)	MOE (GPa)
4	4.5^{*} $(72.1)^{**}$	40.7^{ns} $(23.3)^{**}$	48.0	42.5^{*} (23.7)	10.8^{ns} (36.3)
5	3.9 (40.6)	41.4(17.6)	59.0	46.8 (23.3)	11.3 (18.4)
Average	4.3	40.9	50.7	43.7	10.9

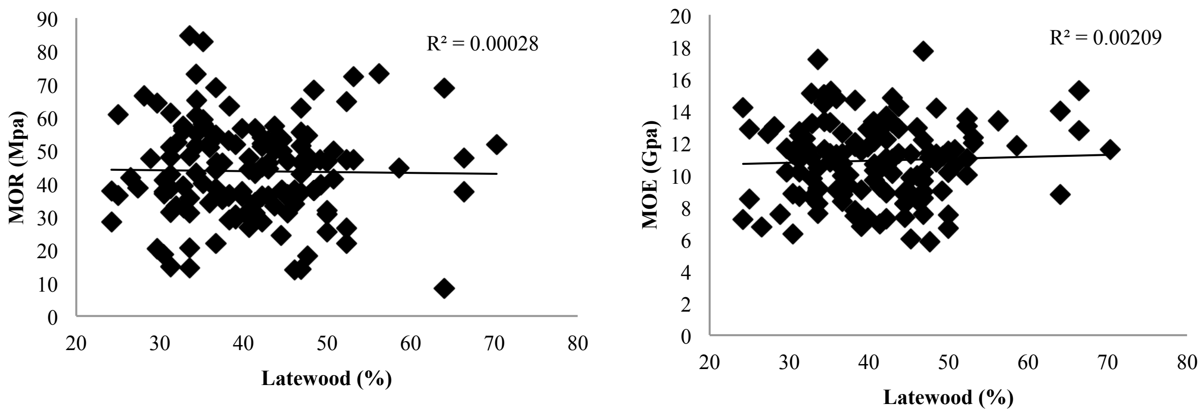
ns: non-significant difference
* Significant at the 0.05 level
** Coefficient of variation

Figures 1 and 2 show the correlation between rings per inch, percentage of latewood and mechanical properties (MOE and MOR). There was no significant correlation between visual characteristics and mechanical properties. It should be noted that the results presented in this study are from a relatively small sample and do not represent the global population of southern pine lumber on the market.



(a) (b)

Figure 1 – Correlation of rings per inch: a) MOR b) MOE



(a) (b)

Figure 2 – Correlation of percentage of latewood: a) MOR; b) MOR

Summary and Conclusions

The average of percentage of latewood and rings per inch for southern yellow pine samples was 40.7% and 4.3, and 50.7% of the boards had presence of pith on at least one end. The mean value for MOR was 43.3 MPa and 10.9 GPa for MOE. There was a significant difference between lengths for rings per inch and MOR. The values found in this research are in accordance to the lumber standard.

There was no significant correlation between visual and mechanical properties indicating that rings per inch, percentage of latewood and presence of pith are not enough to predict MOE and MOR for the small sample of in-grade lumber.

Potentially, this study could have been improved by testing small clear specimens. By testing small clear pieces, the impacts of each characteristic could have been studied individually. It appears that in composite, the sum of the many characteristics associated with each specimen perhaps interact and thus make it difficult to tease out any single factor, such as rings per inch, or percent latewood, as a predictor for stiffness and strength. Multivariate analysis that includes these factors, along with other grade-specific characteristics is likely a more beneficial means of predicting mechanical performance.

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Nondestructive Assessment of No. 2 Southern Yellow Pine Lumber[1]

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Abstract

This study investigated the use of longitudinal and transverse vibration methods to evaluate the mechanical properties of 2x8 southern yellow pine lumber. A total of 138 samples were conditioned to 12% equilibrium moisture content. All samples were first nondestructively tested using transverse vibration equipment (Metriguard E-computer) and a longitudinal vibration method (Fakopp microsecond timer software + microphone device) to obtain the vibration properties in the transverse and longitudinal methods. Dynamic modulus of elasticity (MOE) of each sample was calculated based on the fundamental wave equation. Static bending was subsequently conducted according to ASTM 198 (2012) and the speed of testing followed ASTM D4761 (ASTM, 2012). The results showed significant correlations between the properties determined by nondestructive techniques and the static MOE (r^2=0.769 with transverse vibration, r^2=0.778 with longitudinal vibration). No significant correlations were found for MOR (r^2=0.140 for transverse vibration; r^2=0.156 for longitudinal vibration). This study indicates the nondestructive techniques can potentially be used to evaluate 2x8 southern yellow pine lumber stiffness. These results are not necessarily representative of the entire population of southern yellow pine lumber.

Key words: modulus of elasticity, transverse vibration, longitudinal, vibration

Introduction

Wood is one of the main materials used in construction. It has advantages when compared to materials, such as steel and concrete. It shows considerable mechanical strength and a favorable strength to weight ratio. Also, it is relatively easy to fasten, cut,

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and shape and it is a relatively low cost option compared to other materials. In addition, it is a sustainable, renewable and biodegradable bio-product; however, it needs to be classified to optimize its use.

As a building material, wood has many features which directly influence its in-service performance. Therefore, a full knowledge of its structural potential is a necessity for its correct use in construction. Like other materials used in construction, the physical and mechanical properties of wood should be tested and then classified for structural use (Segundinho et al., 2012).

Nondestructive assessment methods are ways to evaluate physical and mechanical properties of a piece of material without changing its characteristics (Ross et al. 1998). Techniques, such as ultrasound, transverse vibration, longitudinal vibration, and x-ray have been investigated and have been adopted by industry because of their fast responses and high correlations (Brashaw et al., 2009).

The modulus of elasticity (MOE) is one of the most important mechanical properties of wood since it is the indicator of load resistance most frequently used (Amishev & Murphy, 2008). The dynamic methods to characterize wood and other materials calculate the elastic modulus through the natural frequency of the specimen vibration and its geometric parameters. These methods have the advantage of being fast and being repeatable (Cossolino and Pereira, 2010). For clear wood, in general, the correlations between MOE and MOR are relatively strong and repeatable.

Since the 1960s, researchers from the forest products community have been developing non-destructive testing (NDT) tools for evaluating the quality of lumber products, especially with regard to mechanical grading (Divós & Tanaka, 2005). Lumber is more difficult to evaluate than small clear specimens because it has a multitude of interacting and potentially stiffness- and strength-reducing characteristics. In the 1990’s, Ross et al. (1991) developed personal computer software for making transverse vibration NDT tools available to a broader range of wood products manufacturers and users.

Predicting the MOE of lumber with longitudinal stress wave has received considerable research efforts in recent years in terms of lumber grading or pre-sorting (Wang, 2013). The assessment of the quality of raw wood materials has become a crucial issue in the operational value chain as forestry and the wood processing industry are increasingly under economic pressure to maximize its extracted value (Brashaw et al., 2009). The aim of this study is to evaluate mechanical properties of southern yellow pine Number 2-grade 2 2x8 lumber using the longitudinal and transverse vibration techniques.

Materials & Methods

The specimens used in this study were138 full-scale samples (98 samples four meters long and 40 samples five meters long) kiln dried southern pine No. 2 2x8 lumber. Samples were conditioned to 12% moisture content before start the experimental procedure.

Longitudinal vibration

For the longitudinal vibration test two rigid sawhorses positioned at ¼ and ¾ of the length supported the boards, and simple type of foam was used at the contact between sawhorse-board as a way to reduce damping and increase accuracy. To achieve the longitudinal frequencies a microphone was used to capture the vibration. A computer with the Fast Fourier Vibration Analyzer software (Fakopp, 2005) was used to read the natural frequency of each board.

An impact was applied on each test specimen in the longitudinal direction as according to ASTM E1876 (2007). The direction of the wave motion occurs in the same direction as the longitudinal vibration mode. Dynamic modulus of elasticity due to the first longitudinal vibration resonance frequency is given by Equation 1.

$$E_L = \rho \cdot (L \cdot f)^2 \tag{1}$$

where E_L = dynamic modulus of elasticity (MPa), ρ= density ($kg.m^{-3}$), L = beam span (m), f = first harmonic longitudinal vibration frequency (Hz).

Transverse vibration

Boards were simply supported flatwise as a beam spanning the entire length of the board. Each piece was supported on one end by a knife-edge support and at the opposite end by a point support. As such, each piece was permitted to vibrate in an unrestrained manner. Each 2x8 was nondestructively examined using transverse vibration equipment (Metriguard Model 340 Transverse Vibration E-Computer).

Each specimen was then set into vibration by gently tapping it near the center of the span. A load cell measured the frequency of vibration and board weight, and the E-Computer reached the transverse vibration frequency for each piece and calculated the dynamic MOE.

The impact was applied and the signal captured on the transverse direction of the wood according to ASTM E 1876 (2006). The calculation of the elastic modulus due to the first transverse vibration resonant frequency is given by Equation 2.

$$E_T = \frac{f_r^2 \cdot W \cdot L^3}{2.46 \cdot I \cdot g} \tag{2}$$

Where E_T = dynamic modulus of elasticity (MPa); f_r = resonant frequency (Hz); W = board weight (kg); L = beam span (m); I = moment of inertia (m^4); g = acceleration of gravity (9.8 m/s^2);

Static bending test

Following the non-destructive measurements, all specimens were mechanically tested in static bending with a universal testing machine in order to obtain the modulus of elasticity (MOE) and modulus of rupture (MOR). The static bending tests were conducted on each specimen using a four-point bending setup according to ASTM 198 (2012) and test speed followed ASTM D4761 (2012). The load-deflection data was recorded by the machine and the flexural modulus of elasticity is calculated by Equation 3.

$$\mathrm{MOE} = \frac{\mathrm{P}\cdot(3\mathrm{L}^2 - 4a^2)}{48\cdot\delta\cdot\mathrm{I}} \quad (3)$$

where MOE = Static bending modulus of elasticity (MPa), P = Force (N), L = distance between load points (m), δ= midspan deflection (m), I = moment of inertia (m^4).

Modulus of rupture (MOR) was calculated based on Equation 4:

$$\mathrm{MOR} = \frac{\mathrm{P}\cdot\mathrm{L}}{\mathrm{b}\cdot\mathrm{h}^2} \quad (4)$$

where P = maximum transverse load on specimen (N), L = span of the specimen (m), b = thickness of the specimen (m), and h = depth of the specimen (m).

Results and Discussion

Table 1 lists the values corresponding to the dynamic MOE obtained with longitudinal and transverse vibration for each length. The dynamic MOE obtained with longitudinal vibration ranged between 4.8 – 17.9 GPa, with the average being 10.0 GPa including both lengths. There is no significant difference between lengths (α = 0.05).

Table 1. Average, minimum and maximum of dynamic MOE values for each length and method

	Length (m)	MOE (GPa)		
		Average	Min	Max
Longitudinal (GPa)	4	10.0 (27.2)*	4.8	17.9
	5	10.2 (21.9)	4.9	16.1
Transverse (GPa)	4	10.6 (26.8)	5.3	18.4
	5	10.9(20.0)	6.2	16.8

* Coefficient of variation (%).

The dynamic MOE obtained with transverse vibration ranged between 5.3 – 18.4 GPa, with the average being 10.6 GPa including both lengths. There is no significant difference between lengths (α = 0.05). Both methods are suitable to predict MOE.

Table 2 lists the values corresponding to the MOE and MOR obtained with static bending test for each length. The MOE values in static bending for the SYP lumber were 5.8 – 17.7 GPa, with the average being 11.0 GPa including both lengths. Doyle and Markwardt (1966) studying SYP 2x8's dimensional lumber found MOE values ranging from 8.8 – 13.2 GPa.

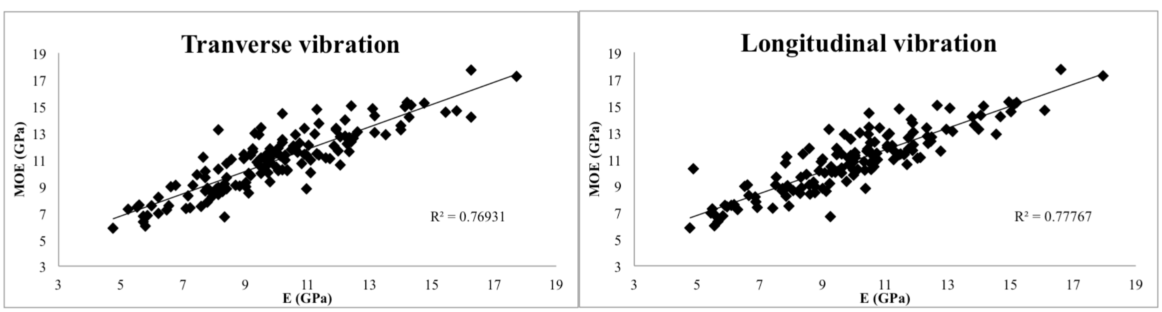
Table 2. Average, minimum, maximum and coefficient of variation of MOE and MOR values for each length

	Length (ft)	Average	Min	Max
MOE (GPa)	4	10.8 (23.3)*	0.846	2.57
	5	11.3 (18.5)*	0.872	2.18
MOR (MPa)	4	42.5 (36.3)*	8.4	84.8
	5	46.8 (23.0)*	21.4	73.2

* Coefficient of variation (%).

The MOR values were between 8.4 – 84.8 MPa (1223 to 12267 psi), with the average being 43.7 MPa (6343 psi) including both length. Doyle and Markwardt (1966) found MOR values ranging from 26.4 – 56.6 MPa (3830 and 8210 psi).

The correlation between modulus of elasticity (MOE) and transverse vibration is shown in Figure 1-a. The correlation between modulus of elasticity (MOE) and longitudinal vibration prediction is shown in Figure 1-b.

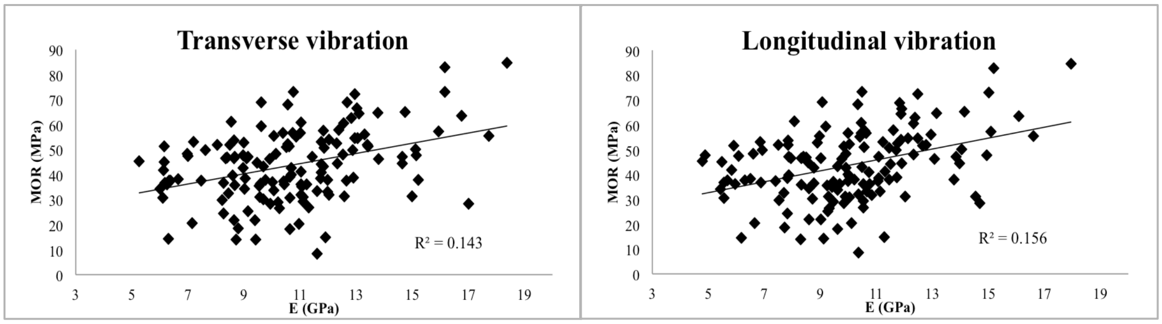


(a) (b)

Figure 1. The correlation between modulus of elasticity (MOE) and transverse vibration is shown in Figure 1-a. The correlation between modulus of elasticity (MOE) and longitudinal vibration prediction is shown in Figure 1-b.

The results showed significant correlations between the properties determined by nondestructive techniques and the static MOE (r^2=0.77 with transverse vibration, r^2=0.78 with longitudinal vibration). Many studies with softwood species already demonstrated the potential of these methods to estimate MOE (Ross et al., 1991; Divós & Tanaka, 1997).

The correlation between modulus of elasticity (MOR) and transverse vibration is shown in Figure 2-a. The correlation between modulus of elasticity (MOR) and longitudinal vibration prediction is shown in Figure 2-b. Linear relationship between dynamic MOE and MOR were not significant for both methods (r^2=0.14 for transverse vibration; r^2=0.16 for longitudinal vibration). The low correlations are largely explained by the presence of knots and other wood defects suck checks, splits and grain deviation present in SYP dimension lumber as well as by the fact that all lumber was in the same grade. Inclusion of multiple grades would have provided specimens of both greater and lesser quality which would have most likely improved these correlations.



(a) (b)

Figure 2. Correlation between MOR and dynamic MOEs

Pellerin (1965) using free transverse vibration of Douglas-fir dimensional lumber found correlation between 0.67-0.93 for different lumber grades. O'Halloran (1972) studying lodgepole pine dimensional lumber using transverse vibration technique found coefficient of correlation equal 0.89. Green & McDonald (1993) using transverse vibration flatwise found correlation equal 0.58 for Northern red oak lumber. França et al. (2015) found r^2 ranging between 0.43 to 0.61 using transverse and longitudinal vibration techniques in *Eucalyptus* sp. clear wood.

Carreira (2012) tested the transverse vibration method with *Eucalyptus* sp. logs in bending test and concluded that this technique was not efficient to provide reliable estimates of the logs MOR. França et al. (2015) affirm that elastic waves such transverse and longitudinal vibrations are not reliable by itself to predict *Eucalyptus* sp. modulus of rupture. Vega et al. (2012) studying chestnut timber found r^2 between 0.10 to 0.17 using three different NDT methods (ultrasound, impact wave and longitudinal waves) concluding that dynamic variables are not adequate by themselves to estimate bending strength. Shmulsky, Seale and Snow (2006) evaluated the acoustic velocity method to predict stiffness and strength of 12 cm diameter southern pine dowels and found a r^2 = 0.66 for correlation between acoustic velocity and stiffness and r^2=0.18 for a correlation between acoustic velocity and strength.

Summary and Conclusions

- Both methods tested are able to predict MOE;
- Longitudinal vibration showed slightly higher correlation between dynamic MOE and static MOE;
- Both vibration methods were not reliable to predict MOR.

- Potentially, this study could have been improved by testing lumber specimens in both higher and lower grades. By including additional grades, a greater range of stiffer/stronger pieces as well as less stiff/weaker pieces would have been evaluated. It seems that in composite, the sum of the many characteristics associated with each in-grade specimen perhaps interact and thus influence the stiffness to strength relationship.

Acknowledgements

The authors wish to acknowledge the support of U.S. Department of Agriculture (USDA), Research, Education, and Economics (REE), Agriculture Research Service (ARS), Administrative and Financial Management (AFM), Financial Management and Accounting Division (FMAD) Grants and Agreements Management Branch (GAMB), under Agreement No. 5B-0202-4-001 and Mississippi State University (USA).

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Gate-to-gate Life-Cycle Inventory Analysis on Carbon Activation of Biochar

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Abstract

Biochar application to forest soils can provide direct and indirect benefits including carbon sequestration. Biochar, the result of thermochemical conversion of biomass can have positive environmental climate benefits and can be more stable when field applied to forest soils than wood. Categorizing the greenhouse gas (ie carbon) emission and carbon sequestration profile is critical to the long-term sustainability of this practice. Using life-cycle assessment as a sustainable metric tool, this study will evaluate the fuel consumed to pelletize, transport, and field-apply biochar produced from a novel thermochemical process. We estimate the global warming potential (GWP) from the electricity consumed during pelletizing and the diesel and gasoline consumed during road and field transport and field spreading of the biochar pellets compared to the carbon sequestration value of the biochar itself. Quantifying GWP will show what the environmental impacts are of consuming primary energy to field-apply biochar pellets.

Session

Biomass and Bioenergy

Moderators:
Jingxin Wang, West Virginia University, USA
Alex Berg, University of Concepcion, Chile

Biomass as an Energy Source in Chile

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Abstract

Twenty-nine percent of Chile's energy matrix is based on forest biomass. A significant proportion of it, nearly 36%, is due to the use of firewood in domestic heating. The remaining part (mainly sawdust, pine bark and harvesting residues of Pinus radiata) is used in industrial boilers to generate heat and electricity and to a lesser extent, agricultural biomass (wheat straw) as fuel.

There are some specific reasons that have driven the use of biomass as an energy source: The existence of large amounts of residual biomass in the forest industry, the high price of electricity in Chile and the possibility to operate co-generation plants, in which thermal energy is used to supply pulp mills, wood-based-panel plants and timber drying kilns, mainly.

The prospects for future development are based mainly on two areas: (1) Substantial improvement of the technology associated with the use of firewood, both in terms of the quality of combustion equipment and fuel; and (2) implementation of low capacity electricity generation systems (0.5 to 2 MWe) that complement current larger plants. In this context, ORC –technology and the use of engines associated to wood-gasification systems may primarily be considered.

Estimating GHG Emissions from the Manufacturing of Field-Applied Biochar Pellets

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Abstract

Biochar application to forest soils can provide direct and indirect benefits, including carbon sequestration. Biochar, the result of thermochemical conversion of biomass, can have positive environmental climate benefits and can be more stable when field-applied to forest soils than wood itself. Categorizing greenhouse gas (GHG) emissions and carbon sequestration profile are critical to the long-term sustainability of this practice. Using life-cycle assessment as a sustainable metric tool, this study evaluated the fuel consumed to pelletize, transport, and field-apply biochar produced from a novel thermochemical process from gate-to-gate on a per functional basis of one oven dry (OD) tonne. In the present study, pellet transport and field application were considered part of the manufacturing process. The fossil GHG emissions released from gate-to-gate manufacturing, 76.6 kg CO_2eq/OD t, was far exceeded by the amount of biogenic carbon sequestered long term at 2,430 kg CO_2eq/OD t, even considering the decay of biochar carbon over 100 years into biogenic CO_2. Biogenic CO_2 as part of the global carbon cycle does not contribute to climate change when the feedstock came from sustainably managed forests, as in this study. Quantifying global warming impact showed that consuming primary energy for field-applied biochar pellets had relatively small contributions to climate change relative to the carbon sequestration potential of the biochar pellets.

Key words: Life-cycle assessment, climate change, forest, biochar, spreading, sequestration

Introduction

Biomass as a sustainable feedstock for creating bioproducts has raised considerable attention (Ragauskas et al 2006; Guo et al 2007; Bozell and Petersen 2010). Biomass-derived fuels and products can reduce the need for petroleum imports while supporting the growth of agriculture, forestry, and rural economies (Roberts et al 2010; McKechnie et al 2011; Cowie and Cowie 2013). In particular, biochar as a bioproduct has received extensive consideration because of its carbon (C) sequestration potential and ability to boost soil productivity (Lehman et al 2006; Lorenz and Lal 2014). Thus, biochar as a byproduct of bioenergy production from biomass, including generation of heat, energy gas, and bio-oil, has the potential to reduce net greenhouse gas (GHG) emissions, improve local economies and energy security (Gaunt and Lehmann 2008; Homagain et al 2014), and possibly increase overall site productivity when added back to the soil.

Biochar application to forest soils can provide direct and indirect benefits as a soil amendment and through C sequestration (Sohi et al 2010; McElligott et al 2011). Biochar, the result of thermochemical conversion of biomass, can have positive environmental benefits and can be more stable when field-applied to forest soils than wood itself (Gaunt and Cowie 2009; Sohi et al 2010; McElligott et al 2011; Cowie and Cowie 2013; Schimmelpfennig et at 2014; USDOE EERE 2015).

Restoration treatments on western U.S. forests produce large quantities of woody biomass that can be used as feedstock for production of biofuels and other bioproducts. Producing bioenergy and bioproducts from such forest thinning or timber harvest byproducts would contribute to achieving broad national energy objectives, including the nation's energy security and reduction of greenhouse gas emissions from fossil fuels. The U.S. Department of Energy and the U.S. Department of Agriculture (USDA) are both strongly committed to expanding the role of biomass as an energy source and envision a 30% replacement of current U.S. petroleum consumption with biofuels by 2030 (Perlack et al 2005). One way to measure biochar's sustainability in the context of the abovementioned features is by conducting a life-cycle assessment (LCA).

LCA as a science-based tool is useful in assessing the claim that expanding bioenergy production from woody biomass has the potential to reduce net GHG emissions. Information provided by this analytical tool is essential for policy makers to make evidence-based judgments on expanding renewable energy production. LCA considers direct and related processes, flows of raw materials and intermediate inputs, waste, and other material and energy outputs associated with the entire product chain or system. Broadly, LCA can assess new products, new processes, or new technologies in an analytically thorough and environmentally holistic manner to guide more robust deployment decisions. LCA can calculate GHG and other emissions over part or all of the whole life cycle of a product.

For our study, we applied LCA to the pelletization and field application of biochar produced from a distributed-scale advanced biomass pyrolysis system, which will be referred to in this paper as the Tucker (developed by Tucker Engineer Associate, Locust, NC) renewable natural gas (RNG) unit (Bergman and Gu 2014; Gu and Bergman 2015). This study is part of a larger USDA project developing and evaluating the Tucker RNG unit that could generate bioenergy and bioproducts for higher value markets. The Tucker RNG unit uses high-temperature conversion (>750 °C) in an extremely low oxygen environment to convert feedstock from forest thinning and mill residues into syngas that can be used for heat and electricity and into biochar for soil amendment or as a precursor in the manufacturing of activated carbon and other industrial carbon products. Syngas-generated electricity is intended to substitute a portion (marginal part) of grid electricity generated from fossil fuels, most commonly natural gas and coal. The system was specifically designed to generate a high-quality biochar to become activated carbon and not as a soil amendment, which sells at a lower price. However, LCA can focus on life-cycle stages that may not be considered once a process becomes commercialized but still in the development phase to evaluate what-if scenarios. In the present study, the what-if scenario was field application of pelletized biochar.

In this paper, LCA estimated the GHG emissions of field-applying biochar pellets in relation to its carbon sequestration potential. This is the first study to evaluate field application of pelletized biochar from a distributed-scale thermochemical conversion system in the United States. We answer the question of how much GHG emissions in kg CO_2-eq were generated from pelletizing biochar, transporting the pelletized biochar, and applying the pelletized biochar back to the forest where the raw material, wood, was harvested relative to the C sequestration potential found in the biochar.

Materials & Methods

The goal of this study was estimating the life-cycle impacts of field application of biochar pellets in relation to its C sequestration potential. To achieve this goal, the life-cycle inventory (LCI) for field-applying pelletized biochar, including processes of pelletizing biochar on a lab scale, transporting the pelletized biochar to the forest, and then field-applying the pelletized biochar, was modeled and conformed to the ISO 14040 and 14044 standards (ISO 2006a,b; ILCD 2010). LCI needs to be built before the impact analysis can be done. LCI, the data collection portion of a LCA, tracks and quantifies inputs and outputs of a system, including detailed resources, raw material, and energy flows.

Development of the LCI includes primary and secondary data. Primary data were collected on pelletization and field application of the pellets. Pelletizing biochar data came from lab runs. Application and spread rate data during field application of the pelletized biochar came from field work, and secondary data on estimates of fuel consumption for the machines used came from literature. As for transportation, the authors assumed that the pelletized biochar was field-applied roughly in the same forest where the feedstock was harvested to produce the biochar itself. The biochar was assumed to be produced at a sawmill located in St. Regis, MT, and then pelletized there at the sawmill as well before transporting to the forest. Secondary data on background processes, including (transportation) fuels and electricity, came from the U.S. LCI Database (NREL 2012).

Gate-to-gate manufacturing unit processes

Pelletization. A laboratory-scale pellet mill built by California Pellet Mill (CPM, Crawfordsville, IN, USA) and powered by a 1.5-kW motor densified the raw biochar. Inputs included raw biochar and electricity. Output was pelletized biochar at the lab. Off-site emissions came from grid electricity.

Transportation. Biochar pellets at the lab were transported 160 km to the forest for spreading. Inputs included biochar pellets and diesel for the pickup truck. Output was biochar pellets. Emissions included cradle-to-gate production and combustion of diesel.

Field-application. Biochar pellets were loaded on a diesel forwarder with a gasoline engine to run the spreader hydraulic system. For the present study, wood pellets were used as proxy because of the limited supply of biochar pellet. For the present paper, the authors used the term “biochar pellets” and not “wood pellets” when referring to field application. Inputs included biochar pellets, diesel, and gasoline. Output was biochar pellets on the forest floor.

The focus of this study was on the biochar product once produced. No upstream environmental impacts were assigned to the biochar before pelletization. In addition, the authors analyzed the biochar pellets for long-term carbon storage in soil (i.e., their carbon sequestration potential). Secondary data were drawn from peer-reviewed literature. With the material and energy inputs and reported emissions, the gate-to-gate LCI model for the field application of pelletized biochar was built in SimaPro 8 to estimate environmental outputs and cumulated energy consumption (PRé Consultants 2015). Within the SimaPro software, inventory data were compiled into the impact category indicator of interest, i.e., global warming (GW).

Scope

This study covers the partial gate-to-gate LCA of field application of pelletized biochar. The present LCA was classified as a partial LCA because the study covered only global warming and no other impact categories that are included in a full LCA. The U.S. electricity grid is composed of many regions with various energy sources (USEPA 2015). The U.S. Environmental Protection Agency (USEPA) has broken the U.S. electricity grid into “eGrids” (USEPA 2015).The eGrid system from the Northwest (NWPP) region included in the analysis is referred to as NWPP. The eGrid NWPP is representative of year 2012 mix of fuels used for utility electricity generation in the northwestern United States. Fuels include coal, biomass, petroleum, geothermal, natural gas, nuclear, hydroelectric, wind, and other energy sources. NWPP electricity grid covers area including Washington, Oregon, Idaho, Utah, most of Montana, Wyoming, Nevada, and northern parts of California, Arizona, and New Mexico.

Functional unit and declared unit

Functional unit is the reference unit used to quantify the environmental performance of a product system. It is also a reference related to inputs and outputs. A declared unit is used in instances where the function and the reference scenario for the whole life cycle of a product cannot be stated and includes only the quantity. For the present study, the authors selected a functional unit, one oven-dry (OD) kg of field-applied pelletized biochar. All input and output data were allocated to the functional unit of product based on the mass of products and co-products in accordance with standards for conducting LCAs (ISO 2006b). Material flows, energy use, and emission data are standardized based on this functional unit within the system boundaries described in the following section. The present study does include grid losses (USEPA 2015).

Unit processes
To complete the life-cycle impact assessment (LCIA), the field-applied biochar pellet system was built from unit processes. LCI databases contain large lists of unit processes. In the product system, starting from the declared unit, related processes are called on and built into the process tree with inputs and outputs matched to the delivery of the declared unit. For the reference fossil fuel chains, GHG performance was calculated using secondary data from the U.S. LCI Database (NREL 2012).

For the present study, the mainstream model of this study, the gate-to-gate manufacturing of the field-applied biochar pellets, was downstream of the thermochemical conversion process. Bergman and Gu (2014) provided a detailed analysis of the Tucker RNG unit itself.

Compiling process data
Starting with the functional unit of 1 OD kg field-applied pelletized biochar, fuels and equipment use and transportation requirements were compiled in the SimaPro model to quantify GHG emissions to the environment. The model then relates them to the 100-year GW impact according to the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) method (IPCC 2007; Bare 2011; USEPA 2014). SimaPro software version 8 now includes the TRACI 2.1 method, which was used in the present study. In addition, biogenic CO_2 had no contribution in estimating GW impact for gate-to-gate manufacturing.

System boundary
Defining the system boundary selects the unit processes to be included in the system. Based on our goal to determine the environmental impacts of field-applied biochar pellets, the authors drew the system boundary to include 1) pelletization of raw biochar, 2) transportation of pelletized biochar, and 3) field application of pelletized biochar. Figure 1 shows the system boundary defined for this partial gate-to-gate LCA study. The cumulative system boundary includes both on- and off-site emissions for all material and energy consumed. Fuel and electricity consumed for pelletizing, transporting, and field-applying unit processes were included in the cumulative boundary (solid line) to calculate the total emissions. The on-site emissions were due to the processes within the dotted line (Fig 1). The off-site emissions resulted from the grid electricity production, transportation, and fuels produced off-site but consumed onsite.

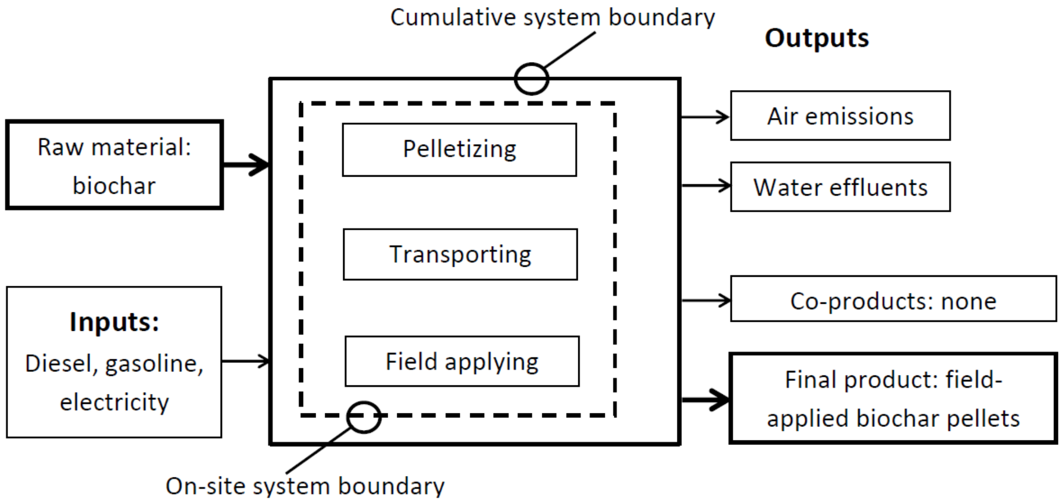

Figure 1. Gate-to-gate system boundaries for field-applying pelletized biochar

Results and Discussion

A lab-scale pellet mill and field application of pellets provided detailed primary data on mass flow, energy consumption, and fuel types. Primary data were modeled; estimates on environmental outputs (e.g., GHG emissions) were derived on a per 1.0 OD t basis.

Inputs and outputs

Pelletization. Several runs of 100% biochar were conducted using the CPM laboratory pellet mill powered by a 1.5-kW motor. On average, net electrical consumption was 44.60 ± 0.23 kWh/t at 27.45% moisture content (MC), which translated to 61.47 kWh/OD t at 0% MC.

Transportation. Pelletized biochar at 27.45% MC was transported 160 km to the forest using a diesel pickup truck. Moisture was considered when transporting the biochar.

Field application. Data were derived from six forest field runs that varied from 0.098 to 6.35 t/h biochar pellet application rate (Table 1). The average pellets applied were 6.35 ± 5.16 t/h. The authors assumed a 1-h run time for the six runs to develop an aggregate value of 25.4 t at 27.45% MC (18.5 OD t/h) and that the pellets were evenly distributed. The 82.1-kW forwarder hauling the biochar pellets consumed diesel fuel, and its consumption was estimated at 10.4 L/h using Brinker et al (2002, table 4). The 13.4-kW gasoline engine used for spreading the biochar pellets consumed 6.77 L/h.

Table 1. Data from field applying biochar pellets per tonne, 27.45% moisture content

Run	Application rate (t/hectare)	Spread rate (hectare/h)	Pellets applied (t/h)	
1	0.145	0.676	0.098	
2	0.997	2.871	2.864	
3	21.214	0.676	14.332	
4	1.793	0.957	1.716	
5	1.432	1.295	1.855	
6	3.008	1.520	4.572	**Stand Dev**
Total			25.436	
Average	4.765	1.332	6.349	5.159

Overall. Table 2 shows the SimaPro modeling inputs. Inputs for the three unit processes were shown with total diesel and gasoline consumption of 3.37 and 2.20 L/OD t of field-applied biochar pellets.

Table 2. Energy consumed per oven-dry t per hour of field-applied biochar pellets

Energy source	Unit	Pelletizing	Biochar pellet transporting	Field applying biochar pellets	biochar Total
Diesel	L	0.00	0.00	3.37	3.37
Gasoline	L	0.00	0.00	2.20	2.20
Electricity	kWh	61.47	0.0	0.0	61.5
Diesel truck	tkm	0	205	0	205

Life-cycle inventory

Cumulative energy consumption for pelletizing, transporting, and field-applying biochar pellets was 1,270 MJ/OD t, with diesel fuel accounting for about 59.0% of the total. Most of the diesel fuel was consumed during transportation. Coal (16.6%) and natural gas (12.4%) were the second and third most important energy sources.

Emission data produced through modeling found that estimated fossil CO_2, methane, and nitrous oxide (N_2O) emissions in kg/m^3 were 73.1, 0.120, and 0.00152 kg/t of field-applied biochar pellets (Table 3).

Table 3. Cumulative environmental outputs for producing 1oven-dry t of field-applied biochar pellets

Substance	(kg/OD t)
Water effluents	
BOD5 (Biological oxygen demand)	1.23E-02
Chloride	2.45E+00
COD (Chemical oxygen demand)	2.32E–02
DOC (Dissolved organic carbon)	2.77E–11
Oils, unspecified	1.55E–03
Suspended solids, unspecified	3.19E+00
Air emissions	
Acetaldehyde	6.84E–05
Acrolein	9.26E–06
Benzene	8.80E–05
Carbon monoxide (fossil)	6.20E–01
Carbon dioxide (fossil)	7.31E+01
Dinitrogen monoxide (N2O)	1.52E–03
Methane	1.20E–01
Formaldehyde	1.11E–04
Nitrogen oxides	5.96E–01
Non-methane VOC	3.33E–02
Particulate (unspecified)	1.53E–02
Phenol	2.54E–11
Propanal	6.03E–10
Sulfur dioxide	1.57E–01
Volatile organic compounds (VOC)	3.14E–02

GHG emission performance

GW impacts of field-applying biochar pellets in relation to its carbon sequestration potential were compared. There are two GHG emission sources: 1) from pelletizing, transporting, and field-applying (Table 4) and 2) from decay of biogenic carbon of the field-applied biochar pellets into CO_2 (Table 5). Based on Wang et al (2014), the authors calculated that 66.3% of the biochar pellets with an original moisture-free carbon content of 90% remained after 100 years (Gu and Bergman 2015). Carbon was converted to CO_2 by multiplying by 44/12. Therefore, the amount of biogenic carbon sequestered long term was estimated to be equivalent to 2,432 kg CO_2eq/OD t, far exceeding the fossil GHG emissions released from manufacturing, 76.6 kg CO_2eq/OD t. By contrast, far more biogenic CO_2 was emitted once the biochar pellets were field-applied.

Table 4. GHG emission gate-to-gate manufacturing performance of field-applied biochar pellets

Units	Pelletized biochar, at mill	Pelletized biochar, at forest landing	Pelletized biochar, field applied	Total manufacturing emissions
kg CO2eq/OD t	19.6	40.8	16.2	76.6
Percentage	25.5%	53.3%	21.1%	100.0%

Table 5. Stability and decay of field-applied biochar (biogenic) carbon

Units	Labile carbon[a]	Recalcitrant carbon[b]	Recalcitrant carbon[c]	Total carbon
kg CO2eq/OD t	330	538	2432	3300
Percentage	10.0%	16.3%	73.7%	100.0%

[a] Decayed away after 1 year
[b] Decayed away after 100 years
[c] Intact after 100 years

Conclusion

Categorizing GHG emissions from human activities such as biochar pellets helps in identifying contributions to climate change. Bioproducts, including biochar, can have a vital role in helping to mitigate GHG emissions. In the present study, gate-to-gate manufacturing of the field-applied biochar pellets had a relatively small contribution to climate change compared with the carbon sequestration potential.

Sequestering biochar carbon in forests (i.e., soils) does not necessarily stop decay of biochar. Thus, estimating decomposition of biochar (biogenic) carbon once applied turns out to have a far larger impact than the gate-to-gate manufacturing fossil GHG emissions. However, biogenic CO_2 as part of the global carbon cycle does not contribute to climate change when the original feedstock was derived from sustainably managed forests as it was in this case. In addition, quantifying decay of recalcitrant carbon, which depends on many factors (Gaunt and Cowie 2009; Sohi et al 2010; Lorenz and Lal 2014), shows it has a substantial contribution to climate change as well.

Study assumptions and limitations that may affect the final results include transportation distance of biochar pellets to the forest of wood origin, use of wood pellets instead of biochar pellets, and that the pellets applied in the forest were evenly distributed. In addition, the other major two GHG emissions were not included and may have an indirect impact on climate change.

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Economic and Environmental Analyses of Energy Crops for Bioproducts in the Northeastern United States

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Abstract

A techno-economic (TEA) model together with a life cycle assessment model were developed to examine the economic and environmental benefits of utilizing energy crops for bioproducts. Three energy crops of hybrid willow, switchgrass and miscanthus grown in marginal agricultural land or abandoned mine land in the Northeastern U.S. were considered in the analytical process for the production of diesel, bio-power and pellet fuel. The TEA model considered all the cost components in the LCA, and also the capital and operating costs of bioprocessing. The LCA model included feedstock development, harvest, transportation, storage, preprocessing, energy conversion, distribution and final product usage. Sensitivity analysis was conducted to assess the effects of energy crop yield, transportation, conversion efficiency, capacity of facility and internal rate of return (IRR). The required selling price (RSP) of bio-fuel was higher than that of pellet fuel and biopower. The environmental impacts in terms of GHG emissions, fossil energy consumption, and water usage were more sensitive to biofuel types than to feedstocks. Sensitivity analysis also indicated that transportation was a major factor affecting both GHG emissions and delivered costs of biomass.

Key words: Biomass utilization, life cycle assessment, techno-economics, energy crops, biomass management.

1. Introduction

Biomass is considered to be a possible substitution of fossil energy resources to reduce the greenhouse gas emissions. The interest in the usage of cellulosic biomass for bioproducts has been steadily increased due to the environmental and energy dependence concerns (Paul 2009). Biomass could be used to produce different forms of bioenergy products, such as firewood, pellet, electricity, ethanol, and biofuels. However, biomass feedstock production usually requires land cover change to provide the same amount of energy as fossil fuels (Searchiger et al. 2008). Consequently, the production cost to produce bioenergy from biomass is typically higher than fossil fuels (Brown 2015).

Many analyses have been conducted on biomass supply chains in terms of economic, environmental or life cycle assessments. Earlier economic analysis of biomass utilization focused on biomass-fired power plants (Kumar *et al*. 2003, Perilhon et al. 2012), such as optimization of plant size based on available biomass, and the cost of different sized pellet facilities (Sultana *et al*. 2010, Pirraglia *et al*. 2013). On the other hand, life cycle assessments (LCA) were conducted separately to analyze environmental impacts of biomass utilization. GHG emissions could be reduced 30-63% through utilizing biomass pellet fuels instead of natural gas (Fantozzi and Buratti 2010), and 56-77% from pyrolyzed biofuels compared to fossil fuels (Snowden-Swan and Male 2012).

Although the utilization of biomass presents lower environmental burden, the handling cost of biomass is usually higher than fossil fuels (Sharma et al. 2013). The techno-economic analysis conducted on fast pyrolysis estimated that the cost of this biofuel can range from \$0.4/gallon to \$3.07/gallon (Ringer et al. 2006; Wright et al. 2010). Brown (2014) recently reviewed techno-economic analysis of fast pyrolysis and found the required selling price (RSP) changed from \$1.93-\$3.70/gal of gasoline equivalent. A range of costs were shown using different boiler systems for bio-power generation (IRENA 2012), including the capital cost of \$1.8-\$5.7 million/MW and operational and maintenance cost contribution 9%-20% of total cost. Cost of pellet facility also varies dramatically according to the physical location and capacity of pellet facility, ranging from \$122/ton to \$170/ton (Sultana et al. 2010).

There appears a necessity to analyze the environmental and economic impacts of utilizing bioenergy crops for major possible pathways at a regional scale. In this study, three bioenergy crops (hybrid willow, switchgrass and miscanthus) were considered to produce three bioenergy products, i.e.: bio-fuel, bio-power and pellet fuel. The objectives of this study were to: (1) develop a cradle-to-grave life cycle assessment (LCA) model to examine the environmental impacts of utilizing the energy crops for bioenergy products in the northeastern U.S., (2) perform an economic analysis of the bioenergy feedstock supply chains, and (3) conduct sensitivity analysis of the production of the bioenergy products according to energy crop yield, transportation distance, conversion rate and pretreatment strategy, facility capacity and internal rate of return (IRR).

2. Materials and Methods

2.1 Study Area and Base Case Scenario

The study area is the northeastern U.S. The available marginal agricultural land and abandoned mine land are over 2.8 million ha (Graham 1994) and 0.5 million ha (Rodrigue and Burger 2004), respectively. These regions are generally with rocky and sloped soils and is compatible to the development of perennial energy crops. The temperate climate in this region also provides the conditions of producing biomass of higher yields. Three biomass feedstocks: hybrid willow, switchgrass and miscanthus were included in this study, which are being considered as the dedicated energy crops in the Northeastern U.S. Three bioenergy products: biofuel of fast pyrolysis, bio-power, and pellet fuel. The capacities were 1,000 bbl/day, 20 MW and 50,000 dry tons per year for bio-fuel, bio-power and pellet fuel facilities.

2.2 Economic Analysis

Costs in field operations of energy crops were adjusted based on the settings by Duffy (2013) and Schweier and Becker (2012). This included the machines for land preparation, plantation, fertilizer and pesticide spray, harvest. The round-trip transportation of wood chips and bales were assumed to be \$0.38 $ton^{-1}\cdot mile^{-1}$(Kerstetter and Lyons 2001). Average storage cost of feedstock was assumed \$5 dry ton^{-1}. The capital cost, operational and maintenance cost of fast pyrolysis were adjusted from the results of techno-economic analysis conducted by Wright et al. (2010). Average costs of biomass fired power plant in IRENA's report (2012) were used as facility cost to produce bio-power. A techno-economic analysis by Sultana et al. (2010) provided costs to operate a pellet facility. Internal rate of return was assumed 15% in base case. Required selling price (RSP) at facility gate was calculated.

2.3 Life Cycle Assessment

The system boundary of this cradle-to-grave LCA model (Figure 1) included land preparation, plantation establishment, harvest, transportation, storage, preprocessing, energy conversion, distribution and final usage. The environmental impacts will be assessed in terms of the GHG emissions, blue water consumption, fossil fuel consumption and human health impacts. The health impacts considered in this study were carcinogenics, respiratory effects, ozone depletion and human toxicity. The functional unit (f.u.) was 1,000 MJ of energy equivalent bioenergy product produced in the system. The LCA model was developed using the environmental modeling tool SimaPro v8 (PRé Consultants 2014).

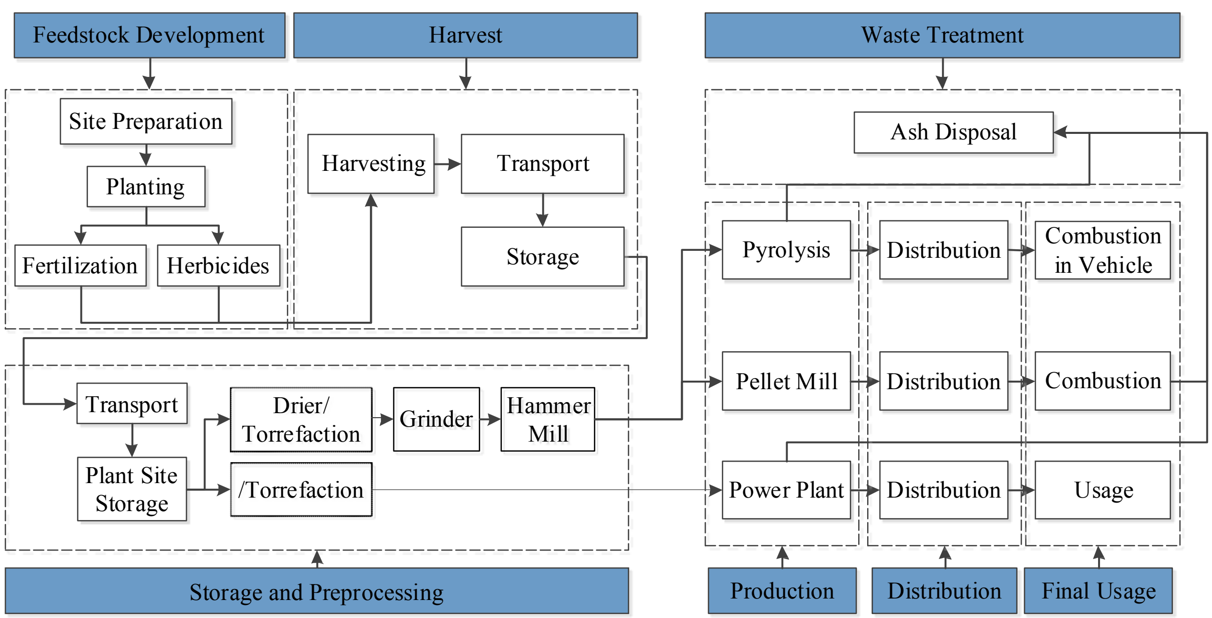

Figure 1. System boundary and processes of the three energy crops for three bioenergy products.

2.4 Sensitivity and Uncertainty Analyses

The sensitivity analysis was considering yield of energy crop, conversion rate, transportation distance and IRR. The configurations of all the parameter were in Table 1.

3. Results

3.1 Base Case Analysis

The cost of each component in the supply chain was analyzed by feedstock and energy product (Figure 2). Operation and maintenance usually cost more than other components, which was ranging from 10% in miscanthus to bio-power to 50% in willow to pellet fuel. Willow had lower cost in plantation and harvest than the other two energy crops. Storage was a small portion of total cost, which only accounted less than 1%.

RSP was calculated for the three bioenergy products: $/bbl for bio-fuel, $/MWh for bio-power, and $/dry ton for pellet fuel (Table 2). For the production of same bio-energy product, Product from willow had lowest RSP which was 0.5%-5.8% lower than the other two crops. And switchgrass had highest RSP. RSPs were also converted to per MJ basis for comparisons (Table 2). The production of bio-fuel required highest RSP.

Table 1. Parameter configurations for base case and sensitivity analysis.

Parameter	Base Case	Sensitivity Setting	Note
Willow – Yield	12.4 odt/ha[1]	10.7 - 14.1 odt/ha	Yield increases from minimum to maximum yield by 10% of their difference.
Switchgrass – Yield	9.6 odt/ha	6.6-12.6 odt/ha	
Miscanthus - Yield	17.8 odt/ha	10.9-24.7odt/ha	
Transportation	50 miles	10 – 100 miles	The distance increases by 10 miles each time.
Transportation-Pellet	30 miles	10-60 miles	The distance increases by 10 miles each time.
Bio-fuel - Conversion rate	0.46 odt feedstock/bbl of fuel	0.39-0.53 odt feedstock/bbl of fuel	Amount of feedstock demand increases from minimum to maximum yield by 10% of their difference.
Bio-power – Conversion rate	0.94 odt feedstock/MWh of bio-power	0.71-1.18 odt feedstock/ MWh of bio-power	
Pellet – Conversion Rate	1.18 odt feedstock/ton of pellet	1.11-1.24 odt feedstock/ton of pellet	No Waste was assumed to produce pellet.

Note: [1] odt is oven dried tonne.

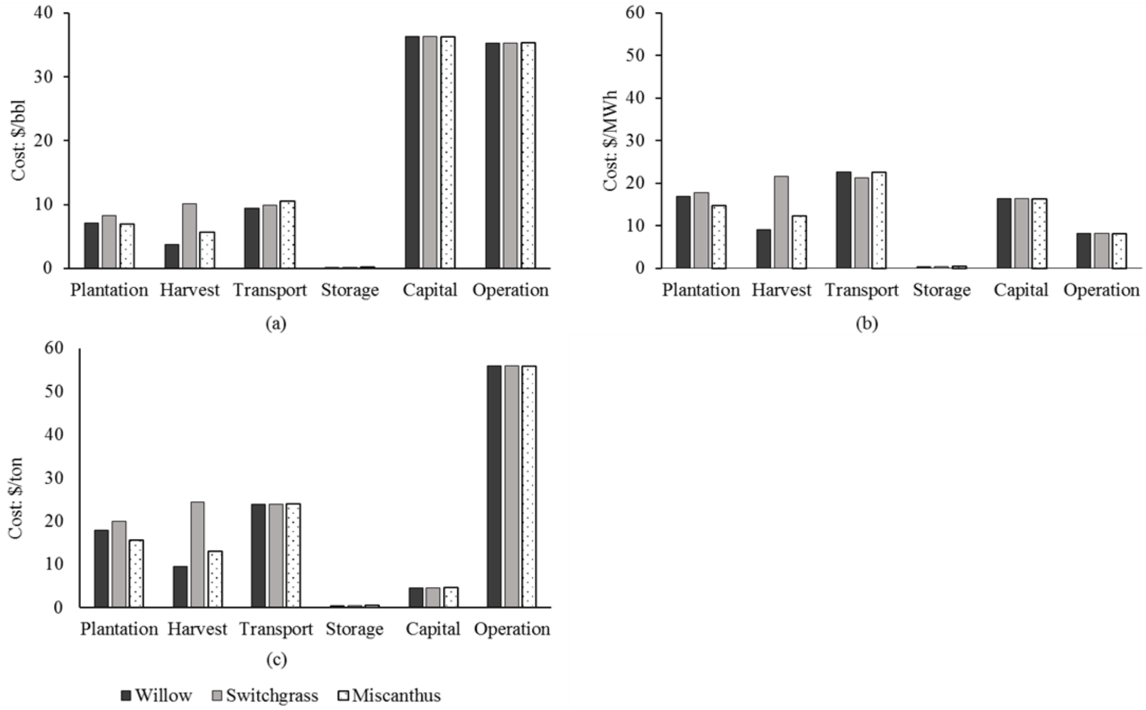

Figure 2. Cost components of the biomass supply chain by energy crops and bioenergy products: (a) bio-fuel; (b) bio-power; (c) pellet.

Table 2. Required selling price of bioenergy products by energy crops.

Crops	Bio-fuel: $/bbl ($/GJ)	Bio-power $/MWh ($/GJ)	Pellet: $/ton ($/GJ)
Willow	158.99 (31.6)	112.2 (31.1)	116.1 (6.1)
Switchgrass	164.66 (32.7)	124.4 (34.5)	132.9 (7.4)
Miscanthus	159.48 (31.7)	113.3 (31.5)	117.2 (6.9)

The most emissions occurred in the “Storage and preprocessing” and “Production” processes. The bio-power production presented the lowest GHG emissions among the three bioenergy products, with an emission of less than 10 kg CO_2 eq per 1,000 MJ of electricity produced. Among three feedstocks, using willow shrub for bio-power generation demonstrated the lowest emission at 5.96 kg CO_2 eq. There were more obvious differences of LCA impacts among the three bioenergy products than among the three energy crops (Figure 3). Two-way ANOVA showed that more than 95% of the LCA impact variance was explained by different utilizations of bioenergy products.

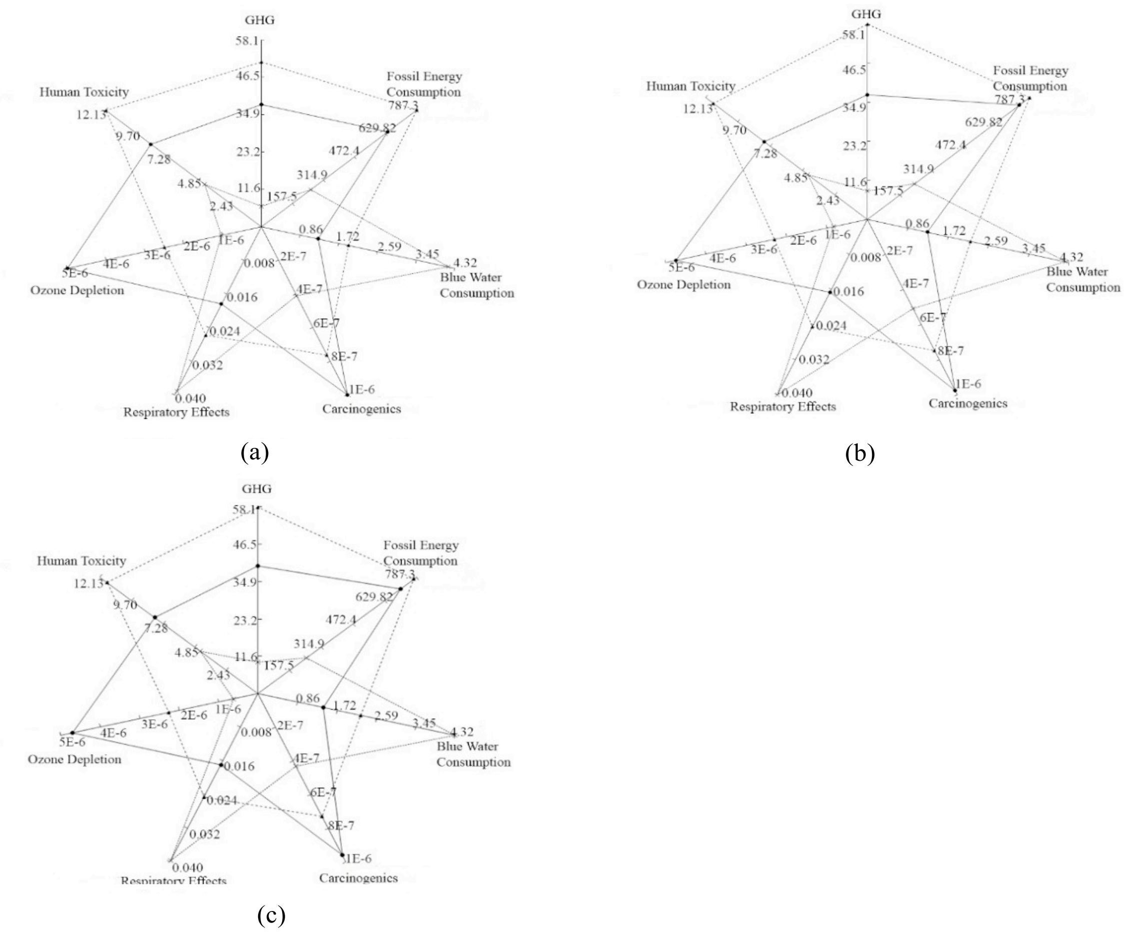

Figure 3. LCA impacts of GHG emissions, fossil energy consumption, blue water consumption and human health impacts by energy crops: (a) willow by bioenergy products; (b) switchgrass by bioenergy products and (c) miscanthus by bioenergy products.

3.2 Sensitivity analysis

Several factors affect the RSP of bioenergy products including yield of energy crops, transportation distance of biomass, conversion rate and required IRR. In the production of biofuel and bio-power, the RSP was very sensitive to IRR and conversion rate. Transportation distance was the third most sensitive factor.

Both conversion rate and transportation distance had prominent influences on the environmental impact indices when biomass was used for liquid fuels and electricity. However, the impacts were not significant when biomass was used for pellet fuel production, except considering fossil energy consumption and human toxicity by changing transportation distance. By comparing the environmental impacts with changing yield of energy crops, it always had higher influence to produce bio-fuel and bio-power than to produce pellet fuel. Blue water consumption did not have obvious change along the change of yield of crops

4. Discussion

4.1 Cost Analysis and RSP

Operation and maintenance were usually the major cost component which made up to 50% of the total cost and followed by transportation, crop plantation and harvest. The production of pellet fuel had low cost in feedstock logistics and capital cost and high cost for electricity consumption at facility, so the percentage of operation and maintenance cost at pellet mill was higher than other two bio-product production systems. Willow always had lower cost than perennial grasses because of its high energy content which cause lower amount of biomass consumption to produce same amount of energy equivalent bio-product. In this study, bio-char and off-gas were recycled in the process of fast pyrolysis (Jones and Male 2012), or the operation and maintenance cost to produce bio-fuel could be even higher. Because less pretreatment was required in power plant, the operation and maintenance cost was lower in power plant. But if different boilers were used, the cost could be even higher (IRENA 2012).

Because of efficient harvest system and low amount of feedstock demand, bio-products from willow always had lower RSP than perennial grasses. Switchgrass had much lower yield than miscanthus, so the RSP of bio-products from switchgrass was higher than miscanthus. But the miscanthus tends to have low yield where the states have cold and dry weather (Miguez et al. 2009). The RSP of liquid fuels produced by fast pyrolysis was $2.34-$2.48/gal, which was in Brown (2015) indicated range. The average annual price of electricity in 2013 by state in Northeast was ranging from $78.1/MWh in West Virginia to $159/MWh in Connecticut according to EIA Electric Power Monthly report (2015). The RSP of bio-power was in this range, so the biomass fired power plant could be economic feasible in some states. The pellet price was lower in this study may be because of lower cost in feedstock logistics than direct purchase and lower capital cost for large scale pellet facility.

4.2 Environmental impacts

Most of the GHG emissions occurred in the "Storage and preprocessing" and "Conversion" processes at facility site. So the change of GHG emissions among different bioenergy products could be mostly explained by the different procedures at facility. The production of bio-power emitted less GHG emissions than the production of bio-fuel or pellet fuel. This is because the heat and electricity provided by biomass in power plant were provided by biomass, thus the energy conversion rate is low and more feedstock is required in power plant (Perilhon 2012). The GHG emissions were higher when produce pellet fuel because of the high electricity consumption for operating pellet mill, dryer, grinder and hammer mill. This electricity consumption was considered as fossil energy produced by coal in the LCA model. If the electricity consumed to produce bio-fuel and pellet fuel was generated by biomass or other renewable resources, the emissions could be lower. Fast pyrolysis is an energy intensive process to produce bio-fuel, the energy consumption was reduced through recycling byproducts, off-gas and bio-char, for preheating (Jones and Male 2012). Power plant typically needs more water for cooling, and consequently the water consumption of bio-power generation is higher than the production of bio-fuel and pellet fuel.

4.3 Sensitivity and Uncertainty Analyses

Conversion rate had less effect on GHG emissions in power plant than in the production of bio-fuel. This is because feedstock in power plant did not need to be dried though there was more feedstock required in power plant to produce same amount of energy. The improvement of conversion also reduces the fossil energy consumption, water consumption, human health effects because of the reduction of feedstock demand.

Fossil energy consumption and human toxicity were sensitive to transportation distance because of most of toxic emissions were contributed by transportation fuel combustion. The environmental burden of bio-power showed high sensitive to feedstock transport distance. This is because power plant requires large amount of biomass to produce 1,000 MJ energy equivalent bio-power. The actual yield could be lower than the yield estimated in this study because the yield in the first two or three years was pretty low to establish the stand.

Longer transportation distance will quickly increase the biomass logistics cost. It is essential to reduce the transportation distance in biomass logistics models. However, large scale facility always requires longer distance. For fossil fuel facility, cost will be reduced in large facility, but this is not always the case for bio-facilities. Larger facility requires more biomass which could increase the biomass handling cost. Increasing yield of energy crops, increasing plantation acreage of energy crops, improving conversion rate and reduce scale of facility will reduce the transportation distance. IRR was sensitive to produce bio-fuel because large proportion of total cost was investment of capital cost. The sensitivity of RSP to conversion rate in power plant was because a little change of conversion rate will bring more change on demand of feedstock. In willow to bio-product systems, willow handling system always had low proportion of cost, so it was less sensitive to yield and conversion rate.

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Biofuels from Forest Residuals – What is on the Minds of Stakeholders?

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Abstract

Engaging regional stakeholders as partners in the Northwest Advanced Renewables Alliance (NARA), a project assessing the feasibility of establishing a sustainable woody biomass to biofuels and co-products industry in the Pacific Northwest (PNW), is critical in gaining trust, identifying local assets, understanding community acceptance, and examining meaningful and viable supply chain coalitions. As part of the assessment, NARA is charged with evaluating the social, environmental, and economic sustainability of such an industry. The Outreach Team serves as a conduit between NARA researchers and community stakeholders, helping transfer the science and technology of biofuels and co-products to communities and engaging stakeholders in building regional coalitions for facilitating rural economic development.

Collaborative work between NARA teams to better understand the landscape of stakeholder perceptions regarding production of biofuels and co-products from post-harvest forest residuals will be highlighted. Results from a survey of stakeholders in the Northwest region of the US indicate concern with forest conditions and recognition of economic benefits yet worry about the negative impacts a biofuels industry would have on forests. Analysis of published news articles and personal conversations with stakeholders, especially those representing the environmental community, will be discussed in light of perceived benefits and concerns related to the biofuels industry.

Poster Session and Student Competition

Moderator:
Manja Kuzman, University of Ljubljana, Slovenia

Effect of Barks on the Physical and Mechanical Properties of Phosphate Bonded Wood Composites of Black Wattle (*Acacia mearnsii* De Wild)

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Abstract

In South Africa, forestry and wood processing generates about 4-6 million tons of wood waste per year. In this study, the effect of bark on properties of phosphate bonded wood composites was investigated. Barks and sawdust of black wattle (*Acacia mearnsii* De Wild.) were collected from EC Biomass, South Africa. After drying, the barks were chipped, milled and sieved through a 1.0 mm mesh. The binding matrix was prepared using a reactive magnesia, phosphoric acid and class S fly ash. The ash was added at 10 - 50% loading. The bark was added to the wood at 10, 20, 30, 40 and 50% loading and mixed thoroughly with the inorganic matrix. A control experiment without ash and bark was also considered. The experiments were carried out in four replicates. The composites were formed in a rectangular mold and compressed at room temperature and a pressure of 200KPa. After de-molding, the composites were cured in a conditioned room for 96 h. Thereafter, physical and mechanical tests were conducted to evaluate the properties of the composites.

A central composite design (CCD) was used to determine the best conditions to optimize the properties of the composites. The study demonstrated that barks of *Acacia mearnsii* could be incorporated into wood residues in phosphate-bonded composites with a significant improvement in properties. The products are environmentally friendly and can be engineered to meet industry performance standards and consumer acceptance taste. The proposed product can be used for ceiling, partitioning, wall claddings and underlayment.

Keywords: *Acacia mearnsii*, fly ash, magnesia, mechanical properties, phosphate bonded wood composites, phosphoric acid, physical properties

Introduction

The application of chemically bonded phosphate ceramics (CBPC) has been increasing over time. This 21st century material is employed in architecture and civil engineering. It can be used as adhesives, cements or as coatings for materials, therefore providing a wide range of applications (Laufenberg and Aro, 2004). Chemically bonded phosphate ceramics (CBPCs) are formed by acid-base reactions between an acid phosphate (such as that of potassium, ammonium, or aluminum) and a metal oxide (such as that of magnesium, calcium, or zinc) (Jeong and Wagh, 2002). The reaction is exothermic and sets rapidly into a crystalline mass similar to ceramic (Wagh, 2004). They are mainly magnesium and iron-phosphate ceramics, although specialty formulations have been developed for biomaterials applications using calcium phosphate based ceramics. The most employed of the basic elements is magnesium due to its moderate solubility between calcium and iron in the phosphoric acid medium (Wagh, 2013). CBPCs are produced at ambient conditions and can be applied in high volumes. They are applied in stabilization of hazardous and radioactive wastes, structural materials including road repair and architectural products (Jeong and Wagh, 2002).

Preliminary investigations proved that wood and other industrial waste could be recycled to produce phosphate-bonded composites. Studies by Laufenberg and Aro (2004), Donahue and Aro (2010), Chi (2012) produced phosphate bonded fibre composites using magnesium phosphate cement. In one report, Pine shavings and sawdust were used as raw materials for a set of baseline experiments with one-third-phosphate binder. Pressing to three densities (0.6-1.25 g/cc), the mechanical properties obtained compared with those of wood cement products (Laufenberg and Aro, 2004). In another report, waste paper sludge was bonded with phosphate binder using different ratios of waste fibre to binder (0.63-1.1) with the addition of fly ash as fillers. All properties evaluated on the composites except the modulus of rupture (MOR) compared with those of low-density particle board (Donahue and Aro, 2010). Chi (2012) investigated the interfacial properties between sugar maple and magnesium phosphate cement. The author reported that using a phosphate/magnesium ratio of 3:1, failure and initial crack stress values can be maximized.

In this study, industrial waste streams from the wood industry were incorporated into prepared magnesium phosphate matrix, and the materials were mixed and compressed to form composite boards. This study aims to provide value additions to wood waste such as sawdust and barks while investigating their effects on composite properties.

Materials

Waste Residues

The residues utilized for this research were barks and saw dust of Acacia *mearnsii*. The materials were sourced locally in South Africa.

Magnesium oxide

The magnesium oxide utilized for this study was MAGOXBPPO, a heavy magnesium oxide from Macco Organiques, Zahradnl, Czech Republic. This material had the following composition: Assay 96% min; Calcium <1.1%; Iron <0.05%; Acid insoluble substances <0.1%; Free Alkali and soluble salts <2.0%, Heavy metals <0.002%; Arsenic <0.0003%; Loss on ignition <10.0% and Bulk density (loose) 400-600 g/l.

Monopotassium phosphate

Monopotassium phosphate is commonly used as plant fertilizers and as a food ingredient (salt). For this research, we used MKP 0-52-34, a white crystalline product purchased from Shijiazhuang Lvhe Fertilizer Technologies Co. Ltd, China. This product had the following composition: KH_2PO_4 >98%; P_2O_5 >51.2%; K_2O >33.5%; Chloride <0.2%; Water insoluble <0.2%; Moisture <1.0% and PH 4.3-4.7. Wagh (2004) reports that acid phosphates with a P_2O_5 content of 50-60% may be suitable for the production of chemically bonded phosphate ceramics.

Fly ash

This product was obtained from Ulula Ash, South Africa and complies with the SANS 50450-1:2011 Class S specification. Class S Fly ash (SFA) is an ultra-fine powdery residue obtained from coal fired power plants and it is a South African Bureau of Standards (SABS) approved product. It is of structural concrete grade, finer than cement and is used as a partial replacement for cement. In addition to acting as extenders or fillers in Chemically Bonded Phosphate Ceramics, fly ash reduces the heat of the acid-base reaction, increases the quantity of binder in the mix by generating more binders and enhances durability and strength of the final product (Wagh 2004; Wagh 2013).

Methods

Board formation

The waste material was dried and milled with a hammer mill to pass through a 1 mm sieve screen. Milled samples were conditioned for about 72 h at 20 ^{o}C and 70% relative humidity (RH). The materials for the boards were measured out from the central composite design (CCD). The mass of water used was calculated from a modified formula used in wood cement composites as:

$$W = P + (F - M)\ 2B \qquad \text{Equation 1}$$

W is mass of Water in the board; P is mass of phosphate binder; F is fibre saturation point; M is moisture content of the fibre; B is mass of fibre.

The materials were mixed thoroughly by mass and water was added while stirring the composites together. The slurry was poured into a steel mould measuring 218 x 77 x 40 mm and a steel bar 27 mm thick was placed on the composite to fit into the mould. The set up was arranged in the laboratory press and a pressure of 200 KPa was applied at room temperature. After 5 minutes, the mould was removed from the press and the composite was demoulded. The same procedure was repeated for all the replications in the experiment. The formed boards were allowed to air-cure in the laboratory for 24 h. Thereafter, they were conditioned at 20 ^{o}C and 70% RH for 96 h before testing.

Testing

Testing of the boards was carried out according to ASTM Standards (D1037-99). The properties evaluated include density, modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA), and thickness/volume swelling (TS/VS). Samples for sorption test were cut using an angle grinder with a concrete blade into dimensions of 75 x 50 mm. The thickness of all samples used in the test was 13 ± 1.2 mm based on the set up configuration of the steel mould.

Statistical analysis

The experiment was designed on a central composite design (CCD) using STATISTICA Software v5. In this study, two (2) variables were considered. They include the bark content from 10 - 50% of the total wood content; and the fly ash content from 10 – 50% of the total inorganic content. The binder ratio of KH_2PO_4 to MgO was kept constant at 3:1 (100 g wt.) while the wood content was also kept constant at 50 g. The CCD was used to prepare the combinations of the materials in the design. This resulted in 10 experimental runs using the standard design. A control experiment without considered variable was also carried out giving a total number of 11 board types (Table 1). Four replications of all the experiments were carried out resulting in a total of 44 experiments.

Table 1 Combinations of the experiment based on CCD

Board types	Bark content (g)	Ash content (g)	Wood and bark (g)	Water (ml)
A	5	10	55	122.7
B	5	50	55	162.7
C	25	10	75	127.3
D	25	50	75	167.3
E	0.85	30	50.85	141.7
F	29.14	30	79.14	148.2
G	15	1.72	65	116.7
H	15	58.28	65	173.2
I	15	30	65	145.0
J	15	30	65	145.0
K (Control)	0	0	50	111.5

Results and discussion

Density

The mean densities of the boards ranged from 0.98 to 1.25 g/cc. Board D with a high bark and fly ash content had the highest density of the boards. Bark is a heavy and heterogeneous material and so invariably contributes to the density of the boards. Board K had the lowest density of 0.98 g/cc. This is due to the fact that the boards did not contain bark and fly ash as in the control.

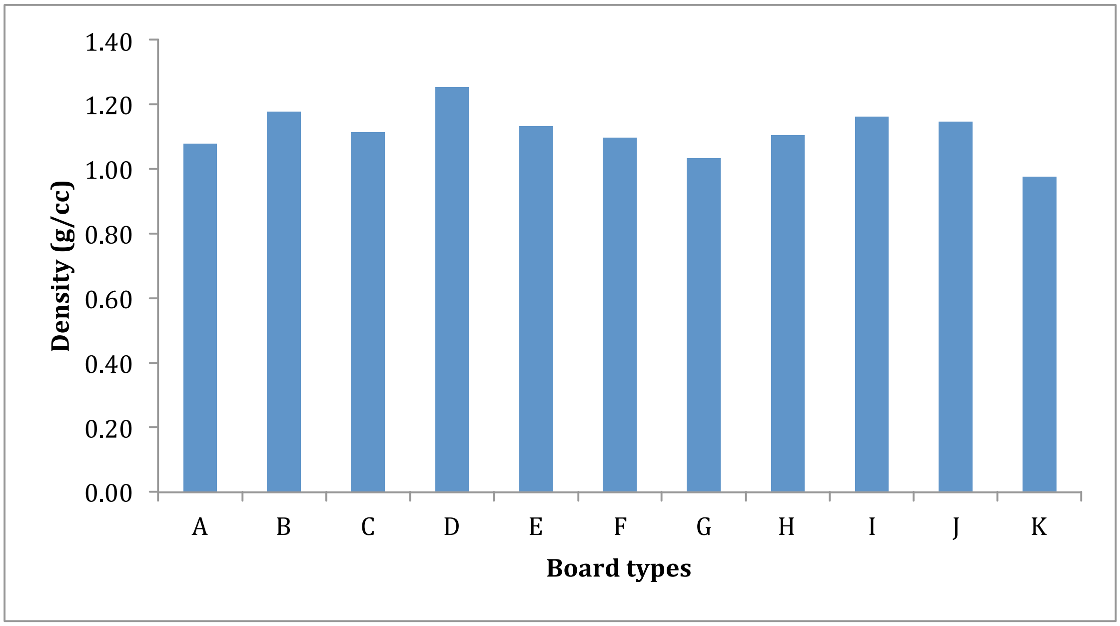

Fig. 1 Mean Density of the Boards

Modulus of Rupture (MOR)

The mean MOR of the boards is shown in the figure below. Board D had the highest MOR (7.32 MPa) possibly as a result of the high content of bark. Bark contains substances that may react with the phosphate values and lead to the formation of more bonds. This results in better bonding in the composites and hence higher density and strength properties. Since density has an important role in the mechanical response of cements and ceramics (Colorado *et al*., 2011), it is a major determinant of the strength properties of composites. Therefore, it is expected that the denser boards have better strength properties. In a similar way, board K that has the lowest density also has the lowest MOR of 2.29 MPa.

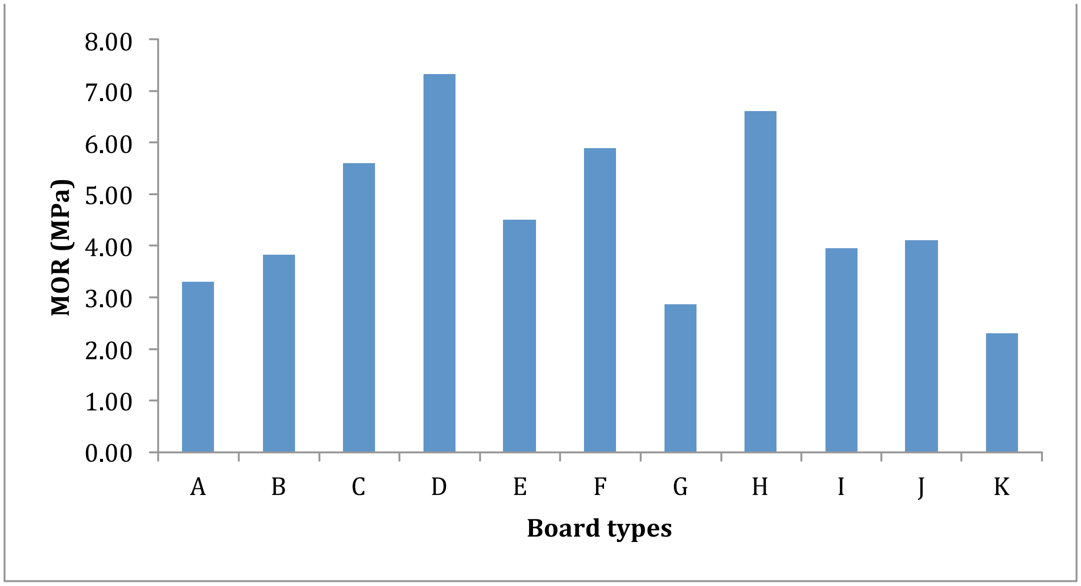

Fig. 2 Mean MOR of the Boards

Modulus of Elasticity (MOE)

The mean MOE values follow same trend with the MOR as a mechanical property. Board D had the highest mean value of 88.3 MPa while board K had the lowest mean value of 31.33 MPa. This is also due to better compaction in Board D as a result of high content of bark and fly ash. Fly ash enhances the cementing mechanism of phosphate composites (Wagh, 2013)

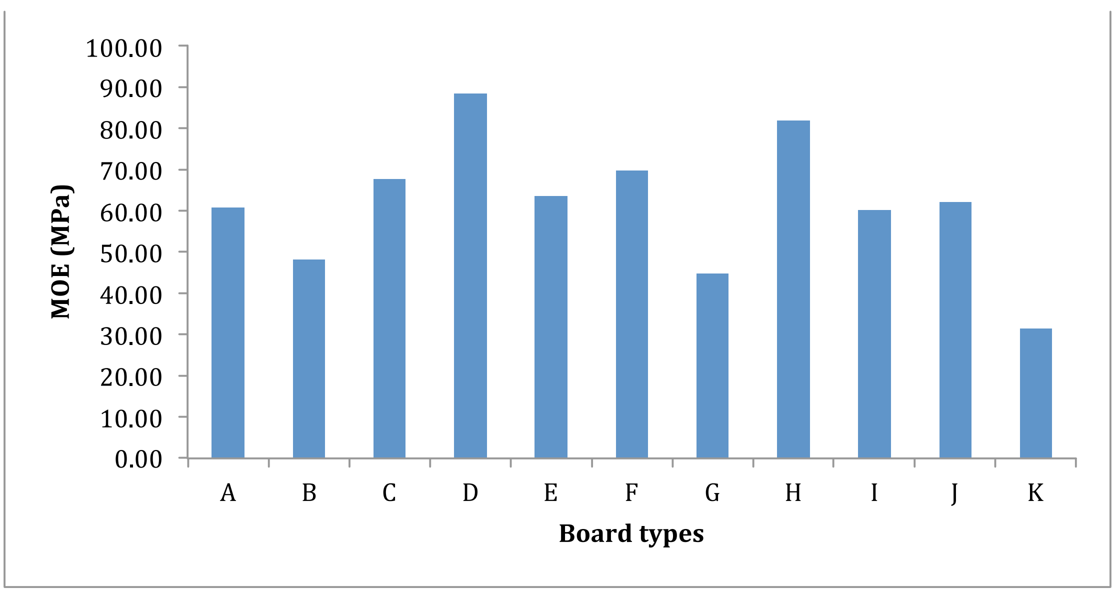

Fig. 3 Mean MOE of the Boards

Water Absorption (WA)

The mean WA of the boards varied from 14.52 – 23.48%. Board D has the lowest WA due to better compaction of the boards. Board G had the highest WA followed by the control with a mean value of 22.40%. This result suggests that bark and fly ash content play a major role in enhancing compaction and reducing moisture movement in the composites.

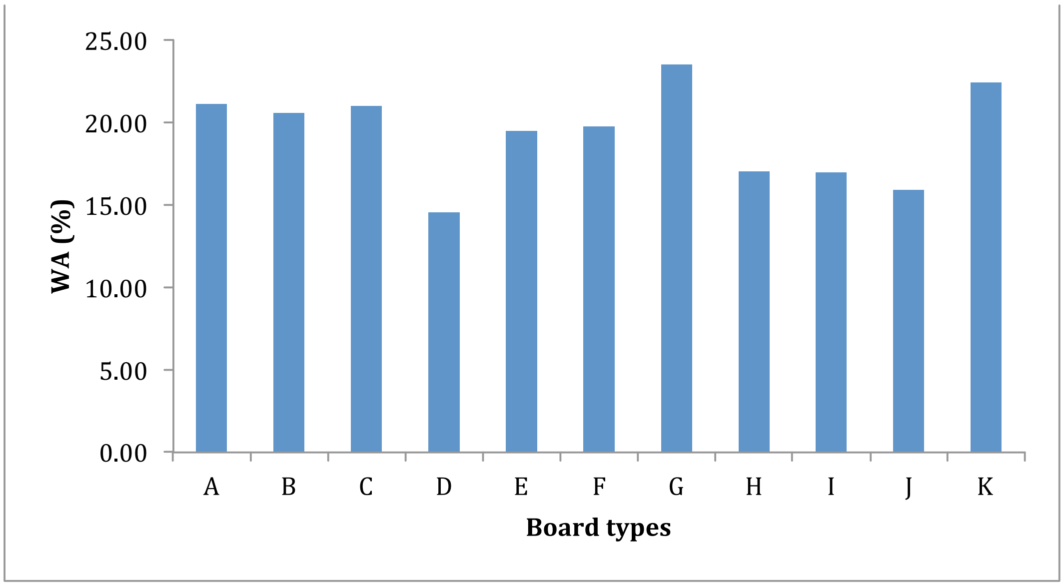

Fig. 4 Mean WA of the Boards

Thickness/Volume swelling (TS/VS)

The mean TS/VS of the boards are low ranging from 0.09 – 5.48% for TS; and 0.06 – 4.71% for VS. Board E with the lowest bark content had the highest TS and VS of all the boards followed by the control. This indicates that high bark and fly ash content enhances encapsulation of the cellulosic fibres and prevents edge and linear expansion. Board B had the lowest TS while Board J had the lowest VS of 0.09% and 0.06 respectively.

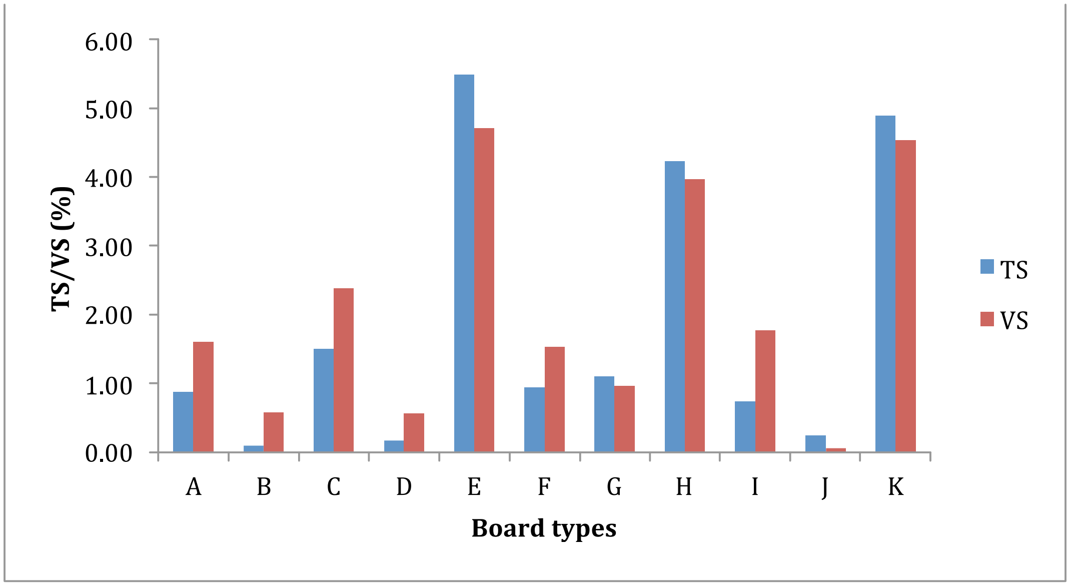

Fig. 5 Mean TS/VS of the Boards

Conclusion

From this study, it is clear that ground bark can be added to phosphate bonded wood composite to enhance its properties. A mixture of bark and fly ash in adequate amount increases all properties including density, MOR, MOE while decreasing WA, TS and VS. The best effect was obtained at 50% loading of bark and fly ash. Within the study design, addition of bark improves all the properties evaluated. The result did not show the limit to which bark can be added favorably to phosphate-bonded composites. Therefore, other studies should be directed to determine the maximum limits for the addition of barks, beyond which reduction of properties if any may be encountered. The proposed product can be used for ceiling, partitioning, wall claddings and underlayment.

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Opportunities and Challenges for the Adoption of Glued Laminated Bamboo (*Guadua weberbaueri*) in Joinery Sector Acting in the State of Acre-Brasil, 2015

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Abstract

This paper addresses the furniture industry in the Amazon. Its objective is to generate information on the adoption of plywood using glued laminated bamboo (Guadua weberbaueri) in the joinery sector of Rio Branco – state of Acre-Brazil. The method adopts identified and analyzed the opportunities, requirements and limiting for the use of bamboo in this process by the Acrean joinery industry. So, it was made a collection of data via the application, in 2015 a questionnaire in this group of firms acting in Rio Branco. From the results generated, it can be inferred that: (a) the glued laminated bamboo has the potential to be applied in various items of furniture making and (b) bamboo can replace the raw material originally used in joinery (wood, plywood and MDF).

Problems and Possible Solutions to the Wood Waste from the Wooden Housing Production in Brazil

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Abstract

Brazil has experienced a crescent seek for housing alternatives in relation to masonry, and the wooden houses have demonstrated as a very rational and sustainable possibility. However, the production of building parts and components can present environmental liabilities, both if the timber companies which compose this chain do not have efficient plans for the management of their generated waste and if these companies do not present technologically advanced production lines. These wood-based wastes from the civil construction activities are found in the pure and natural modes or through the chemical modification of wood. Both residual examples can pollute and result in irreversible environmental problems if assertive actions are not applied for their control and discard. Nevertheless, this study aims to discuss the problem about the topic of wooden waste from civil construction, as well as share proposals to help in the mitigation of this Brazilian current question.

Key words: Public policies, wood waste, timber industrialization, wooden buildings

Introduction

Currently, Brazil has presented an increasing search for wood-based housing as a more sustainable alternative than the use of masonry. These wooden buildings have various construction models, which include from a pure design present in this lignocellulosic material and to examples mixed with other materials.

Nevertheless, the volume of wood waste generated in civil construction is still expressive, due to its massive utilization as structures, walls, roofing, fencing, flooring, windows and doors, stairs, scaffolding, etc. Because of these multiple uses, a visible amount of residual wood material is generated in this application, both by artisanal production practices as the low level of industrialization of these components and parts.

Thus, in Brazil, the buildings still produce large amount of waste due to the errors in the project execution, unskilled and or minimally skilled labor, inadequate packaging and transport of the wood and its composites, or by the absence of management activities, which involve this building production.

Wood-based products for construction

Wood is a biodegradable material and it constitutes in a sustainable possibility, provided that it is from forest plantations or managed natural forests.

The construction is considered the main market for the products from timber industry in world. This occurs not only quantitatively, but it also occurs by the opportunity to use a large variety of wood-based products (Zenid, 1997). The sectors of timber industry and civil construction represent a significant share of the national socio-economic scenario (Capanema et al., 2013).

According to ZENID (1997), wood-based products applied in buildings can be divided in two major groups: timber simply sawn and processed, which can be planed, machined, framed, etc.; and, wooden composites, which include the examples of laminated, fiber, and particle boards.

Regarding the finished goods and high added value products, timber can be used both in broader and complex forms (wood-based housing, roofing or structures), as the most simple and compact compositions (construction components and parts, windows, doors, etc.).

Zenid (2009) emphasizes that the wooden products used in civil construction can present from none to a high level of processing and beneficiation, such as beams, joists, boards, rafters, battens, ceilings, flooring, baseboards, walls, etc. According to Capanema et al. (2013), timber is popular and widely used, especially in construction, because besides the most common uses, wooden houses are increasingly requested.

Wood waste

Pereira et al. (2010) emphasize that wood waste is solid waste of the organic composition and of industrial origin. This lignocellulosic waste can be used to produce higher added value products, such as crafts and reconstituted wood products (Franco et al., 2010).

In the sense to improve the wood utilization, many studies have been developed to reduce the wood waste in forest harvesting operations, *e.g.*, cutting optimization to increase its yield (Franco et al., 2010). The waste generated by industries has been an environmental problem to be solved, even in timber chain, whereas the wood has a high potential of reuse (De Araujo et al., 2014). This contrast amplifies the unconcern by the timber industry with the waste subject and its possible environmental liabilities in Brazil.

The timber production chain in Brazil still suffers with several difficulties related to the waste management, because most sectors within this chain never account or classify their waste (De Araujo et al., 2015). Despite of the wide and deep Brazilian legislation, most Brazilian timber companies do not care about their waste generated by their activities. Then, De Araujo et al. (2015) state that the absence of waste management for the timber chain is a chronic problem present in all Brazilian states, whereas the local Governments rarely stimulated the industrial clusters with assertive policies to mitigate this problem.

Therefore, the energy generation has been the most popular utilization to eliminate the lignocellulosic waste in the timber sector. A great example can be verified by the study of Gonçalves et al. (2009), which verified the proposal of briquettes production, based on the mix about urban solid waste and timber waste of *Eucalyptus grandis* machining.

Treated-wood waste

Timber has low resistance to degradation by fungi, biological agents, insects and weather, which degrade the wood, especially when it is stored or located in humid spaces (CRUZ & NUNES, 2009). For that reason, the timber should be treated to increase its durability in structural uses. However, any activity involving its production, handling, utilization and disposal must be observed preventively.

According to ABPM (2015), treated-timber waste management in Brazil presents the following specific standards:

a) NBR 10004: for solid waste – classification;
b) NBR 10005: procedures to obtain extracts leached from solid waste;
c) NBR 10006: procedures to obtain solubilized extract of solid waste;
d) NBR 10007: sampling of solid waste;
e) NBR13896: non-hazardous waste landfills – criteria for design, construction and operation;
f) NBR10157: hazardous waste landfills – criteria for design, construction and operation;
g) Conama - 307/2002: waste management of civil construction.

The disposal of treated-wood waste with CCA (Chromated Copper Arsenate) cannot be made by the same way as other waste, and it deserves special attention (Santos et al., 2011). This finding is indicated by Ferrarini (2010), which assumes that obtained results in his work on leaching tests for the classification of wood waste treated with CCA suggest that they deserve more attention before its final disposal, whereas the arsenic element can cause, due to its toxicity, adverse effects resulting from its interaction with the environment, people and animals.

Discussion

The production sectors related to the timber construction generate two main examples of wood waste:

a) Pure;
b) Chemically modified.

While the pure waste result of manufacturing activities of solid wood without any presence of chemical constituents of preservatives, the chemically modified wood waste represent those from the activities related to all the preservative treatments or from the manufacturing of wood-based panels by the use of resins, binders, protective agents, etc.

Despite their positive characteristics of biodegradability and high reusability, the pure wood waste, if generated in large quantities, handled and disposed without any prior plan, this situation can cause an environmental liability, being difficult to be eliminated.

Moreover, the waste generation of chemically modified wood – originating from treated wood or wood-based panels – should be controlled because this material has constituents potentially harmful to the environment. Thus, the entire production process involving the handling, manufacturing or disposal deserves exclusive attention, due to the possible release of dangerous substances and contaminants.

Both the handling for the wood treatment as the wooden boards manufacturing promote a situation of direct contact with chemical substances for the workers. In this case, some environmental contamination resulting from these activities can occur, emphasizing the need for protection and control of these waste emissions and generations.

The utilization of wooden composites with the presence of chemical substances in their compositions should be observed with caution and attention, especially in the processing and compositions with other chemicals and in processes at high temperatures. In such cases, this waste can generate emissions of toxic substances and pollutants.

In addition, the cutting operations of treated wooden parts also constitute in a danger task, whereas the worker inserted in this industrial activity shall use appropriate safety masks, depriving the possibility of inhalation of dust and small particles from these production operations.

Proposals

Through these problems, it is necessary to indicate proposals aiming that the wooden housing sector reaches the efficiency of other industrial sectors, such as:

a) To encourage the wooden housing manufacturers to identify, quantify and select their wastes, according to the:
   i. Composition type (untreated and treated solid wood, and wood-based composites such as boards and beams);
   ii. Generated waste volumes (amount of waste from the manufactures);
   iii. Identification of the presence of chemical constituents, *e.g.*, preservatives, additives, resins and adhesives, paints, stains, waxes, varnishes, dyers, and waterproofing sealants.
b) To create public policies with assertive goals to:
   i. Encourage these industries in the selective collection of their wood waste produced in their manufactures, with view to their effective separation;
   ii. Educate and aware about the correct disposal and reuse of the many possibilities of chemical waste, such as from boards and treated lumber. This action should clarify the possible implications of improper disposal or reuse, *e.g.*, the burning of wooden composites (beams and boards) in furnaces for the production of food in restaurants, bakeries, contaminating their foods;
   iii. Stimulate the technological improvement of the machinery from forest-timber chain, enabling the reduction of the wood waste generation from forestry and manufacturing operations, as well as the domestic production of high-tech machinery for the operations of harvesting and wood machining, in this later case, involving cutting, sanding, drilling, etc.;
c) To create and establish a technical standardization for the production processes, according to the peculiarities of each wooden housing typology to optimize the raw material use, consequently reducing the volume of waste generated in forest and industry;
d) To encourage the reuse of waste, especially from the stages of harvesting and transportation of wood, in order to generate new small manufacturers of recycled sustainable higher added value products;
e) To encourage the research and the formation of new companies, via incubators and technology parks, which properly recycle toxic waste materials, such as treated wood and boards, to produce new manufactured goods;
f) To stimulate the creation of new associations and unions in order to agglutinate in regions these wooden housing manufacturers, assisting them in symbiosis through partnerships and in the guidance of these assertive actions aforementioned.

Conclusions

Through the appointed proposals to mitigate the problems aforementioned, it is expected that all the companies from this forest-timber chain will be attracted for their respective manufacturing improving and reduction of the wood waste generation.

And, in this same reasoning, it is expected that the Brazilian Government can contribute with assertive stimulating measures and laws to encourage and to strengthen the wooden housing companies to act in order to seek for greater production efficiency and a better management of the various wastes generated by the forest-timber chain, particularly by the wooden housing sector.

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Typology of Sustainable Forest Certification

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Abstract

Certification systems have become a promising market-based approach to achieving sustainable forest management. Numerous certification programs exist, including ecolabels, chain of custody certification, forest products certification, forest management certification, and environmental management certification. For these programs to be effective, consumers must understand how various certification systems align with their sustainability values. To better understand the scope of these programs, this presentation creates a typology of a wide array of prominent sustainability oriented certification systems, including the Forest Stewardship Council (FSC), Program for the Endorsement of Forest Certification (PEFC), which acts as an umbrella to the Sustainable Forestry Initiative (SFI) and Canadian Standards Association (CSA), ISO14001, Rainforest Alliance, Paper by Nature, and LEED certified wood.

Natural Durability of two Species of African mahogany Planted in Brazil against Termite Attack[1]

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Abstract

The objective of this study was to evaluate the natural resistance of *Khaya ivorensis* and *Khaya senegalensis* planted in Brazil. Five trees from each species were used to evaluate the resistance to feeding by subterranean termites (*Nasutitermes* sp.) and dry wood (*Cryptotermes*) termites. The samples were cut from for four different radial positions. *Khaya senegalensis* wood showed a significantly greater natural resistance to subterranean termite. For dry wood termite tests, *K. ivorensis* showed better results than *K. senegalensis*, but the difference was not significant. Overall, both species exhibit similar natural durability properties as Brazilian mahogany, supporting the potential to replace Brazilian mahogany wood and meet the demand of the wood products industry.

Key words: subterranean termite. dry wood termite. *Khaya ivorensis*. *Khaya senegalensis*

Introduction

Wood is a biological material susceptible to attack by wood-destroying organisms, and a greater or lesser degree of deterioration depends on environmental conditions (Teixeira, Costa and Santana, 1997). The wood decay process depends on numerous internal and external factors such as humidity, sunlight, aeration, temperature, amount and type of extractives, heartwood and sapwood. These factors have a direct role in determining the wood natural durability (Cavalcante, 1985).

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Termites are one of the factors most responsible for damage to wood (Lopez and Milano, 1986). Thus, the knowledge of the natural resistance of the wood is important to understand, to make recommendations of its use, as well as to avoid unnecessary spending on replacement of damaged parts.

The commercial interest in African mahogany in Brazil is due to the fact that in the regions where the native Brazilian mahogany occurred, its concentration has been reduced considerably. The characteristics of African mahogany wood are considered similar to the Brazilian mahogany such as color, grain design, natural resistance and physical and mechanical properties (Pinheiro et al, 2011).

However, there is a lack of information concerning the natural resistance of this species planted in Brazil, which is an important consideration when turning the plantation into a commercially viable material that meets the demand for a good quality product. Therefore, the objective of this study was to evaluate the natural resistance of *Khaya ivorensis* and *Khaya senegalensis* planted in Brazil again subterranean termites and dry wood termites.

Materials & Methods

Wood samples were obtained from five 19-year old trees of *Khaya ivorensis* and *Khaya senegalensis* cut from an experimental plantation located in Sooretama, Brazil. Each tree was cut into five logs approximately 3.0 m in length and transformed into planks 8.0 cm thick. The second logs of each tree were used with portions of 100% heartwood and 100% sapwood. The samples were quarter-sawn into pieces 23 mm x 6 mm x 70 mm (with larger dimensions in fiber direction*)*. The samples were divided into four parts in the radial direction, from pith to bark (IHP = inner heartwood with pith; IH = intermediate heartwood; HSI = heartwood/sapwood interface; S = sapwood). The blocks were conditioned to a constant weight at 6% equilibrium moisture content (EMC).

Subterranean Termites Test

Subterranean termite testing followed the ASTM D3345: Standard method for laboratory evaluation of wood and other cellulosic materials for resistance to termites (ASTM, 2006), Fifteen samples were used for each position having a total of 60 samples for each species. Pine sapwood (*Pinus* spp.) was used as a control. Samples were placed at the bottom of 500 ml flaks, covered with 200 g of sterile, sifted sand. One gram of *Nasutitermes corniger* Motsch (approx. 300 individuals) was then added to each flask and allowed to feed for 28 days. After the test period, samples were removed from the container, adhering sand removed, and air-dried reconditioned to a constant weight at 6% EMC. Percent mass loss, visual rating of termite attack on test blocks based on the AWPA scale, and percentage termite mortality in each jar were measured (see Table 1).

Table 1. ASTM classification for termite mortality and visual rating of blocks (ASTM D3345 (2006))

Termite Mortality	(%)
Slight	0 to 33
Moderate	34 to 66
Heavy	67 to 99
Complete	100
Visual Rating	**Levels**
Sound, surface nibble permitted	10
Light attack	9
Moderate attack, penetration	7
Heavy	4
Failure	0

Dry Wood Termites Test

Dry wood termites testing followed the method Accelerated Laboratory Test of Natural Defense or Preserved Wood Termites to attack the *Cryptotermes* Gender (Family Kalotermitidae) – IPT/DIMAD D-2 (1980) developed by the Institute of Technological Research of the State of São Paulo (IPT, 1980). Flasks of 500mL were filled with 350 g of soil dampened to constant moisture content with 80 ml of sterile water. Each bottle received four wood samples (one from each radial position). Ten samples were used for each position, where six samples were exposed to a natural soil and four were exposed to sterilized soil (sterilized in an autoclave at a temperature of 120 ± 1 ° C for one hour), with a control sample of pine sapwood (*Pinus* spp.). The samples were exposed for 120 days in a conditioned room (27 ± 1 ° C and 75 ± 5% relative humidity). After this period the samples were removed from the container, brushed free of debris, and air-dried overnight. Blocks were then reconditioned to a constant weight at 6% EMC to calculate percent mass loss. Termite mortality occurring at the end of the exposure period was also recorded. Table 2 shows the classification for visual rate system of termite attack based on IPT/DIMAD D-2 (1980)

Table 2. Visual rating system of dry wood termite damage (IPT/DIMAD D-2 (1980))

Visual Rating	Levels
No damage	0
Superficial damage	1
Moderate damage	2
Heavy damage	3
Failure	4

SAS version 9.4 was used to perform the statistical analysis. Means were separated using Tukey's test ($\alpha = 0.05$) for the sources of variation detected as significant by an F test.

Results and Discussion

Subterranean Termite Testing

Average percent mass loss and coefficient of variation for *K. ivorensis* and *K. senegalensis* are presented in Table 3 along with termite mortality averages and visual ratings for the two species.

Table 3. Results from *Khaya ivorensis* and *Khaya senegalensis* exposed to feeding by subterranean termites

Species	Mass Loss (%)				Average
	IHP	IH	HSI	S	
K. ivorensis	(68.9)** 20.3 C*	(46.3) 26.7 BC	(14.2) 36.7 A	(12.0) 32.3 AB	29.2 A
K. senegalensis	(75.9) 3.8 A	(93.6) 4.71 A	(127.2) 3.40 A	(119.4) 6.42 A	4.6 B
Species	**Termite Mortality (%)**				**Average**
	IHP	IH	HSI	S	
K. ivorensis	(120.9) 41.6 A	(149.7) 29.0 A	(67.5) 20.5 A	(141.3) 31.1 A	30.12 B
K. senegalensis	(0.0) 100 A	(0.0) 100 A	(0.0) 100 A	(0.0) 100 A	100 A
Species	**Visual Rating**				**Average**
	IHP	IH	HSI	S	
K. ivorensis	(34.6) 6.39 A	(31.7) 3.77 B	(66.1) 2.89 B	(24.5) 3.39 B	4.1 B
K. senegalensis	(9.6) 9.5 A	(12.8) 9.1 A	(9.9) 9.2 A	(11.0) 9.0 A	9.2 A

* Averages within a row followed by the same letter are not significantly different, as gauged by Tukey's test ($p \leq 0.05$)
** Coefficient of variation (%)
IHP = inner heartwood with pith; IH = intermediate heartwood; HSI = heartwood/sapwood interface; S = sapwood

For *K. ivorensis*, the heartwood/sapwood interface was the most attacked position and inner heartwood with pith more resistance among the positions within species. For *K. senegalensis*, the sapwood was the most attacked position, while heartwood/sapwood interface showed a higher resistance compared to other positions. However, there was no significant difference between positions ($\alpha = 0.05$) for both species. The *K. senegalensis* was significantly more resistant than *K. ivorensis* ($p < 0.0001$). .

The inner heartwood with pith in *K. ivorensis* showed the highest termite mortality and heartwood/sapwood interface had the lowest average of termite mortality. For *K. senegalensis*, all positions showed the same percentage of termite mortality. There was no significant different between position ($\alpha = 0.05$) for both species. Based on the ASTM D3345 (2006) classifications, *K. ivorensis* had a slight rate of termite mortality, while *K. senegalensis* had complete rate termite mortality (Table 1). *K. senegalensis* wood had a significant higher value of termite mortality ($p < 0.0001$).

Based on the visual rating of termite damage, in *K. ivorensis* wood, heartwood/sapwood interface had a significantly higher termite damage rate (α = 0.05) among the positions. For *K. senegalensis* wood, sapwood had the highest damage rate and inner heartwood with pith had the highest rate of termite damage, but there was no significant difference between positions (α = 0.05). Based on visual system of ASTM D3345 (2006), the level of termite attack of *K. ivorensis* is heavy and for *K. senegalensis* is lightly attacked. There was significant difference between species, where *K. senegalensis* had the highest rank in visual grade level ($p < 0.0001$).

Dry Wood Termite Testing

The results for dry wood termites test are presented in Table 4.

Table 4 – Average percent mass loss, coefficient of variation and visual rating of the wood samples of *K. ivorensis* and *K. senegalensis*

Species	Mortality (%)				Average
	IHP	IH	HSI	S	
K. ivorensis	(34.6) 50.0 A	(36.9) 36.5 BC	(51.1) 27.5 C	(29.9) 38.5 B	38.1 A
K. senegalensis	(33.8) 40.0 A	(38.1) 39.5 A	(38.8) 35.5 A	(21.3) 45.0 A	40 A
Species	**Visual Rating**				**Average**
	IHP	IH	HSI	S	
K. ivorensis	(116.8) 0.7 C	(44.2) 1.1 B	(59.5) 1.4 B	(26.4) 2.7 A	1.7 A
K. senegalensis	(41.5) 1.4 BC	(78.4) 1.1 C	(35.5) 1.9 AB	(20.3) 2.4 A	1.4 A

* Averages within a row followed by the same letter are not significantly different, as gauged by Tukey's test ($p \leq 0.05$)
** Coefficient of variation (%)
IHP = inner heartwood with pith; IH = intermediate heartwood; HSI = heartwood/sapwood interface; S = sapwood

For *K. ivorensis* wood, inner heartwood with pith presented the significantly higher rate for termite mortality (α = 0.05). In *K. senegalensis* wood, sapwood had highest average of termite mortality and heartwood/sapwood interface showed the lowest average of termite mortality. There was no significant difference between positions (α = 0.05) and between species ($p = 0.2262$).

Sapwood in *K. ivorensis* showed a statistically higher (α = 0.05) visual rating, while intermediate heartwood had the lowest visual rating. For *K. senegalensis*, sapwood had the greatest level of termite attack and intermediate heartwood had the lowest level of termite damage. However, there was no significant difference (α = 0.05) between positions. Based on IPT/DIMAD D-2 (1980) visual rate system, both species had a moderate damage. There was no significant difference between species ($p = 0.1825$) in visual rate level.

SUMMARY AND CONCLUSIONS

The *K. senegalensis* wood was more resistant to subterranean termite than *K. ivorensis* because this species showed significantly better results for mass loss, termite mortality and visual rating. There was a significant difference between positions for *K. ivorensis* wood in visual rating, where inner heartwood with pith showed the highest visual rate level ($\alpha = 0.05$).

For dry wood termite test, *K. ivorensis* showed better results for mass loss and visual rating, but the difference was not significant ($\alpha = 0.05$). Related to positions, there was a significant difference in mortality and damage of termite attack for *K. ivorensis* wood, where sapwood a significant higher damage level of termite attack ($\alpha = 0.05$). Thus, both species can be considered resistant to dry wood termite attack.

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Soy Products for Wood Bonding

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Abstract

Understanding the structure-property relationships for proteins as adhesives is complicated due to the complex and changeable colloidal nature of most proteins. An abundant source of protein in many parts of the world is the soybean, but the inexpensive soy flour is only 50% protein with the remainder being an approximately equal split of soluble and insoluble carbohydrates. These carbohydrates have been considered the cause of the poor strength under wet conditions for bonded wood products. However, removal of the soluble and/or insoluble carbohydrates did not lead to dramatic improvement in wet bond strength, showing that the native protein is not a great adhesive. In contrast, hydrothermal treatment of the purer proteins provided much higher strength showing the importance of thermal history when considering the use of soy protein in adhesive systems.

Key words: soybean**,** protein, adhesive, wood, viscosity, bond strength

Introduction

Soybeans have been used mainly for their nutritional utility rather than as an industrial product. The soybean is not eaten whole to any great extent, but is converted into other raw materials that are used in many food products. After removal of the protective hull, the bean can be processed to make tofu and soy milk directly. For the most part the crushed beans are solvent extracted to isolate the valuable soy oil. The remaining meal is mainly used as animal feed after heat treatment to make it more digestible; however, the defatted soy is also processed to make a variety of flours, concentrates, and isolates. Each of these classes of soy is not a single product, but a group of products with different properties. Thus, it is important to understand what specific soy material is being used and what specific processing steps were used to obtain a given soy product.

The only commercial soy product that has its proteins in the native state is the defatted (hexane extracted) soy that has not undergone any significant thermal treatment. This type of product would typically be denoted with a high PDI value of 90, where PDI means protein dispersibility index (measurement of colloidal solubility). However, high PDI does not automatically correlate to a lack of thermal history in other products. All other commercial soy products have proteins in a non-native or denatured state. The proteins in the bean provide a number of biological functions; thus, there is no reason to expect the native state should provide the best adhesive properties. The processing conditions used for other soy products change some or all of the proteins from their native state to a denatured state. To understand this from the aspect of using these products in industrial applications, we have to understand the ways that these products are processed and how these conditions may affect the structures of proteins.

Proteins have four levels of structure: primary (amino acid sequence of the polypeptide backbone), secondary (localized crystalline regions including α-helices and β-sheets), tertiary (whole molecule structure), and quaternary (super structures formed by interaction of multiple protein chains) (Figure 1) (Creighton 1984). The different proteins in soy have unique distribution of the amino acids so there are considerable differences in the resultant higher order structures. These differences include the two types of polypeptide subunits that form the major protein glycinnin and three polypeptides that form the second major protein conglycinnin. A variety of other proteins are also present in the soy. The soy meal and the flour made from it also contain carbohydrates that can be divided into three classes, glycoproteins (covalent carbohydrate-protein structures) as well as soluble and insoluble carbohydrates. About half of he carbohydrates are soluble consisting mainly of sucrose, raffinose, and stachyose, and half insoluble carbohydrate polymers of rahmnose, arabinose, galactose, glucose, xylose, and mannose (Bainy et al. 2008).

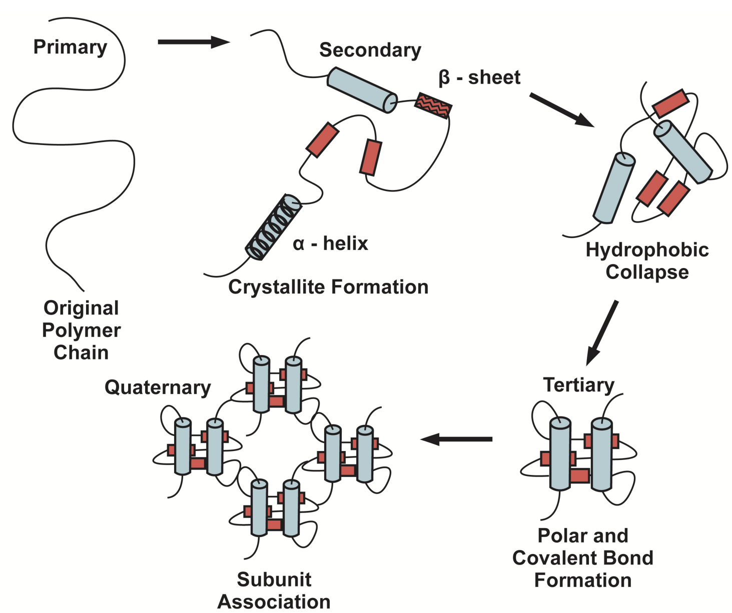

Figure 1. Folding of the proteins as they are synthesized showing all four levels of structure.

In processing soybeans the first step is nearly always a crushing step for hull removal and extraction of the valuable oils with hexane (Sun 2005). The defatted soy is then either dried using the vacuum method to remove the remaining hexane yielding the white flakes used to make the isolate and concentrate or ground into 90 PDI flour, or it is heated to remove the remaining hexane and denature the proteins for improved digestibility of the meal to produce the 20 PDI flour used to as animal feed. There is also an intermediate flour of 70 PDI which is made using the second method albeit with less aggressive heating. These are the three main types of soy flour available commercially.

The next class of soy products is the soy concentrates in which the soluble carbohydrates have been removed. Due to nature of the process required to make concentrates from the defatted white soy flakes, all concentrates contain denatured soy protein. To separate the soluble carbohydrates from the protein fraction involves an aqueous ethanol extraction. The protein content is increased from about 50% to 70% (Sun 2005). This material can then be dried to give a final product after just the extraction step or further modified via jet cooking. Jet cooking involves a rapid heating of the aqueous dispersion of the soy concentrate with high pressure steam in a tube reactor and then cooling and drying it quickly after passing it through an orifice using a vacuum evaporation. The degree of jet cooking plays an important role on the structure/function relationship of the resultant concentrate, producing a variety of products (too numerous to list here) with specific properties for use in the food industry. What is important to note is that each type of concentrate can be expected to contain proteins in various denatured states depending on the conditions of heat and shear that they are subjected to. .

The final class of soy product is soy protein isolates in which the insoluble and soluble carbohydrates have been removed to yield products with greater than 90% protein content. The isolate products require a more complicated process. The first step is to dissolve the majority of the proteins and soluble carbohydrates in water under slightly basic conditions so that they can be centrifuged to remove the insoluble carbohydrates (Sun 2005). The proteins are then precipitated by lowering the pH to the protein isoelectric point and centrifuging to remove the soluble carbohydrates. The precipitate can then be suspended in water, neutralized, and isolated by evaporation of the water. A similar process using a two or three stage lowering of the pH can provide the conglycinnin and glycinnin protein fractions whose crystalline structure has been determined. However, the information on the structure of the native soy protein isolate (NSPI) has limited bearing on the commercial isolate (CSPI) because all the CSPIs are jet cooked to provide greater functionality for food applications (Egbert 2004). Thus attempts to relate the performance of commercial protein isolates to native soy protein structures has provided little value due to the highly denatured state of the jet cooked CSPI. As with the soy concentrates, the degree of jet cooking can alter the level of denatured states in soy isolate yielding a variety of products with specific end use properties. In addition, there are also enzymatic treatments that can further alter the properties.

All commercial soy products can serve as wood adhesives as long as one is interested only in dry adhesive strength. Rarely is this the case, however, because most wood products need some level of water resistance. Thus, the most important aspect for selecting soy products is evaluation of the resultant adhesive bond after exposure to water, typically by prolonged soaking. Two other important aspects for selecting soy products as wood adhesives are the solids content and viscosity. Because hot pressing turns the water to steam that can rupture the composite when the platen pressure is released, minimal water content is valuable. As with any system, higher solids yields higher viscosity which can be especially difficult when using soy products which thicken rapidly even at relatively low solids contents. In order to better illustrate some of the adhesive properties of different soy products, the properties of different soy products are compared under the same bonding and testing conditions. The results are discussed in light of the process conditions used to obtain the soy products.

Materials & Methods

The soy flours used were the following: Prolia™ 200-90, Prolia™ 200-70, and Prolia™ 200-20 (Cargill Inc., Cedar Rapids. IA). The soy concentrates were Arcon® F and SM (ADM, Decatur, IL). The commercial soy protein isolates were PRO-FAM® 646, 781, 875, 891, 955, 974 (ADM)

A Horiba D-47 pH meter was used to measure pH values. Apparent viscosities were measured using a Brookfield Digital Viscometer Model RVTD (Stoughton, MA), with a #6 spindle at 5 rpm. A similar shear history for the samples was ensured by vigorously hand mixing the sample for 30 seconds, allowing it to stand for 10 seconds, inserting the spindle into the sample, switching on the viscometer motor and then recording the viscosity value 10 seconds after the spindle started moving.

The soy dispersions were made by dispersing soy into water at a given solids level. The mixture was then hand stirred for 30 minutes to complete the process. The pH and viscosity of the dispersions were measured.

The various soy dispersions were tested for their wood bonding strength using an Automated Bond Evaluation System (ABES) Model 311c tester (Adhesive Evaluations Systems, Inc., Corvallis, OR) for forming and breaking the bonds to determine strength and wood failure. The wood used for the test was hard maple and the wood samples bonded were 117 mm along the grain × 20 mm across the grain × 0.6 mm thick strips. During processing with the ABES, a 5-mm wide strip of adhesive was applied to one wood specimen and was then immediately overlapped with another. This area was then hot pressed in the ABES unit at 0.2 MPa for 120 seconds at 120°C. After this time period, the platens were retracted and the full specimen was removed from the unit. All samples (7 for dry testing and 7 for wet testing of each formulation) were allowed to re-equilibrate at 22°C and 50% relative humidity at least overnight before testing.

For testing bond strength, half of the specimens were tested dry and the other half were tested wet, after a four-hour water soak at 22°C. Each sample was placed back into the

ABES unit and the grips were engaged. The grips then pulled each sample and the maximum load at failure was recorded. The bond strength was calculated by dividing this load by the adhesive overlap area of 100 mm^2 to give the shear bond strength. The percentage of wood failure was also recorded (not reported herein); the fracture was mainly in the wood outside the bonded area for the dry samples and the failure was in the adhesive for the wet samples. The standard deviations in strength and wood failure were calculated for each combination, and differences were determined by comparing two standard deviation error bars for the different combinations.

Results and Discussion

Solids and viscosity

The adhesive has to be fluid enough to apply in the commercial equipment, which varies from roll coater for plywood to spray applicator particleboard. Soy adhesive viscosities cannot be directly compared to those of phenolics or amino adhesives because the soy adhesives are generally shear thinning while the others are Newtonian. The measured viscosity of soy adhesives can vary greatly depending on the shear history and as well as the selection of spindle and RPM's used during the measurement.

For most soy products, the viscosity increased slowly as a function of solids, then a transition occurred and the viscosity increased very rapidly (Frihart and Satori 2013). This is more typical of a dispersion than a solution. With the molecular weights of subunits being over 20 kD and the aggregates over 150 kD (Kinsella 1979), reaching a viscosity less than 1 Pa·s with a 20% solids would be surprising for a solution (Frihart and Satori, 2013). Thus, the soy is dispersed in water, with some dispersions being more stable than others. The term solubility used with soy does not mean true solubility, but describes how easy the soy is to wet with water. While the term dispersibility is used to describe how stable the protein dispersion is to centrifugation.

Bond strength

For these bond strength comparisons, we used the small scale specimen tests because this test allows for using a wide range of viscosities without a great variation in soy strength and emphasizes cohesive strength of the soy.

Because of economic and availability reasons, the flour is the most widely used soy source for adhesive applications; in particular, the 90 PDI flour with the native proteins is the basis for comparisons of soy performance. The original hypothesis was that the most dispersible protein should result in the best cohesive and adhesive strength, but very little difference and no discernable trend was seen. Both the wet and dry bond strengths were virtually unchanged using 90, 70, and 20 PDI flours with the amount of soy flour at 20%, 25%, 30%, and 35% in water (Frihart and Satori 2013). Thus, there does not seem to be any benefit to having native structure compared to some level of denaturation of the proteins produced during production of the different soy flour types. Not only did the PDI not influence the results, but also the creamy nature of the high PDI flours was not better in these tests than the gritty 20PDI flour. The PDI does play a role in making larger standard plywood specimens, where the 20 PDI flours were more difficult to spread due to more rapid loss of the water to the wood during sample preparation (Wescott 2008).

One could assume that removing the soluble sugars in making the concentrate would allow a straight-forward comparison of strength compared to the soy flour. However, denaturation of the proteins to insolubilize them for the extraction from the soluble carbohydrates does not allow a direct protein to protein comparison with any of the soy flours. Initial comparisons of high PDI soy flour and Arcon F concentrate showed only a slight increase in dry and wet strength. The low wet strength observed using Arcon® F, led to the conclusion that the soluble sugars do not greatly affect the bond strength as illustrated in Table 1. However, if another concentrate, Arcon® SM is used, the conclusion would be different in that removal of soluble sugars generated a large gain in the wet strength. The difference seems to lie in the fact that the Arcon® SM is jet cooked while the Arcon F™ is not. Thus, we hypothesized that the jet cooking enhances the wet bond strength in the concentrates, and contribution from the removal of the soluble sugars minimal. Other process differences cannot be ruled at this stage since we do not know all the details of the commercial processes.

	% Solids	ABES dry strength		ABES wet strength		pH	Viscosity, cPS
		MPa	SD	MPa	SD		
Prolia™ 200-90	15%	5.4	0.8	0	0	6.25	660
Arcon® F	15%	6.6	0.7	0.7	0.1	6.80	<100
Arcon® SM	15%	6.6	0.5	2.0	0.3	6.75	75,200

Table 1: Bond strength comparison of soy flour and concentrates.

The literature was confusing in that Sun and coworkers published data that the native soy protein isolate (NSPI) had poor wet strength, but we have continually observed very high strengths from the commercial soy protein isolate (CSPI). However the bond strength tests were done differently between the two labs thus generating a need for further investigation. Making our own NSPI showed that it was only slightly better than the soy flour, but much poorer than the CSPI when tested using the same protocol (Table 2). Discussions with a CSPI supplier led to the understanding that all CSPIs were jet cooked for increased functionality in food products (Egbert, personal communication). We tested a variety of CSPIs to determine if most CSPIs provide high bond strength. Table 2 shows that most CSPIs yield enhanced wet strength compared to either soy flour or the NSPI. The major exception is PRO-FAM® 781, which was probably enzymatically cleaved as indicated by the substantially lowered viscosity. This further supports the notion that jet cooking is a way to produce stronger wood adhesives made from soy products. Unfortunately, all the jet cooked samples have much higher viscosities than those not thermally treated. The solids/viscosity ratios of CSPI make these soy products much less practical for use as wood adhesives.

	% Solids	ABES dry strength		ABES wet strength		pH	Viscosity, cPs
		MPa	SD	MPa	SD		
Prolia™ 200-90	15%	5.4	0.8	0	0	6.25	660
NSPI	15%	4.6	0.7	1.1	0.6	7.01	<100
PRO-FAM® 646	15%	8.0	0.5	2.4	0.5	6.36	36000
PRO-FAM® 781	15%	4.1	0.6	0	0	6.90	10
PRO-FAM® 875	15%	7.3	0.8	1.9	0.2	7.06	952
PRO-FAM® 891	15%	7.0	0.4	2.2	0.2	7.16	31300
PRO-FAM® 955	15%	5.1	0.9	1.5	0.2	5.40	<100
PRO-FAM® 974	15%	8.3	0.7	2.1	0.5	7.15	57000

Table 2: Bond strength comparison of soy flour, concentrates, and isolates.

This research shows that drawing conclusions from adhesive research can be misleading if you do not understand how the soy has been processed prior to formulating the adhesive.

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Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products – Ecosystem services and competitiveness in the Bio-economy

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Abstract

Ecosystem approach broadens the sustainability perspective within the forest sector. Economic and ecological aspects may be linked together. The ecosystem concept allows a wide frame for sustainable forests and forest products both in private and public forests. Private owners play a key role in sustaining forest ecosystems providing resources for markets and at the same time enhancing development locally. In Finland, the non-industrial private forest (NIPF) owner sector has a large importance.

Different ecosystems form promising opportunities for business. In the Green Economy multiple ecosystems are taken into consideration. Forest ecosystem services provide an opportunity for value creation. Forests and forest products with certification, green building with carbon − ecosystem services provide opportunities in markets in the future. In the bio-economy, stakeholders have an important role in active, sustainable and diverse use of forests and providing sustainable forest products.

Competitiveness is in an important role in the policy framework.

Keywords: Sustainable development, forests, forest products, ecosystem services, bio-economy, stakeholders, competitiveness

Introduction

The research on "Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products" is a literature review and based on a qualitative study. It is broadly outlined and combines organizational information and research information from several academic sources with a number of search words. It is based on organizational information and research articles from relevant databases.

Research questions in the framework of "Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products" include the following:

1. How is stakeholder collaboration represented in an international and national policy framework and what is the role of corporations in the corporate social responsibility approach?
2. How do stakeholders represent green economy with bio-economy and green growth and the CSR in ecosystem services?
3. Whether to the Advocacy Coalition Framework approach with an international and national policy aspect, how can the sustainable development and competitiveness be enhanced with green growth, green economy and bio-economy? (Conceptual approach.)

Ecosystem services in the Bio-economy with stakeholders

Certification, green building and developing carbon and other ecosystem markets have importance also in the future. Biomass certification development involves many stakeholder groups including governments, companies, NGOs, transnational and international organizations and international initiatives. Policy influence in the forestry can be highlighted.

The new EU Forest Strategy in 2013 includes goals for competitiveness and sustainable forestry and use of forests enhancing ecosystem services.

The Strategy for "Innovating for Sustainable Growth: A Bioeconomy for Europe" (2012) encourages to participatory engagement, responsibility and private investments.

Stakeholders have been engaged in the Finnish Bioeconomy Strategy (2014). The Finnish Bioeconomy Strategy promotes economic development and aims to prevent the decline of ecosystems.

The Finnish Bioeconomy Strategy (2014) aims to generate new economic growth referring to an economy that is based on renewable natural resources producing e.g. energy, products and services. The Finnish Bioeconomy Strategy is based on the sustainable development.

Competitiveness in the Bio-economy with stakeholders

The Bioeconomy Action Plan in "Innovating for Sustainable Growth: A Bioeconomy for Europe" of the European Commission includes the improvement of markets and competitiveness in bioeconomy. It also contains strengthened policy interaction and stakeholder engagement.

Within the Europe's Bio-economy Strategy (2012) investments in research and innovations, strengthened stakeholder engagement and policy interaction, improved markets and competitiveness are highlighted taking into consideration climate change and natural resources.

The strategic goals of the Finnish Bioeconomy Strategy (2014) include "A competitive operating environment for the bioeconomy", "New business from the bioeconomy", "A strong bioeconomy competence base" and "Accessibility and sustainability of biomasses".

National and international framework in ecosystem services and competitiveness in the Bio-economy with stakeholders

In the Environmental Policy of Metsähallitus in Finland, "multi-objective management of natural resources and securing ecosystem services", "responsibility for the environment" and "continuous improvement" and "openness and co-operation" are accentuated. Responsibility for the environment may be ensured with regulations, environmental commitments, forest certification standards and international agreements.

There are opportunities in wood based products. One of the strategic objectives of the Government Forest Policy Report to the Parliament, covering the use of Finnish forests up until the year 2050 is that forests are in active, sustainable and diverse use. Sustainable development can enhance business opportunities. It is stated that the Bio-economy will enhance the sustainable economy in Finland.

Bio-economy can be seen as a new turn in the economic development. In the future, services and diversity and forest products can provide a much larger amount of possibilities for opportunities in the forest sector in Finland.

Forest owners' role in providing ecosystem services in the policy context is important. Fulltime agricultural entrepreneurs comprise about 16 % of forest owners in Finland. Internationally large amount of private forest ownership in Finland forms a competitive factor for Finland.

The target of the Bio-economy Strategy of the European Commission in 2012 is to bolster a worldwide approach to a resource use which is more sustainable including knowledge of international biomass sustainability and new markets.

Research results propose that corporate responsibility may advance value creation in forest-based companies. Responsibility can be seen as a competitive tool for the industry.

Conlusions

Stakeholders have an important role in the green approaches and a significant role in the markets. Ecosystem services may supply resources to markets and can enhance local development.

In Finland, private forest owners have a significant role in competitiveness sustaining forest ecosystem services and providing wood for the forest industry. Forest owners' role is important in providing resources for the ecosystem services in the markets in Finland. Forest owners' role is important for the sustainability and for the competitiveness.

Sustainable development can be revealed in the green concepts and in the stakeholder collaboration.

Corporations have a significant role in the Corporate Social Responsibility, CSR, which is present in green concepts and in the bio-economy approach. There are national and international opportunities in the competitiveness within the Bio-economy.

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4.

Durabilidad Natural de Madera de Dos Especies de *Eucalyptus*: *E. bosistoana* y *E. sideroxylon*

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Abstract

In this paper, the natural durability of two *Eucalyptus* species (*E. bosistoana and E. sideroxylon*) planted in Uruguay was compared with that of *E. tereticornis*. Twenty-year-old tree specimens used in this study had originally been planted for trials of *Eucalyptus* species able to grow on soils developed on basalt. *Populus sp*. and *Pinus taeda* were used as references. The durability of these species was evaluated against one white rot fungus (*Coriolus versicolor*) and one brown rot fungus (*Gloeophyllum trabeum*). The two *Eucalyptus* species were classified as not durable, while *E. tereticornis* can be considered resistant.

KEYWORDS *E. bosistoana* , *E. sideroxylon*, natural durability wood, brown rot fungi, white rot fungi

INTRODUCTION

For millennia, wood has been and continues to be widely used in many indoor or outdoor applications. It is a renewable resource that can be produced sustainably requiring relatively low levels of energy for its transformation. However, it is prone to decay by biotic (fungi, bacteria, marine borers, insects) and abiotic (UV and IR radiation, moisture, fire, etc.) agents. Wood decay leads to changes in products that result in economic losses due to aesthetic deterioration or loss of physical and mechanical features linked to the properties of the lignocellulose matrix. Builders using wood have always recognized the inherent resistance of certain timber species to attack by different living organisms, classifying species according to their fitness for terrestrial constructions, aquatic constructions or sea-going vessels in view of their natural durability. Whereas the physical and mechanical properties or aesthetic attributes of timber species define their potential use, durability determines their life span and ultimately their fitness for purpose. Natural durability of wood is defined as the inherent resistance of wood to attack by wood destroying organisms (EN 350-1:1994). The natural durability of wood is the result of complex phenomena that depend on wood density, lignin content, type and amount of extractables, anatomical characteristics, sapwood/heartwood ratio and other factors including environmental factors, growth conditions, forest management, origin, genetics and age (Plaschkies et al. 2014; Jebrane et al. 2014). Standard EN 350-1: 1994 currently defines the requirements for determining the natural durability against fungi, termites and marine borers and describes the classification of durability for the most important European wood species. Although laboratory and field tests defined in the standard do not give a complete description of the behavior of wood in real applications, they constitute a first step toward classification.

Large areas of eucalypts have been planted in locations outside their native Australia, in view of their rapid rate of growth and an increasing demand for their wood. This has led to an increase in the amount of available information on wood properties of *Eucalyptus* grown as exotic. The properties of wood from exotic *Eucalyptus* trees differ from those of trees grown in Australia due to their rapid growth and younger age at harvest (Sanchez Acosta, 1999).

Consideration of the durability of wood in construction uses is fundamental to modern international design standards. Since the heartwood of eucalypts cannot be treated chemically, in this study, the natural durabilities of two *Eucalyptus* species (*E. bosistoana* and *E. sideroxylon)* planted in small areas in Uruguay were determined and compared with that of *E. tereticornis*, a species widely regarded as durable in Uruguay. Tree specimens were 20 years old and were originally planted for trials of *Eucalyptus* species able to grow on soils developed on basalt. *Populus sp.* and *Pinus taeda* were used as references. The durability of these species was evaluated against one white rot fungus (*Coriolus versicolor*) and one brown rot fungus (*Gloeophyllum trabeum*) througth a mini block test.

MATERIALS AND METHODS

Wood samples

E. bosistoana and *E. sideroxylon* trees used in this study were supplied by the Glencoe Experimental Station of Uruguay's Institute for Agricultural Research, INIA (32º0132,52" S, 57º0907,54" W, Paysandú, Uruguay), from a study on the adaptability of Eucalyptus species to basalt conditions for use as shade and shelter for livestock (Balmelli and Resquin, 2005). Trees were planted at a density of 1,600 trees/ha with spacing of 2.5 x 2.5 meters. Thirty trees were selected according to trunk shape and health status, and their diameters were measured. Seven individuals of each species were selected on the basis of diameter distribution among the trees. The selected trees were processed at a sawmill located at the Bernardo Rosengurtt Experimental Station (EEBR) of the Faculty of Agronomy of Uruguay's Universidad de la República within ten days of felling. *Populus sp., E. tereticornis* and *Pinus taeda used* as references were supplied by the Bernardo Rosengurtt Experimental Station (EEBR); no data is available on the plantation conditions. In all cases, wood from adult trees was used.

200 wood blocks of each species (*E. bosistoana, E sideroxylon, E. tereticornis, Populus sp.* and *Pinus taeda*) of dimensions (50 ± 0.5) mm x (25 ± 0.5) mm x (15 ± 0.5) mm were used. The density of wood blocks at a 12% water content differed from the mean density of blocks by less than 10%. After conditioning at 20 ± 2 °C and 65 ± 5% relative humidity until constant weight, blocks were tested for resistance to Basidiomycota in a mini block test (Bravery, 1978).

Organisms, media and culture conditions

Gloeophyllum trabeum (H 2130 CCMFQ) and *Coriolus versicolor* (H 2140 CCMFQ) strains from the Microbiology Department at the Faculty of Chemistry of Uruguay's Universidad de la República were used. The strains were maintained on malt extract (12.5 g/L) and agar (20 g/L) medium at 5°C.

Petri dishes 90 mm in diameter containing 2% malt extract and 1.5% agar were inoculated with each of the fungi and cultured until the mycelia fully covered the dish surface. Finally wood blocks were placed in threes in the Petri dishes.

For the calculation of dry weight before testing, additional blocks and reference specimens were conditioned and oven-dried at 103 °C for 18 h. After steam sterilization two blocks of the same tree species were placed in a flask on the surface of mycelia, using glass spacers between the blocks. 10 replicates were used for each fungal species. The inoculated blocks were incubated at 22 ± 2 °C and 70 ± 5% relative humidity for 8 weeks. Removing the mycelia, weight loss was determined based on the oven-dried weight of blocks.

RESULTS AND DISCUSSION

Table 1 shows weight losses determined for blocks of wood of the different species following fungal exposure. After 8 weeks of incubation, although weight loss values were low for the different species, low variation coefficients showed consistency in fungal behavior.

Based on these results, the heartwood of *E. bosistoana* and *E. sideroxylon* can be considered Class 1 according to Standard EN 350-1, do not durable (Table 2).

	C.versicolor		***G.trabeum***	
	Weight loss (%)	**Desv. Est.**	**Weight loss (%)**	**Desv. Est.**
Populus sp	18,51	2,55	12,41	0,41
Pinus taeda	15,18	4,52	18,46	0,19
E tereticornis	11,19	0,07	10,25	0,12
E bosistoana	23,17	1,75	23,19	1,68
E sideroxylon	25,83	3,03	24,82	2,83

Table 1: Weight loss (expressed as a percentage) for the different wood species after fungal decay tests against Basidiomycota

	Weight loss (%)	
	C. versicolor	*G.trabeum*
Pinus taeda	0,82	1,49
E tereticornis	0,60	0,83
E bosistoana	1,25	1,87
E sideroxylon	1,40	2,00

Table 2: Weight loss expressed like x= weight loss specimen/ weight loss reference

These results are only indicative of trends and cannot strictly be compared with the results of standardized laboratory tests or field studies. However, these values are not consistent with literature data. For example, Scheffer and Morrell (1998) reported *E. bosistoana* and *E. sideroxylon* to be very resistant species. Both were classified as Class 1 according to Standard EN 350-2. The heartwood of these species is also classified as resistant (Class 1) by Australian Standard AS 5604 (http://www.timber.net.au/).

E tereticornis was classified as Class 2 (Scheffer and Morrell, 1998), being moderately durable against attack by *Gloeophyllum trabeum* but resistant to *Trametes versicolor* (Carvalho et al. 2015), and Tinto (1991), cited by Sanchez Acosta (1999), classified the heartwood of *E tereticornis* as of medium durability when in contact with soil and durable when exposed to air.

In the literature, different species of *Populus sp*. have been classified as Class 4 (Scheffer and Morrell, 1998) or 5 (not durable), according to EN 350-2 (Van Acker et al. 2003), supporting the selection of poplar as a reference species. However, weight losses for *Populus sp*. in this study were smaller than for the other wood species.

The nutritional characteristics and needs of fungi are reflected in their preferences for certain woods. In this study, no preferences were observed, although *E. sideroxylon* showed the highest weight loss.

The resistance of wood is dependent on diverse factors that vary according to species and even within individual trees, such as the chemical composition of wood (Eaton and Hale 1993) and environmental factors (Viitanen et al., 1997), among others. These factors can be used for the analysis of these results; in particular the quantity and type of extractables has a large influence on the durability of wood, although no correlation has been found in a field test between average total extractables and destruction index (Jebrane et al. 2014).

The influence of chemical composition on the durability of wood will be studied in leaching tests conducted prior to fungal exposure and by chemical analysis of each wood species.

Environmental factors, in particular the type of soil where the sample trees were grown, may have had a positive influence on tree parameters like canopy density and foliage, but growth on basalt may have negatively affected the durability of these wood species, in *particular E sideroxylon*. *Populus sp., E. tereticornis* and *Pinus taeda* used as references (all supplied by EEBR) had lower weight losses than the test species, highlighting the effect of the growing site on the durability of these woods.

Field studies are known to provide a more realistic scenario owing to natural aging and detoxification of biocide compounds through non-target organisms; however, laboratory studies provide better reproducibility of experimental conditions (Meyer et al. 2014). For this reason the results obtained using mini blocks of wood, will be compared with another laboratory test based on Standard EN 113 (1989) and a field trial according to Standard EN 252 ( ).

CONCLUSIONS

Weight losses in this preliminary test show that the heartwood of *E. bosistoana* and *E. sideroxylon* can be considered Class 3 according to Standard EN 350-1. Only the ongoing standardized laboratory test and field test will be able to confirm or contradict these results.

In future work, these indexes will be compared with those of old Eucalyptus trees growing on soils with different characteristics.

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Assessment of Pre-fabricated Wooden Homes as an Affordable Housing Alternative for Low Income Households

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Abstract

Suitable housing is one of the fundamental necessities for socio-economic development. Yet a huge population in developing world is living in substandard houses. High construction costs, low income, inefficient techniques, lack of resources are few of the many causes behind it. On the other hand, the countries like United States have substantially decreased its construction costs by engineering new materials and developing efficient systems. Composite materials, factory built prefabricated houses, advanced production methods, better designs and access to abundant wood resources makes U.S. a world leader in wood construction industry.

This study attempts to link this surplus market of U.S. to deficit markets of select Latin American countries and propose an affordable housing alternative for low income households. Linking the manufacturer with the buyers overseas would need efficient logistics and marketing systems. Case studies and surveys will be conducted to assess the key aspects of housing deficits in target demographics. Production and supply capabilities of prefabricated house manufacturers in U.S. will be evaluated for adaptation to foreign markets. This research aims to find an affordable and long term alternative to reduce housing deficits. The findings will also contribute to opening of new markets for exports of prefabricated wooden buildings. The same approach can also be used to support export of other wood products from U.S

Understanding Eco-innovation in Slovenia

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Abstract

Eco-innovation is crucial to Europe's economic competitiveness; environment-friendly technologies have a positive impact on businesses and contribute to job creation. A survey of perceptions and attitudes about eco-innovation and eco-design among Slovenian enterprises was conducted. The survey included micro, small and medium enterprises, and large companies. Analysis of the survey revealed that eco-design in Slovenia is underexploited. Only approximately 50% of all respondents have established an innovative environment for sustainable development or support for eco-innovation processes. Based on the survey results it was concluded further development and promotion will require comprehensive policies at the local and national levels. Specifically, policy solutions should advocate combining eco-innovation and adopting a life-cycle design approach. These policies could result in the development of successful innovations at a breakthrough level.
Eco-innovation and eco-design present Slovenian enterprises with the opportunity to create new markets where they could dominate and prosper. Furthermore, Slovenia could become an important contributor to the European Union goal of becoming a smart, sustainable, and inclusive economy by fully satisfying the objectives of four "Europe 2020" Flagship initiatives while simultaneously contributing to reducing climate change.

Key words: Eco-design, eco-innovations, opinion, market potential, analysis, Slovenia

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Three Grades of Liquid Urea-formaldehyde (UF) Resins with Different Formaldehyde Emission Levels such as Super EO (SEO)

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Abstract

Three grades of liquid urea-formaldehyde (UF) resins with different formaldehyde emission levels such as super E0 (SE0), E0 and E1 were modified by adding different amounts of microfibrillated cellulose (MFC) that had been isolated by mechanical disintegration of pulp fibers. Thermal properties of these UF resins were investigated to understand thermal curing and degradation behaviors of the modified UF resins, using differential scanning calorimetry (DSC) and thermogravimetry analysis (TGA). The DSC thermograms showed an exothermic curing reaction, and the curing peak temperature of modified UF resins heavily depended on the emission resin grade with an increasing order from E1, E0 to SE0. The addition of MFC into the UF resins gradually increased curing peak temperature suggesting a decrease in the resin reactivity. TGA results showed three main thermal degradation temperatures for the modified UF resins except the SE0 UF resin, which had four degradation temperatures.

Keywords**:** microfibrillated cellulose; thermal stability; urea-formaldehyde; formaldehyde emission grade

Introduction

Microfibrillated cellulose (MFC) is described as a long and flexible cellulosic nano-material and is obtained from cellulose fiber by mechanical disintegration. MFC possesses several interesting properties, such as a highly expanded surface area and very high aspect ratios of the fibrillated fibres (Andresen et al. 2006). The MFC could be as small as 3-10 nm in thickness with typically a broad range of 20-40 nm, since it consists of aggregates of cellulose foods, paints, cosmetics and pharmaceutical products (Turbak et al. 1983, Chauhan and Chakrabarti 2012).

Urea-formaldehyde (UF) resin is dominant in resin consumption in the wood-based composite industry. A major drawback of UF resin is brittleness, or a tendency of developing microcracks, which limits mechanical performance of UF-bonds [4,5]. Previous studies revealed that the bonding performance of wood composites bonded with UF or phenol-formaldehyde (PF) resin could be improved by the incorporation of the MFC into the UF resin (Stoeckel et al. 2013, Veigel et al. 2012, Kwon et al. 2015). For example, Veigel et al. (2012) prepared particleboards bonded with UF resins containing 1 wt% CNF, and reported a reduced thickness swelling and better internal bond and bending strength than the counterpart produced with pure UF resins. In other study, the tensile shear strength of the single lap-joint wood specimens increased by 5.7% when 3 wt% of the MFC was incorporated into the UF resin (Kwon et al. 2015). However, a further increment in the MFC content up to 5 wt% decreased the tensile shear strength of the specimens (14.3% of control specimen). In the same study, it was concluded that higher bond strength for the UF resins with 3 wt% the MFC could be explained by the MFC's reinforcemen (Veigel et al. 2012) in UF resins.

One of the most important variables affecting the properties of thermosetting UF resins is the degree of cure. Thermosets are crosslinked through the curing process resulting in significant changes in the mechanical and physical properties. Various methods are available for the determination of the degree of cure, including spectroscopic, chromatographic techniques and thermal analysis. Thermal analysis including differential scanning calorimeter (DSC) and thermogravimetric analysis (TGA) serves as important analytical tools in understanding the structure-property relationships and thermal stability of resins and composite materials (Nakagaito and Yano 2008, Park and Kadla 2012)

Although the bonding performance and curing properties of the *aminoplastic* resins such as UF and PF have been investigated in several studies (Stoeckel et al. 2013, Veigel et al. 2012, Kwon et al. 2015), there is no extensive information on the thermal analysis of different formaldehyde/urea ratio UF resins modified with the MFC based on the literature search. The objective of this study was to investigate the effect of MFC loading on the thermal stability of three formaldehyde emission grades of UF resin such as super E0, E0, and E1 grade UF resins using DSC and TGA tests.

Materials & Methods

Materials

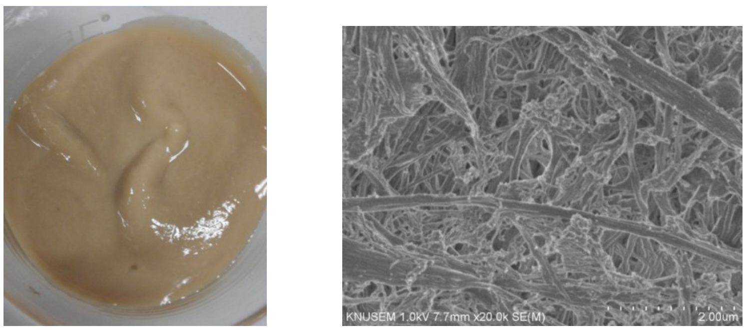
Three different formaldehyde emission grades of commercial liquid UF resins such as E1, E0, and Super E0 (SE0) classified according to a particleboard standard (KS F 3104) were supplied from an adhesive manufacturer (*Hansol HomeDeco* Co. Ltd., Jeonju, S. Korea). The specifications of these three grades of the UF resins are presented in Table 1.

Table 1 Specifications of three different types of the UF resins.

UF resin grade	Non-volatile solid content (wt %)	Jel time (s, 100 °C)	Viscosity (cPs)	pH	Specific gravity	F/U ratio
E1	60.5	124	184	8.11	1.250	1.2
E0	63.3	119	160	7.87	1.255	0.9
SE0	66.3	725	104	7.7	1.252	0.7

F/U: formaldehyde/urea.

The wood flour (40 mesh, *Pinus densiflora*) was suspended in distilled water and then the concentration of suspension was adjusted to 1 wt%. The suspension was then passed through wet disk mill (*Supermasscolloider* MKCA6-2, Masko, Japan). The rotational speed of disks was set to 1.800 rpm. The reduced clearance between rotational disks was 150 µm from fiducial zero point. Operation cycles were repeated from 1 pass to 15 passes. The average size of resulting MFC was found to be 79 nm (average of 100 MFC samples). The concentration of the MFC suspension was adjusted to 5 wt%. A photograph showing the MFC (5% microfibrillated cellulose and 95% water) and the SEM image showing the microstructure of the cellulose fibril are presented in Figure 1.



(a) (b)

Figure 1. (a) photograph showing microfibrillated cellulose (5% microfibrillated cellulose and 95% water) and (b) SEM image showing the microstructure of the cellulose fibril.

Preparation of Modified UF Resins with MFC

The SE0, E0 and E1 class UF resins were modified with different amounts of 5 wt% MFC suspension. The preparation of the modified UF resins is presented in Table 2. The UF resins were mixed with different amounts of the MFC suspension using a magnetic stirrer (1000 rpm) for 3 h at room temperature to achieve a proper distribution of MFC in the UF resin.

Table 2. Mass compositions of three types of modified UF resins with MFC suspension.

MFC content (wt %)	UF resin (g)	MFC (g)	Hardener (g)
0	11.25	0	1.125
10	10.00	1.25	1
20	8.75	2.50	0.875
30	7.50	3.75	0.75
40	6.25	5.00	0.625

MFC: microfibrillated cellulose. UF: urea-formaldehyde.

To modify UF resin by adding MFC suspension, five addition levels of MFC suspension from 0, 10, 20, 30, and 40 wt% based on the total weight of UF resin and MFC suspension were added to liquid UF resins (Table 2). And then ten percent of ammonium sulfate ($(NH_4)_2SO_4$) was also added to the resin based on the total weight of the UF resins plus MFC suspension. The hardener was added into the resin mixture during the last 5 min.

Thermal Analysis of the UF Resins Modified with the MFC

Thermal behavior of the MFC-modified UF resins were studied in a pressurized differential scanning calorimetery (DSC) (Q10, TA Instruments, USA) according to ASTM D3418-08. To determine the influence of the increasing amount of the decayed wood or sound wood on the thermal properties of WPC, test sample of 4-5 mg of each type of WPC was placed in an aluminum pan and then heated from 10 to 250 °C at a heating rate of 10 ºC/min under the nitrogen flow.

Thermogravimetry analysis (TGA) of each type of WPC was carried out in an inert environment of gas nitrogen flowing 100 mL/min using a Universal V4.7A TA (USA) analyzer. The specimens having a weight between 9 mg and 10 mg were heated from 10 to 400 °C at a heating rate of 20 ºC/min. The corresponding weight loss (%) and its derivative weight loss (min/%) were recorded.

Results and Discussion

Typical DSC thermograms of the pure UF resins are presented in Figure 2. As expected, the pure and modified UF resins showed an exothermic curing reaction. This was good consistent with the literature. In a previous study, Liu and Laborie (2010) reported that in presence of nanocrystalline cellulose, the total heat of reaction underlying the cure exotherm increased significantly The curing peak temperature as an indicator of the UF resin reactivity ranged from 94.4 °C to 97.4 °C for the E1 resin, while those of the E0 resin ranged from 95.1 °C to 101 °C. And those of the SE0 resin ranged from 102.5 °C to 109.5 °C. The formaldehyde emission grade strongly affected the curing peak temperature of the UF resins with an ascending order of the E1, E0 and SE0. This result shows that the SE0 grade UF resin is the lowest reactivity followed by the E0 and then E1 grade resin. As the MFC loading increases, the curing peak temperature gradually increased for all three grades of UF resins, suggesting a decrease in the resin reactivity. This could be due to the added MFC component that is not involved in the curing reaction of UF resins. And the occurrence of broad endothermic peaks of is believed to be responsible for thermal degradation of MFC and some of UF resin components. The peak temperature was quite reproducible.

The Tp3 values of the UF resins showed a similar trend to the Tp2 values. The Tp3 values of the E0 grade pure or MFC modified UF resins slightly higher than those of the E1 grade UF resins. The Tp3 of the E1 and E0 grade resins decreased with increasing MFC content while the Tp3 of the SE0 grade resin increased. The Tp3 values of the SE0 grade UF resins significantly lower than those of the E1 and E0 grade resins (Table 3). After reaching a maximum, the Tp3 of the SE0 grade UF resin gradually decreased as the MFC content increased. The SE0 UF resin showed another thermal degradation temperature at 180 °C. It did not change the thermal degradation temperature much as the MFC content increased. It is not clear what component is responsible for this degradation temperature, which requires further study on the SE0 resin.

Table 3. TGA and DSC peak temperatures, and weight loss of pure and MFC modified UF resins.

MFC (wt%)	TGA peak temperatures (°C)									
	E1 grade UF resin			E0 grade UF resin			SE0 grade UF resin			
	TP1	TP2	TP3	TP1	TP2	TP3	TP1	TP2	TP3	TP4
0	61.9	222.7	269.0	62.0	234.2	272.2	57.6	179.1	237.6	273.2
10	63.6	222.6	268.4	59.6	232.0	267.6	61.2	182.7	238.8	271.9
20	66.4	223.4	264.7	65.9	232.9	264.6	62.6	179.1	239.4	269.7
30	68.2	221.4	260.2	62.7	231.7	262.9	63.8	183.2	238.3	269.2
40	69.2	220.2	260.2	67.5	229.3	263.1	64.2	181.3	237.6	265.5

MFC: microfibrillated cellulose. UF: urea-formaldehyde.. TGA: Thermogravimetry analysis.

MFC (wt%)	DSC peak Temperatures (°C)			Weight loss (%) (max 396 (°C)		
	E1	E0	SE0	E1	E0	SE0
0	94.4	95.2	102.6	86.1	86.9	85.3
10	94.5	94.9	103.4	87.3	87.7	84.1
20	96.2	95.6	103.5	87.9	88.2	89.4
30	96.4	96.3	105.2	91.6	89.4	85.0
40	97.5	101.0	109.1	89.5	91.5	85.5

DSC: differential scanning calorimeter

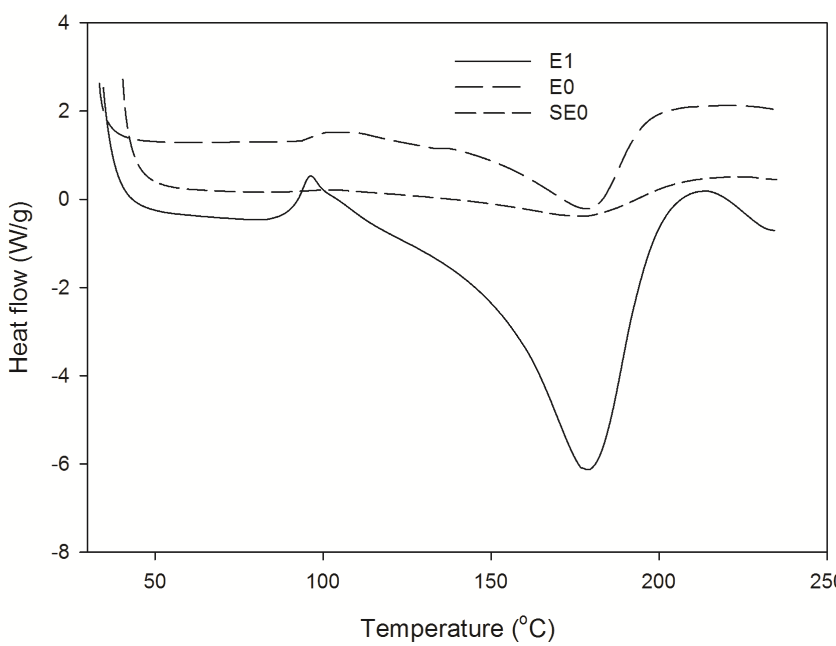


Figure 2. Typical DSC thermograms of pure UF resins modified by the addition of

The modified UF resins displayed three main thermal degradation temperatures at around 66 °C, 223 °C, and 265 °C, which were believed to be responsible for the water evaporation, the degradation of cellulose, and cured UF resin, respectively. However, the SE0 UF resin has an additional degradation temperature at around 190 °C, leading to four degradation temperatures. For all three grades of UF resins, the Tp1 gradually increased with an increase in the MFC content, indicating that the Tp1 was attributed to the evaporation of free water in the MFCs and UF resin in the first stage of the degradation. A similar result was reported in previous studies (Youssef et al. 2015, Ching et al. 2015). However, Tp2 at around 230 °C did not change with an increase in the MFC content. Due to the low decomposition temperature of hemicellulose, lignin and pectin, the Tp2 was related to the thermal decomposition of the MFC. Previous studies reported that the decomposition temperature of the MFC started at around 220 °C (Quiévy et al. 2010, Nguyen et al. 2013). Below 220 °C the observed endothermic peaks for all the samples correspond to physical loss of water while above 220 °C several phenomena like dehydration, volatilization of tars and charring can occur (Scheirs et al. 2001).

The Tp2 values of the E0 and E1 grade UF resins decreased as the MFC content increased, indicating that this temperature was related to the degradation of the cured UF resin at around 230 °C. However, the Tp3 of the SE0 resin slightly increased with increasing MFC content up to 30 wt%. Further increment in the MFC content decreased the Tp3 of the SE0, but it was higher than that of the pure SE0 resin. The DSC results showed that the thermal stability of the SE0 slightly increased with the MFC up to about 30 wt%. However, this was not observed for the modified E1 and E0 grade resins because their Tp2 and Tp3 slightly decreased with increasing MFC content.

The results obtained from the TGA thermograms showed that the E1 (222.7 °C) and E0 (234.2 °C) grade pure UF resins had the highest initial decomposition temperatures (Tp2). These results revealed that the best overall thermal stability was observed in the pure and the MFC modified E1 grade UF resins, followed by the E0 and super E0 grade UF resins (Table 3). The addition of the MFC into the E1 and E0 grade UF resins decreased the overall yield of the samples, but this was not observed for the SE0 grade UF resin. In general, the weight losses of the pure and modified E1 and E0 grade UF resins were similar each other, and they were higher than the weight loss of SE0 grade UF resin, except for the 20 wt% MFC loading level of SE0 grade UF resin. Moreover, when comparing the solid residue of the three grade UF resins, all the pure UF resins had greater solid residue/char content as compared to the UF resins with the MFC. This shows that the thermal behavior of all the pure UF resins was better than that of the MFC filled UF resins. Although the weight loss of the pure UF resins was lower than that of the UF resins with the MFC, the addition of cellulose only decreased the overall residue. This result showed that the MFC incorporation into UF resins resulted in only minor losses in the final thermal degradation. This can be explained by the fact that the charred layer acts as insulation and thus a physical barrier to heat transfer (Atta-Obeng 2011, Liu and Laborie 2010).

Summary and Conclusions

This study investigated the influence of reinforcing effect of MFC to thermal properties of three formaldedyhe emission grades of UF resins. The results showed that the incorporation of the MFC addition into the UF resins affected the thermal curing and degradation behavior. The DSC thermograms showed an exothermic curing reaction, and the curing peak order from E1, E0 to SE0. The addition of MFC into the UF resins gradually increased the curing peak temperature suggesting a reduction of the resin reactivity. The incorporation of the MFC into the E1 and E0 grade UF resins decreased thermal degradation peak temperatures, in particularly Tp2 and Tp3 of these resins, which meant a lower thermal stability of the modified resins than the counterpart. However, thermal stability of the SE0 grade UF resin slightly improved because Tp2 and Tp3 increased. The minimum weight loss was observed in the MFC modified SE0 UF resin, followed by E0 and E1 grade UF resins. Based on the findings obtained from the present study, it can be said that the enhancement in the thermal stability of SE0 grade UF resin facilitates the use of the MFC for use in the SE0 grade resin.

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Multi-scale Investigation of Adhesive Bond Durability

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Abstract

Moisture durability is essential for wood composite products, especially those used in building construction, where products are prone to weathering. The main focus of this research is to determine if adhesive penetration into the cell wall has a positive influence on bond durability. This study uses bonded Douglas-fir test specimens varying in bonded surface cell type (earlywood vs. latewood), bonded surface orientation (longitudinal vs. tangential), and adhesive type (low and high molecular weight phenol-formaldehyde, and a polymeric diphenylmethane diiscoyanate). Half of each type of test specimen undergoes accelerated weathering and the rest remain dry. All samples are mechanically tested in lap shear. The stress and strain around the bondline are measured using Digital Image Correlation (DIC). Smaller samples (2mmx2mmx10mm) are cut from the previously tested samples and scanned at the Advanced Photon Source (APS) using micro X-ray Computed Tomography (XCT). Samples are then sectioned down to a 50 micron by 50 micron area where we identify adhesive penetration into the cell wall from the micro-XCT data. These samples are scanned a second time on a higher resolution beamline at the APS. This technique gives high resolution (1.3µm3/voxel and better), 3D images where cell wall penetration can be analyzed at the nanometer scale. The mechanical test results, DIC results, and XCT images will be compared and used to quantitatively measure effects of moisture on the bondline.

Factors Contributing to Business Success of Forest Products Industry in Coastal Communities Affected by Climate Change

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Abstract

Coastal businesses and industries in North Carolina are affected by gradual as well as extreme weather conditions due to climate change more now than they have ever been. This paper includes results from case studies of a small sample of forest products business owners (timber harvesters, timber buyers, saw-timber and pulp and paper mills) and related trades to illustrate the strategies business owners within the forest products industry and other secondary markets in a key region have taken to mitigate climate change impacts. Additionally, this paper discusses the perceived resource (e.g., species transition to more salt tolerant species) and market issues (e.g., demand for existing products) that are likely to impact the future of these communities in the face of land loss and land use change as a result of sea level rise in these areas. These results are based on in-person interviews with the business owners in five counties of the NC coast in fall 2015 using unstructured questionnaire.

Nondestructive Assessment of *Eucalyptus grandis* vs *Eucalyptus urophylla*[1]

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Abstract

This study investigated the use of stress wave and ultrasound methods to evaluate the acoustic and mechanical properties of seven clones of 13-year-old *Eucalyptus*. A total of twenty-one 5.0 by 5.0 by 76.0-cm samples, three from each clone, were conditioned to 12% equilibrium moisture content. All samples were first nondestructively tested using a Fakopp and Sylvatest Duo device to obtain basic acoustic properties in longitudinal, radial and tangential directions. Dynamic modulus of elasticity (MOE_d) of each sample was calculated based on the fundamental wave equation. Static bending modulus of elasticity (MOE_e) and hardness were subsequently evaluated according to the ASTM D143 standard. The results showed good correlations between the properties determined by nondestructive techniques, and the MOE_e (r^2=0.83 with stress wave, r^2=0.83 with ultrasound). No correlations were found for hardness (r^2=0.07 stress waves; r^2=0.09 for ultrasound). This study indicates the nondestructive techniques can potentially be used to evaluate *Eucalyptus* wood quality

Key words: wave velocity, modulus of elasticity, hardness Janka

Introduction

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Eucalyptus spp. is commonly used for reforestation in Brazil to meet the demands of various forest-based industries and the consuming public. The majority of this wood is used for pulp and paper, and charcoal. Members of this genus are popular because of their fast growth (Bisola and Deamrco, 2011).

Nondestructive evaluation is a common procedure in wood industry for evaluating the fundamental properties of wood and wood products. Ultrasonic and stress wave techniques have become widely used to assess the strength properties of living trees, logs, sawn timbers, and wood-based materials because of its rapid, portable, cost-effective, and easily used performance (Ross, 2015).

Several factors influence the propagation of ultrasonic waves in wood. Foremost among these are the physical properties of the substrate, anatomical characteristics of the species, moisture content, the environmental conditions (e.g. temperature and humidity) and procedure used for taking measures (Bucur and Böhnke, 1994).

The ultrasound method can detect defects in wood, such as knots, cross grain, bark pockets, insect holes, splits, decay, and reaction wood. Detection of defects in wood by nondestructive ultrasonic methods have been investigated by many researchers with a variety of ultrasonic parameters (Ross et al., 1992).

The objective of this study was to evaluate the accuracy and reliability of stress wave and ultrasound methods for predicting modulus of elasticity (MOE) and Janka hardness of *Eucalyptus grandis* x *Eucalyptus urophylla*.

Materials & Methods

The specimens used in this study were 13-year-old trees from seven clones of *Eucalyptus grandis* x *Eucalyptus urophylla* planted in Alcobaça, Brazil. Three samples from each hybrid were cut with dimensions 50 x 50 x 760 mm for static bending test according to ASTM D143 (2006).

Stress wave and ultrasound measurements were conducted on each wood specimen to obtain the stress wave velocity. A stress wave was initiated by a hammer impact at one end of the specimen. To predict the MOE by longitudinal stress wave used one-dimensional wave equation:

$$MOEd = C^2 \cdot \rho \tag{1}$$

where MOE_d = dynamic MOE (MPa); C = wave velocity (m/s); ρ = density (kg/m^3).

Following stress wave and ultrasound measurements, all specimens were mechanically tested in bending to obtain the modulus of elasticity (MOE_e). The static bending tests were conducted on each specimen using center-point loading according to ASTM standard D-143.

The dimension (cross section size and length) and mass of each specimen was measured at each moisture condition during the experimental process and density was calculated. After ultrasound, stress wave, and static bending tests were completed, 50 x 50 x 150-mm oriented Janka hardness and moisture samples was cut from each specimen remnant, according to ASTM D143 (2006). Moisture content of the specimen was determined using the oven-dry method (ASTM D 442-92). SAS version 9.4 was used to perform the statistical analysis. Means were separated using Tukey's test (α = 0.05) for the sources of variation detected as significant by an F test.

Results and Discussion

Average and standard deviation for specific gravity, ultrasound velocity in longitudinal, tangential and radial directions, and stress wave velocity in longitudinal direction obtained from 13-year-old clones of *Eucalyptus grandis* x *Eucalyptus urophylla* are summarized in Table 1.

Table 1. Average values and standard deviation of ultrasound and stress wave velocities obtained from clones of *Eucalyptus grandis* x *Eucalyptus urophylla*

Clone	Density	Velocity (m/s)			
		Sylvatest Duo			Fakkop
	(kg/m^3)	Radial	Tangential	Longitudinal	Longitudinal
No.1	737.4 (15.4)[2]	1831.67 A[1] (81.67)	1273.19 A (101.89)	5757.58 B (0.01)	5561.24 AB (46.76)
No. 2	664.0 (20.22)	1681.16 AB (72.90)	1370.16 A (227.25)	6015.91 A (27.42)	5787.78 A (92.37)
No. 3	745.8 (11.17)	1705.56 AB (50.55)	1473.56 A (81.69)	5602.39 B (59.97)	5390.25 BC (38.23)
No. 4	684.4 (8.61)	1760.18 AB (79.99)	1485.58 A (106.81)	5549.25 BC (121.68)	5340.69 BC (94.12)
No. 5	710.0 (12.46)	1876.35 A (61.08)	1465.57 A (99.53)	5322.35 C (108.84)	5125.85 C (132.64)
No. 6	585.8 (9.42)	1546.50 B (15.94)	1256.58 A (185.81)	5678.72 B (12.26)	5494.04 AB (22.88)
No. 7	642.8 (25.80)	1564.71 B (72.85)	1375.41 A (83.34)	5693.53 B (74.43)	5548.04 AB (70.66)

[1] Means with the same letter are not significantly different.
[2] Standard deviation

The density values for Eucalyptus ranged from 585 to 737 kg/m^3. The ultrasound radial velocity ranged from 1546 to 1876 m/s. In tangential direction the velocities ranged from 1273 to 1485 m/s. The average for stress wave longitudinal velocity was 5693 m/s, and for ultrasound longitudinal velocity was 5548 m/s.

For tangential velocities, there was no significant difference between clones (Tukey $p<0.05$). In all other directions there was a significant difference between clones for stress wave and ultrasound velocities. Clone 2 showed the highest averages for longitudinal velocity in both devices. Clone 5 had the lowest average. Both acoustic-based techniques seem to have good potential to be used to segregate Eucalyptus wood by stiffness.

Average values and coefficient of variation of stress wave, ultrasound, and static bending MOE from clones of *Eucalyptus grandis* x *Eucalyptus urophylla* are shown in Table 2.

Table 2. Average values and coefficient of variation of stress wave, ultrasound, and static bending MOE from clones of *Eucalyptus grandis* x *Eucalyptus urophylla*

Clone	MOE (MPa)			Janka hardness (MPa)
	Stress wave	Ultrasound	Static bending	
No.1	22746 (1.69)[1]	24570 (1.81)	14163 (0.64)	52.36 (6.46)
No. 2	22196 (0.57)	24574 (3.62)	13919 (3.33)	39.47 (9.59)
No. 3	21610 (1.13)	23636 (1.56)	13975 (0.14)	51.65 (11.61)
No. 4	19450 (37.5)	21314 (5.00)	12395 (8.24)	45.65 (9.56)
No. 5	18635 (7.33)	20513 (6.21)	11745 (3.05)	45.28 (5.50)
No. 6	17612 (1.87)	19294 (0.47)	11700 (2.23)	30.36 (10.09)
No. 7	19760 (2.58)	21905 (5.45)	12567 (2.79)	37.39 (7.41)
Average	20287	22258	12924	43.17

[1] Standard deviation (%).

The stiffens from static modulus of elasticity (MOE_e) of specimens ranged from 11700 to 24574 MPa with a mean value of 12924 MPa for *E. grandis* x *E. urophylla*. The relationship of stress wave and ultrasound dynamic modulus of elasticity (MOE_d) to MOE_e for Eucalyptus wood is illustrated in Figure 1.

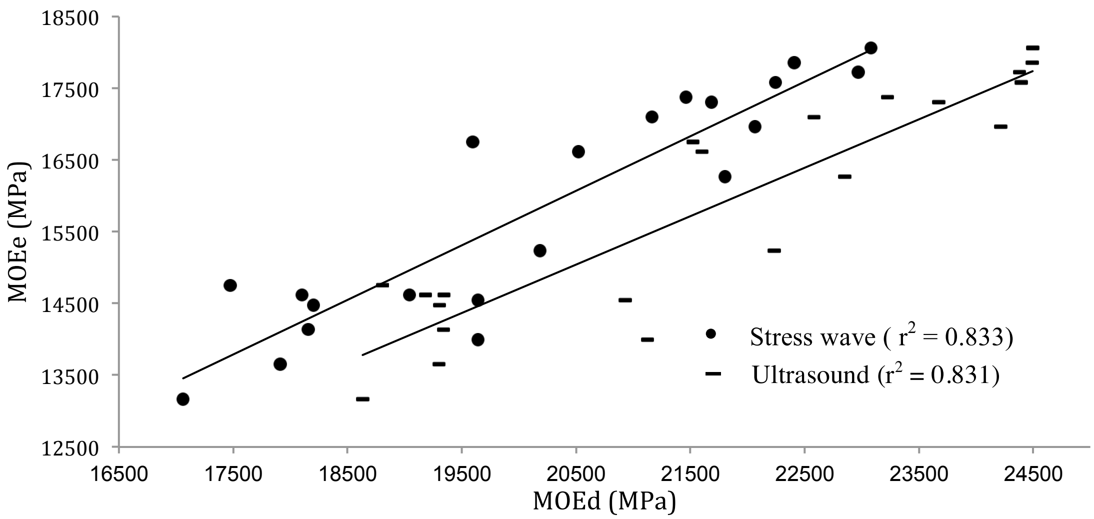

Figure 1. Relationship between dynamic modulus of elasticity (MOE_d) and static modulus of elasticity (MOE_e) for Eucalyptus wood

In general, the dynamic MOE of values obtained by stress wave and ultrasound techniques were very closely correlated with the static MOE for all clones. The correlation coefficients were 0.831 (stress wave MOE_d vs. MOE_e) and 0.833 (ultrasound MOE_d vs. MOE_e) for samples from seven clones of *E. grandis* x *E. urophylla*.

Several international studies showed significant correlations between MOE_d and MOE_e with r^2 ranging from 0.57 to 0.89 (Oliveira et al., 2005). Targa et al. (2005) found strong correlations between vibration MOE and static MOE. For *Eucalyptus grandis* and *Eucalyptus citriodora* the correlation coefficients were 0.87 and for *Eucalyptus saligna* the correlation was 0.76. For *Araucaria angustifolia* a native softwood from Brazil, Stangerlin et al. (2008) found r^2=0.91 for juvenile wood and r^2=0.95 for adult wood.

Miná et al. (2004) found r^2=0.58 for the relationship between MOE_d and MOE_e, studying ultrasound waves in *Eucalyptus citriodora* poles. Horáček, et al (2012) found r^2=0.52 studying the relationship between stress wave dynamic MOE and static MOE for *Pinus sylvestris* L.

Janka hardness of the specimens ranged from 28.5 and 57.5 MPa with an average of 43.2 MPa. Clones 1 and 3 showed moderate/elevated hardness values, indicating higher difficulty of machining but greater ability to withstand loading. As such, these clones may be useful for manufacturing flooring. Clones 2, 4, and 5 had moderate hardness values. Clone 6 had the lowest hardness values, indicating better of machining potential, but also lower potential for floorshing. The lack of a relationship of stress wave and ultrasound longitudinal velocity to Janka hardness for Eucalyptus wood is shown in Figure 2.

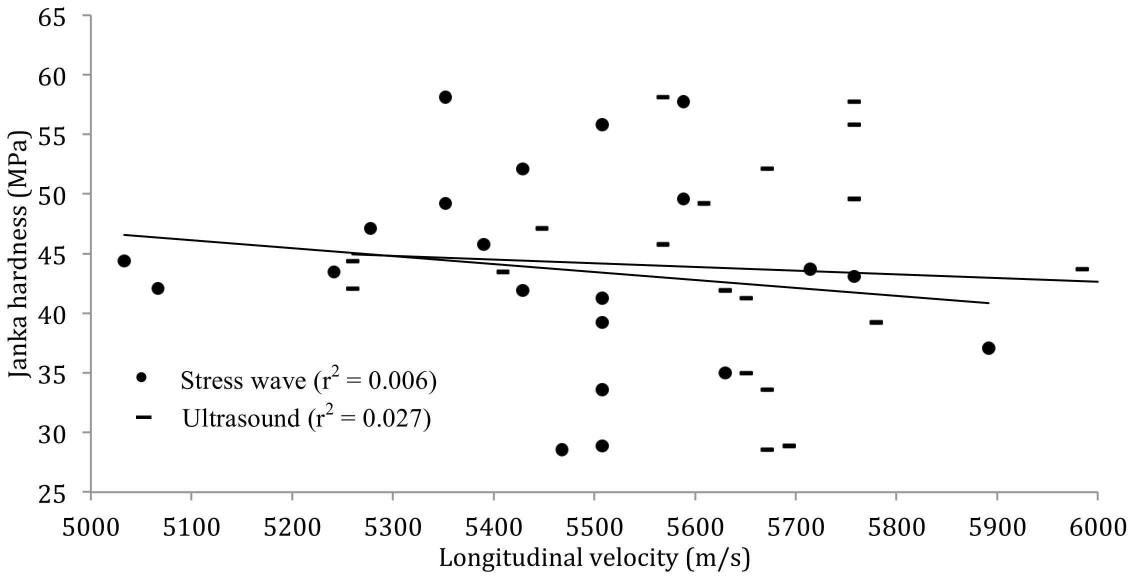

Figure 2. Relationship between longitudinal velocity and Janka hardness for *Eucalyptus* wood

There appeared to be very little correlation between stress wave and ultrasound velocities and Janka hardness. The non-destructive evaluation and Janka hardness are both directly related to wood density, which would suggest that there should be some correlation. However, Janka hardness is a very localized property or measure whereas stress wave and ultrasound techniques because wave transmission are based on global properties. This difference between local versus global properties likely explains much of the weak correlation.

Summary and Conclusions

- There is no significant difference between stress wave and ultrasound longitudinal velocities.
- It is necessary to understand what characteristics of wood are making the wide range of velocities.
- Acoustic-based techniques have good potential to be used to segregate different clones using stress wave and ultrasound techniques.
- Radial velocity was higher than tangential velocity for all seven clones as expected.
- MOE_e can be successfully evaluated by longitudinal stress wave and ultrasound. There is no significant difference between both techniques obtaining velocities in longitudinal direction.
- It was not possible to evaluate Janka hardness using stress wave and ultrasound techniques as their respective correlations were weak.

Acknowledgements

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Sustainability Factors Leading to Advanced Biofuel Cellulosic Project Success

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Abstract

This research aids in the development of a framework of knowledge acquisition determining a progression of causal factors impeding the success of Advanced Biofuel projects. To address this issue; a survey and interviews were conducted among Biofuel Academia, Advanced Biofuel projects, parts of US Government (DOE, EPA, EIA, USDA), and members of the Bioeconomy, with a 58% response rate to provide specific incite on an initial set of Advanced Biofuel sustainability factors, and previously unknown barriers impeding marketability and distribution of co-products and byproducts. Addressing this issue yielded a progression of 41 main barrier categories specific to different years, status, types, and technology of projects since the 2005 EPAct. The surveyed individuals have indicated that politics is the main barrier. A notable secondary finding, all remaining factors from both: government agencies DOE, USDA, EPA, EIA, and the Advanced Biofuel industry, share responsibility for its rise and fall as the Bioeconomy surfaces with its winners, after 10 years. These results will more successfully direct projects entering the Advanced Biofuel pathway. During the timeline of this thesis 18 of the Advanced Biofuel projects have been shut-down or cancelled, and some are privately for sale

Characterization and Enzymatic Hydrolysis of Genetically Modified Pinus Taeda with Decreased Lignin Content and Incorporated Syringyl Lignin

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Abstract

The aim of this research is to investigate the cell-wall modification and recalcitrance of genetically modified loblolly pine with reduced lignin content and incorporated syringyl lignin. Pyrolysis molecular beam mass spectroscopy (Py-MBMS) was utilized to measure lignin content in genetically modified and control pine samples. Sugar release was measured after pretreatment (none, hot water, and dilute acid) followed by enzymatic hydrolysis. Results demonstrated that decreased lignin resulted in significantly higher glucose and xylose yields after enzymatic hydrolysis compared to the control pine, with greater beneficial effects observed under lower severity pretreatment conditions. In addition, a good linear correlation was found between lignin content and glucose release indicating significantly reduced recalcitrance in low lignin pine samples. In a genetically modified construct for syringyl lignin production, Py-MBMS, and thioacidolysis were used to measure significant accumulation of syringyl (S) lignin monomers in wood. The incorporation of S lignin units in coniferous wood is unprecedented, and represents an exciting breakthrough in biomass research. These results for the characterization and greater hydrolysis yield of genetically modified P. taeda with reduced lignin content and incorporation of S lignin represent the potential of softwood to be a viable bioenergy/biochemical feedstock and opens up exciting new avenue of research.

Session

Sustainable Wood Construction

Moderators:
Sudipta Dasmohapatra, North Carolina State University, USA
Carlito Calil, Universidade de São Paulo, Brasil

Wood Waste Generated by the Wooden Housing Manufacturers in the Brazilian State of São Paulo

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Abstract

The inconvenience with the generation of wood waste has become an increasing problem among companies of the forestry sector. For that reason, the study aimed to obtain and disseminate the data on the generation and disposal of timber waste of the wooden-housing manufacturers, located in São Paulo State, aiming to assist them on the potential for reuse of their wood waste. For this evaluation, it was applied a questionnaire directed to the owners or their representatives, in order to obtain the volume, characteristics and final destination of the wood waste produced exclusively for a single-story housing unit of 100 m^2. It was discovered that most of these house manufacturers have no control or quantification of their residues, and many even have an accurate separation process aiming their reuse. Then, a real opportunity of processing of these wooden wastes in manufactured goods is lost. Thereat, it was discussed the current situation of these timber companies, indicating some ideas for improving their wood waste management. A simple selective collection realized in these industries and on respective building sites could help to mitigate this evident environmental liability. This collection system could be based on the separation of waste into colored dumpsters or containers for three destinations: solid wood, treated wood and wood-based panels. Public incentives will help this sector to achieve its sustainable development with cleaner productions.

Key words: Environmental liability, wooden houses, construction, proposals

Introduction

Arruda Filho et al. (2012) point out that the reuse or recovery of waste helps in the health issues and in the preservation of natural reserves of raw materials, as well as it eliminates storage costs, allowing savings for the companies.

The Brazilian law 12.305/2010 indicates that solid waste is essentially a discarded object, substance or material resulting of the society activities, in solid or semi-solid conditions, with characteristics which impede its elimination in public sewers or watercourses (Brasil 2010).

The most usual way to eliminate lignocellulosic waste is its use for energy generation, as describe Gonçalves et al. (2009), which evaluated the briquettes production mixing urban solid waste and wood waste of *Eucalyptus grandis*, as well as Souza et al. (2010), which studied the production of biogas by the biodegradation of lignocellulosic waste from the banana culture.

In addition to energy purposes, the lignocellulosic wastes have extensive reusability, both in the form of new composites and as basic raw material for high value added products. In the first case, some possibilities of production of agro-industrial waste-based boards result of the use of: maize (Sampathrajan et al. 1991), sugarcane bagasses (Okino et al. 1997) or peanuts and rice straws (Caraschi et al. 2009). Concurrently, cement composites may be produced, in a practicable way, by the use of wooden particles (Lima and Iwakiri 2012), or with treated wood (Wolfe and Gjinolli 1999). Furthermore, wood particles can be applied in the wood-plastic composites (Yamaji and Bonduelle 2004; Cui et al. 2008). The second option primarily indicates the possibility of manufacture of finished products by the waste recovery such as: scraps and trims of lumber and wooden boards for musical instruments (Pereira et al. 2011) or sawmill waste for small wooden objects (Lopes 2006; Vieira et al. 2010). It also can be added the discarded pieces of treated wood with large dimensions, which are commonly reused for the manufacture of rustic furniture or of beams and posts for construction. These large pieces are exemplified by the fence posts, railway sleepers (ties), structural beams and posts from demolitions and electric poles.

The macro industrial sector of forestry-timber covers all stages in this area, which starts at the forest level with the planting, management and harvesting activities, transportation and movement of logs, ending with the wood processing in forest-timber products, which use solid or composite wood; this last is obtained by the reduction of wood logs in thick or fine particulates, fibers or chips. The main products resulting from this processing are: lumber, furniture, wooden houses, musical instruments, toys, household items, beams and boards (MDF, OSB, LVL, PSL, glulam, plywood, etc.), cellulose and paper, and different ones. Of all the forest-timber industrial processes, the construction is among the leaders in waste generation. The main examples of the construction activities are: logging stages; first log sawing in wooden blocks (post, beams, etc.); manufacture of construction parts and elements; manufacture of disposable devices as forms for concrete, scaffolds and boxes; surface and dimensional adjustments, as well as grooving and drilling stages for lumber preparation realized on construction site.

Gonçalves and Bartholomeu (2000) emphasize that, in Brazil, technologically backward of the wood extraction in forest is similar to the observed in the wood processing and its mechanical classification.

In the case of sawmills focused on construction parts, large quantities of residual raw materials are lost due to obsolete machinery. Although this material presents potential uses, the Brazilian reality is somewhat complex and stagnant, whereas the timber and construction sectors necessitate reliable data for their self-evaluations.

Thus, this paper aims to present and discuss data on waste generation of wooden housing manufacturers located in the Brazilian state of São Paulo, aiming to help them with ideas proposals on the potential for waste reuse.

Materials & Methods

The materials analyzed in this research refer to the Brazilian manufacturers of wooden houses located in the São Paulo state.

In relation to the methodology, it was organized in three stages:

a) Quantification of the companies located in the São Paulo state, which produce exclusively wooden housing;
b) Identification and quantification of the wooden waste generated, which were realized by an evaluation stage in the analyzed companies;
c) Analysis of the obtained data, discussion and proposal of some ideas for the forest-timber sector.

During the evaluation stage a data collection was directly realized with the owners or business partners of these companies. And its main focus was to verify the aspects of:

a) Wooden waste volume by company (in cubic meters), from the production of a single-story house unit of 100 m^2 of building area (SSH);
b) Types and characteristics of wood waste generated by the production of this SSH;
c) Final destination of these wood wastes produced in the manufacture of this SSH.

After the realization of this evaluation, the data were organized in tables and graphs to support the discussions on the generation of wooden waste in the wooden housing sector of the São Paulo state. Because it is a simple random sample survey, the margin of error– realized between the total population and the number of evaluated timber companies – was calculated to check the maximum tolerable range for surveys. For that reason, it was unnecessary the use of experimental design. Finally, solutions and ideas were indicated to diagnose and minimize the environmental liabilities caused by these companies in the stages of timber processing, *i.e.*, after the logging stages as well as after the production of wood composites (boards and structural composite lumber). No company has own forests to supply itself, *i.e.*, all the companies acquire wooden logs directly from forest suppliers. The quantification of wood waste generated in the logging stages (planting, management, harvesting and transportation) was not considered.

However, these preliminary stages unvalued in this paper are frequently discussed in the literature about forest waste (Couto et al. 1984; Baggio and Carpanezzi 1995; Valério et al. 2007; Bellote et al. 2008; Bortolin et al. 2012; Kretschmer et al. 2013; Ribeiro 2013; among other authors).

Results and Discussion

Response

The investigation lead-off summarized in a survey realized in specialized magazines, regional associations, industrial professional and government documents, in which it was possible to determine, in the Brazilian state of São Paulo, a population of 36 companies with expertise in wooden housing production. Of this total, 29 manufacturers were visited in 18 cities in this aforementioned state. In other 7 companies, their respective owners did not want or could not participate of this evaluation. However, a distinct fraction of the analyzed population was achieved, within the tolerable margin of error (Table 1).

Table 1: Simple random sampling of the wooden housing manufacturers

Total Population (industry number)	Analyzed Sample (industry number)	Margin of Error (%)
36	29	8,0

Wood Waste

The types and characteristics of wood waste were classified into three classes:

a) Sawn wood: solid native or reforested wood (without the presence of chemicals);
b) Treated wood: chemically treated sawn wood (native or reforested);
c) Composites: OSB (oriented strand boards), plywood, fiber cement, glulam beams (glued laminated timber), CLT (cross laminated timber), and I-joist (web in OSB and flanges in sawn wood or plywood).

Figure 1 shows the number of companies, which generate wood waste according the class.

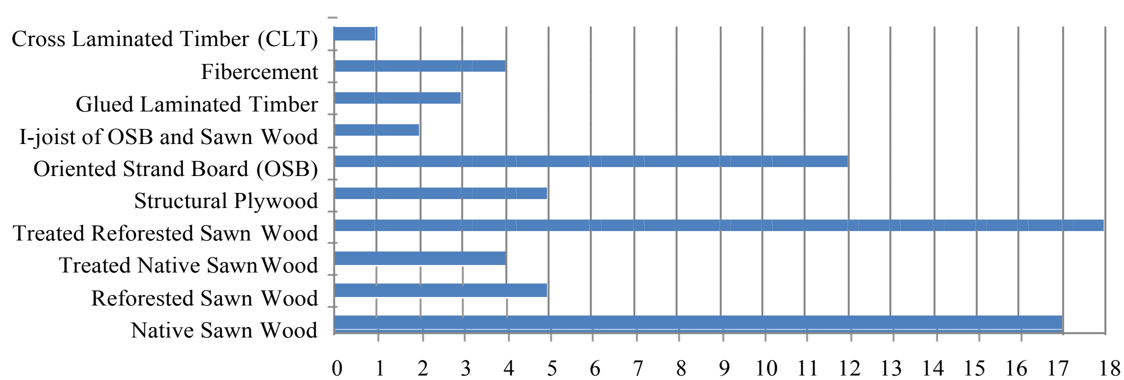

Figure 1. Classes of the wooden-based waste according to the number of companies.

The main waste consisted of the utilization of treated reforested sawn wood, native sawn wood and OSB panels. In these three types, twelve or more companies were generating sources. The generation of waste based on wood composites is increasing, whereas some companies are using CLT, glulam, I-joists and plywood in their wood houses. Moreover, four companies generate fiber cement waste, which present similar destination with other cement wastes. These evaluated companies do not quantify separately, by class or type of raw material, the waste from their manufactures, and they do not have a specification of the characteristics of this generated waste, for example, according to the shape or size: scraps, trims, dust, chips and other particulates. The amount of companies according to their waste destinations was presented in the Table 2.

Table 2: Destination of the wooden waste according to the characteristic and companies

Waste Destination	Classes of Wood Waste (number of companies)		
	Sawn Wood	Treated Wood	Composites
Reuse small pieces in products[1]	20	15	10
Dumpster for landfill site	10	12	10
Biomass for energy	5	4	3
Outdoor incineration	2	1	–
Donation for artisans[2] / companies[3]	9	7	5
Sale for other companies	11	8	5
It does not generate this waste	7	10	16

[1] reuse trims and shaving in the houses or other manufactured products of this company
[2] use in the production of small objects, decorative art and furniture
[3] use as animal fodder, fertilizer, furniture and manufactured goods

The most serious environmental problem is related to the waste destination for landfill site. Despite of this problem is widely common for construction in Brazil – especially for small producers of brick houses – this problem is also visible and similar to the wooden houses companies. This environmental liability shall be promptly interrupted by efficient inspections and severe punishments to polluting companies. Another clear trend can also be observed in the Table 2, which some companies burn their waste for energy biomass. Four companies use treated wood in the energy production, and three companies use composites for the same purpose. Particularly, it is a strong demonstration of deficiency of the public authorities to regulate the use of treated wood waste. Despite of the large amount of Brazilian laws about environmental problems and restrictions, the local government is inefficient in the elucidation of the best destination to the wood waste with the presence of preservatives (treated lumber) or adhesives (panels). Another evident problem could be related to the handling and processing of treated wood by artisans, fact which could involve health problems to the uninformed craftsmen. This problem could be elucidated by the utilization of personal protective equipment in the direct handling with treated wood. The application of this waste in gardening products and its restriction for the use in household items shall also be explained for these workers. And fortunately, the highest percentage of the companies has lower impact and efficient destinations of their wooden wastes such as reuse in other smaller house parts or other products.

It was realized an evaluation of the wood waste generation (in cubic meters), according to stages and production limitations to produce a single-story house unit of 100 m^2 (SSH).

Table 3: Waste generation by the companies according to their production stages

Estimative of wood waste by production stage for a single-story house of 100 m^2 (m^3)					
Evaluated Companies	First Cutting	Second Cutting	Plant Machining	On Site Machining	Total Estimative
01 [WFR]	–	–	–	5.00	5.00
02 [WFR]	–	–	–	5.00	5.00
03 [HCO]	–	–	4.00	–	4.00
04 [HCO]	–	–	–	5.00	5.00
05 [HCO]	–	–	4.00	–	4.00
06 [WFR]	–	–	–	0.85	0.85
07 [HCO]	–	–	–	1.00	1.00
08 [CWO]	–	–	–	0.25	0.25
09 [HCI]	3.00	1.50	0.50	–	5.00
10 [WFR]	–	–	–	1.00	1.00
11 [MOD]	–	–	0.60	–	0.60
12 [HCO]	–	–	–	3.00	3.00
13 [HCI]	10.00	3.00	1.44	–	14.44
14 [HCO]	–	–	–	0.20	0.20
15 [HCO]	–	–	–	0.50	0.50
16 [PBO]	–	–	–	0.18	0.18
17 [PBO]	–	–	–	0.75	0.75
18 [PBO]	–	–	–	2.00	2.00
19 [MOD]	–	–	0.50	–	0.50
20 [PBO]	–	–	–	4.00	4.00
21 [HCO]	–	–	5.00	5.00	10.00
22 [HCO]	–	–	0.54	–	0.54
23 [HCI]	2.00	0.25	0.50	–	2.75
24 [LHI]	–	–	2.70	–	2.70
25 [WFR]	–	–	–	2.00	2.00
26 [MOD]	–	–	2.20	–	2.20
27 [PBO]	–	–	2.50	2.50	5.00
28 [PBO]	–	–	–	5.00	5.00
29 [CLT]	–	–	10.00	0.20	10.20

[WFR] Wood frame manufacturer with on-site production
[HCO] Horizontal Clapboard house with on-site production of semi-finished parts
[HCI] Horizontal Clapboard house with complete industrial production
[CWO] Clapboard and Wainscot house with on-site production
[MOD] Modular house for building site manufacturer with complete industrial production
[PBO] Post-and-beam house with complete on-site production
[LHI] Log-home house with complete industrial production
[CLT] Modular home of CLT panel with complete industrial production

The complete lack of general control of the waste by each company resulted in a share of approximate values (Table 3). The volumes of wooden waste generated in the production of a SSH were based on the average values reported by each company. In all evaluated cases, these companies reported average values according to the volumes contained by dumpster (garbage container). The amount related to the waste estimation showed in this table corresponds to the final volume of wood waste stipulated by each company in their manufacturing stages of a SSH unit of 100 m^2 of building area. Due to the huge variation among the house techniques as well as between the possible different mechanization and management practices and production of each company, it was valued the total volume per company, instead of the total volume per technique. This option intended to highlight the amplitude between the total volumes of waste generate per SSH per company. This discrepancy is possibly summarized in the lack of standardization of production stages and the low technology for the timber housing industry.

By means of the survey of the volumes of waste generated per SSH of 100 m^2, it could be verified that the housing techniques of wood frame (WFR) and modular (MOD) are more rationalized in the raw material utilization, due to the use of small wood parts. In opposite way, the two variations of horizontal clapboards (HCO and HCI) require a large volume of raw materials, causing a substantial wood waste generation. The recent construction technique based on the modularization of cross-laminated timber (CLT) still generates a noticeable amount of waste, because of its high demand for raw materials and due to the absence of high-tech machines for the production of these prefabricated panels in Brazil. Another strongly visible situation reflects in the inequality of the waste production among the manufacturers of the same technique, which is characterized by the lack of control of the inputs processing and strongly justified by the reasons of low mechanization, lack of preventive maintenance for the machinery, low-skilled hand labor, and partial knowledge of the sawing techniques and the production of construction elements. Most of the wood waste is often discarded because of its poor management in production and on site levels, as the wastes are commonly mixed together with other wood waste, or together with non-cellulosic wastes such as plaster, cement, sand, plastic, glass, etc. The separation of waste from different origins – if it is realized on construction site – could be a simple alternative to assist in the reuse of the potential of waste from small companies. Larger companies – with production lines and sawmills – could also achieve benefits from a similar strategy of waste separation, whereas these companies have larger structures and spaces in their plants to stock, at least temporarily, waste volumes to be destined for another product and or partner. In the 36 mapped companies, it was verified that the metropolitan regions of São Paulo (capital) and Campinas showed the two major concentrations of producers of wooden houses in the state, which are among the most relevant Brazilian industrial hubs. This scenario favors partnerships to reuse, in other manufactured goods, the wood waste generated by the companies for the wooden housing sector. Through a simple symbiosis, a producer of furniture or decorative items could reuse scraps or shavings generated by a wooden housing manufacturer. On the other hand, wood particles generated by the same housing manufacturer could be applied to wood-based composite industries for boards. These partnerships contribute to mitigate the problem of the lack of planning for wood waste reuse in other durable goods. This strategy could be stimulated by public incentives as tax reductions or exemptions.

A significant problem, about the waste with presence of chemical constituents, consists of an unexplored theme by the industries of the wooden housing sector. In most chemical wastes, the uncontrolled conventional burning is entirely forbidden, due to the release of dangerous toxicities, and possibly carcinogenic, both the treated solid wood and for the wood-based boards glued with synthetic resins. In addition, the cutting operations of the treated wood pieces also constitute in a dangerous task, whereas the workers inserted in this activity can inhale dust and small particles with chemical. In this case, it is important the use of appropriate masks to reduce the direct contact during this specific operations. The reuse of wooden composites should be observed with attention, especially in the case of processes and compositions with other chemical constituents and in processes at high temperatures. In these cases, toxic substances and pollutants emissions can be released.

Summary and Conclusions

The study found that the biggest problem originated in the lack of preoccupation about the production of wood waste generated by the evaluated companies. They do not have detailed information about their wastes from their production stages, and also the exact volumes by type of waste generated. In this case, only general estimations of the average volumes generated were obtained, emphasizing the need for measuring and continuous controls by those companies. The quantification of their wood waste could be performed by precise volumetric methods, and their respective controls could be based on the best practices for industrial waste management. The problems still evidenced on account of inadequate management in each production stage, low rationalization of raw materials, low reuse of waste and the absence of a selective separation of these wood wastes. Thus, a simple selective collection of these lignocellulosic wastes performed in the companies and on the building sites would contribute in the reduction of this environmental liability. This collection system could be based on the separation of wood waste into three possible destinations: solid wood, treated wood and wood-based panels. This method could apply a similar process to the residential garbage, *i.e.*, through the utilization of different colors applied in dumpsters or containers to identify the three possible wood waste types.

Finally, a lack of an incisive public policy is observed – not only in the São Paulo state as nationwide – which could mitigate the environmental liabilities generated by this issue; in particular, the chemically modified lignocellulosic wastes from treated wood by chemical preservatives or wood-based composites (panels and beams) glued with synthetic resins.

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Comparison of Timber-House Technologies in Slovenia and in Sweden

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Abstract

Although they are few in number, most Slovenian timber buildings combine contemporary styling with energy-efficiency measures that bring them close to passive house standards. Slovenia's construction industry is widely recognized as being advanced in the field of low-energy buildings. As energy-efficient building methods gain importance, timber passive houses can play an increasingly important role in the future.

The long tradition of timber construction in Sweden is going from strength to strength thanks to the development of advanced, timber structures. Builders and designers know that timber is not only an economic building material but it also has the added bonus of being environment-friendly. The industrial manufacture of single-family housing has a long tradition in Sweden, and about 90% of all single-family houses are built with at least a frame of timber. The Swedish national building code has allowed the construction of multi-storey timber housing since the mid-1990s. Today, 15% of the newly built residential multi-storey buildings have a timber frame, and 80% of the student housing built in Stockholm uses industrialized timber construction systems. This paper give an introduction to Slovenian and Swedish timber building technologies with an emphasis on the future use of wood as a sustainable architectural construction material.

Key words: Architecture, energy-efficiency, passive housing, timber construction.

Introduction

In Slovenia, the predominant methods of timber construction include panel construction, wood-frame construction, and solid-wood construction. Primary wood products used in these methods range from solid wood to various wood-based composites. In solid-wood constructions glued-laminated timber (glulam), cross-laminated timber (CLT), laminated-veneer lumber (LVL), and laminated strand lumber (LSL) are used for walls, floors, and roofs. In wood-frame constructions, wooden wall sections are assembled from studs and crossbars of various dimensions. For the exterior and interior faces, various panel-based systems are used. Besides drywall panels and gypsum board, particleboard, cement-bonded panels, fibreboard, oriented-strand boards (OSB), and LVL are also used. Although the production of CLT panels and their use in timber construction is increasing, the use of solid wood has lost its historical dominance and has been replaced by different engineered wood products.

In Sweden, it was not possible to use timber as a frame material in the construction of houses with two or more floors until 1995. Regulations that regulated the choice of frame material excluded wood, as a result of a number of devastating fires in Swedish cities at the end of the 19^{th} century. As a consequence, no development of multi-storey timber housing took place and other materials such as steel and concrete were used. The current regulations prescribe instead a material-independent functional requirement, and the use of timber as a material in multi-storey housing has increased to approximately 15% of all newly built multi-storey houses. The development towards an industrialised construction and manufacture within the timber building sector has in recent years led to an increase in prefabricated structural components of solid wood, engineered wood products (EWP), and non-wood materials that are assembled at the construction site. In contrast to multi-storey housing, the industrial manufacture of single-family timber housing has a long tradition in Sweden. The majority of the on-site and prefabricated single-family houses built in Sweden have timber frames, but this is not the case in the rest of Europe where less than 10% of the single-family houses have a wooden framework (Dol and Haffner 2010).

Building Techniques in Slovenia and in Sweden

Several common techniques are available for the construction of buildings with supporting frameworks of wood. One way is to use structural wood members to form a frame which is covered by structural wood panels, where the foundations are generally of concrete. This building technology is often used in the construction of single-family houses but also in the construction of multi-storey buildings. Another technique uses CLT for the supporting framework, walls and joists, and the walls have to be insulated to give the building a high level of energy efficiency. The technique is well adapted to the construction of multi-storey buildings. A third technique is a system of columns and beams, where glulam is used to a large extent for the load-bearing structure. The primary criteria are load-bearing strength, rigidity, lateral stability, wind resistance etc., but all these systems satisfy as well modern criteria for fire safety, permissible sound levels and energy efficiency. Special consideration must be given to these functional criteria in the case of multi-storey buildings and well-tested technical solutions are now widely available (Fig. 1).

Figure 1: *| 1.1 House Rant, Škofja Loka, Slovenia, 2013, | 1.2 Villa Emils Backe, Smedstrop, Trosa, Sweden, 2014, | 1.3 Mölle by the sea, Mölle, Sweden, 2013*

Most Slovenian wooden-house producers offer houses with a wood-panel construction, although timber-frame constructions and CLT systems are also used. Wood-panel constructions have been present in Slovenia for more than 35 years. The beginnings of pre-fabricated construction started after World War II, when barracks were built for the people who had been left without shelter and those who had migrated from the countryside to the city. In the past 30 years, timber construction has undergone major changes, the most important changes being the transition from on-site construction to factory prefabrication, the transition from elementary measures to modular building and the development from a single-panel to a macro-panel wall prefabricated system. These changes have greatly improved the efficiency of fabricating timber constructions.

In Sweden, the dominant frame system for single-family timber houses is based on timber studs; i.e. walls that consist of vertical studs with insulation material inserted between the studs and usually faced inside with gypsum- or wood-based panel materials, and outside with some type of façade covering. The façade covering can be brick, plaster or solid timber. The level of completion in the factory varies depending on the choice of façade covering, because only timber façades can normally be prefabricated. The floor structure is prefabricated in the same way as the walls. Single-family timber housing businesses employ one of two strategies for the final stage: manufacturing plane elements in the plant and transporting them to the site for final assembly or assembling the plane elements in the factory and then shipping them as complete volumes to the final building site.

Several modern timber-house companies manufacture building elements, such as roof trusses, joist floors and wall units, themselves. In contrast, they almost always purchase the doors, windows and carpentry ready-made from external manufacturers. The method of producing a house or parts of a house in an industrial production environment is termed "prefabrication," and this is the dominant method of building single-family timber houses in Sweden. Approximately 90% of the single-family houses in Sweden are built with timber frames. A single-family timber house in Sweden usually has a floor area between 50 and 250 m^2 and is seldom more than two storeys. The volume of wood in a normal-sized Swedish single-family house with a timber frame is, depending on the size and building method, between 10 and 30 m^3.

A few manufacturers use CLT systems. During the manufacture of the unit, the shapes are trimmed, openings are left for windows, doors, etc., and the thickness is levelled if necessary. Prefabricated CLT panels are delivered directly to the construction site. The producers of houses with CLT systems do not have their origins in the tradition and company culture associated with single-family timber houses. The most appealing reason for using the CLT system is that the wall units and joist floors have a high load-bearing capacity and stiffness. Not surprisingly, their initial use in Sweden was for multi-storey buildings.

Construction on-site

The oldest method of construction is on-site building. The building materials are transported to the building site and the various elements are assembled on site and then erected. The method requires a great deal of organization and planning on the building site. Risks associated with damage to materials and prefabricated structural components, and moisture damage must be considered (Fig. 2).

Of necessity, on-site construction tends to take a long time. With the on-site building technique, wall components are generally assembled resting on joists or the ground and then erected manually. In Slovenia, a non-negligible amount of wooden houses have appeared recently, constructed on-site through smaller tradesmen (carpentry workshops). On-site construction is very rare in Sweden for single-family houses, but occurs with larger buildings where the frame is of glulam or CLT.

Figure 2: *| 2.1 Hus N, Linnaeus University, Växjö, Sweden. 2011. | 2.2 Waldorf school, Ljubljana, Slovenia, 2013, | 2.3 House S, Velike Lašče, Slovenia, 2014*

Off-site Prefabrication

In both Slovenia and Sweden, the trend is towards a higher degree of prefabrication, i.e. a greater part of the building work takes place at an industrial plant in a well-controlled environment with approved quality assurance. The actual on-site assembly of the building until the roof is laid takes only one or two days. The prefabrication can include various components such as wall and floor elements, roofs, trusses etc., but also modules, so called volumes. Both components and modules are prefabricated with insulation, installations, windows and doors (Fig. 3).

Prefabricated components of wood are relatively light in weight and can be erected to heights of several storeys using simple lifting equipment. With prefabricated wood modules, the total cost is up to 20-25% lower than to building on-site. This is partly due to a time saving of up to 80%. In Slovenia, most of the large house manufacturers offer off-site prefabrication houses - panel construction (The Section of Slovenian Manufacturers of Prefabricated Houses). In Sweden, the of-site manufacture is totally dominating for single-family houses and this method of manufacture is also becoming more and more common for multi-storey housing built with different building systems.

Figure 3: *Examples of off-site prefabrication. A building process with prefabricated component or modules is faster, less weather-sensitive and provides better control over costs*

Modular System

Working with modular systems is a huge help, since it is difficult to design traditionally and then translate the design to an industrial context. It is easier to adapt the construction and organisation of the building to the limits of the system from the beginning. For example, the modules have to be of a size that can be transported by lorry and that will fit on roads and under bridges. The modules also have thicker structural beams than normal, which can be a challenge if the building height is restricted. In addition, the system requires an early commitment in the project, with very little scope for making changes later. The advantages of industrial construction in wood are: less time on the building site, less transport, less disruption for neighbours, good cost control and no drying time compared with that for in situ concrete (Fig. 4).

Figure 4: *| 4.1 Residential apartments Skagersvägen, Stockholm, 2013, | 4.2 Multi-residence buildings, Ekorren, Skellefteå, 2009, | 4.3 Student housing, Kungshamra, Stockholm, 2002*

Multi-storey Buildings

Until recently, national building regulations in many European countries have restricted the use of timber frames for the construction of multi-storey buildings, since many countries have refrained from using flammable materials because of uncertainty about fires risks in the buildings. However, extensive research has shown that material-neutral building regulations are preferable and, for over a decade, function-based regulations have been common in many countries.

Modern building regulations have contributed to an increase in the construction of multi-storey timber buildings of up to eight storeys. The increase can be attributed to several important factors such as a lower cost of wood-building compared with construction using other materials, and advantages of using wood in industrial building, together with a growing environmental awareness, where the choice is motivated by the fact that wood is a renewable material and that its use reduces CO_2 emissions, provided that the timber is harvested in forests where sustainable forestry, with replanting and management plans, is practiced.

Of the primary criteria (load-bearing strength, rigidity, lateral stability, wind resistance etc.), the question of lateral stability is especially important because the construction is relatively light. A common practice in the case of buildings with six or seven floors is to build the ground floor in concrete and secure the timber structure to the concrete. Wind loads are transferred via joist elements and shear walls to the ground. Good stability is achieved by utilizing diaphragm action.

An important consideration when designing multi-storey buildings with a load-bearing wood frame is the transfer of sound. Multi-storey buildings made of timber can be given an outer architectural design that suits the location where the building is erected. There are different regulations regarding the permissible height of a wood building, mostly due to fire-safety reasons. Table 1 summarizes the allowable numbers of storeys in Slovenia and Sweden depending on whether or not a sprinkler system is installed.

Table 1. *Number of storeys allowed to be built in a wooden building in Slovenia and Sweden*

Building properties	**Sprinkler**	**Sweden**[1)]	**Slovenia**[2)]
Load-bearing structure	YES	″ 5	″ 5
Load-bearing structure	NO	″ 5	″ 3
Wooden façade claddings	YES	″ 5	max. 6[3)]
Wooden façade claddings	NO	≥ 1	max. 3[3)]
Wall and ceiling linings in flats (surface linings of ordinary wood)	NO	≥ 1	--[4)]
Wall and ceiling linings of untreated wood in escape routes	NO	≥ 1	--[4)]
Wall and ceiling linings of fire-retardant treated wood in flats	NO	≥ 5	--[4)]
Wall and ceiling linings of fire-retardant treated wood in escape routes	NO	≥ 5	--[4)]
[1)] Mahapatra and Gustavsson (2009); [2)] RS, Ministry of the Environment and Spatial Planning (2010); [3)] See Table 8 and 4) see Table 5 in reference [2)] RS, Ministry of Environment and Spatial Planning (2010)			

In Sweden, the market share of the use of wood in multi-storey buildings increased from 1% in 2000 to 15% in 2012 (Mahapatra et al. 2012), while in some other countries, as in Slovenia, the growth has been very slow. In Slovenia there is only a very small share of wooden multi-storey buildings; mostly two-storey buildings as touristic facility, schools and some residential buildings (Fig. 5).

Figure 5: | 5.1 Car park, Ekorren, Skellefteå, 2009, 4 storey, | 5.2 Multi-residence Älvsbacka Strand, Skellefteå, 2009, 7 storey, | 5.3 Residential building Portvakten, Växjö, 2009, 7 storey, | 5.4 Youth Hostel Punkl, Ravne na Koroškem, Slovenia, 2014, 2 storey

Conclusion

Positive aspects of wood as a structural material include its strength, environment-friendliness, simple handling and appropriateness for industrial use, but knowledge gaps have led to a reduction in the use of wood by structural engineers and architects.

The forest provides infinitely renewable raw materials. As demands on economic frugality and the use of biocycles become increasingly stringent, the use of wood becomes an increasingly important option. Wood is also well suited for modern architecture. Walls and floors can be constructed and assembled in the factory, in dry conditions and with great joinery precision. At the construction site, the modules are assembled quickly and efficiently.

Wood for multi-storey building structures has a market share of about 15% in Sweden but is almost non-existent in Slovenia. It seems that the wood construction system in Sweden is passing from a formative to a growth phase, while in Slovenia it is still in the formative phase. Single-family wooden housing has a long tradition in both countries, but it is more dominant in Sweden than in Slovenia.

Attitudes towards wood construction also vary between Slovenia and Sweden. In Slovenia people have concerns regarding fire safety and the durability of wooden building, but this is not the case in Sweden (Hemström et al. 2014). The use of wood frames in building constructions is promoted to different degrees; in Sweden there is a wide range of programs to promote multi-storey wooden buildings, whereas in Slovenia there is from 2014 a program to promote the use of wood in general, but not specifically for the construction of multi-storey buildings. In 2014, Slovenia also adopted Green Public Procurement (GPP). In the construction sector in Slovenia, GPP is primarily affected and regulated by the technical specifications and award criteria for buildings, where it is generally required that 30% of in-built material (by volume) must be wood or wood-based, and of this 50%, i.e. 15% of the total volume, can be substituted by products with EcoLabels I or III (Kitek Kuzman and Kutnar 2014).

Slovenia, like several other European countries, is increasing the energy performance of buildings by encouraging investors or buyers to select more energy-efficient technologies through measures that make them more price-competitive with low-interest loans or subsidies. Lower interest rate loans are also offered by the Slovenian Environmental Public Fund. These loans are intended for the construction or renovation of passive or very low-energy houses or for energy-efficiency measures (installation and replacement of solar collectors, biomass boilers, heat pumps, ventilation with recuperation, external building fixtures, insulation of the facade and roof). This is not the general situation in Sweden.

We see opportunities for further development and future trends in high prefabrication, partnership and increased responsibilities for planning and construction, improved and systematic feedback of experiences, team cooperation. Demonstration projects are vital to show the various actors team work, e.g. the wood industry, architects, builders, and housing associations, the technical and the business potential of wood as a multi-purpose building material.

There are numerous challenges associated with the construction of wooden buildings, and these challenges are best met through further research and more pilot projects to increase the knowledge of life cycle costs, construction costs, maintenance costs, sound and vibrations, through the general increase in the number of wooden buildings that are being erected.

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InnoRenew CoE - Renewable Materials and Healthy Environments Research and Innovation Centre of Excellence - Innovative Renewable Material Uses Living Laboratory (LL InnoRenew)

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Abstract

A consortium lead by the University of Primorska was awarded a grant by the European Commission under the Horizon 2020 Teaming grant instrument to develop a Center of Excellence. The purpose of the funds is to increase innovation excellence in Europe in general, especially in member states underperforming in innovation. The advanced partner, the Fraunhofer Institute for Wood Research – Wilhelm-Klauditz-Institut, serves as a “tutor” to support the development of the new Center. Seven other Slovenian institutes and research groups are part of the consortium that will develop the new Renewable materials and healthy environments research and innovation centre of excellence (InnoRenew CoE). In order to develop the most effective Business Plan the consortium has established a living laboratory, the Innovative Renewable Material Uses Living Laboratory (LL InnoRenew). This public-private-people relationship was established with stakeholders representing industry, consumers, researchers, and policy makers.. The objective of the LL InnoRenew is to create an environment to discuss the project, develop creative and innovative new ideas, provide critical feedback, and ensure stakeholder involvement in the development of the Business Plan of the new CoE. This presentation presents the LL InnoRenew, its structure, activities, and main conclusions resulting from the activities of the living lab LL InnoRenew.

Key words: Renewable materials, built environment, human well-being, innovation, living laboratories, ergonomic design

Introduction

A consortium led by the University of Primorska was awarded a grant by the European Commission under the Horizon 2020 Teaming grant instrument to develop a business plan for a Centre of Excellence in cooperation with an advanced partner from a high performing and complementary institute elsewhere in Europe. The aim of the instrument is to increase innovation excellence in Europe, especially in member states categorized as underperforming in innovation. The advanced partner, Fraunhofer Institute for Wood Research – Wilhelm-Klauditz-Institut (WKI), serves as a mentor to support the development of the business plan and Centre of Excellence. Seven other Slovenian institutes and research groups are part of the consortium that will prepare the business plan and develop the new "Renewable Materials and Healthy Environments Research and Innovation Centre of Excellence" (InnoRenew CoE). In order to develop an effective business plan, the consortium has established a living laboratory, the Innovative Renewable Material Uses Living Laboratory (LL InnoRenew). This public-private-people relationship was established with stakeholders representing industry, consumers, researchers, and policy makers. The objective of LL InnoRenew is to create an environment to discuss the project, develop creative and innovative new ideas, provide critical feedback, and ensure stakeholder involvement in the development of the business plan for the new CoE. After identifying potential stakeholder groups, their role and level of involvement in the LL InnoRenew was defined. This presentation presents the best practices of LL InnoRenew, its structure, activities, and the main conclusions resulting from its activities.

Living laboratory

A living lab is an ecosystem for experimentation and co-creation with real users in real life environments. End users, together with researchers, industrial firms, and public institutions jointly explore, design, and validate new and innovative products, services, solutions, and business models with the support and use of information and communications technology (ICT). It is a user-centred, open-innovation ecosystem often operating in a territorial context (e.g. city, region), integrating current research and systemic innovation processes within a public-private-people partnership.

Living laboratory LL InnoRenew

LL InnoRenew was created to aid in the establishment of an effective business plan for the InnoRenew CoE and with the intention to advance scientific excellence in Slovenia in a wide range of fields related to renewable materials (e.g. wood, hemp, grasses) including: construction, biology, chemistry, polymers, social sciences, cultural heritage, computing, mathematics, psychology, kinesiology, modelling, simulation, design, logistics, deployment, risk-assessment, decision making, and management. The objective of the LL InnoRenew is to create an environment to discuss the InnoRenew CoE project, develop creative and innovative new ideas, provide critical feedback, and ensure stakeholder involvement in the development of the business plan of the new CoE. Consortium partners of the InnoRenew CoE project are all members of the LL InnoRenew as well as many national and international stakeholders.

Stakeholders

Stakeholders participating in LL InnoRenew can be categorised into six main groups defining their roles:

- **R&D institutions**: national and international institutions develop creative and innovative new ideas, provide critical feedback
- **Associations**: national and international associations perform outreach to broader communities of different sectors
- **SMEs & Large Companies**: national and international companies define the needs and evaluate the focus of the CoE's R&D activities
- **Municipalities**: Slovenian municipalities support and perform outreach to the general public
- **Government Bodies**: national and international bodies provide information regarding legislation, strategic development, etc.
- **Citizens**: national and international citizens express their needs, opinions, and creative ideas.

Stakeholders who chose to be close collaborators of the InnoRenew CoE were asked to sign a Declaration of Intent to Participate. These stakeholders are actively involved with the InnoRenew CoE partners in all LL InnoRenew activities, whereas other interested parties may more passively participate through social media. Table 1 summarises the members of the LL InnoRenew as of January 10^{th}, 2016.

The LL InnoRenew currently engages 19 SMEs, furniture producers, wooden housing, architects, engineering companies, etc., 2 regional development agencies, the Slovenian Ministry of Education, Science and Sport and the Forest Technology Platform, InnovaWood, Society of Wood Science and Technology, Wood Based Composite Centre from Oregon, etc.

Table 1: Stakeholders of LL InnoRenew as of January 13, 2016.

Institutions	**50**
Project partners	9
Active Stakeholders (declaration letter signed)	41
Social media followers	**652**
LinkedIn	291
Twitter	168
Facebook	193

Social Media

Social networks are used by LL InnoRenew as a way to engage broader audiences and individuals in separate stakeholder groups. Social media networks are used as an international arena, where specific questions arising from focus groups, surveys, workshops, and the living lab in general can be discussed.

InnoRenew engages professionals with LinkedIn, interacts with the general population on Facebook (https://www.facebook.com/pages/InnoRenew-CoE/454740938032850), and posts updates and information via Twitter (@InnoRenewCoE) to reach a wider scientific audience.
Posts and discussions are being added to social media regularly, following social media ethics and rules.

LinkedIn
LinkedIn is used for discussions with the professional public that InnoRenew partners have in their networks and beyond. Specific questions coming out of focus groups, surveys, workshops, and LL InnoRenew in general are explored with members of the InnoRenew LinkedIn group. Furthermore, LinkedIn is used for validation of conclusions as well as for generation of new ideas.

Twitter
Our Twitter audience is developing and looks to be largely scientific and professional, having a similar demographic makeup as the LinkedIn group. However, this audience will likely consist of a larger portion of people and organisations with distant or no relationship to the CoE or its members. The main purpose of our Twitter account is:

- Idea generation
- Discovery (learn what other researchers in various fields are doing, especially in terms of science communication)
- Relationship building and creating familiarity/knowledge of the CoE's fields of study with a broader audience of scientists and interested parties.

Facebook
LL InnoRenew uses Facebook to reach the general public. Selected discussions of focus groups, workshops, and even discussions on LinkedIn and Twitter are further explored on Facebook. The aim of Facebook discussions is to receive a variety of opinions and perspectives from the general public, including non-scientific perspectives.

Activities of LL InnoRenew
Based on the defined objective of LL InnoRenew, many activities were created: workshops, personal meetings, an online forum on the InnoRenew CoE website, social media, round table discussions, conferences, fairs, etc. Already, three workshops have been organised and held between October and December 2015:

- InnoRenew CoE Services Workshop
- Impact and Communication Workshop
- Understanding Innovation Workshop

The first two workshops were led by representatives of the project coordinator, University of Primorska, who gave presentations on the topics in question and updates on project work, followed by exhaustive discussion and a direct exchange of ideas between InnoRenew CoE partners and LL InnoRenew members. The third workshop was led by Prof. Dr. Eric Hansen, a global expert in forest sector business and innovation from Oregon State University, Oregon, USA. This hands-on workshop explored the importance of group dynamics, culture, and teamwork in innovation. The day ended with a discussion to identify opportunities to increase innovation in the Slovene wood sector and within the InnoRenew CoE. Participants of the workshop identified what they thought were the top 5 most significant gaps in the Slovenian innovation system:

- Small market and limited investment capital
- Lack of collaboration between business and research (identified by researchers and one industry member)
- Interdisciplinary links between the industry and education not just "wood science"
- Difficult to find agreement between the government, public, and business
- Poor or non-existent innovation culture
- Lack of pride in domestic products/brands (identified mostly by researchers)
- Risk aversion

Conclusion

Workshops and other activities of LL InnoRenew are used to disseminate and expand upon the findings of focus groups and surveys, which were performed during the development of a market analysis of the forest sector in Slovenia and Europe. This analysis examines current research needs within the industry, the needs and knowledge of the general public, identifies opportunities within the market for new business, assesses risks, and identifies barriers to future development. The project partners are developing the InnoRenew CoE the same way they hope the industry will begin developing their products by asking for stakeholder engagement in their research, development, and innovation activities. So far the InnoRenew CoE community has learned from industry and consumer stakeholders through focus groups, surveys, and direct conversations. Among other things, they have learned that in general, the industry values research and development but feels it is lacking in the forest sector. Consumers want to be more engaged in product development, and feel like the industry hasn't been innovative in the last 20 years, which aligns well with the perceived lack of R&D expressed by industry members. Based on industry member responses from surveys regarding their needs from an R&D institution, the CoE is establishing key services to offer, areas of research that are most needed and valued, and identifying knowledge gaps and opportunities within the industry.

Acknowledgement

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Session

Early Stage Researcher

Moderators:
Paige McKinley, Oregon State University, USA

Effect of Barks on the Physical and Mechanical Properties of Phosphate Bonded Wood Composites of Black Wattle (*Acacia mearnsii* De Wild)

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Abstract

In South Africa, forestry and wood processing generates about 4-6 million tons of wood waste per year. In this study, the effect of bark on properties of phosphate bonded wood composites was investigated. Barks and sawdust of black wattle (*Acacia mearnsii* De Wild.) were collected from EC Biomass, South Africa. After drying, the barks were chipped, milled and sieved through a 1.0 mm mesh. The binding matrix was prepared using a reactive magnesia, phosphoric acid and class S fly ash. The ash was added at 10 - 50% loading. The bark was added to the wood at 10, 20, 30, 40 and 50% loading and mixed thoroughly with the inorganic matrix. A control experiment without ash and bark was also considered. The experiments were carried out in four replicates. The composites were formed in a rectangular mold and compressed at room temperature and a pressure of 200KPa. After de-molding, the composites were cured in a conditioned room for 96 h. Thereafter, physical and mechanical tests were conducted to evaluate the properties of the composites.

A central composite design (CCD) was used to determine the best conditions to optimize the properties of the composites. The study demonstrated that barks of *Acacia mearnsii* could be incorporated into wood residues in phosphate-bonded composites with a significant improvement in properties. The products are environmentally friendly and can be engineered to meet industry performance standards and consumer acceptance taste. The proposed product can be used for ceiling, partitioning, wall claddings and underlayment.

Keywords: *Acacia mearnsii*, fly ash, magnesia, mechanical properties, phosphate bonded wood composites, phosphoric acid, physical properties

Introduction

The application of chemically bonded phosphate ceramics (CBPC) has been increasing over time. This 21st century material is employed in architecture and civil engineering. It can be used as adhesives, cements or as coatings for materials, therefore providing a wide range of applications (Laufenberg and Aro, 2004). Chemically bonded phosphate ceramics (CBPCs) are formed by acid-base reactions between an acid phosphate (such as that of potassium, ammonium, or aluminum) and a metal oxide (such as that of magnesium, calcium, or zinc) (Jeong and Wagh, 2002). The reaction is exothermic and sets rapidly into a crystalline mass similar to ceramic (Wagh, 2004). They are mainly magnesium and iron-phosphate ceramics, although specialty formulations have been developed for biomaterials applications using calcium phosphate based ceramics. The most employed of the basic elements is magnesium due to its moderate solubility between calcium and iron in the phosphoric acid medium (Wagh, 2013). CBPCs are produced at ambient conditions and can be applied in high volumes. They are applied in stabilization of hazardous and radioactive wastes, structural materials including road repair and architectural products (Jeong and Wagh, 2002).

Preliminary investigations proved that wood and other industrial waste could be recycled to produce phosphate-bonded composites. Studies by Laufenberg and Aro (2004), Donahue and Aro (2010), Chi (2012) produced phosphate bonded fibre composites using magnesium phosphate cement. In one report, Pine shavings and sawdust were used as raw materials for a set of baseline experiments with one-third-phosphate binder. Pressing to three densities (0.6-1.25 g/cc), the mechanical properties obtained compared with those of wood cement products (Laufenberg and Aro, 2004). In another report, waste paper sludge was bonded with phosphate binder using different ratios of waste fibre to binder (0.63-1.1) with the addition of fly ash as fillers. All properties evaluated on the composites except the modulus of rupture (MOR) compared with those of low-density particle board (Donahue and Aro, 2010). Chi (2012) investigated the interfacial properties between sugar maple and magnesium phosphate cement. The author reported that using a phosphate/magnesium ratio of 3:1, failure and initial crack stress values can be maximized.

In this study, industrial waste streams from the wood industry were incorporated into prepared magnesium phosphate matrix, and the materials were mixed and compressed to form composite boards. This study aims to provide value additions to wood waste such as sawdust and barks while investigating their effects on composite properties.

Materials

Waste Residues

The residues utilized for this research were barks and saw dust of Acacia *mearnsii*. The materials were sourced locally in South Africa.

Magnesium oxide

The magnesium oxide utilized for this study was MAGOXBPPO, a heavy magnesium oxide from Macco Organiques, Zahradnl, Czech Republic. This material had the following composition: Assay 96% min; Calcium <1.1%; Iron <0.05%; Acid insoluble substances <0.1%; Free Alkali and soluble salts <2.0%, Heavy metals <0.002%; Arsenic <0.0003%; Loss on ignition <10.0% and Bulk density (loose) 400-600 g/l.

Monopotassium phosphate

Monopotassium phosphate is commonly used as plant fertilizers and as a food ingredient (salt). For this research, we used MKP 0-52-34, a white crystalline product purchased from Shijiazhuang Lvhe Fertilizer Technologies Co. Ltd, China. This product had the following composition: KH_2PO_4 >98%; P_2O_5 >51.2%; K_2O >33.5%; Chloride <0.2%; Water insoluble <0.2%; Moisture <1.0% and PH 4.3-4.7. Wagh (2004) reports that acid phosphates with a P_2O_5 content of 50-60% may be suitable for the production of chemically bonded phosphate ceramics.

Fly ash

This product was obtained from Ulula Ash, South Africa and complies with the SANS 50450-1:2011 Class S specification. Class S Fly ash (SFA) is an ultra-fine powdery residue obtained from coal fired power plants and it is a South African Bureau of Standards (SABS) approved product. It is of structural concrete grade, finer than cement and is used as a partial replacement for cement. In addition to acting as extenders or fillers in Chemically Bonded Phosphate Ceramics, fly ash reduces the heat of the acid-base reaction, increases the quantity of binder in the mix by generating more binders and enhances durability and strength of the final product (Wagh 2004; Wagh 2013).

Methods

Board formation

The waste material was dried and milled with a hammer mill to pass through a 1 mm sieve screen. Milled samples were conditioned for about 72 h at 20 ^{o}C and 70% relative humidity (RH). The materials for the boards were measured out from the central composite design (CCD). The mass of water used was calculated from a modified formula used in wood cement composites as:

$$W = P + (F - M)\ 2B \qquad \text{Equation 1}$$

W is mass of Water in the board; P is mass of phosphate binder; F is fibre saturation point; M is moisture content of the fibre; B is mass of fibre.

The materials were mixed thoroughly by mass and water was added while stirring the composites together. The slurry was poured into a steel mould measuring 218 x 77 x 40 mm and a steel bar 27 mm thick was placed on the composite to fit into the mould. The set up was arranged in the laboratory press and a pressure of 200 KPa was applied at room temperature. After 5 minutes, the mould was removed from the press and the composite was demoulded. The same procedure was repeated for all the replications in the experiment. The formed boards were allowed to air-cure in the laboratory for 24 h. Thereafter, they were conditioned at 20 ^oC and 70% RH for 96 h before testing.

Testing

Testing of the boards was carried out according to ASTM Standards (D1037-99). The properties evaluated include density, modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA), and thickness/volume swelling (TS/VS). Samples for sorption test were cut using an angle grinder with a concrete blade into dimensions of 75 x 50 mm. The thickness of all samples used in the test was 13 ± 1.2 mm based on the set up configuration of the steel mould.

Statistical analysis

The experiment was designed on a central composite design (CCD) using STATISTICA Software v5. In this study, two (2) variables were considered. They include the bark content from 10 - 50% of the total wood content; and the fly ash content from 10 – 50% of the total inorganic content. The binder ratio of KH_2PO_4 to MgO was kept constant at 3:1 (100 g wt.) while the wood content was also kept constant at 50 g. The CCD was used to prepare the combinations of the materials in the design. This resulted in 10 experimental runs using the standard design. A control experiment without considered variable was also carried out giving a total number of 11 board types (Table 1). Four replications of all the experiments were carried out resulting in a total of 44 experiments.

Table 1 Combinations of the experiment based on CCD

Board types	Bark content (g)	Ash content (g)	Wood and bark (g)	Water (ml)
A	5	10	55	122.7
B	5	50	55	162.7
C	25	10	75	127.3
D	25	50	75	167.3
E	0.85	30	50.85	141.7
F	29.14	30	79.14	148.2
G	15	1.72	65	116.7
H	15	58.28	65	173.2
I	15	30	65	145.0
J	15	30	65	145.0
K (Control)	0	0	50	111.5

Results and discussion

Density

The mean densities of the boards ranged from 0.98 to 1.25 g/cc. Board D with a high bark and fly ash content had the highest density of the boards. Bark is a heavy and heterogeneous material and so invariably contributes to the density of the boards. Board K had the lowest density of 0.98 g/cc. This is due to the fact that the boards did not contain bark and fly ash as in the control.

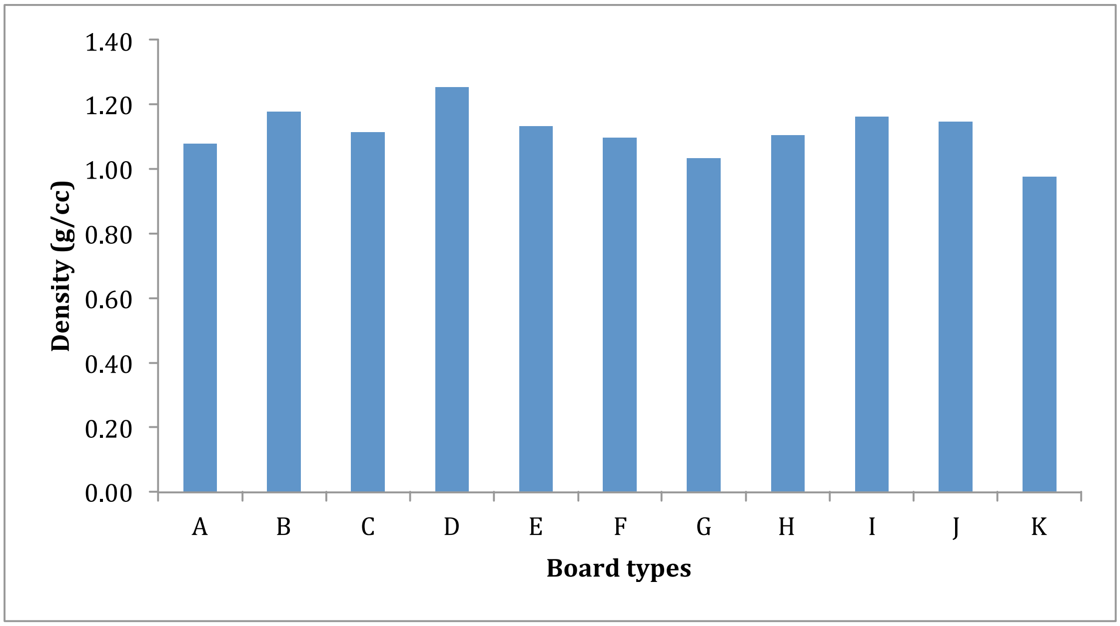

Fig. 1 Mean Density of the Boards

Modulus of Rupture (MOR)

The mean MOR of the boards is shown in the figure below. Board D had the highest MOR (7.32 MPa) possibly as a result of the high content of bark. Bark contains substances that may react with the phosphate values and lead to the formation of more bonds. This results in better bonding in the composites and hence higher density and strength properties. Since density has an important role in the mechanical response of cements and ceramics (Colorado *et al*., 2011), it is a major determinant of the strength properties of composites. Therefore, it is expected that the denser boards have better strength properties. In a similar way, board K that has the lowest density also has the lowest MOR of 2.29 MPa.

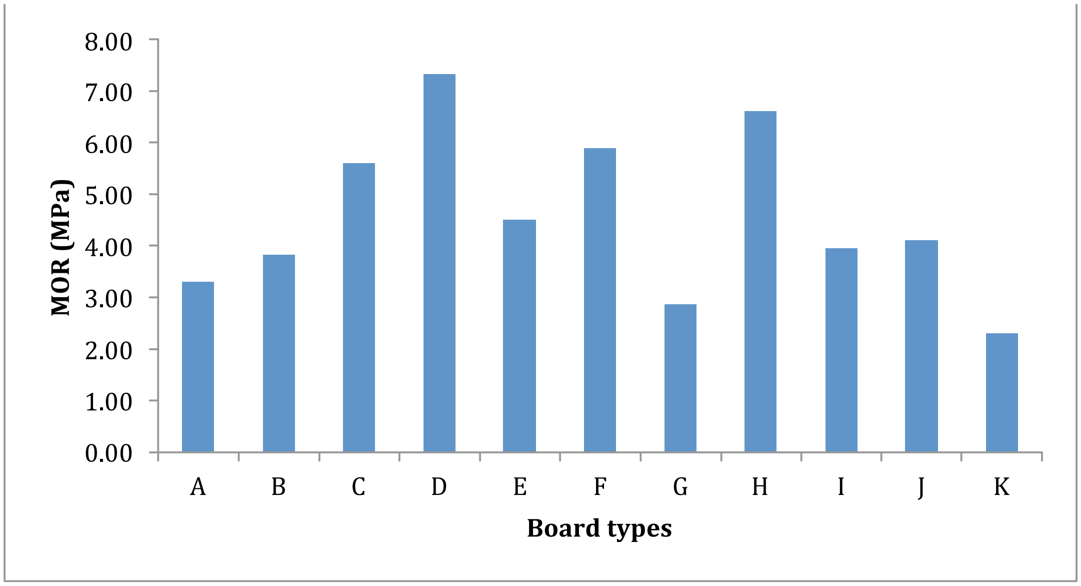

Fig. 2 Mean MOR of the Boards

Modulus of Elasticity (MOE)

The mean MOE values follow same trend with the MOR as a mechanical property. Board D had the highest mean value of 88.3 MPa while board K had the lowest mean value of 31.33 MPa. This is also due to better compaction in Board D as a result of high content of bark and fly ash. Fly ash enhances the cementing mechanism of phosphate composites (Wagh, 2013)

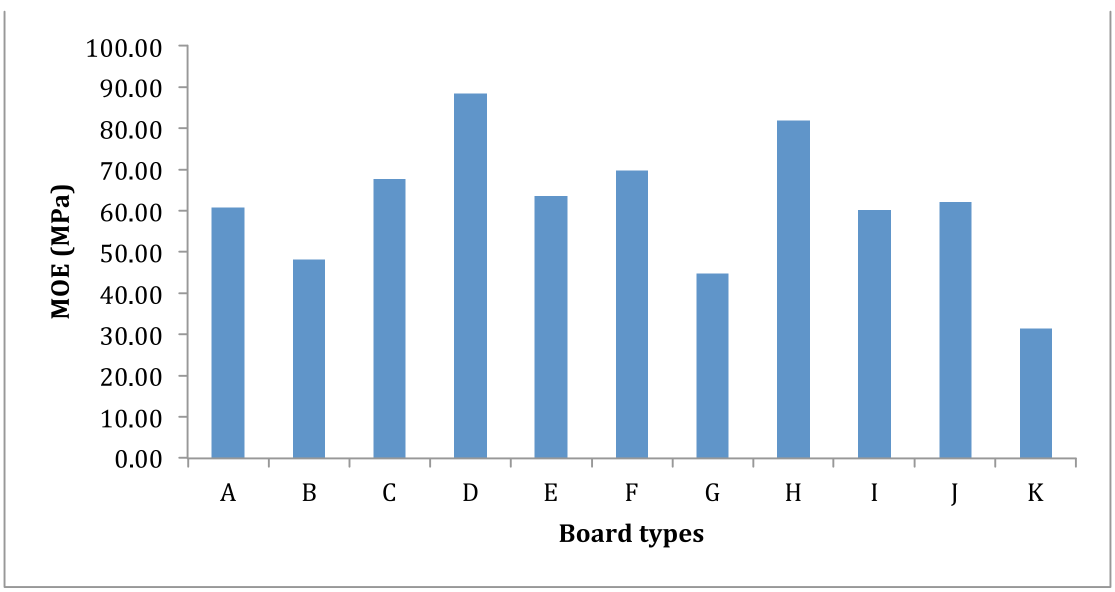

Fig. 3 Mean MOE of the Boards

Water Absorption (WA)

The mean WA of the boards varied from 14.52 – 23.48%. Board D has the lowest WA due to better compaction of the boards. Board G had the highest WA followed by the control with a mean value of 22.40%. This result suggests that bark and fly ash content play a major role in enhancing compaction and reducing moisture movement in the composites.

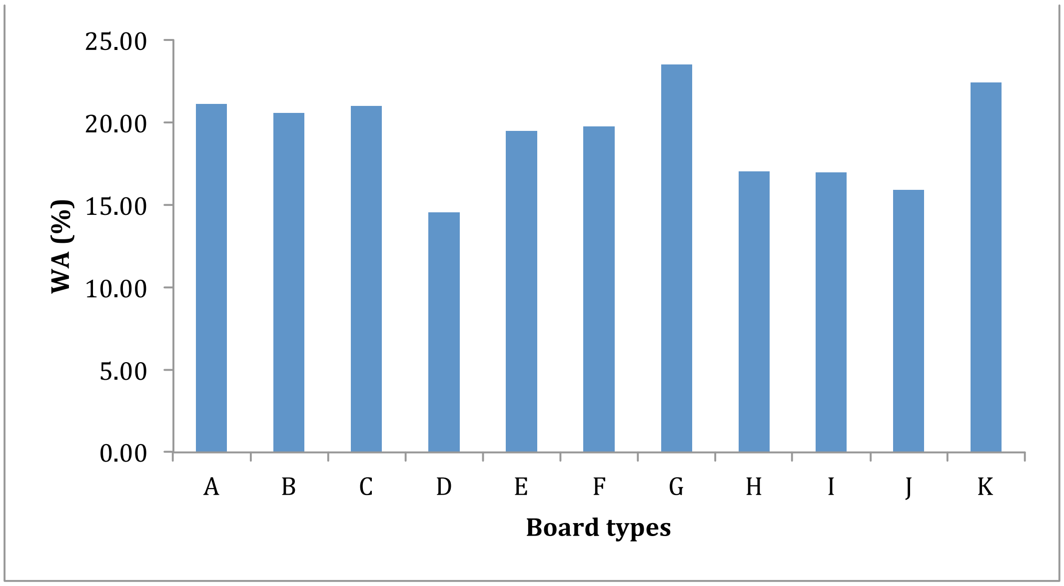

Fig. 4 Mean WA of the Boards

Thickness/Volume swelling (TS/VS)

The mean TS/VS of the boards are low ranging from 0.09 – 5.48% for TS; and 0.06 – 4.71% for VS. Board E with the lowest bark content had the highest TS and VS of all the boards followed by the control. This indicates that high bark and fly ash content enhances encapsulation of the cellulosic fibres and prevents edge and linear expansion. Board B had the lowest TS while Board J had the lowest VS of 0.09% and 0.06 respectively.

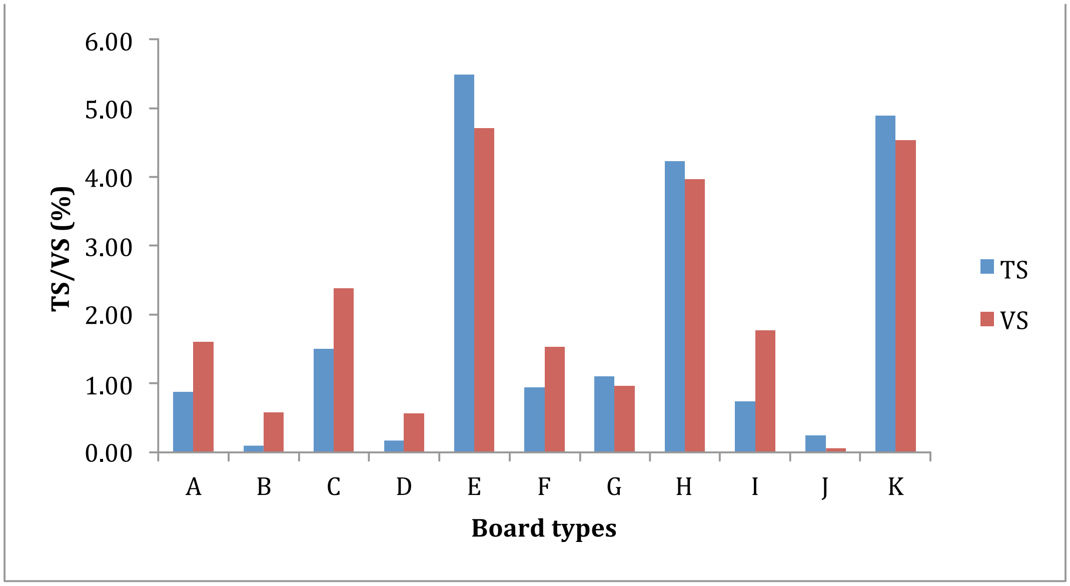

Fig. 5 Mean TS/VS of the Boards

Conclusion

From this study, it is clear that ground bark can be added to phosphate bonded wood composite to enhance its properties. A mixture of bark and fly ash in adequate amount increases all properties including density, MOR, MOE while decreasing WA, TS and VS. The best effect was obtained at 50% loading of bark and fly ash. Within the study design, addition of bark improves all the properties evaluated. The result did not show the limit to which bark can be added favorably to phosphate-bonded composites. Therefore, other studies should be directed to determine the maximum limits for the addition of barks, beyond which reduction of properties if any may be encountered. The proposed product can be used for ceiling, partitioning, wall claddings and underlayment.

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Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products – Ecosystem services and competitiveness in the Bio-economy

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Abstract

Ecosystem approach broadens the sustainability perspective within the forest sector. Economic and ecological aspects may be linked together. The ecosystem concept allows a wide frame for sustainable forests and forest products both in private and public forests. Private owners play a key role in sustaining forest ecosystems providing resources for markets and at the same time enhancing development locally. In Finland, the non-industrial private forest (NIPF) owner sector has a large importance.

Different ecosystems form promising opportunities for business. In the Green Economy multiple ecosystems are taken into consideration. Forest ecosystem services provide an opportunity for value creation. Forests and forest products with certification, green building with carbon − ecosystem services provide opportunities in markets in the future. In the bio-economy, stakeholders have an important role in active, sustainable and diverse use of forests and providing sustainable forest products.

Competitiveness is in an important role in the policy framework.

Keywords: Sustainable development, forests, forest products, ecosystem services, bio-economy, stakeholders, competitiveness

Introduction

The research on "Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products" is a literature review and based on a qualitative study. It is broadly outlined and combines organizational information and research information from several academic sources with a number of search words. It is based on organizational information and research articles from relevant databases.

Research questions in the framework of "Sustainable Development – International Framework – Overview and Analysis in the Context of Forests and Forest Products" include the following:

1. How is stakeholder collaboration represented in an international and national policy framework and what is the role of corporations in the corporate social responsibility approach?
2. How do stakeholders represent green economy with bio-economy and green growth and the CSR in ecosystem services?
3. Whether to the Advocacy Coalition Framework approach with an international and national policy aspect, how can the sustainable development and competitiveness be enhanced with green growth, green economy and bio-economy? (Conceptual approach.)

Ecosystem services in the Bio-economy with stakeholders

Certification, green building and developing carbon and other ecosystem markets have importance also in the future. Biomass certification development involves many stakeholder groups including governments, companies, NGOs, transnational and international organizations and international initiatives. Policy influence in the forestry can be highlighted.

The new EU Forest Strategy in 2013 includes goals for competitiveness and sustainable forestry and use of forests enhancing ecosystem services.

The Strategy for "Innovating for Sustainable Growth: A Bioeconomy for Europe" (2012) encourages to participatory engagement, responsibility and private investments.

Stakeholders have been engaged in the Finnish Bioeconomy Strategy (2014). The Finnish Bioeconomy Strategy promotes economic development and aims to prevent the decline of ecosystems.

The Finnish Bioeconomy Strategy (2014) aims to generate new economic growth referring to an economy that is based on renewable natural resources producing e.g. energy, products and services. The Finnish Bioeconomy Strategy is based on the sustainable development.

Competitiveness in the Bio-economy with stakeholders

The Bioeconomy Action Plan in "Innovating for Sustainable Growth: A Bioeconomy for Europe" of the European Commission includes the improvement of markets and competitiveness in bioeconomy. It also contains strengthened policy interaction and stakeholder engagement.

Within the Europe's Bio-economy Strategy (2012) investments in research and innovations, strengthened stakeholder engagement and policy interaction, improved markets and competitiveness are highlighted taking into consideration climate change and natural resources.

The strategic goals of the Finnish Bioeconomy Strategy (2014) include "A competitive operating environment for the bioeconomy", "New business from the bioeconomy", "A strong bioeconomy competence base" and "Accessibility and sustainability of biomasses".

National and international framework in ecosystem services and competitiveness in the Bio-economy with stakeholders

In the Environmental Policy of Metsähallitus in Finland, "multi-objective management of natural resources and securing ecosystem services", "responsibility for the environment" and "continuous improvement" and "openness and co-operation" are accentuated. Responsibility for the environment may be ensured with regulations, environmental commitments, forest certification standards and international agreements.

There are opportunities in wood based products. One of the strategic objectives of the Government Forest Policy Report to the Parliament, covering the use of Finnish forests up until the year 2050 is that forests are in active, sustainable and diverse use. Sustainable development can enhance business opportunities. It is stated that the Bio-economy will enhance the sustainable economy in Finland.

Bio-economy can be seen as a new turn in the economic development. In the future, services and diversity and forest products can provide a much larger amount of possibilities for opportunities in the forest sector in Finland.

Forest owners' role in providing ecosystem services in the policy context is important. Fulltime agricultural entrepreneurs comprise about 16 % of forest owners in Finland. Internationally large amount of private forest ownership in Finland forms a competitive factor for Finland.

The target of the Bio-economy Strategy of the European Commission in 2012 is to bolster a worldwide approach to a resource use which is more sustainable including knowledge of international biomass sustainability and new markets.

Research results propose that corporate responsibility may advance value creation in forest-based companies. Responsibility can be seen as a competitive tool for the industry.

Conlusions

Stakeholders have an important role in the green approaches and a significant role in the markets. Ecosystem services may supply resources to markets and can enhance local development.

In Finland, private forest owners have a significant role in competitiveness sustaining forest ecosystem services and providing wood for the forest industry. Forest owners' role is important in providing resources for the ecosystem services in the markets in Finland. Forest owners' role is important for the sustainability and for the competitiveness.

Sustainable development can be revealed in the green concepts and in the stakeholder collaboration.

Corporations have a significant role in the Corporate Social Responsibility, CSR, which is present in green concepts and in the bio-economy approach. There are national and international opportunities in the competitiveness within the Bio-economy.

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Forest Landowners' Assessment of Climate Change Risk in Coastal North Carolina

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Abstract

Average temperatures in United States have risen two degrees F for the past 50 years, and this trend is expected to continue in the future as the net amount of greenhouse gas emissions are estimated to increase. An increase in temperature lengthens growing seasons for forest landowners, while sea-level rise and salt intrusion contributes to the loss of land, land use change, and possibly forest products markets in the long term. This study provides an overview of forest landowner and industry stakeholders' perceptions of risks and challenges associated with climate change, particularly with sea level rise and salinity in the inner banks region of North Carolina coast. In addition, adaptation strategies for mitigating and reducing climate change risks to forestland use, products, and market is also examined. The outcome will help government and policy makers to understand perceived risks as well as adaptation tools that the forest products communities are interested in implementing.

The Use of Daily Drying Rate to Decrease Kiln Drying Time of Juvenile *Tectona grandis L.* Wood

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Abstract

It was measured as a way to compare the speed of drying between the schedules rather than as a way to reduce the drying time of Tectona grandis wood from juvenile plantations. The drying schedule (DS) was modified for to attain a daily drying rate (DRdaily) value of 20%/ day during the first stages and by the time the wood reached 30% moisture content (MC), the DRdaily remained in 8% per day until the end of DS. The best DS, as a way to decrease the drying time, reduced this time from 140 hours to 105 hours, maintaining DRdaily conditions and saving 33% of energy consumption, but there is a slight decreasing in dried-lumber quality. The variation of DRdaily in different DS varied and time has been drying and this behavior can be modeled mathematically by the equation Y = a*t + b. Of the factors compared, the greatest influence on DRdaily was dry-bulb temperature and wet-bulb depression. Both relations show an inflexion point in the relation DRdaily-MC, indicating the points where schedule parameters (temperatures and humidity relative) must be changed to achieve the required drying rate. The points are 80% in fast DS and 40% in slow drying schedule.

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Systematic Review of the Environmental Performance and Sectoral Competitiveness of Canada's Forest Industry

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Abstract

Canada's forest products industry has long been one of the nation's most important economic engines, providing high quality employment, generating wealth, and contributing to the social fabric and wellbeing of communities from coast to coast. While historically, the sector's competitive advantage was linked to an abundant resource basket, such advantages are no longer certain in today's complex globalized economy. While Canada's forest products sector represents one of the world's most progressive examples of environmental stewardship, the degree to which this provides the sector a competitive advantage is unclear. This gap in knowledge forms the basis of this systematic review, the goal of which is to strengthen our understanding about of the link between environmental performance and industry competitiveness, especially as it pertains to the Canadian forest products sector. Through a rigorous and systematic literature review, this study will explore, in depth, the environmental performance-competitiveness link in the Canadian forest sector, identify critical knowledge gaps, and propose a future research agenda.

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