Mendel University in Brno

COST Action FP1407 2nd Conference

Innovative production technologies and increased wood products recycling and reuse

Brno, Czech Republic
29 – 30th September 2016

Editors: Andreja Kutnar, Matthew Schwarzkopf, Michael Burnard, Václav Sebera, Eva Troppová

Mendel University in Brno

COST Action FP1407

Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)

Innovative production technologies and increased wood products recycling and reuse

Second COST Action FP1407 International Conference
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Center for Industrial Research Techlab, s.r.o.
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Lars Tellnes - Norway
Callum Hill – The United Kingdom
Ana Dias – Portugal
Edo Kegel – Netherlands
Michael Burnard – Slovenia
Lauri Rautkari – Finland

Content

Session IV

SECOND DAY, September 30th 2016

FP1407 training school and STSM session

Poster Session

Session V

PREFACE

Welcome to the second international conference of COST Action FP1407 "Understanding wood modification through an integrated scientific and environmental impact approach" (ModWoodLife). The conference "Innovative production technologies and increased wood products recycling and reuse" held in Brno, Czech Republic from September 29th till September 30th 2016 is the second conference of COST Action FP1407. The conference will focus on presenting state-of-the-art production technologies in wood modification, as well as development of recycling technologies and systems for modified wood, related barriers, and challenges. Special emphasis will be given to cascade use of wood and related environmental impacts.

Although FP1407 has been running for only a bit more than one year, I am pleased we will hear about the extensive collaborative research our COST Action already enabled. In the first grant period 13 Short Term Scientific Missions (STSM) were completed. Researchers examined modified wood in a variety of innovative ways from surface densification to life cycle assessment. Please visit the web page of the COST Action FP1407 and learn about the research and collaborations performed through STSMs and other activities in the first grant period. In addition to research, we had a very successful training school on Life Cycle Assessment organized by Luke in Finland. Working group 2 had a successful meeting "LCA of wood modification processes: where are the weaknesses in inventories?" in collaboration with COST Action FP1303 and participated at the LCA Forum discussion at ETH Zurich. We organised the "Application of NIR spectroscopy in wood science and technology" workshop with our colleagues from IVALSA in Italy. I would like to express my sincere gratitude to the organizers of these networking events that have delivered our objectives and have enabled our COST Action to make an impact in European research. Together, the participants and organisers of these events have extended the reach of and developed further interest in the field of wood modification and environmental impact assessment. Also, I would like to express a special thank you to all of the members that have helped us reach out to a broader audience through all of your scientific contributions and other outreach activities. It is important we continue with these activities and keep working closely with industry to make FP1407 a truly effective Action.

I am positive the fruitful discussions at this conference will enable your research activities and outcomes to reach an interested and helpful audience. This exchange of knowledge is an excellent opportunity to meet new colleagues is a great opportunity to develop new collaborations. I would like to encourage you to continue your great work, use the time at the conference to build new relationships and friendships, and to use all the tools and opportunities COST provides. Furthermore, please join FP1407 on social media, share your work through our social media profiles, encourage more discussions, and help us make a strong and wide impact with our COST Action.

I am convinced that our 2nd conference will strengthen our collaborations and help build new ones. I wish you fruitful discussions and successful networking in Brno.

Andreja Kutnar
Chair, COST FP1407

PREFACE

Dear participants, I would like to welcome you in Brno (Czech republic) at 2nd conference within the COST Action FP1407 on topic “Innovative production technologies and increased wood products recycling and reuse”.

Brno has become important center of new technologies and science within the space of the Czech Republic in last 8 years. This has happened by gaining variety of research capacities enabled mostly by European funding (CEITEC, ADMAS etc.) and the same, although in lower scale, has happened also in wood products research at Mendel University in Brno (Research Center of Josef Ressel). I am glad that this conference takes place in Brno because it is another important mile stone to support Brno's research in wood products and put Brno as important partner in wood product research on European map.

The conference focuses on innovation and environmental aspects of using wood and wood products. This is very actual problem with respect to challenges for all involved: scientific community, industry and common users. I hope the conference will give you an opportunity to meet your colleagues, exchange ideas and strengthen mutual cooperation, so the Wood Products' community will become stronger and more successful in promoting its visions in our society.

Václav Sebera

ModWoodLife

CONFERENCE PROGRAM Thursday, September 29th, 2016

09:00	Registration	
09:30 – 09:45	Welcome	
	Václav Sebera and Andreja Kutnar	
09:45 – 10:30	Keynote lecture	Chair: Andreja Kutnar
	Klaus Richter	Cascade use of wood - illusion or silver bullet for sustainability
10:30 – 11:15	Presentations	Chairs: Robert Németh and Eva Troppová
	Rozanska and Policinska-Serwa	Antique wooden floor reuse possibilities in view of their usage properties preservation
	Rademacher et al.	Native oak wood properties- limitations in wood utilization and possibilities of quality improvement
	Markström E., Bystedt A., Fredriksson M., Sandberg D.	Perceptions of Swedish architects and contractors for the use of bio-based building materials
11:15 – 11:45	Coffee break	
11:45 – 13:00	Presentations	Chairs: Ćhristelle Ganne-Chedeville and Lars Tellnes
	Marra M., Guercini S.	Life cycle assessment of wood wool cement board using recycled wood
	Paajanen O., Turunen H., Peura J.	Preparing the life cycle assessment of wax modified wood products
	Sandak A., Sandak J.	End-of-life transformation strategies for bio-based building materials
	Tellnes L.G.F.	Potentials and barriers to increased wood products recycling in Norway
	Dolezal F., Boogman P.	Current state of the discussion between PEF and EPD as the preferable life cycle assessment scheme for wooden construction products
13:00 – 14:15	Lunch	
14:15 – 15:45	Presentations	Chair: Dennis Jones and Fanni Fodor
	Fodor F. et al.	Modification methods of hornbeam (Carpinus Betulus L.) wood in order to achieve high-quality products
	Paoloni F., Ferrante T., Villani T.	Wood pre-treatments: a short review
	Ferreira J., Herrera R., **Esteves B.**, Domingos L.	Thermally modified pine boards - an environmental comparison of Portuguese and Spanish case studies
	Janiszewska D., **Sandak** A., Sandak J., Fellin M.	Wood liquefaction – an alternative way for end of life transformation of wood waste
	Archila-Santos H.F., Ansell M.P., Walker P.	Elastic properties of thermo-hydro-mechanically modified bamboo (Guadua Angustifolia Kunth) measured in tension
	Rousek R., Horáček P.	Influence of steaming at lower temperatures on permanent fixation of compressive deformation of densified wood
15:45 – 16:15	Coffee break	

16:15 – 17:30	Presentations	Chair: Franz Dolezal and Emilia Markström
	Straže A.	Hardness of thermally modiffied ash determined by static- and acousto-dynamic method
	Elaieb M.T. et al.	Study of thermal parameters from eucalyptus wood after heat treatment
	Dos Santos P.S.B., Da Silva S.H.F., Gatto D.A., **Labidi J.**	Colour changes of wood by two methods of aging
	Demirel G.K. et al.	Dimensional stability and mechanical properties of epoxidized vegetable oils as wood preservatives
	Németh R., Bak M.	Long-term in service evaluation of strip parquet with modified wood face layers
17:30	**Closing of the first day**	
18:30 – 19:30	Core group meeting	
20:00	Conference dinner	

ModWoodLife

CONFERENCE PROGRAM Friday, September 30th, 2016

09:00 – 10:10	STSM Session	Chairs: Lauri Rautkari and Peter Rademacher
STSM Training	**Tarmo Räty**	Introduction LCA to wood material practitioners - feedback from the FP1407 LCA Training school 2016
	Peñaloza D. and Kutnar A.	Life cycle assessment of wooden windows with wax-treated frames
	Neyses B., Rautkari L., Yamamoto A., Sandberg D.	Reduction of the set-recovery of surface-densified Scots pine by pre-treatment with sodium silicate or sodium hydroxide
	Schwarzkopf M.J. et al.	Chemically modified lampante oil as a wood preservation treatment
	Griebeler C.G. de O., Tondi G., Schnabel T., Iglesias C.	Effects of natural weathering on surface colour and cracking of thermally modified eucalyptus wood
	Bekhta P., Krystofiak T., Lis B., Proszyk S.	Evaluation of surface quality and adherence of thermally compressed and finished wood veneers
	Kuzman M.K. and **Sandberg** D.	State of the art and future trends in timber-house technologies in Slovenia and Sweden
10:10 – 11:25	Poster Session	Chairs: Anna Sandak and Mike Burnard
	Žlahtič M. and Humar M.	Surface properties of thermally wood after artificial and natural weathering
	Akbas S., Temiz A., Alma MH.	Wood plastic composites made of recycled and remediated creosote treated wood-aspects on screw withdrawal properties
	Aoues Y. et al.	Optimal and reliable design of timber beams for a maximum breaking load considering thermal and hydrological effects
	Silvia da Silva H.F., Dos Santos P.S.B., Gatto D.A., Labidi J.	Liquefaction of kraft lignin using different solvents
	Gurau L., Campean M., Ispas M.	The influence of the heat treatment duration on the surface roughness of beech processed by planing
	Hamada J. et al.	Effect of silver pin's forest management on radial density distribution, thermal behaviour and final quality of the heat treated wood
	Herrera R., Gordobil O., Llano-Ponte R., Labidi J.	Esterified lignin as hydrophobic agent for use on wood products
	Odounga B., **Moutou Pitti** R., Toussaint E., Grédiac M.	Mode I fracture of tropical species using the grid method in constant environments: experimental results
	Salan T. and Alma H.M.	A preliminary study on the delignification of wood blocks via microwave assisted atmospheric organosolv method the production of holocellulosic scaffolds
	Salca E.A. and Hiziroglu S.	Evaluation of hardness of heat treated yellow poplar wood
	Schnabel T., Haas R., Huber H.,	Surface modification using infrared radiation

	Petutschnigg A.	
	Silveira E.A. et al.	Wood thermal degradation: Prediction of process parameters, solid mass yield, by two mathematical models
	Svrzić S. and Mandić M.	Abrasive water jet cutting (AJWC): Wood material - jet interaction
	Alma M.H. and Salan T.	Phenolation of wood and its applications for the production of engineered polymeric materials
	Turunen H., Paajanen O., Peura J.	Development of wood modification – high melting point wax and hot oil treatments
	Burawska I. and Zbiec M.	Enhancement of low grade timber with synthetic materials
11:30 – 11:55	Coffee break	
11:55 – 12:55	Presentations	Chairs: Ana Dias and Diego Peñaloza
	Beesley L., Norton G., Mollon L.	Mobility and toxicity of heavy metal(loid)s from contamined wood ash application to soils
	Fellin M., Negri M., Felicetti M., Monsorno V.	Maintaining wood naturalness: production of biocompatible wooden floors and monitoring of heavy metals, VOC and radiation
	Robles E., Herrera R., Gordobil O., Labidi J.	Bio-cascading of heat treated wood after service life to obtain lignocellulosic derivatives
	Escamilla E.Z., Habert G., Wohlmuth E.	CO_2 the untapped resource. Life cycle assessment of glue-laminated wood solutions for housing in the Philippines
12:55 – 13:55	Lunch	
13:55 – 14:55	Working group meeting	
	WG1: Product Category Rules	Dick Sandberg and Robert Németh
	WG2: Life Cycle Assessments	Christelle Ganne-Chedeville
	WG3: Environmental products declarations	Ana Dias
	WG4: Integration, dissemination and exploitation	Edo Kegel and Michael Burnard
14:55 – 15:20	Reports of WG leaders and conference conclusions	
15:20 – 15:50	Coffee break	
15:50 – 17:00	MC meeting	
18:00 – 22:00	**Social program**	

ANTIQUE WOODEN FLOOR REUSE POSSIBILITIES IN VIEW OF THEIR USAGE PROPERTIES PRESERVATION

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Keywords: antique wooden floor, antique wood properties, durability of wood, floor reuse

Research background

The quality of wooden floors and parquets is assessed on the basis of how aesthetically pleasing they are and their long-term durability. Floor quality depends, most of all, on the technical and aesthetic properties of wood as a construction material. These properties include: hardness, elasticity, resistance properties, abrasion resistance, and resistance to microbiological corrosion. Also of importance is the floor structure (Fig.1), the quality of its installation, methods of assembly, and surface finish. The usage conditions are also very important, because parquets that are properly conserved and used in stable heat and humidity conditions, degrade at a slower rate.

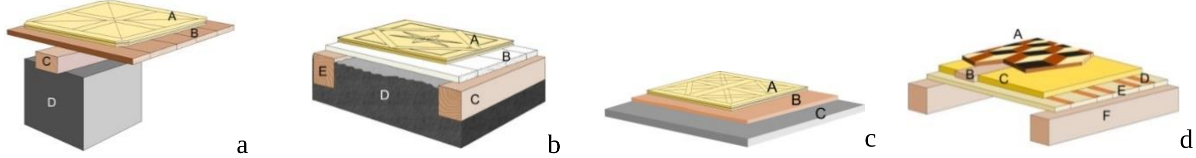

Figure 1. Diagram of floor construction: in the Przewrotne Manor House (a: A – panel, B – boarding/decking, C - ceiling beams, D – bricked post), in the Ball Room of the Łańcut Castle (b: A – panel, B – boarding, C - beams, D – sand), in the Chapel of the Łańcut Castle (c: A-panel. B - sand, C - concrete) and in the Chinese Room of the Łańcut Castle (d: A – parquet, B – additional beams, C – layer of sand, D – boarding/decking, E - glued strips of cloth, F – ceiling beams).

Aim, scope, and methodology

This study analysed the usage properties of antique, decorative wooden floors to decide if they can be used again and if they meet EU standards.

The sample of antique floors in Poland covered 76 rooms in 21 buildings dating from the 19th century.

Non-destructive and portable methods are preferred in contemporary conservation practice to limit the impact on the antique object and because the basic requirement consists of applying the method in situ. However, when assessing the usage value of floors situated in antique buildings that are still in use, the floors have to safely support dead loads related to their own weight as well as dynamic loads related to the movement on their surface. In these cases, it is necessary (if possible) to meet contemporary construction standards that often require verification through destructive tests.

Results

The antique floors in this study have a non-uniform degree of technical wear. In some cases (Tab.1), the hardness and resistance to abrasion of antique oak and elm wood was comparable or even higher (with the reservation of high standard deviation) than the hardness and abrasion resistance of contemporary wood [1]. Hardness, resistance to abrasion, and resistance to scratches depend on the sample collection point, that is: on the microclimate conditions. Also the bending strength and modulus of elasticity tests conducted on antique wood samples gave results that were comparable with the values indicated in reference publications for contemporary wood. The density of the tested antique wood was also comparable with the average values of contemporary wood density.

Table 1. Results of hardness, wear resistance, and deflection tests of oak.

Manor House location	Loss of mass [g]	Standard deviation [g]	Hardness [N/mm^2]	Standard deviation [N/mm^2]	Deflection at maximum force [mm]	Standard deviation [mm]
Falejówka	0.50	0.13	33.2	3.1	10.2	2.87
Tarnowiec - external corner	0.35	0.15	31.2	5.5	14.77	2.19
Tarnowiec - traffic path	0.23	0.09	39.4	5.8	11.87	2.72
Tarnowiec - internal corner	0.32	0.18	39.1	6.6	10.9	2.34
Contemporary oak	0.46	0.07	37.6	3.1	-	-

The static and dynamic load bearing capacity test results of antique wood resistance were used as the basis for numerical simulations that confirmed the capability of antique parquets to transfer their own structural loads and live loads [1].

In view of the dynamic floor parameters such as shock absorption and controlled deflection, antique constructions have similar characteristics as contemporary floors exposed to frequent dynamic loads and are able to meet the contemporary standards EN 14342 [2].

Due to the differences in historical value of antique floors, they require repairs done with methods and materials similar to the original ones, or reconstruction works that would respect the initial patterns and structures with the use of contemporary materials.

In Europe, years of research has been conducted by scientific centres, industry associations, and opinion-makers permitted to standardise the requirements for entire sectors, including wooden floors and the materials they are made of. The dimensions of the cross-section of load bearing elements that transfer loads from the floor, such as joists, binding joists, or bricked posts have to fulfil the requirements of the design standards specified in Eurocode EC 5. The production of parquet materials is regulated by CPR (EU) 305/2011 that requires the application of European harmonised standards.

Only the fulfilment of European standards by antique floors can be the basis to recommend the preservation or replacement of an antique wooden floor. The fulfilment of requirements specified in the standards requires one to avoid the dangers related with the usage of unverified materials. However, in justified cases, European regulations allow the use of innovative, author's solutions different than the typical ones, but their properties still have to be verified individually, which is often costly.

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[1] Rozanska A., Burawska I., Policinska-Serwa A., Korycinski W., Mazurek A., Beer P., Swaczyna I. **(**2012) Study of Antique Wooden Floor Elements of Chosen Buildings from South-Eastern Poland. Proc. of the 8th International Conference on Structural Analysis of Historical Construction SAHC’12, 15-17 October, Wroclaw Poland: 905-913 *(article)*

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NATIVE OAK WOOD PROPERTIES – LIMITATIONS IN WOOD UTILIZATION AND POSSIBILITIES OF QUALITY IMPROVEMENT

Peter Rademacher[1], Radim Rousek[3], Marian Krüger[2], Jan Baar[3], Petr Čermák[3], Eckhard Melcher[4], Gerald Koch[4], Robert Németh[1], Petr Pařil[3], Zuzana Paschová[3], Daniela Paul[4], Tanja Potsch[4], Daniel Vavřik[5], Ivana Kumpová[5], Tamás Hofmann[1], György Sipos[1], Miklós Bak[1], František Hapla[2]

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Keywords: oak wood, heartwood components, durability class, wood property/ modification,

Oak is known to be strong as a living tree and robust and durable as heartwood material. In contrast to this a lot of evidence indicates tremendous variation of the durability of the wood and a wide range of determined durability classes [1]. Traditional fungi tests classified oak heartwood, following EN 350-1:1994, as durability class 1-2. However, new tests especially in ground contact [1] but also in the case of lab tests using non-standard basidiomycetes (e.g. *Donkiopora expansa)* led to a downgrading into the classes 2-4 [2, 3]. Processes to improve the durability by wood modification techniques are discussed.

As a joint project, researchers from Germany, Czech Republic, and Hungary investigated details on the mechanisms of this less attended variability of heartwood durability. In this, study, structural, physical, and chemical analyses have been carried out and the first results are shown here.

The following investigations have been carried out or are still ongoing respectively:

- Structural/optical investigation
  - Growth
  - Microscopy
  - Color
  - Computer Tomography (CT)
- Physical investigation
  - Density
  - Fiber saturation range
  - Swelling/Shrinkage
- Chemical investigation
  - Amount of extracts
  - Content of phenolic compounds (heartwood components)
    - Sum (Photo-Spectrometry; UV-microspectrophotometer [UMSP])
    - Single components (HPLC)

The aim of the investigation was to find correlations between the structural, physical, and chemical characteristics, showing a relationship between cell wall growth-activity and extract production of the wood and its interaction with physical and biological properties (Fig. 1). The results show interesting correlations between site and growth parameters and the production of phenolic compounds in the heartwood, partly accompanied by coherent color and moisture related properties [4, 5].

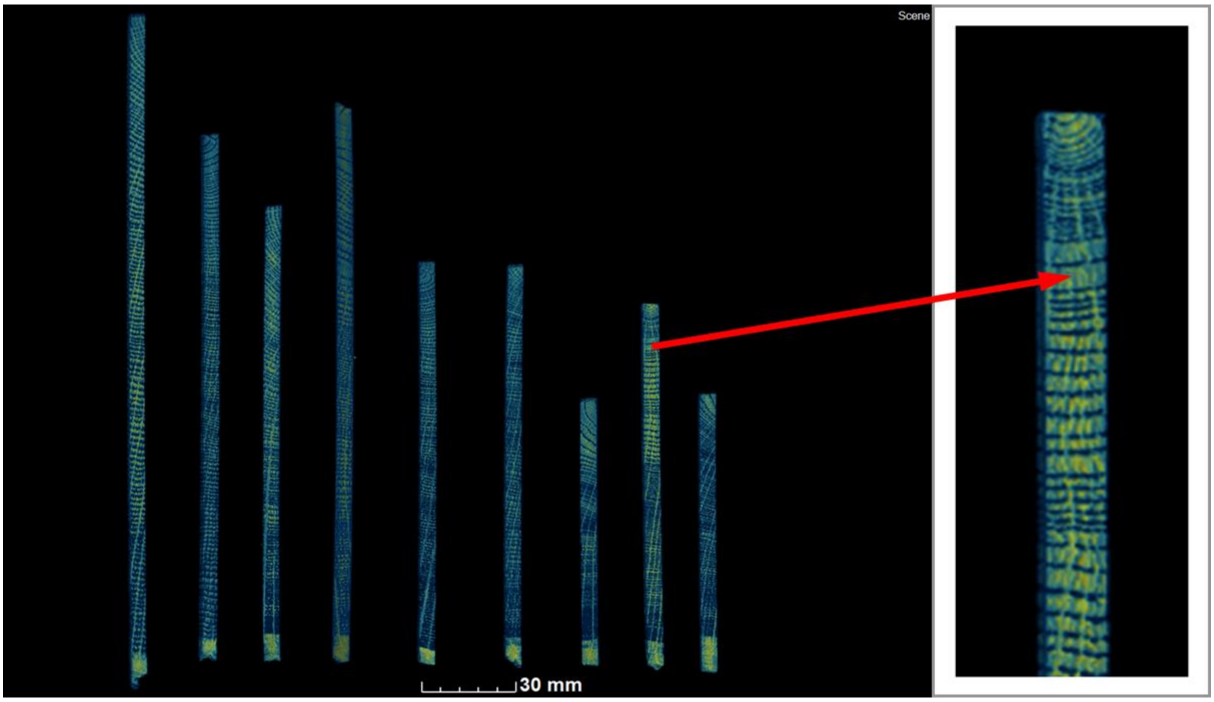

Figure 1: CT-density distribution of nine oak radius from yield classes 1 (3 left samples), YC 4 (3 middle) and YC 5 (3 right). CT-scaling: from blue (low density) to yellow (high density).

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PERCEPTIONS OF SWEDISH ARCHITECTS AND CONTRACTORS FOR THE USE OF BIO-BASED BUILDING MATERIALS

Emilia Markström[1,2], Anders Bystedt[2], Magnus Fredriksson[1], and Dick Sandberg[1]

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Keywords: architecture, energy-efficiency, passive housing, timber construction

To cope with the upcoming transition to a bio-based society it is necessary to implement wood and wood-industry residues to a higher degree for replacing fossil-based materials. Construction and housing is one of the largest users of materials. In Europe, the building sector accounts for 40% of the total use of materials and energy, 40% of the greenhouse gas emissions, and 40% of the waste (the 40-40-40 rule). The need to reduce the whole-life energy consumption of buildings has highlighted the role that materials based on forest or agricultural biomass can play in such structures. When buildings have net zero energy consumption, a major part of their overall environmental burden consists of their embodied energy and the associated greenhouse gas emissions [1]. Compared with other materials, the energy needed to convert materials based on forest or agricultural biomass into the final product is significantly less.

Architects and contractors are key-decision makers for the selection of materials in the construction sector, and how they perceive wood as a building material is therefore of high importance for the replacement of fossil-based materials with wood.

The present study is intended to contribute to the understanding of the probability that bio-based materials are chosen in residential buildings and to the understanding of drivers and barriers for an increased use of bio-based building materials. This was a pre-study based on Swedish architects and contractors, and it will be extended to the European level.

The methodological approach rests on the theory of planned behaviour (TPB) [2] and on innovation theories [3]. TPB was used to evaluate the probability that bio-based materials will be selected and innovation theories were used as tools to interpret the results. Since the focus of the study was on capturing attitudes, perceptions, and decision-making processes, a qualitative approach with semi-structured interviews was used.

Table 1 summarizes the answers from architects and contractors based on the thematic questions. More detailed information about the study can be found in [4].

The majority of the respondents mainly thought of wood and wood-based products as bio-based building materials. The conclusions should be read with this in mind. The results indicate that the probability of bio-based materials being chosen in apartment buildings in Sweden is currently low, due to the lack of incentives to select bio-based materials, a general lack of knowledge of these materials, the conservative nature of and the limited profit margins within the construction industry, the somewhat negative attitude towards bio-based materials among contractors, the existence and spread of bad examples, risks associated with introducing new materials, and issues regarding durability, fire requirements and moisture.

A clear difference between architects and contractors was that the architects had a more positive attitude towards bio-based materials and a more open mind regarding the introduction of innovations, whereas the contractor perceived a higher level of behavioural control. However, the results indicate that the attitude among the contractors has started to change in a more positive direction. Other main findings were that green building certificates, if altered, were seen as a promising way to increase the use of bio-based materials as well as other environmental standards and regulations.

Table 1: Summary of the answers from architects and contractors about the use of bio-based building materials.

<table>
<tr><th></th><th>Architects</th><th>Contractors</th></tr>
<tr><td colspan="3">Intention</td></tr>
<tr><td>Attitudes towards bio-based materials</td><td>Positive
Perceived a sceptical attitude within the construction industry but also noticed an increased interest</td><td>Mixed
Indications of increased interest of selecting bio-based materials</td></tr>
<tr><td rowspan="2">Attitudes towards innovations</td><td colspan="2">The industry is reluctant to introduce innovations, mainly due to earlier bad experience
Uncertainties regarding quality over time are seen as one major risk</td></tr>
<tr><td>Most of the architects can consider being the first to try an innovation</td><td>Most of contractors preferred that someone else first try an innovation</td></tr>
<tr><td>Career effects</td><td colspan="2">Knowledge and experience of bio-based materials is valued within the construction industry to some extent</td></tr>
<tr><td colspan="3">Perceived behavioural control</td></tr>
<tr><td rowspan="2">Possibilities to impact material selection</td><td colspan="2">Developers are perceived to have the greatest impact regarding the interior</td></tr>
<tr><td>Can influence the exterior
Mixed opinions regarding possibilities of influencing the amount of bio-based materials used</td><td>Large influence on the selection of frame material
Perceived that they can impact the amount of bio-based materials used</td></tr>
<tr><td>Knowledge and experience</td><td colspan="2">Knowledge of bio-based materials in the industry is regarded as low
Indications of limited experience with bio-based materials</td></tr>
<tr><td colspan="3">Drivers and barriers</td></tr>
<tr><td rowspan="2">Drivers</td><td colspan="2">Currently weak drivers; green building certification to some extent and local strategies for wood construction in some municipalities
Important future drivers:
• Stronger incentives in green building certification
• Demands and regulations regarding environmental issues
• Evidence that the materials maintain a certain quality over time
• Increased knowledge of bio-based materials, an increased discussion about these materials and better access to information about them
• Highlight relative advantages
• Product and process development</td></tr>
<tr><td></td><td>Important future drivers:
• Client demands
• Proof of cost-effectiveness</td></tr>
<tr><td rowspan="2">Barriers</td><td colspan="2">Low incentives for choosing bio-based materials
Existence and propagation of bad examples
Fire requirements
Conservative industry</td></tr>
<tr><td>Lack of knowledge among building engineers and architects
Insufficient marketing of bio-based materials</td><td>Want to streamline the use of currently used systems
Acoustic requirements</td></tr>
</table>

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LIFE CYCLE ASSESSMENT OF WOOD WOOL CEMENT BOARD USING RECYCLED WOOD

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Keywords: LCA, LCI, wood wool cement board, recycling

This paper presents a study on the environmental impacts of wood wool cement board (WWCB) production through a comprehensive life cycle inventory (LCI) database for its manufacture. It was developed by a sensitivity analysis of the raw material sources using the life cycle assessment (LCA) methodology. A cradle-to-gate LCA was performed considering logs obtained during forest thinning as the conventional wooden resource versus the recycling of wood building waste. The sensitivity analysis was carried out taking into account the influence of the percentage of recycled wood.

WWCB consists of a wood strand component that is bonded within an inorganic mineral matrix as concrete. It is produced in slabs, tiles, and building blocks for thermal and acoustic insulation of roofing, walls, and flooring. It is weather and fire resistant and has good thermal inertia and compression strength. Production volume of these panels is low compared to the resin-bonded wood composites. However, the potential market for these products is significant. A comparative environmental impact assessment of inorganic and resin bonded products has still not been investigated due to a lack of data.

Aged wood waste often out performs virgin wood during production of WWCB. Degradation of wood fiber hemicellulose improves wood-cement bonding strength [1]. WWCB producers have interest in utilizing this resource but don't use wood waste feedstock due to the presence of pollutants, the shape of the timber, and its dimensional incompatibility with processing equipment and technologies.

Life Cycle Assessment

LCI inputs and outputs are listed in Table 1. The functional unit adopted was 1 kg of the WWCB produced. The mass unit allows a better comparison with other insulating materials. LCA assumptions are based on information provided by industrial partners and professional judgment. The factory site in Northeast Italy is considered representative of the state of the art with 100 thousand m^3 per 40 million kg of final product. The system boundaries take place from log transport, wood working, mixing, board formation and shaping, drying and finishing operations, as well as the activities associated with the production of the main materials, energy, and transport applied in the process. Instead of virgin wood, it has been proposed to use recycled timber waste of carpentry and building demolition. This has been possible by a new demolition collection centre 40 km from the factory.

All the data related to the inputs and outputs were obtained by on-site measurements during a 2 year period. Secondary data were provided by Ecoinvent v3.1 and JRC ILCD databases. The impact assessment was performed using the ReCiPe Midpoint (H) v1.12 method and processed by SimaPro 8.0.5 software.

Table 1: LCI of 1 kg of wood wool cement board.

Inputs		Outputs	
Water, groundwater consumption	0,28658 kg	Methanol	0,00627 g
Industrial wood, softwood, under bark, u=140%, at forest road	0,41731 dm³	Dimethyl formamide	0,00208 g
Portland cement, at plant	0,40647 kg	2-Butoxyethanol acetate	0,00170 g
Limestone, milled, loose, at plant	0,14997 kg	Benzene, ethyl-	0,00015 g
Sodium formate, at plant	0,00301 kg	Isopropyl acetate	0,00055 g
Calcium chloride, CaCl2, at plant	0,00319 kg	Acetone	0,00050 g
Alkylbenzene, linear, at plant	0,00095 kg	Ethanol	0,00029 g
Packaging, corrugated board, at p.	0,00053 kg	Heptane	0,03156 g
Packaging film, LDPE, at plant	0,00014 kg	Particulates, unspecified	0,01094 g
Electricity, medium voltage, at grid	0,05505 kWh	Wood, sawdust	0,01566 kg
Heat, natural gas, at boiler >100kW	0,35113 MJ	Rejects	0,01450 kg
Transport, lorry >32t, EURO3	120,4 kgkm	Packaging waste	0,00003 kg

According to this method the most important life cycle damage category was “resources” due to the wide use of fossil fuels in cement, electricity, and sodium formate processes. Moreover, “human health” damage was affected by the high amount of particulate matter that influence “respiratory inorganics” impact. Finally, forest activities have a direct affect on “agricultural land occupation” impact of the “ecosystem” damage category.

The environmental impacts associated with virgin and recycled wood were considered according to the Ecoinvent database [2] as industrial wood and residue wood processes, respectively. The main differences between virgin logs and recycled timber are explained by the reduction of the environmental impact caused by harvesting activities. To discuss boundaries and limitations of this study, a sensitivity analysis was completed. A range of 0 % to 30 % was analysed to evaluate the effect of this assumption. Recycled waste quality requirements and production systems specifications were considered to develop the recycling management. Moreover, two life cycle impact categories show a significant affect on recycled percentage: “agricultural land occupation” and “climate change”. Figure 1 shows the variation of the results in relation to the percentage of recycled timber. Raising the fraction of recycled wood from 0 to 30% respect to virgin wood decreases the consumption of land (-13% m² yr of “agricultural land occupation”) and reduces the global warming potential (-4% CO_{2eq} to air) of “climate change” per functional unit of WWCB.

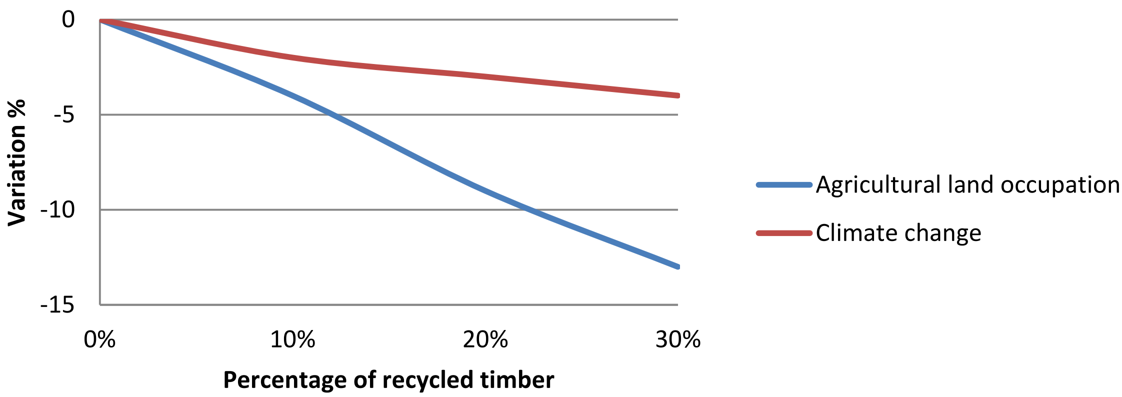

Figure 1: Variation of agricultural land occupation and climate change versus recycling.

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PREPARING THE LIFE CYCLE ASSESMENT OF WAX MODIFIED WOOD PRODUCTS

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Keywords: Wood modification, LCA, high melting point wax

Introduction

This extended abstract discusses the use of LCA in a wood modification process. The aim is to understand better what kind of process wax modification is from an LCA viewpoint and how to make a LCA about a wax modification process. A device for wood modification was built at the Mikkeli University of Applied Sciences [1]. The device can be used for various wood treatments or modification techniques, ranging from heat treatment to impregnation. In this abstract the focus is on wax modification technology. The operating temperature of the device can be up to 200 °C and the maximum pressure is 15.5 bar. Therefore, a wide range of treatment substances can be used like waxes with high melting points. As a part of a research project, LCA tools are planned to be used to evaluate the performance of wax modified wood products.

The wax modification process and LCA

The modification process and its material and energy flows are presented in Figure 1. It should be noted that the figure represents a unit process and therefore does not include a complete product system as described in LCA standards [2].

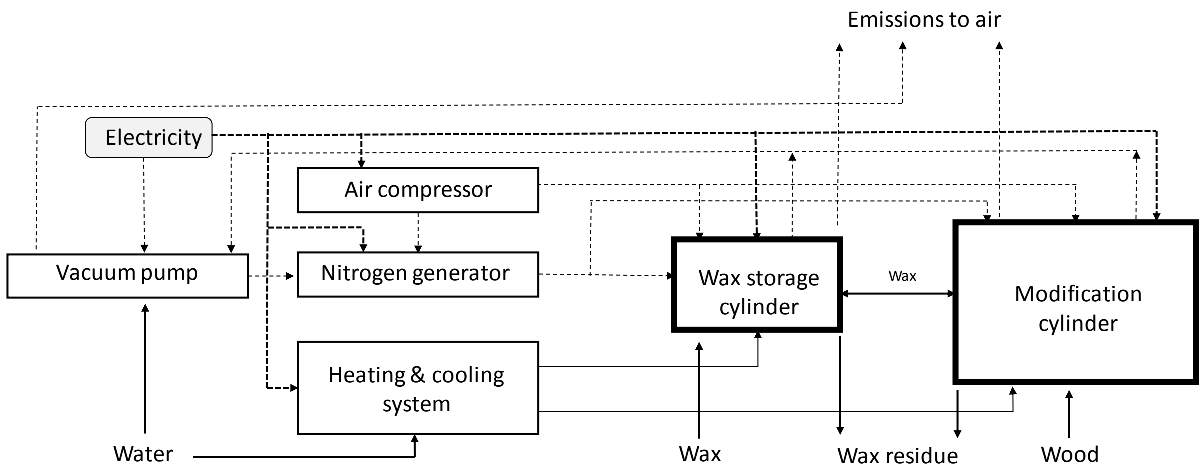

Figure 1. Wax modification process.

The process starts when a wood component is sealed in a chamber. There is an oil circulation system that both heats and cools the chamber, if necessary. The wax is melted to liquid form in a heating cylinder. The liquid wax is then pumped with air pressure, although in high temperatures non-flammable nitrogen is used. Compressed air is used to operate the valves in the system. As the pressure is lowered in the chamber, there are some emissions to the atmosphere and often some wax residue or waste is produced in the process. For all functions in the process electricity is used as well as a water cooling system and vacuum pump. The simplified system presented above is a pilot scale system. While the basic process is similar to that of a full scale industrial system, details will be different and will have an impact on the results of the LCA. For instance, the choice of energy sources, heat, and recycling of process waste. It is also important to consider how the modification process can be scaled up to a larger manufacturing process seeing as the modification is just one part of the manufacturing process.

A comparative LCA study would be a good tool to increase understanding of the environmental impact of modified wood products. Comparing untreated material provides some results, but including other materials that are commonly used in specific end uses will help to put the results in context. For example, a window frame could be used as the final product in a comparative study about the performance of modified wood products. Wooden window frames are traditional wood products, but in some markets the wood has been replaced by plastic or metal – the reason being perceived durability, costs, etc. The durability of wood windows can be improved by using durable wood species, coatings, or by modifying the raw material.

A window is a relatively simple product from the LCA point of view, as there are relatively few subcomponents: glass, some metal in the form of lock components, connectors, the frame material, and some seals. The choice of frame material has an effect on the connector and seal materials. The raw materials and production process of the non-organic frame materials are quite different compared to wood products, but on the other hand manufacturing and material data is available. The goal of the comparative study would be to evaluate the performance of window frames manufactured from different materials. Defining the boundaries and allocation procedures are not easy, as the manufacturing processes vary a lot. Also the service life and end of life stage vary considerably between different materials.

The aim in wood modification is to improve the performance of a wood product. Many promises can and have been made about the advantages of various modification procedures. While the performance may be better, the modification process itself consumes energy and in most cases some substances are also used in the treatment process. Does the improvement in the product properties justify the more complicated manufacturing process, increased costs, material and energy inputs? LCA is a valuable tool: even though it is focused on the environmental performance of the product, the approach and framework help to understand the manufacturing process better also from other viewpoints.

Acknowledgements

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END-OF-LIFE TRANSFORMATION STRATEGIES FOR BIO-BASED BUILDING MATERIALS

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Keywords: bio based materials, end-of-life transformations

According to recent reports [1], the EU market for recovered materials and waste is still underdeveloped. This is the case especially with discards originating from construction and demolition sites which generate one of the highest volumes of waste in Europe. A lot of efforts are currently directed at improving the efficient use of materials. These can be achieved by implementing the following strategies [2]:

- better project planning; ensuring greater use of resource and energy efficient products
- promoting more resource-efficient manufacturing of construction products; using recycled materials
- promoting more resource-efficient construction and renovation; reducing construction waste

Bio-based materials have the potential to produce fewer greenhouse gases, require less energy, and produce smaller amounts of various toxic pollutants along their lifecycle. The expansion of bio-based products availability and their wide utilization in modern buildings is a derivative of the Europe 2020 strategies. However, in order to successfully implement novel materials into building industry it must be demonstrated that they are significantly more favorable than the corresponding mineral and fossil-based alternatives, be technically competitive, and reasonably durable [3]. It is expected that bio-materials will play an increasingly important role in the future to assure the sustainability of the construction sector.

Sustainability aspects might be improved by selecting superior and optimal performing products. In that case the quantity of materials used for construction might be reduced as the reparation and maintenance might be postponed or even avoided. The alternative is to increase re-use and recycling options for facade materials.

The BIO4ever project is a multi-disciplinary study dedicated to fulfilling gaps of lacking knowledge on some fundamental properties of novel, bio-based building materials with a special focus on building facades. The goal is to assure sustainable development of the wood-related construction industry, taking into consideration environmental, energy, socio-economic, and cultural issues. The project promotes innovative facades made from biomaterials with minimal environmental impact and aims to improve sustainability of biomaterials by proposing alternative transformations at the end-of-use.

Among the 120 investigated materials, some of them were already manufactured with wood wastes and recovered fibres. On the other hand, extensive campaigns are planned to find the optimal end-of-life transformation for investigated materials. In addition to validating state-of-the-art methods (Figure 1), alternative trials for material transformation by using fungi and insects will be conducted. It may even be possible to convert at least some of material waste into a high protein source, seeing as at least 1900 insect species have been documented as edible [4]. As a result of these actions, bio based products and by-products of manufacturing at the end of their life may be used to generate energy and substitute fossil fuels.

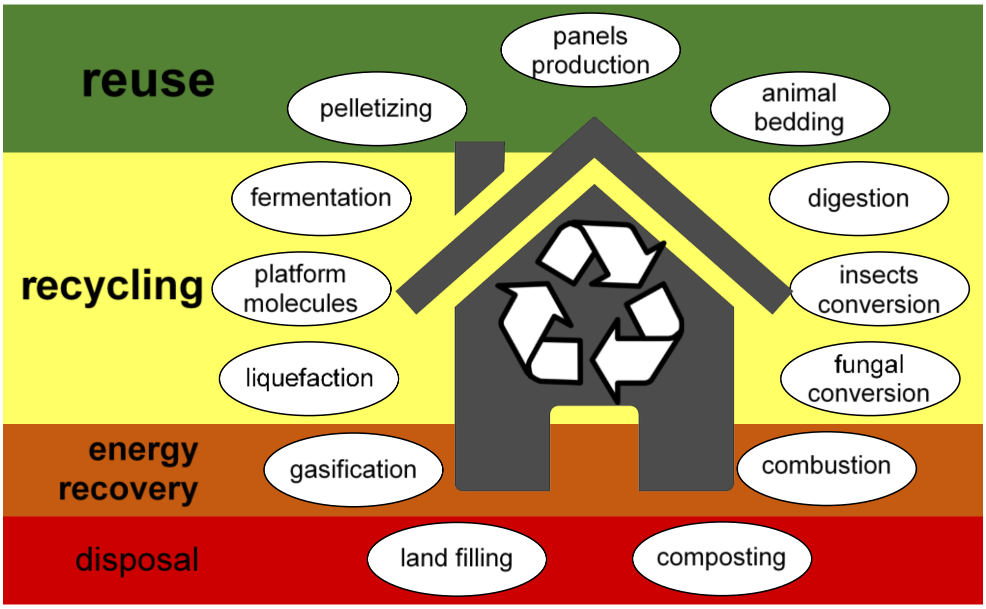

Figure 1: Standard and alternative pathways for end of life transformation of bio based wastes used for the construction sector.

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POTENTIALS AND BARRIERS TO INCREASED WOOD PRODUCTS RECYCLING IN NORWAY

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Keywords: wood recycling, potentials and barriers, climate impacts

The EU framework directive states that member states shall take measures to ensure that 70 % of construction and demolition wastes are prepared for re-use, recycling, or other material recovery by 2020. By recycling, the directive specifies that this does not include reprocessing of materials to be used as fuels [1]. Norway is not a member state, but committed to compliance through the agreement of the European Economic Area. The current situation for wood waste in Norway is however dominated by energy recovery of discarded wood products.

One important reason for wood construction and demolition waste most commonly being recovered for energy production is that there is a surplus of by-products from sawmill industries and that there is a large demand for biofuels. Especially in mid, east, and south of Norway the sawmill industry has a surplus of wood chips as by-products and are being transported increasingly long distances to Sweden for energy, but considerable amounts are still used for pulp chips, animal bedding, and as a raw material in particleboard manufacturing.

New potential for recycling of wood products could be found where forest or sawmill by-products are used today, but also by substituting fossil or mineral resources. The substituting of industry by-products does not seem rational from a national perspective, but when considering local market conditions, it could possible where demand is far away from sawmills and with local waste resources. The different kind of waste flows are classified in the Norwegian standard NS 9431 [2] and the wood related ones are shown in Table 1.

Table 1: Classification of waste according to NS 9431:2011 [2].

Waste code	Classification term	Description
1141	Clean wood	Building materials, packaging, pallets, etc. without surface treatment
1142	Treated wood	Demolition wood, transport packaging, etc. treated with paint, varnish or chemicals that does not count as hazardous waste
1143	Chips, strands, bark	Also slabs
1149	Mixed processed wood	
7098	CCA-impregnated wood	Pressure impregnated wood that contains CCA
7154	Creosote impregnated wood	

The potential uses of recycled wood in Norway for landscaping, animal bedding, and particleboard are in several cases far from the sawmill industry. In order to use wood waste in such applications, the waste flows must reach an end-of-waste state according to the European waste directive. These requirements are:

(a) The substance or object is commonly used for specific purposes;
(b) a market or demand exists for such a substance or object;
(c) the substance or object fulfils the technical requirements for the specific purpose and meets the existing legislation and standards applicable to products;
(d) the use of the substance or object will not lead to overall adverse environmental or human health impacts

These requirements have been further specified for several waste streams like glass and steel, but not for wood waste. For use in particleboard, the European Panel Federation has made standard delivery conditions for recycled wood [3] and thus should be sufficient criteria for that end-of-waste state reached for recycled wood to be used in particleboards. These criteria could also be sufficient for other uses such as landscaping and animal bedding. After market conditions, the lack of more specific quality guidelines for different uses of recycled material is believed to be one important barrier for increased recycling of wood in Norway.

Previous studies assessing the climate impacts of recycling wood for particleboard instead of energy recovery have found that energy recovery is beneficial for climate when it is substituting fossil energy [2]. However, this assessment does not evaluate the timing of greenhouse gas emissions from biogenic sources of which have been found to be of major importance [5]. Including such effects in climate impacts in life cycle assessments (LCA) could change to favor recycling and lead to a higher focus on cascade use of wood resources. The inclusion of harvested wood products (HWP) in national greenhouse gas inventories could also lead to possible financial benefits if it is sufficiently included in emission trading schemes.

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CURRENT STATE OF THE DISCUSSION BETWEEN PEF AND EPD AS THE PREFERABLE LIFE CYCLE ASSESSMENT SCHEME FOR WOODEN CONSTRUCTION PRODUCTS

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Keywords: wooden building products, life cycle assessment, EPD, PEF

On one hand, harmonized standards for the assessment of sustainability of construction products and buildings have been developed since 2006 by CEN TC 350. These standards are used as the methodological structure for Environmental Product Declarations (EPDs) for construction products. On the other hand, DG Environment started an initiative called Product Environment Footprint (PEF) in 2010 together with the Joint Research Center (JRC), since the European Commission considered EPDs as too difficult for the communication with the consumer. Both sustainability assessment schemes refer to ISO 14040 and ISO 14044 as the fundamental base for life cycle assessment (LCA). Since the European Commission insists on harmonization of these two schemes and its focus is laid on PEF, CEN TC 350 got the chance to modify its method with huge impact on the construction product industry with numerous EPDs already realized.

Environmental product declarations

EPDs are a reservoir for product environmental data, used for building assessment and certification. The main part of an EPD is a LCA of a building product. Meanwhile EPDs are established in Europe as the main source for environmental data of building products. Product category rules for wood and wooden products have been developed on European and national levels with reasonable and satisfying content.

Product environmental footprint

The PEF label and method are still being developed in the second stage of a pilot phase with several different products, mainly food, but with insulation material as the only construction product as well. Nevertheless, development of PEF is part of the flagship initiative of the European 2020 strategy “A resource efficient Europe”. From these pilot product calculations, product category rules (PCR) are derived. Since wood and wooden products are not part of this pilot phase, a PEF wood PCR still does not exist.

Different indicators and methodologies in EPD and PEF

Although the methodology of PEF is still under development, it can be stated that already existing parts are not consistent with the already finished and standardized EN 15804 methodology. Not only are different environmental indicators used, but even the calculation methods behind the same indicators are different as shown in parts of Table 1.

Table 1: Excerpt of a list of environmental indicators of EPD and PEF methodology.

EPD/EN 15804			PEF		
Impact category	Impact assessment method	Source	Impact category	Impact assessment method	Source
Global warming	CML – IA v3.9	Leiden 2010	Climate change	Bern model	IPCC 2007
Acidification	CML – IA v3.9	Leiden 2010	Acidification	Accumulated exceedance model	Seppälä 2006, Posch 2006
-*)	-	-	Ionizing radiation HH	Human health effect model	Dreicer et al. 1995
-	-	-	Land use	Soil Organic Matter model	Milà I Canals et al. 2007
Photochemical ozone creation	CML – IA v3.9	Leiden 2010	Photochemical ozone formation	Lotus-Euros model	Van Zelm et al. 2008

*) no indicator for this environmental impact in EPD/EN 15804 system

Wood related aspects in PEF methodology development

Certain aspects of life cycle analysis are not yet completely developed in the PEF scheme. Therefore, so called position papers are elaborated and discussed within PEF product category forum members. One of these papers, called "Guidance and requirements for biogenic carbon modeling in PEFCRs," [1] seems to completely ignore already existing consolidated research about carbon content of products and its impact on climate change. Standards such as PAS 2050[2], ISO 14067[3], or EN 16485[4] obviously are not taken into account. Otherwise, all emissions emitted within three centuries are considered as temporarily stored and shall not be considered in the calculation of the default EF impact categories but may be included as "additional environmental information". Biogenic carbon emitted later than three centuries after its uptake is considered as permanent carbon storage.

State of the discussion PEF-EPD

The European Commission seems to insist on a single assessment scheme for products. Therefore, CEN TC350 puts efforts into a harmonization of EN 15804 with PEF methodology. The difficulty appears based on the fact that results of construction products in EPDs have never been foreseen to be compared on a product level, but serve as a basis for construction assessment and comparison on the building level. On the contrary, the main characteristic of PEF is a single number value, derived from all calculated indicators with the aim to be compared with a benchmark, obtained from a certain number of assessments of products from the same product category. It still seems to be a long way towards a satisfying solution for environmental impact assessment of all products.

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MODIFICATION METHODS OF HORNBEAM (*CARPINUS BETULUS* L.) WOOD IN ORDER TO ACHIEVE HIGH-QUALITY PRODUCTS

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Keywords: hornbeam, heat treatment, acetylation, wood modification

Common hornbeam (*Carpinus betulus* L.) covers 5.22 % of the forested area in Hungary (about 111,806 ha). It is a subsidiary tree next to beech and sessile oak and it is usually harvested after 60 to 80 years. The trunks tend to be curved, twisted, and ridged [1]. Hornbeam wood is greyish-white – lightness (L*) of 82.20, red/green value (a*) of 3.99, yellow/blue value (b*) of 18.20 [2]. From a cross sectional view, wavy annual rings and diffuse pores can be observed. It has a very dense structure and high proportion (66%) of very long (2.3 mm on average) and thick-walled fibers. It is not resistant to fungi and insects and is categorized as class 5, according to EN 113. On soil contact it will completely degrade in 2 to 3 years and if it is exposed to sunlight it will turn grey in 3 to 5 months. It has high equilibrium moisture content (EMC), fiber saturation point, and volumetric swelling which makes it dimensionally unstable in areas with changing climates. Its high density, compression (CS), and bending strength (BS), Brinell hardness, and modulus of elasticity (MOE) are perfect for applications where hardness and wear-resistance are key factors. The utilization of hornbeam is problematic as defects in the wood make it difficult to process and the low dimensional stability and durability narrow the possible fields of use to indoor applications. For these reasons hornbeam is mainly used as firewood in Hungary (50 to 60 %) [1]. The aim of this study was to discuss the current state of hornbeam modification and to make suggestions for further research which could widen its usage.

Thermal modification of hornbeam was the subject of several studies in Turkey [3,4] and Iran [6,7] where the physical and mechanical properties were evaluated according to different temperatures (130 to 210 °C) and treatment times (3 to 12 hours). All papers identified a reduction of physical and mechanical properties while increasing the treatment temperature and duration. These results were confirmed by chemical analysis [5].

At the Institute of Wood Science in Sopron, the heat treatment of hornbeam has been the topic of several scientific papers since 2006. According to these studies, the physical properties improved as the EMC decreased from 11.4 % to between 4.5 % and 8.5% [8-13], the shrinking rate decreased from 18.5 % to between 7.5 % to 17.8 % [8-11] and the maximum swelling decreased from 114 % to 87 % [13] which all indicated better dimensional stability. The color darkened and the grain texture became more dominant (L* < 60, a* > 8, b* > 25) [8-12] but due to photo degradation specimens turned gray in the same way untreated wood does after 6 months of outdoor exposure [9-11,13]. The color stability did not deteriorate but some natural surface treatment is needed after heat treatment [9-11,13]. The material became harder, more rigid, and brittle. It was observed that the material was 7.7 % lower in density [13], had increased in CS and BS, reduced in MOE [9-11], had a 37 % to 49 % higher Krippel-Pallay hardness, slightly higher wear resistance, but 3 to 5 times lower resistance to waterjet abrasion [12]. The durability increased as supported by fungi culture laboratory tests, heat-treated hornbeam had 86 % lower mass loss [9-11], and soil contact tests classified it as Class 0-1 according to EN 252 after 6 months of outdoor exposure [13]. All of these properties depend a lot on the temperature (140 °C to 180 °C) and treatment time (2 to 6 hours).

Acetylation had not been performed on hornbeam before. A cooperation was made between Accsys Technologies (NL) and the University of West Hungary where hornbeam was acetylated under industrial conditions. The efficiency of the treatment is indicated by the weight gain of 15 % and the low EMC of 4.5 %. There was also a lower swelling rate (-60 to 82p.p.), high anti-swelling efficiency (81 % to 88 %), increased density (+ 4 % to 15 %), higher CS (+ 43 %), higher BS (+ 20 % for dry and + 93 % for saturated samples), higher MOE (+ 36 % for saturated samples), and increased hardness (+ 49 % to 68 % for dry and + 111 % to 163 % for saturated samples). It was classified as durability class 1 according to EN 113. The color changed to a greyish brown tone (L*=50.05, a*=6.97, b*=20.42) [14].

Hornbeam has much more potential to be used for more applications than it is used now. If high-quality raw material is selected and proper process parameters are chosen during the modification treatment hornbeam can have a bigger share of the wood market. Therefore, it could be a perfect feedstock for the manufacturing of parquet flooring, wood sidings, garden furniture, gates, fencing, and decking. Other modification techniques could also be tested on this wood.

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WOOD PRE-TREATMENTS: A SHORT REVIEW

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Keywords: wood, durability, pre-treatments, Life Cycle Assessment

Pre-treatments to improve wood durability, as well as their impact on Life Cycle Assessment (LCA) are important aspects to take into account in the first phase of a project. The objective of this paper is to study the effects pre-treatments have on durability of wood when compared with the possibility of reusing wood components over their entire life cycle.

Studies on how artificial/natural processes change the mechanical, physical and chemical properties of wood are undertaken in different scientific fields. The biology of wood studies the chemical and natural processes that affect it. The study is often focussed on the biochemistry and molecular composition of wood, and analyses how the various chemical processes (both natural and otherwise) affect the characteristics of the material, determining the decay of performance and the deterioration of the components. Material engineering studies the mechanical modifications of parameters (e.g. modulus of elasticity, modulus of rupture) without considering the implication that pre-treatment choices have in the building process.

In this article we provide a review of the most important pre-treatments for improving wood properties (e.g. strength, water absorption, etc.) compared with processing times and LCA parameters. In particular, we started with a literature review to gather an overall understanding about the different processes that can be applied to improve material durability, and propose a preliminary pre-treatment classification.

Durability can be defined as the material's capability to ensure adequate values of performance and functional levels over its entire lifetime. As known, wood has undesirable reactions to atmospheric agents if it's not sufficiently protected. There are different pre-treatments that can change its physical, chemical, or mechanical properties. These processes can be applied alone or in combination [1] and are subdivided into:

- Thermal pre-treatments
- Chemical pre-treatments
- Mechanical pre-treatments

Thermal pre-treatments use high temperature steam (up to 230 °C) or hot water (up to 180 °C) [5]. Laboratory tests show that these processes increase the dimensional stability of wood and resistance to moisture variations. In particular, these results were widely observed in wood panels (OSB, MDF, WPC). It is also observed that these wood preservation techniques prevent or at least reduce the possibility of attacks by biological agents such as insects and fungi [3]. A drawback of this process is a decrease in the mechanical properties of wood. Different laboratory tests have shown how both the modulus of elasticity (MOE) and modulus of rupture (MOR) steadily decrease after the thermal pre-treatment.

Chemical pre-treatments can be applied on the external layer of the material, or by means of long lasting impregnation of the components. Chemical treatments are usually administered on wood to prevent performance reduction, improve water resistance, reduce the effects of ultraviolet radiation, or decrease flammability [6][7].The property of the material to absorb chemical treatments is related to material's hydrophilicity. Treated wood must be non-toxic and recyclable at the end of its service-life [3]and this property is not always guaranteed with all chemical treatments.

Mechanical pre-treatments are used to reduce the internal moisture. Different tests were performed in China and Japan, to investigate the relation between compression rate and moisture content. There is no clear evidence of how the compression ratio, compression direction, and compression speed affect the decrease of moisture content and mechanical properties. The speed of compression should influence the efficiency of processing, and the final moisture content [8].The tests show that the material undergoes no substantial decrease of both MOE and MOR parameters.

In conclusion, besides providing indications about the different pre-treatment methods, this paper will also assess their impact on the environment. In this study we want to propose an innovative approach to understand both the advantages and disadvantages of the described treatment procedures, thus providing a novel contribution in the field of construction and wood design.

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THERMALLY MODIFIED PINE BOARDS - AN ENVIRONMENTAL COMPARISON OF PORTUGUESE AND SPANISH CASE STUDIES

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Keywords: EPD, LCA, Pine boards, Heat treatment

Thermal modification is a well-known process to improve some of the most important wood properties by using heat in a low oxygen environment. The main changes are the reduction of equilibrium moisture content, increased dimensional stability, and increased resistance against fungi [1]. As no chemical compounds or other extraneous constituents are added to wood in the process, it has a potential of being a green building material. At the moment, there are only two companies in Portugal [2] and one company in Spain producing modified wood by heat treatment [3].

The main aim of this study is to compare the environmental profile of thermally modified pine boards produced by a Portuguese and a Spanish company using the Life Cycle Assessment (LCA) methodology described in ISO 14040 [4] and ISO 14044 [5] standards and Product Category Rules for preparing an environmental product declaration (EPD) for construction products and construction services [6].

For an EPD that covers a "cradle to gate" assessment period, the declared unit is applicable instead of functional unit and in this case is 1 m^3 of thermally modified pine boards.

The system boundary for the product system is represented in a simplified way (Fig. 1).

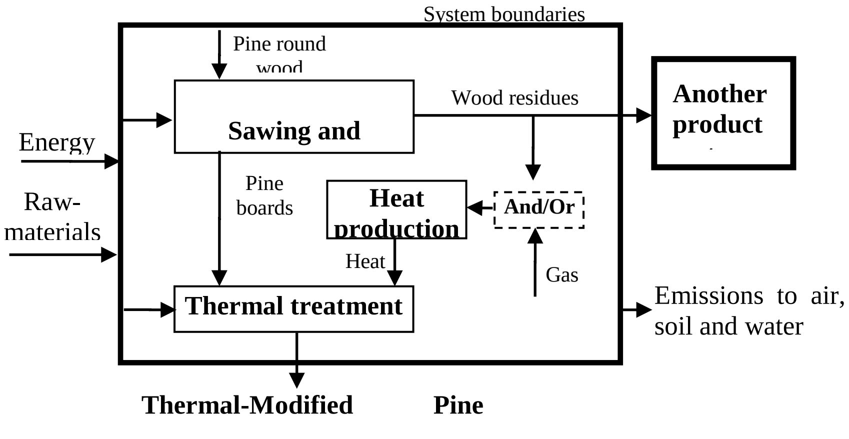

Figure 1: The system boundaries of the study.

As the sawing and planning processes of the product system deliver the products (pine boards) and co-products (e.g. bark, sawdust, chips) that can be used as raw materials for other product systems, the environmental burdens of this process are allocated to product and co-products based on their economic value.

The datasets for the products and processes included in the system boundaries are from companies and related to the year 2014. The thermal treatment used was Thermo I (intense treatment) to allow treated pine boards to be used in exterior decking or as cladding.

The inventory analysis and impact analysis have been performed using the LCA software SimaPro 8.1.0.60 [7] and its associated databases and methods. The method chosen for impact assessment was EPD-2013 V1.01 [8]. The impact categories considered were: acidification (AC), eutrophication (EU), global warming (GWP 100a), photochemical oxidation (PO), ozone layer depletion (ODP), and abiotic depletion (AD).

Fig. 2 shows the result of comparative environmental profiles of the thermally modified pine boards produced by the companies in this study.

Figure 2: Comparative profiles of the thermally modified pine boards. AC (acidification); EU (eutrophication), GWP 100a (global warming), PO (photochemical oxidation), ODP (ozone layer depletion), and AD (abiotic depletion)

The contribution of Portuguese and Spanish treated boards to climate change (CC), is almost equal. The Spanish treated boards are better than Portuguese for acidification (65%), eutrophication (52%), ozone layer depletion (87%), and abiotic depletion (61%) with the opposite being true for photochemical oxidant formation (66%).

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WOOD LIQUEFACTION – AN ALTERNATIVE WAY FOR END OF LIFE TRANSFORMATION OF WOOD WASTE

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Keywords: wood waste, liquefied wood, spectroscopy, non destructive evaluation

Various wood products have become more frequently re-used, recycled, and discovered as raw materials for platform molecules. Recycled wood products are in most cases made from post-consumer and post-industrial resources. Wood wastes must be cleaned and processed to remove any contaminants and to reduce the particle size. After these processes, this material may be used to manufacture a range of high quality products for different markets. One of the possible alternative methods of the management of lignocellulosic waste materials is their liquefaction. The goal of this research was to evaluate the possible transformation of various wood wastes by means liquefaction.

The raw materials investigated in this study included mixed hardwood/softwood sawdust, bark, standard pine, and beech particles. These materials were characterized with two complementary non-destructive methods, Fourier transform near infrared spectrometer (FT-NIR) and X-Ray fluorescence spectrometry (XRF).

A VECTOR 22-N FT-NIR produced by Bruker Optics GmBH was used to make spectral measurements between 4000 cm^{-1} and 12000 cm^{-1}. The spectra pre-processing included computation of derivatives and vector normalization. Derivatives were calculated according to the Savitzky-Golay algorithm (2nd polynomial order, 17 smoothing points). OPUS 7.0 software package (Bruker Optics GmBH) was used for data processing and mining.

The same samples were also measured using the portable XRF, X-MET5100 (Oxford Instruments plc), in order to detect contaminations. The X-ray tube of the instrument was energized with a voltage of 45 kV and a current intensity of 40 μA. Each sample was scanned for 60 seconds. These parameters were selected to meet a reasonable level of accuracy and ensure approximately 300.000 interior counts for each average value.

The raw material samples were then processed by liquefaction according to the protocol as previously described by Janiszewska et al. [1]. The liquefaction reaction was carried out at an elevated temperature of 130 °C with a mixture of solvents from polyhydroxyl alcohols (glycerine and propylene glycol), and p-toluenesulfonic acid as a catalyst. The products of liquefaction were then characterized using the techniques previously described.

XRF analysis did not find the presence of any harmful contaminants (such as heavy metals) in any of the experimented materials, including wooden waste. It confirmed that those materials have a high suitability for additional conversion at the end of their life cycle.

The spectral analysis in the NIR range was measured to screen for the chemical composition. Multivariate data analysis was performed in addition to standard spectra interpretation. Figure 1 presents Principal Component Analysis (PCA) of raw materials (left) and liquefied wood products (right). It is evident that all the raw materials can be easily distinguished before liquefaction; however after the transformation process the same products become more homogenous from the chemical/spectroscopic point of view. This suggests that the type of wood waste used for liquefaction has relatively little effect on the resulting product. It seems that any kind of available wood waste might be used therefore as a primary material for liquefaction. The current work is focused on the investigation of liquefied wood additions on the derived product (particleboard) properties.

Raw materials Liquefied wood products

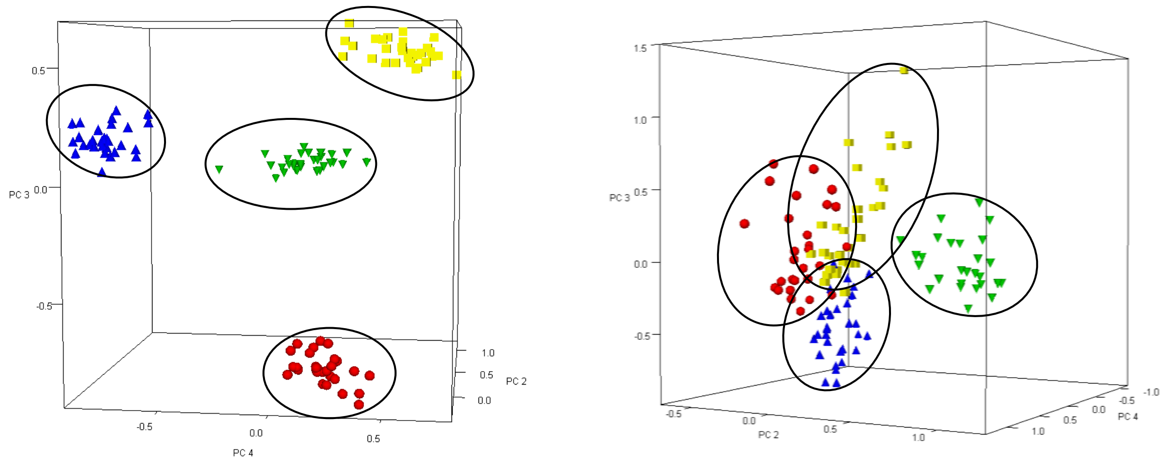

Figure 1: PCA analysis of raw materials used for preparation of liquefied wood (left) and liquefied wood products (right). Note: red = beech wood chips, yellow = pine wood chips, green = bark, blue = mixed hardwood/softwood industrial sawdust.

Both analytical methods used in this study proved to have a great potential for quality evaluation of both raw resources and products of their liquefaction. These allow for non-destructive characterization of various materials at a low cost and within a very short amount of time. Liquefaction of wood and the derived products possess a great potential for practical implementations into various bio-resources converting industries.

Acknowledgments

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ELASTIC PROPERTIES OF THERMOS-HYDRO-MECHANICALLY MODIFIED BAMBOO (*GUADUA ANGUSTIFOLIA KUNTH*) MEASURED IN TENSION

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Keywords: Bamboo, *Guadua angustifolia* Kunth, densification, thermo-hydro-mechanical treatment, engineered bamboo products, cross laminated panel, non-wood forest product.

Introduction

Guadua angustifolia Kunth (Guadua), a tropical species of bamboo, was subjected to thermo-hydro-mechanical (THM) treatments that modified its microstructure and mechanical properties. A THM treatment was applied to lengthwise-cut strips of Guadua without their inner membrane and cortex with the aim of tackling difficulties in the fabrication of straight edged standardised bamboo structural products, and to gain a uniform fibre density profile that facilitates prediction of mechanical properties for structural design. Dry and water saturated Guadua samples (Samples B and C, respectively) were subjected to THM treatments. Sample C was pre-soaked in water for 24 hours prior to the THM densification. The process started with a 10-minute period to allow for plasticisation of the specimen where both pressure and temperature increased to about 6 MPa and 150 ºC. The temperature and pressure were maintained for 10 minutes during the densification stage followed by cooling with a steady drop in pressure. The left side of Figure 1 illustrates the treatment applied with details provided in Figure 2. A densified and fairly homogenous material hereafter referred as to densified Guadua strip (DGS) was obtained. Furthermore, as shown on the right side of Figure 1, Sample C had higher density and fibre content per unit area with little cell damage. This is a desirable feature of densification treatments applied to other cellulosic materials, e.g. wood [1].

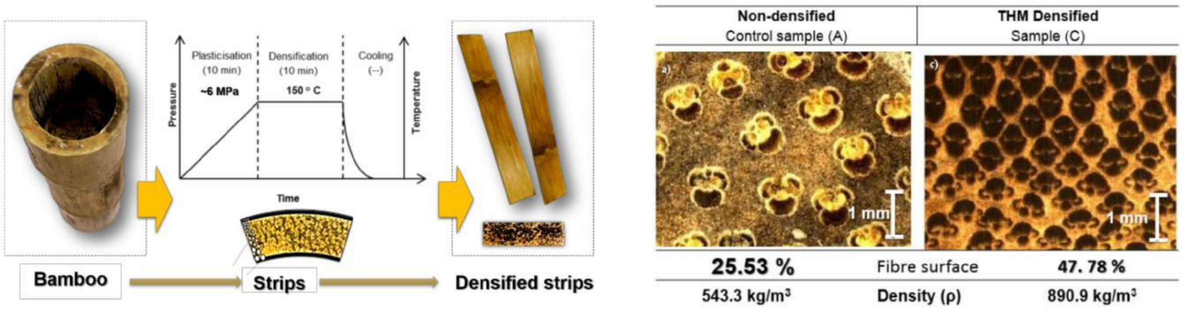
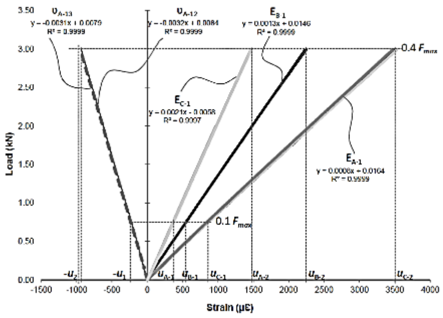


Figure 1: Left: Diagram of the THM treatment applied to Guadua; Right: Optical microscopy images of samples A and C with results of density and fibre area analysis with Image J.

Mechanical properties of small clear specimens of THM DGSs were evaluated by testing in tension and compared to the results of the same test on control sample A. Samples were tested in the elastic range (Figure 2-left) to determine their Modulus of Elasticity (MOE) and Poisson's ratio values. Testing results are presented in Figure 2 (right).



Guadua angustifolia Kunth		Mature 3-5 years old		Section: Middle part of the culm
		Sample A Control (non-modified)	Sample B TM + Dried	Sample C THM + Dried
	Time	0	20 min	20 min
	Pressure	0	6 MPa	6 MPa
	Temperature	0	150º C	150º C
	Compress. Set (C)	0	46.08%	42.51%
	Oven dried density*	543.3 kg/m³	814.6 kg/m³	890.9 kg/m³
			Testing values	
$E_{1,t}$	Mean (GPa)	16.88 ± 0.33	22.80 ± 0.73	30.72 ± 0.43
	CoV	2%	3.20%	1.4%
	Spec. Stiffness	31.06 m²/s²	27.99 m²/s²	34.49 m²/s²
υ_{12}	Mean (GPa)	0.28 ± 0.01	0.33 ± 0.01	0.26 ± 4.20E-03
	CoV	3%	4%	2%
υ_{13}	Mean (GPa)	0.30 ± 0.02	0.33 ± 0.02	0.09 ± 0.02
	CoV	5%	5%	18%

Figure 2. Left: Typical initial load-strain graphs; Right: Consolidated testing results.

Results and discussion

As seen in Figure 2 (right), results for the MOE longitudinal to the direction of the fibres measured in tension ($E_{1,t}$) for sample C showed an increase of almost two fold compared to the value of the control sample (A). Thus, the specific stiffness for THM treated Guadua has also increased. Despite the significant reduction in the radial Poisson's ratio (υ_{13}) for the water saturated sample
(C), no further variation in the Poisson's ratio as a result of densification was observed for control (A) and densified dry (B) samples. υ_{13} and υ_{12} are very small and less precisely determined due to their high scattering of results; similar issues on the determination of the Poison's ratios of wood in compression were found in research conducted by Ling *et al*. [2]. MOE results of non-treated samples of Guadua (Sample A) obtained from the testing programme (Figure 2) are in accord with those reported in the literature for round and small clear specimens of Guadua and other bamboo species [3]. Furthermore, the coefficient of variation (CoV) for the obtained results is in the range of variation for the mechanical properties of clear wood; as defined by the Wood Handbook [4] CoV values for the modulus of elasticity of wood measured in tension parallel to the grain can reach up to 25%.

Conclusion

The significant increase in the MOE values for sample C indicates effective plasticisation of Guadua resulting in DGSs with a flat densified profile and improved mechanical properties. The achievement of a dimensionally stable bamboo product with a uniform density by straight-forward THM modification processes is key for developing high value added products that can benefit from the high stiffness achieved by the densified Guadua strips (DGS) alone or in combination with other timber products. Furthermore, these high added value bamboo products can potentially lock carbon for long periods of time and help reduce the increasing pressure on wood forest resources.

Acknowledgements

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INFLUENCE OF STEAMING AT LOWER TEMPERATURES ON PERMANENT FIXATION OF COMPRESSIVE DEFORMATION OF DENSIFIED WOOD

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Keywords: wood densification, thermo-hydro-mechanical treatment, fixation of deformation, shape memory effect, compression set recovery

Introduction

The technology of wood densification that improves mechanical properties has been known for decades. The utilization of densified wood is limited due to the problems with dimensional stability in wet conditions. The deformation produced during the densification process is not stable and recovers almost totally when re-moistened and heated. This phenomenon is known as shape memory [1] or compression set recovery [2].

Compressed wood can be stabilized by high temperatures but mechanical properties are decreased and the material becomes brittle [3]. High temperature together with low humidity primarily reduces wood hygroscopicity and complete fixation can be unreachable [1]. Shape memory can be eliminated faster or at lower temperatures if the material is treated by saturated steam [2]. For example, complete fixation can be reached in 20 min at 180 °C or 4 min at 200 °C [1].

The process with lower temperatures is more suitable for thick material. It takes more time but the modification of surface layers is less different from the middle and the impact on mechanical properties is reduced. To avoid degradation of cellulose chains the temperature should be under 120 °C [4]. If the temperature is not higher than 100 °C the steaming can be carried out at the atmospheric pressure. This could be an advantage in the industrial process.

Materials and methods

This research focuses on complete elimination of the memory effect by treatment in saturated steam at a temperature of 90 °C. It is based on experimental data of compressed spruce specimens that were published by Navi and Sandberg [1].

In the first step, a model of steaming times for temperatures 80 °C to 200 °C was created using the published equation [1] and the time for the selected temperature was obtained (Figure *1*).

In the second step, the experimental data for 140 °C [1] were analysed and a new model was prepared. The model that describes the influence of steaming time on the compression set recovery was adapted for a 10-day-process at a temperature of 90 °C (Figure *2*). This model will be verified by an experiment with spruce (*Picea excelsa*) and beech wood (*Fagus sylvatica*).

Results and discussion

The model (Figure *1*) shows that the time necessary for complete fixation increases exponentially with a decreasing temperature. Steaming at 90°C could eliminate the memory effect in 10 days. The curved slope indicates that the chemical reactions are sensitive to temperature.

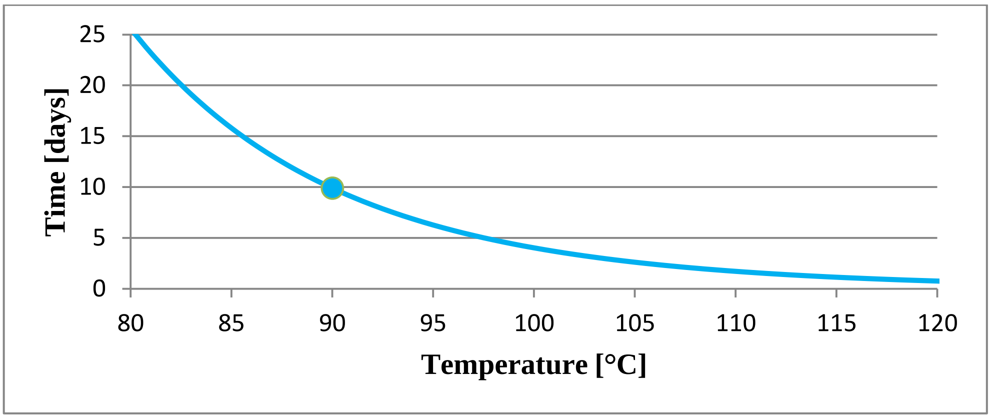

Figure 1: Influence of the steaming temperature on the time necessary to achieve complete fixation. The dot shows the time of treatment of 10 days for a selected temperature of 90°C.

The second chart (Figure *2*) shows that the most significant chemical changes occur at the beginning of the steaming process. The main reaction in this condition is the hydrolysis of hemicelluloses. It is considered to be an important factor that influences the shape memory [1].

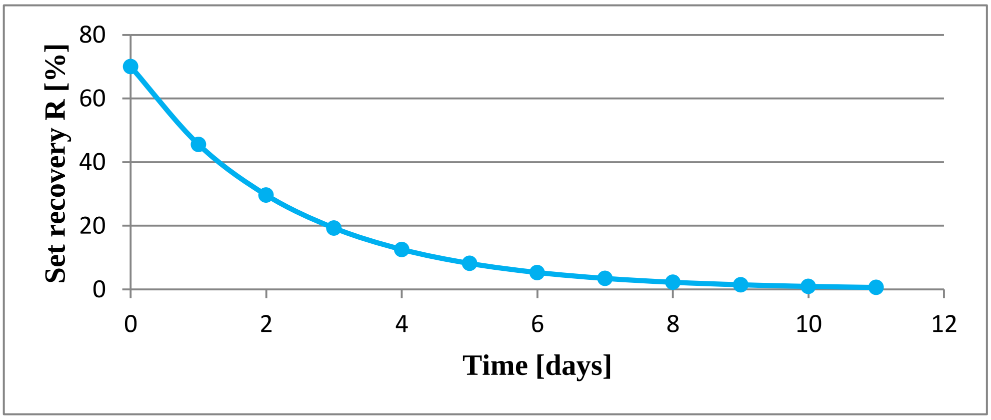

Figure 2: Influence of the steaming time at 90 °C on the compression set recovery.

Conclusion

The model data show that steaming at 90 °C can result in complete fixation of compressive deformation. This hypothesis will be verified by an experiment with spruce and beech wood. Results can help us better understand the issue of the memory effect. Further research is needed to define the chemical changes that are responsible for the stabilization.

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HARDNESS OF THERMALLY MODIFIED ASH DETERMINED BY STATIC- AND ACOUSTO-DYNAMIC METHOD

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Keywords: ash, thermal modification, hardness, acousto-dynamic method

Recently, domestic thermally treated wood has been successful in supplementing or substituting tropical wood species used for flooring in harsh environments and service conditions. In this case high demands on hardness and density of wood flooring exist, where high requirements exist also for dimensional stability, durability, surface and aesthetic properties, as well as acoustic properties.

The aim of this study was to analyze changes of hardness of ash boards (*Fraxinus excelsior* L.), used for outdoor flooring applications, after common industrial heat treatment in unsaturated steam conditions [1]. Two groups with 30 wood flooring boards (20 mm × 50 mm × 30 mm) from untreated (C-control) and heat treated wood (HT) were prepared by random sampling from a flooring company warehouse. After 1-month of conditioning (20 °C, 50 % RH) the standard Brinell method (HB) [2] was applied using the ZwickRoell predefined software procedure (Zwick Z005). In addition to measuring position, an acoustic-dynamic hardness measurement was applied, by equipping of relative size impression method (RSI) with impact sound measurement. The latter method used a free falling steel ball (h = 1.5 m, mass = 110 g) through a tube (Φ = 35 mm). The mean impact sound pressure (P_{avg}) was determined when the ball struck the surface of the specimen (microphone PCB 130D20, NI-9234 DAQ-card, LabView 8.0). ImageJ software was finally used for every diameter of ball impression at Brinell- (D_B) and free fall measurement (D_D).

This study confirmed a significant and expected decrease of wood density (Δρ = -12.7 %) after heat treatment to 597 kg/m^3 [3] which caused a reduction of mean hardness from 29.2 N/mm^2 to 28.1 N/mm^2 (ΔHB = -3.8 %) (Tab. 1).

Table 1: Mean Brinell hardness (HB) and density (ρ) of untreated and heat treated ash wood (CV% - coef. of variation)

Group	HB [N/mm^2]	*CV%*	ρ [kg/m^3]	*CV%*
Untreated	29.2	*11.9*	684	*9.9*
Heat treated	28.1	*19.7*	597	*13.4*

The positive relationship between Brinell hardness and wood density was found in both, treated and untreated specimen groups. Additionally, the free fall ball impression measurements (RSI-method) confirmed practical use since statistically significant dependence of wood hardness to the mean diameter of ball impression (D_D) was confirmed (Fig. 1).

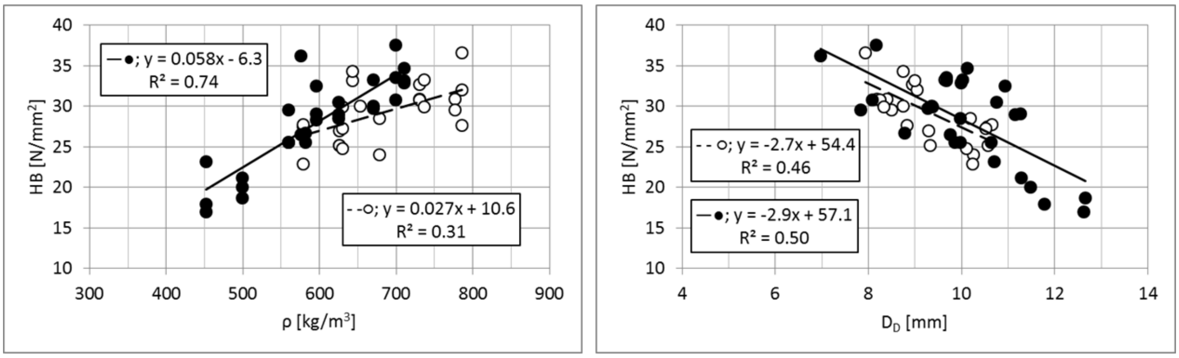

Figure 3 Brinell hardness (HB) of untreated (- - ○) and heat treated ash wood (—●) in relation to the wood density (left) and to the diameter of free fall ball impression (D_D) (right)

This study also confirmed the correlation between acoustic characteristics of emitted sound, as a result of energy transformation of fallen-ball at the specimen surface. Average sound pressure of the emitted impact noise was negatively correlated with size of impression of the fallen steel ball (D_D) at both tested groups (Fig. 2, left). Consequently, the average sound pressure (P_{avg}) is related also to the hardness of wood surface (Fig. 2, right). These relationships made multiple regression modelling of dependence of Brinell hardness (HB) feasible on impression diameter (D_D) and sound pressure (P_{avg}) (Eq. 1; R^2 = 0.54):

$$HB = 9.66 - 1.13*D_D + 1.71*P_{avg} \quad (1)$$

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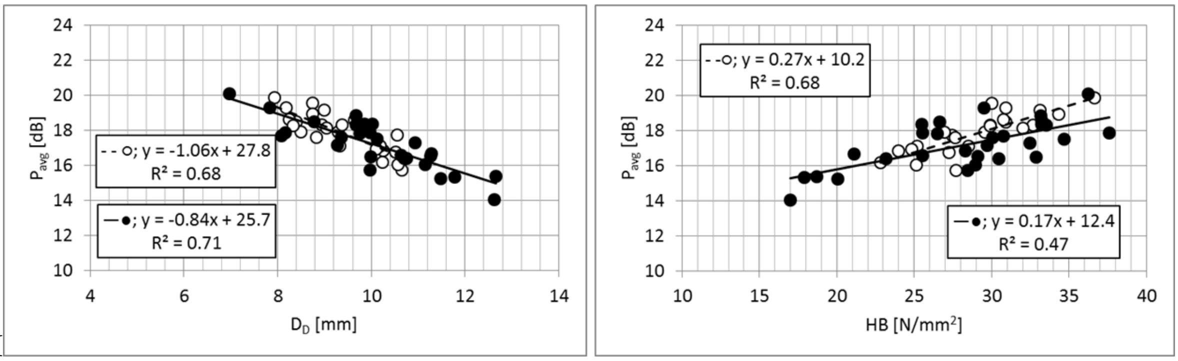

Figure 4 Sound pressure of untreated (- - ○) and heat treated ash wood (—●) in relation to the to the diameter of free fall ball impression (D_D) (left) and to the Brinell hardness (HB) (right)

Conclusions

This study confirmed the usefulness of the fall of steel ball or relative size impression (RSI) method to assess the hardness of untreated and thermally treated ash wood. Additionally, the extra sound pressure measurement of hit of the ball at the wood surface improves the Brinell hardness prediction.

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STUDY OF THERMAL PARAMETERS FROM EUCALYPTUS WOOD AFTER HEAT TREATMENT

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Keywords: Eucalyptus wood, Higher Heating Value, Mathematical Model, Thermal modified, Thermal Parameters.

Because of its fast growing characteristics and intensive biomass production [1,2], Tunisia has planted different eucalypts species in a vast reforestation program after the independence with help of the FAO. Today the product is mainly oriented for apiculture while the biomass is used for energy, charcoal production. The forest regeneration is assured by sprouts.

Within this framework, a national strategy of afforestation started since 1988, with an important reforestation objective of reaching an afforestation level of 15 % by the year 2020 [3].

The objective of this work is to evaluate the calorific properties of different eucalyptus woods (*Eu. oleosa; Eu.gilli; Eu. brevifolia ; Eu. stricklandii ;Eu.largiforens ; Eu. patellaris ;Eu. dumosa; Eu. salmonophloia,* and*Eu. brockwayi*) grown in central Tunisia. The following properties of these species were measured:, higher heating value (HHV), and gas exhaustion during pyrolysis. The measured values were then averaged and compared. The data from the present study can be used to develop a mathematical model of the thermal degradation in eucalyptus wood for industrial purposes [1,4,5,6].

Nine eucalyptus wood species from the Hajeb Layoun arboretum in Tunisia were cut from the stem at breast height for the purpose of the study. The HHV was measured in a calorimeter. The wood samples of each species were extracted and milled into powder to be oven dried. The calorific power of each sample was measured in an adiabatic calorimeter where the ignition temperature was noted. HHV expressed in kcal/kg or kJ/kg, is determined according to the method adapted by Mazghouni [3], using the following equation:

$$HHV = E(Tm - Ti - C) - (a + b)/P$$

Where E is the total water weight resulting during the reaction within the calorimetric system,Tm and Ti are the maximum and initial temperatures, respectively.C is the adjusted temperature (correction) according to heat exchange with external medium.a and $b$are the corrections related to acid formation during the combustion and to parasitical heat, respectively. $P$is the oven dried sample weight.

The inflammation measurement and heat temperatures were monitored instantaneously by a digital probe average allowing measurement from-33 °C to 1700°C±0.01°C. A sample weighting 3 kg was submitted to the combustion. Gas concentration was measured during the combustion every 10 min until obtaining the maximum rate of gas exhausted (CO and CO_2).

The HHV of wood and the ignition temperature from these species varied between 4017Kcal/kg and 4541 Kcal/kg, and between 252°C and 390°C respectively. The samples combustion temperature within the calorimeter was in the range from 463°C to 575°C. The percentage of wood ash after combustion was between 10 % and 22%. The analysis of the experiments conducted during two consecutive years showed that certain species were similar while others were significantly different. Fig.1 shows the values of the higher heating values obtained for the different eucalyptus species. The higher heating values analysis of the wood shows that it is in the range of4017kcal/kg to 4541 kcal/kg with a maximum observed with *Eucalyptus stricklandii* and a minimum observed with *Eucalyptus patellaris*.

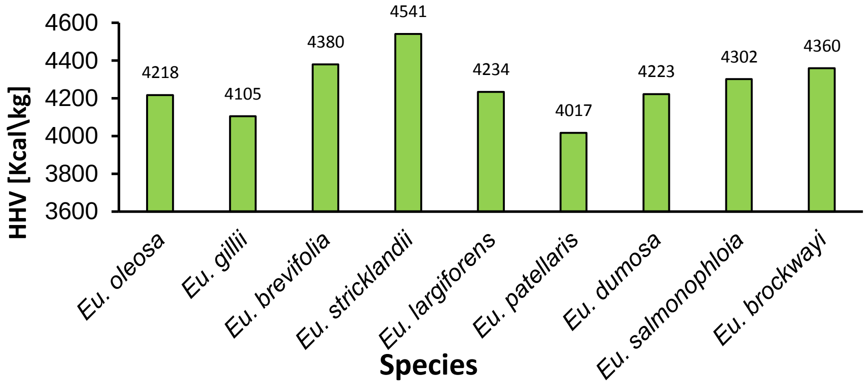

Figure 1: Higher heating values (HHV) average for different *Eucalyptus* species

Based on this study, we have obtained thermal process parameters and can use them in numerical analyses in the future. Of particular importance are the high HHV values, but also that they vary between species. The lowest HHV is 4017 kcal/kg for *Eucalyptus patellaris* and the highest HHV was 4541 kcal/kg for *Eucalyptus stricklandri*. The highest ignition temperature is recorded for *Eucalyptus Brockwayi* at390°Cwhile the lowest ignition temperature of 292 °C was from *Eucalyptus largiforens* (bicolor).

A simple studied species classification based on the temperature of the hearth of the calorimeter, puts the *Eucalyptus brockwayi* at the top with a value of 575°C and *Eucalyptus gillii* at the bottom with a value of 463°C.

The percentage of ash was the highest with *Eucalyptus patellaris* with a value of 22.83% and was lowest with *Eucalyptus dumosa*at10.53%.

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COLOUR CHANGES OF WOOD BY TWO METHODS OF AGING

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Keywords: photo-degradation, CIEL*a*b*, color stabilization, wood technology

Wood is a natural, versatile, and renewable resource used worldwide for different uses. The use of wood in indoor and especially outdoor environments in architecture and construction, introduces it to adverse weather conditions that cause natural degradation, including photo degradation [1]. Among the damage caused by weather, like surface cracking, the product's properties are modified as well as its in service durability level. The *Pinus* forest area is large in Brazil and is intended for various sectors such as bio-energy, panels, and construction.

This study sought to compare outdoor weathering and accelerated weathering methods, in order to verify the effectiveness of the exposure methods to assess product durability. Natural weathering exposure is often used to observe the photo degradation of wood, but is very time consuming, requiring months of exposure. However,using an accelerated weathering method allows one to control the environment with simulated rain, dew, temperature, and irradiation allowing one to obtain results in shorter exposure times.

This study also aimed to characterise the colour change of wood of *Pinus* ssp. exposed to the action of natural weathering and accelerated aging. To achieve this, tests were performed at an outdoor location in the state of Rio Grande do Sul, Brazil. The wood was exposed in the first summer day so that exposure to UV light was the best possible in the first months of exposure. The accelerated aging test was conducted in a Model Bass chamber, according to ASTM G 154. The standard called for a 12 hour cycle consisting of 8 hours of light exposure at 60 °C, 25 min of condensation, and 3.75 h condensation at 50 °C. For the action of natural weathering, colorimetric measurements were performed every 90 days during the period of 9 months, for the accelerated aging test, the colorimetric measurements were performed every 30 hours for a period of 240 h in order to obtain the parameters CIE L*, a*, b*, and the variation of colour between the initial and final time (ΔE) was determined measuring the sample (ends and in the middle), according to the CIE Lab standard.

The results in the accelerated aging test showed significant darkening in the first 120 hours with decrease, after displaying a degree of stabilization of the L* parameter (Figure 1 and 2). While the parameters (a* and b*) are shown growing, with a stabilization after 120 hours.

The results of the natural aging test showed a significant change with reduction of parameters a*, b*, and L* in the first 180 days, after displaying a degree of stabilization of parameters.

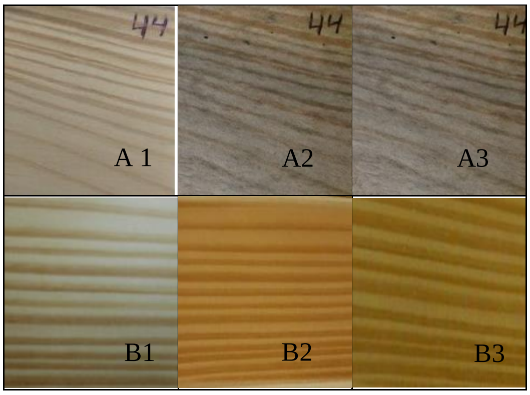

Figure 1: Effect ofcolor changes of Brazilian *Pinus* wood exposed to natural weathering (A) with 0, 90, and 270 days respective and accelerated aging (B) with 0, 120, and 240 hours respectively.

The total colour change (ΔE*) observed in accelerated aging was 17.5, while the natural weathering colour change was greater than31.8.Agreater ΔE* value means a larger amount of colour change during the test. Both methods exhibit noticeable colour variations and are noticeable by eye when compared with non-exposed specimens.

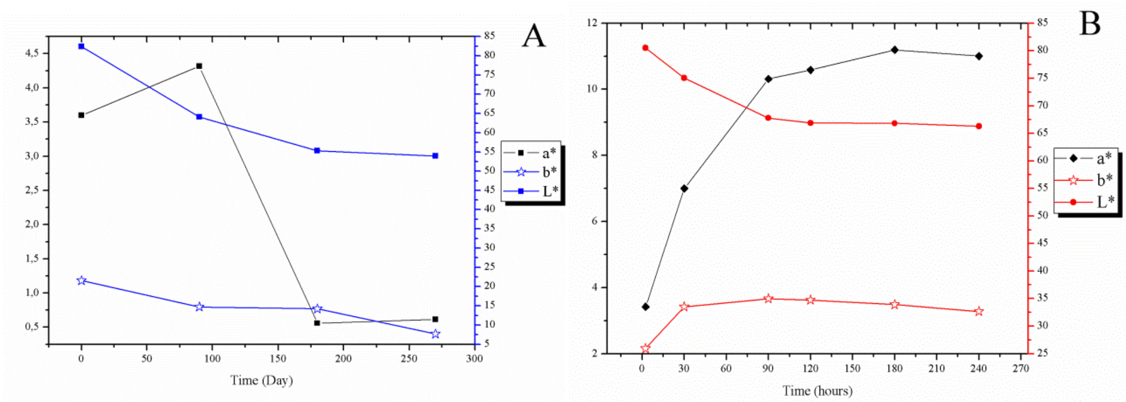

Figure 2: Changes in colour change parameters in Brazilian *Pinus* wood exposed to natural weathering (A) and accelerated aging (B).

Colour variations were observed during the time of exposure of wood for the two tests (natural aging and accelerated aging). Both methods caused significant discoloration of the wood, which showed a greyish colour as a function of exposure. Moreover, it is possible to observe that the accelerated test shows very similar results to the natural test, with the application of reduced times, this is due to high intensity UV light resulting in large discolorations of wood, with a very effective method to evaluate staining wood in outdoor service.

Acknowledgements

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DIMENSIONAL STABILITY AND MECHANICAL PROPERTIES OF EPOXIDIZED VEGETABLE OILS AS WOOD PRESERVATIVES

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Keywords: epoxidized linseed oil, epoxidized soybean oil, mechanical test, water absorption

In recent years, some vegetable oils such as linseed oil and soybean oil, have been used to preserve wood material, and contain no environmentally hazardous chemicals or chemicals harmful to humans. However, based on early studies related to vegetable oils, it was found that vegetable oils do not chemically bond with the wood structure, but rather only fill the cavities in the wood structure. This acts only to prevent the water uptake into wood. Because vegetable oils only act as a barrier to prevent water absorption, higher oil retentions (400 kg/m^3 - 600 kg/m^3) which are not cost-effective, would be needed to be effective in protecting wood.

In this study, to reactivate oil and improve the bonding ability between oil and wood components, epoxidation of vegetable oil was targeted. Thus, more cost-effective oil retention levels between 80 kg/m^3 and 270 kg/m^3 were used due to treat the wood. With epoxidized vegetable oils, oil acids are able to bond to sites normally occupied by water molecules. This study also aimed to reduce leaching of boron compounds. Boron compounds are effective wood protection chemicals which are environmentally friendly and show both insecticidal and fungicidal characteristics. However, boron compounds have some disadvantages such as higher water solubility and an inability to fix to the wood structure. With a combination of boron compounds and epoxidized oils, boron leaching and durability against deterioration were prevented.

Two different epoxidized oils were used, epoxidized linseed oil (ELO) and epoxidized soybean oil (ESO). First, wood samples were impregnated with boric acid (BA) and then impregnated with the epoxidized oil and pure oil using an empty cell method. The variations for impregnation are below:

3 % BA + ELO
3 % BA + ESO
3 % BA + LO
3 % BA + SO

Impregnated samples were cured to facilitate polymerization of epoxidized oils at 70 °C for 14 days. After curing, the samples were conditioned at 20 °C and 65 % RH.

The target retentions used in this study were 80 kg/m^3 to 140 kg/m^3 (Ret A) and 170 kg/m^3 to 270 kg/m^3 (Ret B).

Based on water absorption, specimens with higher retention rates (Ret B) absorbed less water [1]. The lowest water absorption and highest dimensional stability values were observed in the sample impregnated with 3% BA + ESO. Second to this were samples impregnated with 3% BA + ELO. Based on these results, it is found that specimens with epoxidized oils absorbed less water than non-epoxidized oils (Fig. 1). As seen from the results, the target on fixation by epoxidation was accomplished.

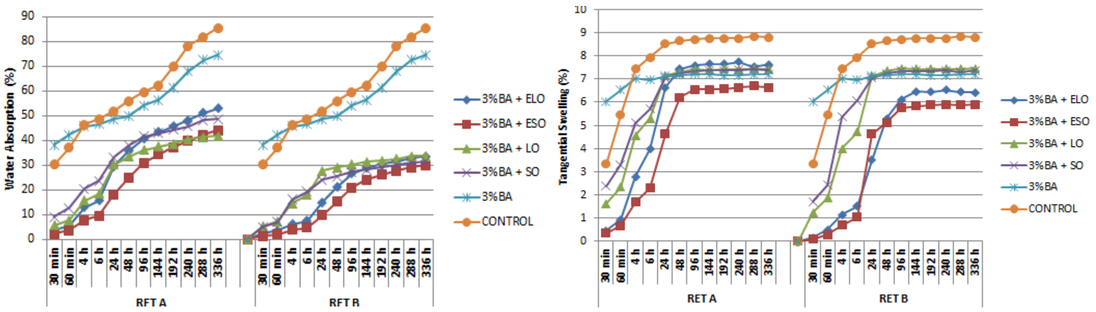

Figure 1: Results of water absorption and tangential swelling

Modulus of Elasticity (MOE), Modulus of Rupture (MOR) and Compression Strength Parallel to Grain (CSPG) were conducted and the results were listed in Table 1 for all variations [2, 3].

Table 1: Results of MOE, MOR, and CSPG

	MOE		MOR		CSPG	
	RET A	RET B	RET A	RET B	RET A	RET B
3% BA+ ELO	9777,75	6881,54	65,963	52,599	49,580	47,612
3% BA + ESO	13257,20	12244,90	101,265	92,288	60,153	59,802
3% BA + LO	15294,30	14914,60	127,268	118,979	64,469	64,971
3% BA + SO	15043,90	14549,90	119,303	118,344	62,149	61,539
3% BA	14164,80		115,869		59,283	
CONTROL	14405,40		107,193		64,396	

As shown in the Table 1, with one exception, the samples treated with un-modified oils show higher MOE, MOR, and CSPG values compared to control specimens. However, the samples treated with epoxidized oils showed lower values for all mechanical properties measured compared to control samples. This could be the result of changing the chemical structure of wood with epoxidized oils and how effectively they were fixed to the wood.

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LONG-TERM IN SERVICE EVALUATION OF STRIP PARQUET WITH MODIFIED WOOD FACE LAYERS

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Keywords: strip parquet flooring, black locust, steaming, Brinell-hardness, abrasion resistance, indoor service test, deformation, dimensional changes

Recently, oak (*Quercus petraea* and *Quercus robur*) has been the most widely used wood species in European parquet production as a face layer (FEP 2009). However, this increasing trend can only be satisfied by using other wood species. It is possible to use other wood species for this purpose which are primarily used as firewood due to their smaller dimensions or lower yield (large ratio of wood defects), but still provide the necessary technical parameters for parquet production. The smaller log diameter is not a big problem in the field of parquet production because of the small dimensions of the parquet friezes. Furthermore, wood defects can be easily removed in production. The following wood species are suitable for parquet production: hornbeam (*Carpinus betulus*), turkey oak (*Quercus cerris*) [1], and black locust (*Robinia pseudoacacia*). By investigating different production technologies for oak face layers from the point of view of the cost, it was found that 80 % to 85 % of the costs are raw material costs [2.]. This result shows the importance of raw material selection.

Due to its extraordinary hardness, decorative appearance, and small available dimensions, black locust wood is expected to be an excellent material for strip parquet flooring. The steaming of the robinia face layers was made in an industrial scale steaming chamber at atmospheric pressure and at two different temperatures. Temperatures were 85 °C (light steamed) and 95 °C (dark steamed), with the same duration of 48 hours. Four different face layers were investigated: oak (O), natural (unsteamed) black locust (N), light steamed black locust (L), and dark steamed black locust (D). The core and bottom layer was made of spruce. Flooring was installed in a heavy-wear student dormitory stair landing (Figure 1.).

Figure 1: The appearance of the floor after installation

Through normal use in a busy student dormitory stair landing, the flooring elements have changed color rapidly but have not suffered significant changes in structure and performance.

Based on this experiment, the effect of steaming on abrasion resistance of flooring top layers was not found to be significant. Oiling significantly increased the abrasion resistance of the steamed specimens, but the differences in abrasion resistance are more likely due to differences in density and annual ring orientation (radial, tangential) than to surface treatment. This makes the evaluation of abrasion tests difficult, but this shortcoming could be compensated by a different experimental design, which includes density as one of the variables and a larger sample size. In general, the measured differences between samples, although sometimes statistically significant, were small from a practical point of view. This is especially true when comparing the abrasion properties of black locust with those of oak, as with one method oak attained superior ratings, while with the other black locust performed better. After the service period, tests were conducted to show how indoor service affects Brinnel-Mörath hardness. As seen in Figure 2, a significant decrease in surface hardness can be observed.

Regarding dimensional changes and deformation, tests yielded similar results for oak and natural black locust, whereas light steamed black locust performed even better, and dark steamed black locust proved to be inferior to all other materials.

Both the in-service and the laboratory tests proved indicated that wood density, grain orientation, and element structure (three-ply) appear to effect the performance of the floor to a much higher degree than the different structure and treatments of the materials used. Black locust wood proved to be suitable for indoor flooring applications.

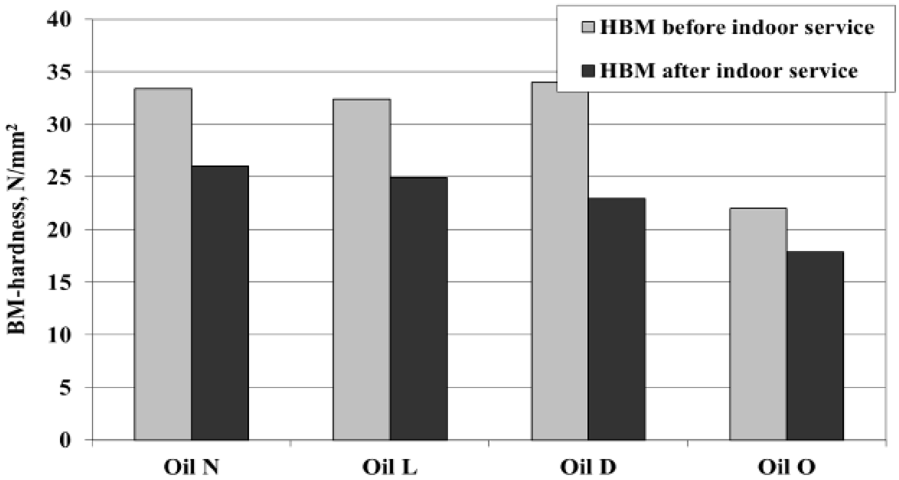

Figure 2: Brinell-Mörath hardness values before and after indoor service.

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INTRODUCING LCA TO WOOD MATERIAL PRACTITIONERS – FEEDBACK FROM THE FP1407 TRAINING SCHOOL 2016

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Keywords: LCA training, networking, wood modification

The COST FP1407 training school on Life Cycle Assessment was organized in Vantaa, Finland between the 26th and 28th of April 2016. The theme of the school was "Life Cycle Assessment - steps and role in product development". The call for the applications was open for 3 weeks in March. Altogether 30 candidates submitted a full application including the online form of the applicant profile and the motivation letter to explain previous experience and interests. 15 trainees were selected, based on COST prioritization rules and the motivation letters. The motivation letters appeared as the most useful and practical criteria. The trainees came from Croatia (1), Germany (2), Finland (2), Italy (2), Latvia (1), Republic of Serbia (1), Sweden (2), Spain (2), Turkey (2), and Ukraine (1). The group of the trainers were: Christelle Ganne-Chédeville (CH), Ana Dias (PT), Lars G. Tellnes (NOR), and Lauri Linkosalmi (FI). The local organizer was Tarmo Räty supported by the team of Luke's LCA experts. As a courtesy of PRé Consultants the trainees were granted a 4 week training license to SimaPro software and Ecoinvent 3.0 database.

The coursework started with 6 hours of lecturing providing an introduction to LCA, 4 hours of applied LCA, and 6 hours were scheduled for student projects. The applications focused on how to use the software and the example of building up an EPD for wooden cladding.

The trainers worked out 7 topics in advance for the student project based on the motivation letters and given time frame for working. Each topic was worked on by a team of 1 to 3 trainees and mentor(s). The wide interest on thermal modification resulted in somewhat overlapping topics. Topics were: 1. Environmental performance of wood densification – any gains over the alternatives; 2. Modelling cascade uses of thermally treated wood; 3. Emissions and side streams of thermal treatment; 4. LCA of thermal treatment - forest to factory gate; 5. LCA of chemically modified wood; 6. Environmental performance of wood-plastic composites; 7. A model for environmental impacts of forest management. Each team followed ISO14040:2006 stages: goal and scope definition, inventory, impact assessment and interpretation of results. All the teams managed to compile at least a preliminary inventory of the topic using SimaPro and presented their results.

Trainee and trainer feedback

Both trainees and trainers were asked for feedback using an anonymous on line survey. The training course was found generally useful. With a scale from 1 to 4, the average usefulness was 3.7 and 3.4 for trainees and trainers, respectively. Tutorials, especially EPDs on wooden claddings and ultralight particle board, were found the most useful topic of the course by trainees, whereas the key learning appeared to be focused on the software and how to proceed with a LCA study. The course was useful also to the trainers. They learned new ways to make LCA and new interesting cases.

If a training school on LCA is to be organized again, both the trainees and trainers agree that the material coverage is adequate but to add one more day to work with student projects, including feedback and presentations. One obvious solution is to assign homework before and after the course. The software providers have produced tutorials that do not require hands on guidance which could be utilized.

Based on the amount of applicants and activity of trainees, there is a demand for another introductory course on LCA of modified wood. The number of applicant was double to what we were able to admit and none of the admitted trainees cancelled. The trainees considered that the next step could be consequential modelling and working with scenarios. Also EPDs gained some interest.

Organizer's point of view

The whole organization of the training school rests on benevolence of the trainers and their home institutions. Four visiting trainers were invited and they were supported by 5 mentors from Luke. This is actually the number you need to run hands on tutorials and student projects in such a short time.

The required effort from the organizer is several working weeks, especially in this case when free form motivation letters were asked for and the syllabus was more than lecturing. Using the on line software to collect application and registration information saves a lot of time.

We tried to get more real world case studies, especially EPD tutorials, but practical cases are still rare or IPR of a business.

A training course should not be a onetime project, but some sort of networking or co-operation should follow. After two months it is too early to say anything yet on how the FP1407 training school succeeded. The immediate feedback was good, but according to a follow up query the trainees has not yet been able to start new projects, but hopefully we see a growing number of modified wood related LCA papers in conferences and journals already in the near future.

LIFE CYCLE ASSESSMENT OF WOODEN WINDOWS WITH WAX-TREATERD FRAMES

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Keywords: Life cycle assessment, wooden window, wax treatment

The building sector needs to mitigate its environmental impacts to avoid irreversible damage. Life Cycle Assessment (LCA) is a tool widely used to assess the environmental effects of decisions made in building projects. Some research has been carried out applying LCA to wooden windows. Tarantini et al. [1] have used LCA in green public procurement using wooden windows to show the applicability of the tool. LCA has been used in combination with building physics tools to select the most environmentally friendly option for window shading [2]. Carlisle and Friedlander [3] highlighted the importance of durability, recycling, and maintenance aspects of window frames by comparing different alternatives using LCA. Finally, the role of LCA in product development and R&D projects has been discussed as well as the project's characteristics that are important to define the role of LCA in product development [4]. The aim of this work is to use LCA to study the environmental effects of a novel, natural-based, wood-treatment process, which is applied to improve the durability of window frames and is currently developed within the WINTHERWAX project. The work was carried out in close collaboration with the company responsible for the wax treatment process, Silvaprodukt, and the window manufacturer MSora, both located in Slovenia.

Method

A cradle-to-grave LCA has been carried out for two types of windows. One window has a frame made of thermally modified wood scantlings treated with natural-based wax. The other window, the "Nature Optimo XLT" model by MSora, has the same type of scantlings but treated with a synthetic coating and since it is currently on the market it has been used as a reference. The functional unit is one window measuring 1.23 m x 1.48 m with a U-value of 0.66 W/m^{2}K used for 40 years. The data for the wax treatment, the production of the wax, and the manufacturing of the windows has been collected on-site, while the rest of the data has been obtained from Ecoinvent 3.0 European datasets adapted to Slovenian conditions by changing energy supply to the Slovenian mix. The wax-treated window does not require coating maintenance, while the reference window does. Data for the MSora window was obtained from a previous study by University of Primorska, as well as Ecoinvent data adapted to Slovenian conditions. A 40-year service can be assumed to for both windows according to test results obtained within the WINTHERWAX project. Global waste treatment market data from Ecoinvent 3.0 was used for the end-of-life. The CML-baseline method has been used for impact assessment.

The results of the study are displayed in Figure 1.

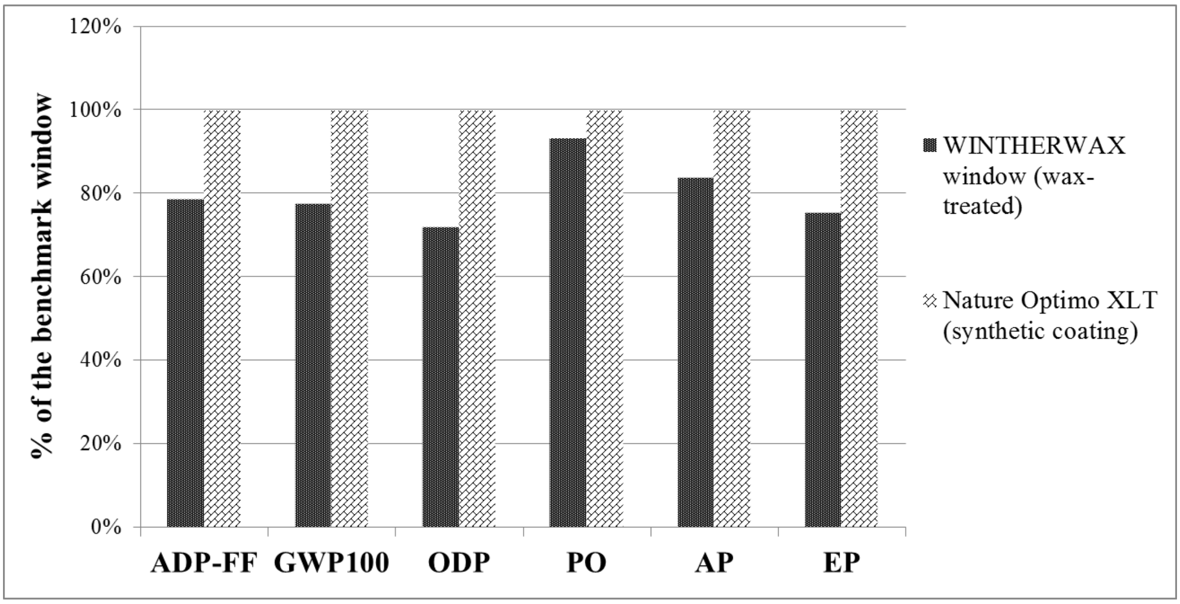

Figure 1: LCA results for the two windows studied, in terms of percentage of the result for the benchmark. The impact categories are: abiotic depletion potential fossil fuels (ADP-FF), global warming potential 100 years (GWP100), ozone depletion potential (ODP), photochemical oxidation potential (OP), acidification potential (AP) and eutrophication potential (EP).

Conclusions

Results show that the wax-treated window has lower impact results than the benchmark in all the evaluated impact categories. This indicates that using the novel wax treatment process for the wooden scantlings in the frame could reduce the environmental impacts of the window. The main source of this difference is the treatment process for the wooden scantlings, as the impacts from the wax treatment are lower than those of the synthetic coating treatment. Another key difference is that the wax-treated window does not require maintenance. Finally, glass production and transports are the two more significant environmental impact hotspots for the wax-treated window.

Acknowledgements

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REDUCTION OF THE SET-RECOVERY OF SURFACE-DENSIFIED SCOTS PINE BY PRE-TREATMENT WITH SODIUM SILICATE OR SODIUM HYDROXIDE

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Keywords: Water glass, compression, wood modification, surface treatment

Surface densification of wood increases its density and hardness. Low-density wood species have a particularly high potential for improved properties, and over the past years the topic has attracted an increased interest within the field of wood modification.

So far, the effects of different densification processes on the properties of the densified wood have been in the focus of research studies [1-3], but industry-related aspects, such as the time consumption or the process costs, have not been considered. In 2016, Neyses et al. surface-densified solid wooden boards in a high-speed continuous roller pressing process, which opens up the potential for industrial applications of this technique [4].

However, elimination of the moisture-induced set-recovery in a cost-effective way is still necessary before industrial implementation is viable. It is possible to eliminate the set-recovery, but the existing techniques are rather time-consuming [5, 6]. The aim of this study was therefore to assess the efficacy of a fast pre-treatment of surface-densified Scots pine to achieve chemical modification of the wood surface.

Sodium silicate and sodium hydroxide were chosen as impregnation agents because they are considered to be both environmentally friendly and cheap. Sodium silicate polymerizes and mechanically stabilizes the wood cells, and sodium hydroxide chemically activates the wood surface.

Scots pine sapwood boards with dimensions of 149 mm x 25 mm x 17 mm were densified in the radial direction using the approach and equipment described by Rautkari et al. [7]. After chemical pretreatment, the specimens were densified on the heated side of the specimen with a compression ratio of 12 % and a closing time of 30 s. After a holding time of 60 s at 130 °C, the specimens were cooled to below 80 °C before being unloaded.

Table 1: Overview of the types of treatment.

Group	Type of treatment	Concentration [volume %]
R	Not pre-treated	-
S20, S50, S80, S100	Na_2SiO_3	20, 50, 80, 100
H0.4, H4, H8	NaOH	0.4, 4.0, 8.0

The specimens were pre-treated with aqueous solutions of either sodium silicate (Na_2SiO_3) or sodium hydroxide (NaOH) (Table 1). For each type of treatment there were 15 replicates. The pre-treatment was carried out by brushing the solutions on the sapwood side of the specimens with a paper towel. The impregnation time until densification was 90 s. The set-recovery was determined according to Laine et al. [4] after one, two, and three wet-dry cycles.

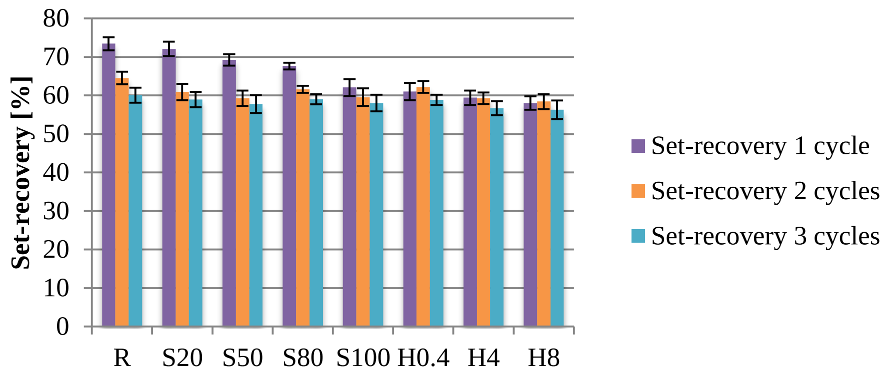

Figure 5: Set-recovery of all groups after one, two and three wet-dry cycles. The colored bars show the average of the 15 specimens in each group. The error bars show the standard deviation.

Figure 1 shows the mean set-recovery after wet-dry cycling. For most groups, the set-recovery decreased between the first and second wet-dry cycle. In general, the effect of the pre-treatment is rather small. The treatment with sodium hydroxide led to a slightly larger reduction in set-recovery than the sodium silicate treatment. In the case of the treatment with sodium hydroxide, a high solution concentration seemed to increase the effect on the set-recovery. In the case of the sodium silicate treatment, there is no clear trend. The higher viscosity of the highly concentrated sodium silicate solutions made it more difficult to wet the surface. As a result, there may be trade-off between the expected effect of the solution and the level of penetration into the wood surface.

The main reason for the rather weak effect of all the tested treatments on the set-recovery could be the short impregnation time. For this reason, further experiments with longer impregnation times will be conducted in the near future.

The verdict about the pretreatment of surface-densified wood with sodium silicate and sodium hydroxide depends on the outcome of further experiments with longer impregnation times. The simplicity of the process and the fact that the treatments are rather harmless from an environmental perspective make the chemicals interesting for further studies.

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CHEMICALLY MODIFIED LAMPANTE OIL AS A WOOD PRESERVATION TREATMENT

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Keywords: olive oil, wood preservation, chemical modification

Olive and olive oil culture in the Istrian region of Slovenia has a long established tradition dating back to the 4th Century BC. The "Istrska belica" variety of olives (Istrian white olives) produced in this region have been praised for their ability to withstand low temperatures, high oil content, good taste, high levels of monounsaturated fatty acids, and their high levels of biologically active molecules including biophenols (phenolic compounds), squalene, and tocopherols [1]. These characteristics may serve another purpose as well: providing protection against degradation in wood products.

A readily usable material from the oil production process that requires no further processing is lampante oil produced during virgin olive oil production. Lampante oil is virgin olive oil that is not fit for human consumption and has undesirable organoleptic and/or chemical characteristics. This oil is typically further refined or used in other technical applications [2]. In addition to lampante oil acting as a hydrophobic agent, it also contains phenolic compounds with antifungal properties with the potential to inhibit or delay the rate of growth in a range of fungi [3]. It is well known that lampante oil phenolic compounds are bioavailable and beneficially alter microbial activity and oxidative processes [4]. With these desirable properties, lampante oil has the potential to be utilized as a natural source of wood preservative, particularly as an alternative to other oil-based preservatives currently in use [5]. However, using olive oil as a wood preservative is still a very limited field of study and the use of plant oils in general has several challenges associated with it. The objective of this study was to investigate the use of modified lampante olive oil as a wood preservative treatment.

Figure 6. Collaborators from the Biocomposites Centre in Bangor, UK, the Norwegian Institute for BioEconomy Research, and the University of Primorska.

This project is an ongoing joint collaboration between the University of Primorska, the BioComposites Centre at Bangor University, the Norwegian Institute for the Bioeconomy (NIBIO), and the Biotechnical Faculty of the University of Ljubljana (Fig. 1). During a

FP1303 STSM at the BioComposites Centre at Bangor University, modified lampante oil was produced from lampante oil obtained in Slovenia. Two distinct methods of maleinisation were used to encourage fixation of the oil with wood. These two modified oils and un-modified lampante oil were used to treat beech and pine specimens at NIBIO (Fig. 2). Along with the Biotechnical Faculty of the University of Ljubljana, the treated specimens will be tested and assessed for leaching, water absorption, dimensional stability, fungi tests, and accelerated weathering in the upcoming months.

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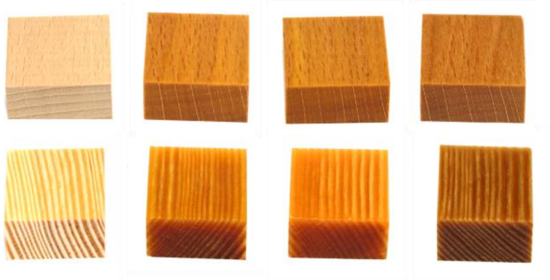

Figure 7. Beech (top row) and pine (bottom row) specimens; Left to right: untreated, un-modified lampante oil, maleinisation 1, maleinisation 2.

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EFFECTS OF NATURAL WEATHERING ON SURFACE COLOUR AND CRACKING OF THERMALLY MODIFIED EUCALYPTUS WOOD

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Keywords: CIElab, cracks, blue gum wood, thermal modification, outdoor exposure

Outdoor conditions can quickly cause degradation of the wood surface reducing its service life and increase its maintenance cost. The greatest changes in the surface properties of wood during outdoor exposure are caused by the ultraviolet light component of sunlight and water [1]. Improvement of thermally modified wood properties and the effectiveness of high temperature thermal modification against weathering have been extensively studied by several authors. Natural weathering exposure studies have indicated that thermally modified wood proved to be more resistant to natural weathering factors than unmodified wood [2].

The aim of this study was to investigate the changes caused by twelve months of outdoor exposure on colour stability and surface cracking of unmodified and thermally modified blue gum wood (*Eucalyptus globulus*) at five different temperatures.

Forty-eight samples of *Eucalyptus globulus* wood from Spain were machined and sanded to the dimensions of 150 mm x 74 mm x 18 mm, and have been conditioned at 65 % relative humidity and 20 ºC for two weeks to a moisture content of 12 %. Eight samples were left unmodified and the rest were dried in a forced convection-drying oven Binder (FD53), at 103 ºC ± 2 ºC, until reaching a constant weight. Then, the thermal modification was performed using the same oven. The modification was held under normal atmospheric conditions, and at five temperatures: 140 ˚C, 160 ˚C, 180 ˚C, 200 ˚C, and 220˚C, for 6 hours.

On May 2015, the set of samples was fixed on a grid tilted at 45º, which was located on the rooftop of a university building in Kuchl, Austria. Following the UNE-EN 927-3 standard, the samples were exposed to above ground natural weathering for 12 months. The wood colour was measured using a Mercury 2000 spectrophotometer (Datacolor) with a 11 mm diameter, according to the CIE 1976 L*a*b* Colour space (ISO 11664-4:2008) using the CIE standard illuminates D65 and a 10º standard observer. The variation in colour has been calculated using the CIEDE2000 (2:1:1) colour difference equation.

The exposure to natural weathering has significantly changed the surface colour of the unmodified and thermally modified samples at 140 ºC, 160 ºC, 180 ºC, and 200 ºC. After 6 months of exposure, these samples have already presented colour variation values (ΔE_{00}) equal or greater than 10 (Figure 1 and 2).

	Unmodified	140 ºC	160 ºC	180 ºC	200 ºC	220 ºC
Before weathering						

After 12 months of natural weathering						

Figure 1. Thermally modified *Eucalyptus globulus* wood samples before and after 12 months of natural weathering.

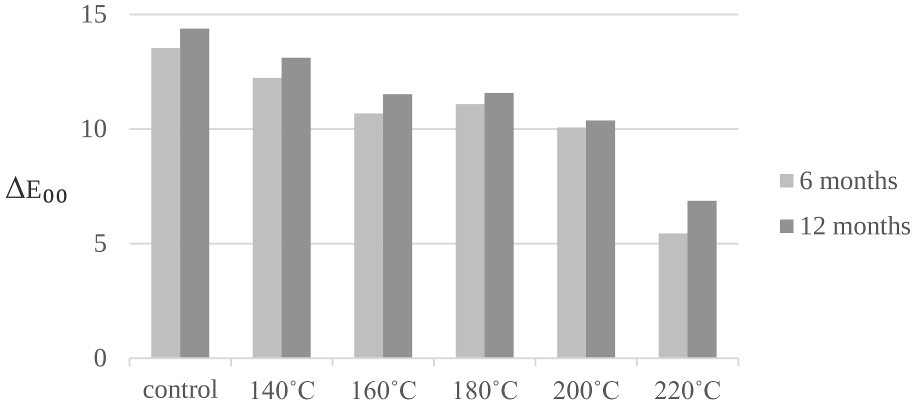

Figure 2: Colour variation

Unmodified samples presented the highest colour change at the end of the test, with ΔE_{00} = 14. Thermally modified samples at 160 ºC and 180 ºC have shown similar colour variations of approximately ΔE_{00} = 11. Specimens treated at 220 ºC had the lowest colour change after 12 months of natural weathering, presenting half the value assigned to unmodified control samples, ΔE_{00} = 7. A considerable number of cracks were observed in unmodified and treated samples at 140 ºC, 160 ºC, and 180 ºC after weathering with large cracks up to 1 mm wide. The number of cracks was found to be very little for samples treated at 200 ºC and 220 ºC. These samples had cracks that were just visible with normal corrected vision which indicates that the treatment at these temperatures contributes to a reduction of cracks caused by outdoor exposure. This study observed that the surface colour of thermally modified *Eucalyptus globulus* wood at the temperature of 220 °C was more stable during 12 months of natural weathering than control samples and other tested treatment temperatures. These samples maintained the dark colour acquired with thermal modification and presented very few, small cracks.

Acknowledgements

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EVALUATION OF SURFACE QUALITY AND ADHERENCE OF THERMALLY COMPRESSED AND FINISHED WOOD VENEERS

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Keywords: thermo-mechanical densification, surface quality, glossiness, adherence, varnish consumption, wood veneers

In recent years there has been a rapid increase in the application of different modification methods to wood and wood materials in order to improve their properties. In particular, thermal, thermo-mechanical, and thermo-hydro-mechanical treatments of wood have been widely studied and applied to improve its properties. Our previous works [1,2] showed that short-term thermo-mechanical densification improves the attractiveness of the wood surface. Such densified wood is characterized by an attractive darker colour and high gloss. This facilitates the application of transparent organic coatings that improve the natural characteristics of wood while leaving the wood structure visible, and so the demand for them has been increasing. A literature review showed that there is a lack of results concerning the surface quality and adherence of thermally compressed wood veneer that has been coated.

Therefore, the purpose of this project was to examine the effect that varying lacquer spread rates and thermal densification processing temperature had on the gloss of coated MDF panels and adherence between thermally densified wood veneer samples and varnishes. This project also evaluated the surface quality of MDF panels overlaid with densified veneer.

Rotary cut veneer sheets of birch (*Betula verrucosa* Ehrh.) with a thickness of 1.55 mm and moisture content of 5 % to 6 % were thermo-mechanically densified between the smooth and carefully cleaned heated plates of a laboratory press at temperatures of 150 ^{o}C, 180 ^{o}C, and 210 ^{o}C. Commercially produced MDF samples were laminated with either non-densified (control) or densified veneer. These samples were used as the substrate for coating. Solvent-based varnish OLI-KS Parkettsiegel 7600 was commercially obtained from OLI-LACKE Comp. OLI-LACKE Comp. and was used for coating the samples. Three different coating systems were used in evaluation of the adhesion strength of coating to densified veneer: type A – 1 layer of varnish (n=1), type B – 2 layers of varnish (n=2), type C – 3 layers of varnish (n=3). Preparations and applications of the varnishes were made according to the manufacturer's recommendations and ASTM D-3023 (2003). Conditioned panels were coated with cited varnish in one, two, and three layers without primer. Panels were coated (both sides) at different spread rates of 50 g/m^2, 75 g/m^2, and 100 g/m^2. The varnish product was applied to every surface of test samples with a roller. In the next step samples were conditioned for a week before adhesion strength tests were carried out based on PN-EN ISO 4624 standard using DeFelsko PosiTest Pull-off Adhesion Tester. The surface quality of overlaid MDF panels with non-densified and densified veneer was evaluated by surface roughness and gloss measurements using Carl Zeiss ME-10 profile gauging profilometer and photoelectric apparatus PICO GLOSS 503 gloss meter respectively.

The reduction in surface roughness values can be observed with increasing densification temperature. The surfaces of the overlaid MDF panels with densified veneer were much smoother than those with non-densified veneer. Gloss measurements showed an increase in the aesthetic qualities of coated MDF panels which were preliminary laminated with densified veneer. The producer recommends to apply a varnish by three times (n=3) with a 100 g/m^2 spread rate for a total of 300 g/m^2. The use of densified veneer achieves higher gloss values even at a lower spread rate of varnish in comparison with using non-densified veneer.

Having a densified and smooth surface of samples with thermally densified veneer resulted in enhanced adherence characteristics between the finishing material and substrate as compared to that of samples with non-densified veneer. Adhesion strength between varnish and densified veneer (compared to non-densified veneer) was improved to 20-75% depending on the number of layers of varnish, varnish spread rate and temperature at which the veneer was densified. In most cases lower average coating thickness (lower spread rate and/or less number of applications of varnish) resulted in relatively acceptable adhesion strength values in overlaid MDF panels with thermally densified veneer.

Table 1: Varnish consumptions during coating of MDF panels overlaid with thermally densified and non-densified veneer.

Spread rate of varnish for non-densified veneer [g/m^2] *	Number of varnish applications for non-densified veneer *	Spread rate of varnish for densified veneer [g/m^2]	Number of varnish applications for densified veneer	Reduction of varnish consumption [g/m^2]
100	3	50	1	260
100	3	50	2	208
100	3	50	3	156
100	3	75	1	234
100	3	75	2	156
100	3	75	3	78
100	3	100	1	208
100	3	100	2	104
100	3	100	3	0

The preliminary findings of this study indicated that veneer thermally densified at different temperatures could be considered as an alternative way of producing coated MDF panels with satisfactory aesthetic and adherence properties. Moreover, the results of a simple calculation show that using densified veneer in coating process makes it possible not only to improve the aesthetic properties of the surface and adhesion strength between coating and such veneer, but also get economic advantages. The varnish consumption was reduced to 78 g/m^2 to 260 g/m^2 (Table 1). In addition, a significant reduction of varnish consumption reduces the emission of harmful substances into the environment and further facilitates the recycling of such coated products. Consequently, the use of thermally densified veneer in coating processes in addition to economic advantages will also have environmental benefits.

The data from this study would be successfully used as quality control tool to develop a better understanding of thermal compression and application of varnishes to the densified wood samples so that such densified veneer can be used more efficiently.

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STATE OF THE ART AND FUTURE TRENDS IN TIMBER-HOUSE TECHNOLOGIES IN SLOVENIA AND SWEDEN

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Keywords: architecture, energy-efficiency, passive housing, timber construction

The main building techniques in Sweden and Slovenia are on-site construction, off-site prefabrication, and modular systems. Single-family wooden housing has a long tradition in both countries but is less dominant in Slovenia than in Sweden, where approximately 90 % of the single-family houses are built with timber frames. Sweden's long tradition of industrial manufacture of single-family timber houses has during the last 15 to 20 years been developed for the manufacture of multi-storey timber buildings. Today, one in every seven new residential multi-storey buildings in Sweden has a timber frame, but this is almost non-existent in Slovenia. It seems that the wood construction system in Sweden is passing from a formative to a growth phase, but that in Slovenia it is still in the formative phase. In Slovenia there are very few wooden multi-storey buildings with most being two-storey buildings such as tourist facilities, schools, and some residential buildings.

On-site construction

On-site construction means that the building materials are transported to the building site where the various elements are assembled and erected. This method requires a great deal of organization and planning. The potential risks associated with this type of construction are damage to materials and prefabricated components, and moisture damage (Fig. 1). Out of necessity, on-site construction tends to take a long time. With the on-site construction technique, wall components are assembled resting on joists or on the ground and then erected. In Slovenia, greater numbers of wooden houses have appeared recently and were constructed on-site through smaller carpentry workshops. On-site construction of single-family houses is very rare in Sweden.

Figure 1: Examples of on-site construction. Left to right: House N, Linnaeus University, Växjö, Sweden. 2011; Waldorf school, Ljubljana, Slovenia, 2013; House S, Velike Lašče, Slovenia, 2014.

Off-site prefabrication

In both Slovenia and Sweden, the trend is towards a higher degree of prefabrication. In this method, 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 only one or two days until the roof is laid in place. The prefabrication can include various components such as wall and floor elements, roofs, trusses, etc. and also volume modules. Both components and modules are prefabricated with insulation, installations, windows, and doors (Fig. 2).

With prefabricated wood modules, the total cost is often 20 % to 25 % lower than on-site construction, partly due to a time savings of up to 80 %. In Slovenia, most of the large house manufacturers offer off-site prefabrication. In Sweden, off-site manufacture dominates for single-family houses and this method of manufacture is also becoming more and more common for multi-storey housing.

Figure 2: Examples of off-site prefabrication. Left to right: Manufacture of wall elements; Window sections ready for transportation to the building site; Manufacture of modules for a modular system.

Modular System

Working with modular systems is a great help since it is difficult to design traditionally and then translate the design into 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 (Fig. 3).

Figure 3: Examples of modular-system housing. Left to right: Residential apartments Skagersvägen, Stockholm, 2013; Multi-residence buildings, Ekorren, Skellefteå, 2009; Student housing, Kungshamra, Stockholm, 2002.

Future trends

Timber multi-storey building has gathered momentum in recent years in European countries. Construction of the first experimental buildings was completed and trust in new timber building is now growing. The number of projects as well as the rising interest from different groups and customers show this trend. We see opportunities for further development and future trends in prefabrication, partnerships and increased responsibilities for planning and construction, improved and systematic feedback of experiences, and team cooperation. 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.

SURFACE PROPERTIES OF THERMALLY WOOD AFTER ARTIFICIAL AND NATURAL WEATHERING

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Keywords: spruce, pine, beech, thermal modification, water exclusion efficacy

The use of wood in outdoor, above-ground applications is increasing in Europe. In order to increase the use of wood in construction applications, more information related to service life and maintenance costs should be provided. Water exclusion efficacy (WEE) is one of the most important factors influencing service life and strongly correlates to wood moisture dynamics, surface properties, and hydrophobicity. Despite the importance of this parameter, WEE is not completely understood. The majority of past experiments were performed on the non-weathered wood. Therefore, the question arises how WEE changes within time, artificial or natural weathering, fungal exposure, etc. It is important to know how the surface properties are changing, for the further use of recycled or reused wood.

WEE can be improved with modifications. In this study thermally modified (TM) wood was used. The wood species chosen for this research work are important in Central Europe, namely, Scots pine sapwood, PsS (*Pinus sylvestris*), Norway spruce heartwood, Pa (*Picea abies*), and beech, Fs (*Fagus sylvatica*) wood. Thermal modification (Tm) was performed according to the commercial Silvapro® process [1], 3 h at 230 °C for Norway spruce and at 215 °C for beech wood. Four different standardized and non-standardized aging procedures were applied. The first set of specimens was exposed to fungi according to the modified EN 113 standard procedure to brown rot (*Gloeophyllum trabeum* - Gt2) or white rot fungi (*Schizophyllum commune* - Scc) for one month. A second set of specimens was exposed to the blue stain fungi (Blue-SF) *Aureobasidium pullulans* and *Sclerophoma pithyophila* as prescribed by the EN 152-1 protocol. Artificially accelerated weathering (AWW) was carried out in a chamber (ATLAS UP, Suntest XXL+) that was set at the most severe typical exterior conditions for 1000 h of exposure (EN/ISO 11341). Additional specimens were exposed to outdoor weathering in the field test site of the Dept. of Wood Science and Technology, Ljubljana for 9 months (OutDW-A) and 18 months (OutDW-B). After exposure, the mass change was determined. Colour changes were evaluated with the CIE L*a*b* system. Afterwards, the influence of aging on the surface properties and moisture dynamics of the wood were determined. The sessile drop method was used for contact angle (CA) measurement on a Theta optical tensiometer (Biolin Scientific). Short term capillary water uptake was carried out on a Tensiometer K100MK2 device (Krüss) (EN 1609).

Results showed the highest mass loss was determined after exposure to degrading fungi. TM wood reduced mass loss compared to non-treated specimens after exposure to biotic factors. AAW resulted in similar mass loss, as OutDW (Table 1). TM reduces short term water uptake on non-aged, Gt2, Scc and Blue-SF aged specimens, after AWW and OutDW the water uptake is similar in all materials tested. The colour of aged specimens mostly changed to darker except of AAW, where it became brighter (Table 1).

Table 2: Mass and Colour Change after Different Ageing Procedures Performed

Wood species	**Ageing procedure**					
	Gt2	**Scc**	**Blue-SF**	**AAW**	**OutDW-A**	**OutDW-B**
PsS	-12.12	-0.54	0.05	-2.48	-1.78	-2.86
Pa	-16.40	0.21	0.52	-2.86	-1.15	-2.16
PaTm	0.09	-0.15	0.18	-2.85	-1.79	-2.29
Fs	-20.81	-1.63	0.09	-2.84	-1.59	-3.86
FsTm	-0.59	-0.18	0.18	-2.87	-1.80	-3.51

	Ageing procedure																				
	Non-aged			**Gt2**			**Scc**			**Blue-SF**			**AAW**			**OutDW-A**			**OutDW-B**		
	L*	a	b	L*	a	b	L*	a	b	L*	a	b	L*	a	b	L*	a	b	L*	a	b
PsS	90.2	2.3	12.2	57.6	6.3	13.9	84.4	3.4	13.3	57.4	2.2	7.5	83.2	3.3	7.5	44.0	1.5	3.4	49.6	0.8	1.8
Pa	86.2	3.2	13.5	66.0	6.4	15.0	81.3	3.8	14.0	58.5	3.2	9.4	81.0	3.0	6.9	41.7	1.4	3.2	40.7	0.9	1.9
PaTm	29.7	3.7	5.1	31.6	5.6	8.4	32.0	4.6	6.2	27.9	3.5	4.5	71.2	2.3	5.6	38.8	2.6	4.9	42.0	1.7	3.0
Fs	72.1	3.9	9.1	55.4	5.9	12.4	69.9	3.7	9.3	50.7	3.0	6.4	87.1	1.9	6.0	42.0	1.1	2.5	46.4	1.0	2.2
FsTm	27.0	3.0	4.5	31.3	4.4	7.2	28.2	3.2	4.8	29.1	3.2	4.6	70.5	1.6	4.3	39.9	1.6	3.1	50.0	1.1	2.4

Table 3: Average Short Term Capillary Water Uptake (g/cm^2) after Different Ageing Procedures Performed on Various Wooden Materials (after 200 s)

Wood species	**Non-aged**	**Gt2**	**Scc**	**Blue-SF**	**AAW**	**OutDW-A**	**OutDW-B**
PsS	0.21	0.18	0.05	0.27	0.37	0.38	0.48
Pa	0.12	0.23	0.03	0.21	0.23	0.30	0.43
PaTm	-0.03	0.06	-0.03	0.11	0.24	0.39	0.46
Fs	0.19	0.28	0.07	0.33	0.23	0.35	0.45
FsTm	0.05	0.11	0.05	0.16	0.13	0.36	0.34

Table 4: Average Influence of Various Ageing Procedures on CA (°) of Water on Wood Surface Measured after 60 sec of Drop Deposition to Surface

Wood species	**Time**	**Non-aged**	**Gt2**	**Scc**	**Blue-SF**	**AAW**	**OutDW-A**	**OutDW-B**
PsS	60	64	64	45	70	15	0	0
Pa	60	93	39	94	55	37	16	0
PaTm	60	95	67	77	66	2	5	21
Fs	60	40	43	56	32	0	12	1
FsTm	60	65	48	61	40	0	14	3

CA measurement is a simple method of quantifying the surface wettability of various specimens. TM increased the CA determined on non-aged beech wood and decreased the CA of spruce wood. After aging, the CA of TM specimens were slightly decreased (Table 3). This decrease was not particularly prominent after blue stain and wood-degrading fungi. Abiotic degradation (AAW) had a more prominent effect on hydrophobicity than biotic factors (wood decay and blue stain fungi).

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WOOD PLASTIC COMPOSITES MADE OF RECYCLED AND REMEDIATED CREOSOTE TREATED WOOD - ASPECTS ON SCREW WITHDRAWAL PROPERTIES

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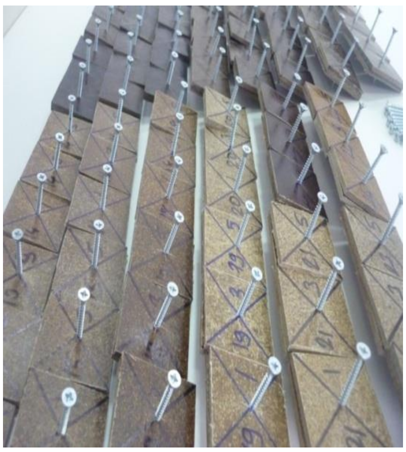
Keywords: creosote, recycle, remediation, WPCs, screw withdrawal

Impregnated wooden materials are stored without any protection method in insecure areas or directly used as firewood. There is no legislation in most countries on how to dispose of these materials that have completed their service life. Thus, the mixing of the heavy metals and toxic chemicals they contain with soil and drinking water over time causes serious environmental problems as well as threatens human health. Consequently, in many countries, it is necessary to recycle the products containing impregnation substances (utility poles used in transmission lines, poles used in the areas in contact with sea water, wooden products used in parks and gardens, etc.) without damaging the environment after they have been used and completed their service life. Mainly pyrolysis systems were tried in the disposal of products containing creosote and Chromated Copper Arsenate (CCA) in the literature, and the gasses and the amount of residues that are formed in these systems cause serious problems. One of the recycling systems in question is wood plastic composites (WPCs).

The feasibility of impregnated utility poles containing creosote that have completed their service life (26 years) in the production of WPCs was investigated but only the screw withdrawal performances of WPCs were examined in this study. Studies on some mechanical properties such as flexural and tensile properties of WPCs have compiled appreciable observation, but regarding performance of withdrawal resistance of WPCs are very limited. The experimental design of the study is presented in Table 1.

Table 1: Composition of wood plastic composites.

Material types	Polymer types: HDPE (%)	Polymer types: PP (%)	Coupling agent (%)	Group ID
Creosote treated wood flour (50%)	50	0	0	C50PE%0
	47	0	3	C50PE%3
	0	50	0	C50PP%0
	0	47	3	C50PP%3
Control (virgin pine flour) (50%)	50	0	0	V50PE%0
	47	0	3	V50PE%3
	0	50	0	V50PP%0
	0	47	3	V50PP%3
Remediated wood flour (50%)	50	0	0	R50PE%0
	47	0	3	R50PE%3
	0	50	0	R50PP%0
	0	47	3	R50PP%3



The creosote treated poles were cut, ground, and remediated via n-Hexane soxhlet extraction then washed with acetone/ethanol solution and dried. Pre and post-remediation processes were analysed, in particular for benzo(α)pyrene and total polycyclic aromatic hydrocarbons (PAHs) content of ground wood flours. The composites were mixed in a single-screw extruder and compression-molded into the test specimens, which were subjected to screw withdrawal tests according to the ASTM D1037 standard. Screw withdrawal resistance is an important engineering property for the potential applications of WPC materials [1].

A large part of the PAHs and especially benzo(α)pyrene content were removed through remediation process 66% and 62%, respectively.

The results of screw withdrawal strengths for WPCs are shown in Figure 1.

Figure 1

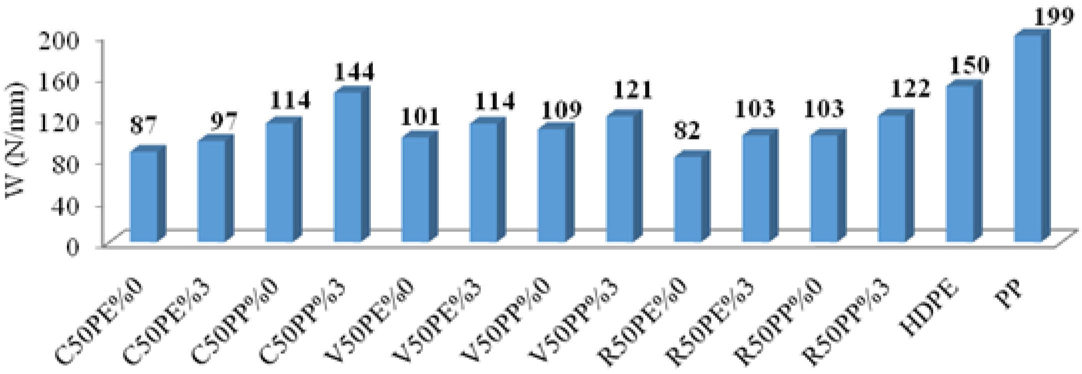


Figure 1: Screw withdrawal strengths of WPCs.

The present study showed that creosote treated poles can be successfully utilized to make wood plastic composites with useful mechanical properties in addition to their ability to remediate. As shown in Figure 1, the resistance ranges from 82 N/mm to 114 N/mm and from 109 N/mm to 144 N/mm for HDPE and PP based WPCs, respectively. The greatest increase resistance was observed when using 3 wt% coupling agent in samples made with 50% creosote treated flour/PP composites. It is known that with filler content less than 60%, withdrawal resistance of WPCs is higher than MDF (medium density fiberboard) and particleboard [2]. Screw withdrawal resistances were improved with the addition of 3 wt% coupling agents for all WPCs. The type of polymer matrix (recycled or virgin HDPE and PP) significantly affected the withdrawal resistance. This finding is also consistent with previous findings [3, 4, 5].

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OPTIMAL AND RELIABLE DESIGN OF TIMBER BEAMS FOR A MAXIMUM BREAKING LOAD CONSIDERING THERMAL AND HYDROLOGICAL EFFECTS

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Keywords: Reliability based optimisation, Finite Element Analysis, Orthotropic materials, Probability of failure, crack growth

The use of bio materials in sustainable construction aims to reduce the environmental impact of buildings. However, wood materials suffer from several drawbacks like uncertainties of timber mechanical properties, knots in the material, and the appearance of cracks. Timber elements exhibit micro-cracks, which can propagate due to fatigue, overload, or creep loading. Thus, crack initiation is one of the most important factors involved in the collapse of timber components in building structures. To predict the crack initiation, many numerical methods have already been developed to characterise the mechanical fields in the crack tip vicinity [1]. In this work, an energy method based on invariant integrals is used to estimate the fracture parameters such as energy release rate and stress intensity factors [2]. The analytical formulation of the T-integral to viscoelastic materials [3] is extended to A-integral in order to take into account the effect of thermal loading and the effect of moisture variation [4]. In fact, the study of the crack growth initiation and crack propagation in timber beams may consider the effect of temperature and the moisture content on the mechanical field distribution in the crack tip vicinity.

Structural optimisation is widely used for effective cost reduction of civil engineering structure. Several works have used the Deterministic Design Optimisation (DDO) approach to design timber trusses [5]. The DDO procedure is based on minimizing an objective function as the structural volume or cost subjected to geometric, stress, and deflection constraints. These design conditions are considered in accordance with Eurocode 5 in order to satisfy the requirements of both the ultimate and the serviceability limit states. However, in the context of fracture mechanic limit state, the DDO based on partial safety factors is not conservative since these safety factors are not calibrated on the basis of the fracture mechanic limit state.

The rational approach considers uncertainties arising from the material properties, crack geometry, and loading parameters in the design optimisation procedure. The Reliability-Based Design Optimisation (RBDO) is developed to balance cost and reliability, where it offers a means to quantify uncertainty propagation and determine a priori the most reliable design that meets performance criteria. However, the RBDO implies the evaluation of probabilistic constraints, which can be performed by nested loops of optimisation and reliability procedures, leading to expensive computation effort for RBDO of real engineering structures [6].

In the present work, a new methodology of RBDO of timber beams considering the crack propagation is proposed. The proposed method uses the Kriging metamodel to approximate the mechanical response (i.e. the stress intensity factors and the energy release rates). The

Kriging metamodel approximation is adopted in order to surrogate the performance functions. The RBDO approach combines updating Kriging approximation by using the technique of constraint boundary sampling to enhance the prediction of the Kriging model. Consequently, the obtained approximation is close to the target limit state function, especially in the vicinity of the most likely failure point. The application to search for the optimal design of timber beams with the maximum strength to the fracture failure shows the interest and the effectiveness of the proposed method.

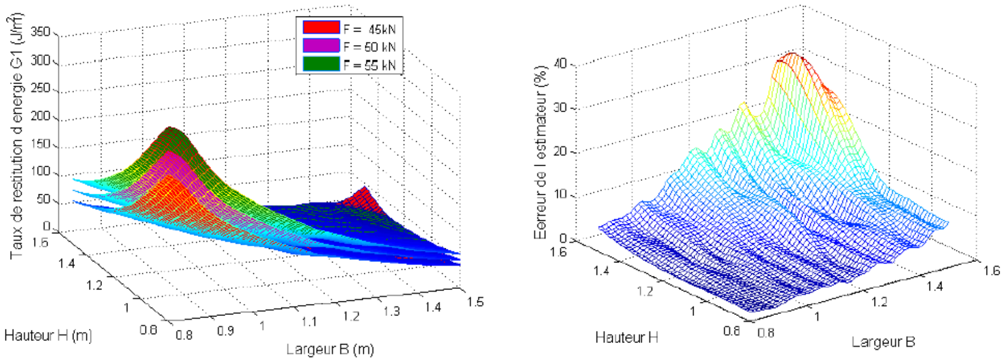

Figure 8: Kriging approximation of the energy release rate and the mean square error.

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LIQUEFACTION OF CRAFT LIGNIN USING DIFFERENT SOLVENTS

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Keywords: renewable resource, polyol, industrial waste

Pulp and kraft paper accounts for about 80 % of the world paper market. As a result, a tremendous amount of black liquor is produced as a waste product of the process. Some chemicals and dissolved lignin are present in the liquor which are in part burned to generate power.

As a natural, aromatic biopolymer, lignin has a tridimensional structure with various functional groups. Among them are phenolic compounds that make lignin a strong candidate to replace petrochemical-based polyols. However, due to the complex structure of lignin it has a low reactivity [1], requiring modification to make it more reactive.

Liquefaction is a thermochemical conversion technique in which lignin is directly converted into a black liquid which is more reactive and can be used as a replacement of fossil-based polyols (e.g. phenolic resin) used in synthesis.

In this study, kraft lignin was precipitated by acidification with sulfuric acid at pH 6 and used without further modification. Polyethylene glycol (PEG) and glycerol (G), or ethylene glycol (EG) and G were using as liquefaction solvents in a solvent:solvent ratio of 80:20 or 90:10 for both combinations of solvents. Liquefaction was carried out putting an appropriate amount of combined solvents in a flask under reflux and heated to 160 ºC. Then, 15 % of lignin was added and reacted for 1 h. The influence of different organic solvents, different ratios, liquefaction yield, and the hydroxyl number of the liquefied lignin were investigated.

The results showed that the lowest yield occurred with PEG + G with a ratio of 90:10 and the lowest hydroxyl number was obtained with PEG + G in both ratios (80:20 and 90:10).

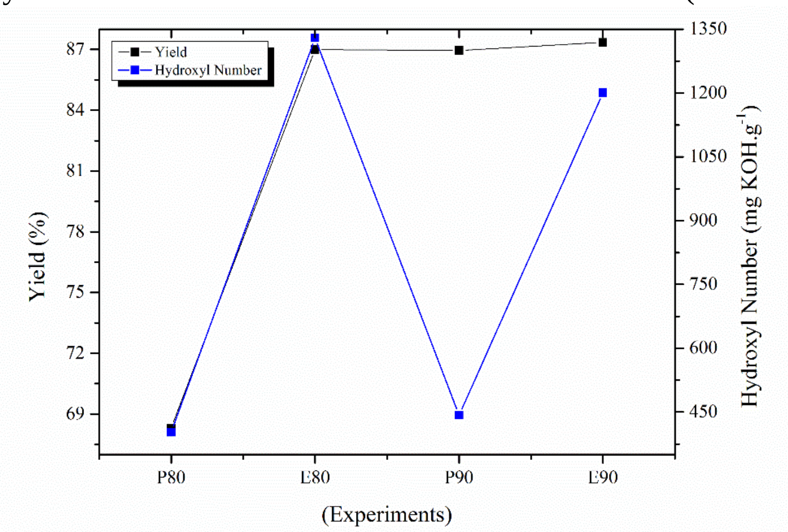

Figure 1: Liquefied lignin with different solvents and solvent ratios. Reaction conditions are 15 % lignin relation solvents, without catalyst, at 160 ºC to 60 min.

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THE INFLUENCE OF THE HEAT TREATMENT DURATION ON THE SURFACE ROUGHNESS OF BEECH PROCESSED BY PLANING

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Keywords: heat treated beech, planing, surface roughness

Research regarding wood heat treatments increased significantly in recent years in an effort to improve certain wood properties. Many aspects have been studied regarding wood dimensional stability, wood durability, mechanical properties, equilibrium moisture content, mass loss, wettability, colour change, chemical modifications, and others. However, limited studies looked into wood machinability and the resulting wood quality [4]. This study is meant to provide information regarding the effect of heat treatments as well as of the duration of the heat treatment on the quality of planed beech (*Fagus sylvatica L.*) surfaces. Specimens were analysed and compared with untreated beech subjected to the same planing conditions.

The method consisted of treating 18 beech wood samples with dimensions of 400 mm x 50 mm x 25 mm. Samples were treated using an electric oven at 200 °C, in air, at atmospheric pressure, for 1 h, 2 h, 3 h, 4 h, 5 h, and 6 h, with 3 replications for each treatment duration. A control set of specimens was prepared with untreated beech. After conditioning for 4 weeks at 20 °C and 55 % RH, both the heat-treated samples (average MC after conditioning = 3 % ± 0.2 %) and the untreated controls (average MC after conditioning in the same environment = 8 % ± 0.5 %) were planed on a Felder D963 machine at a rotation speed of 4567 rpm and a feed rate of 10 m / min by means of a “Silent power” cylindrical cutter head with helical cutters.

Measurements were performed by using a MarSurf XT20 instrument manufactured by MAHR Gottingen GMBH, using a MFW 250 scanning head with a tracing arm with a range of ± 500 μm and a stylus with a 2 μm tip radius and 90° tip angle. This instrument measured the specimens at a speed of 0.5 mm / s and at a low scanning force of 0.7 mN. From each specimen, 3 profiles, 42 mm long, were scanned across the grain (feed direction) at a lateral resolution of 5 μm. The roughness profiles were obtained by filtering each profile with a cut-off 2.5 mm by using a robust filter RGRF (Robust Gaussian Regression Filter) contained in [3]. This filter was tested and found useful for wood surfaces because it is more robust in comparison with the simple Gaussian filter and doesn’t introduce bias related to the wood anatomy. The following roughness parameters were calculated for profiles: *Ra*, *Rq*, *Rt, Rsk, Rku* as well as the primary profile parameters: *Pa*, *Pt* and *PSm* from ISO 4287 [1] and *Rk, Rpk, Rvk* from ISO 13565-2 [2]. For each treatment and roughness parameter a mean value and the standard deviation were calculated. ANOVA and Duncan’s multiple range tests were performed to test significant differences between control and heat treated samples for various durations.

From Table 1 it can be seen that skewness was negative for all profiles tested, while kurtosis was much higher than 3, both indicating that valleys in the profile prevailed compared to peaks. Inherent anatomical valleys were higher in magnitude than the roughness caused by processing. If wood anatomy is not removed from the evaluation, *Rk* is the best indicator of the processing roughness because it is the least biased. Treating beech for 1 h and

2 h had a negligible effect on the processing roughness measured by *Rk*. This parameter increased as relate to the untreated wood with 15 % for 3h and 4h of treatment and with approximately 33 % for treating beech for 5h and 6h. The gradual increase of *Rk* lowered the threshold in the valley domain inducing a reduction in skewness and kurtosis, which means that the effect of wood anatomy on surface quality decreases with the length of treatment. The significance of those results was tested and confirmed by ANOVA and Duncan's multiple range test at a $p < 0.05$ significance level (Table 1).

Table 1: Roughness and primary profile parameters measured across the grain for treated and untreated beech processed by planing (mean values in microns and standard deviations). Statistical analysis used Duncan's multiple range test (p<0.05)

Treatment	Ra	Rq	Rt	Rsk	Rku	Rk	Rpk	Rvk	Pa	Pt	PSm
Untreated	**5.7^{A}**	**8.9**	**55.1**	**-2.2^{A}**	**6.1^{A}**	**9.2^{A}**	**2.2**	**18.3**	**10.8^{A}**	**83.7**	**729.9^{A}**
stdev	0.54	0.77	6.82	0.06	0.44	0.63	0.25	1.31	2.62	18.62	283.38
1h	**5.8^{AB}**	**9.0**	**56.2**	**-2.1^{A}**	**5.8^{A}**	**9.3^{A}**	**3.3**	**18.0**	**8.7^{B}**	**69.5**	**417.6^{BD}**
stdev	0.37	0.66	6.95	0.11	0.43	1.23	1.35	1.89	0.69	8.03	77.88
2h	**5.9^{AB}**	**9.3**	**60.2**	**-2.2^{A}**	**6.2^{AB}**	**9.5^{A}**	**2.5**	**18.4**	**8.5^{B}**	**67.9**	**367.1^{BCD}**
stdev	0.73	1.19	9.99	0.16	0.81	1.86	0.38	2.58	0.94	24.36	48.95
3h	**6.0^{AB}**	**8.8**	**56.6**	**-2.0^{B}**	**5.4^{C}**	**10.6^{AB}**	**2.7**	**16.6**	**8.4^{B}**	**71.6**	**292.6^{C}**
stdev	0.85	0.99	4.19	0.13	0.60	1.73	0.60	1.47	0.30	5.44	54.71
4h	**5.6^{A}**	**8.0**	**51.0**	**-1.9^{B}**	**5.1^{C}**	**10.6^{AB}**	**2.2**	**14.6**	**7.7^{B}**	**60.8**	**284.3^{C}**
stdev	0.28	0.18	6.32	0.13	0.25	1.68	0.53	0.84	0.80	6.72	53.92
5h	**6.0^{AB}**	**8.5**	**56.0**	**-1.9^{B}**	**5.3^{C}**	**12.3^{B}**	**2.9**	**15.1**	**7.7^{B}**	**65.2**	**290.6^{C}**
stdev	0.54	0.52	11.48	0.16	0.47	2.65	0.99	1.03	0.68	9.86	57.03
6h	**6.5^{B}**	**9.5**	**57.0**	**-2.0^{B}**	**5.3^{C}**	**12.3^{B}**	**2.8**	**17.8**	**8.4^{B}**	**68.1**	**327.5^{CD}**
stdev	0.29	0.36	4.21	0.11	0.38	2.63	0.76	1.42	0.91	6.09	53.23

Note: Groups with the same letters in columns indicate that there was no statistical difference (p<0.05) between the samples according to Duncan's multiple range test

The waviness across the grain, included in the primary profile and sensed by *Pa*, *Pt*, and *PSm* in Table 1 generally showed a decrease in magnitude with the duration of treatment and was significantly lower for heat treated specimens as compared with untreated beech wood. It is assumed that thermally treated wood has partly recovered after milling due to its increased elasticity and as a result, smaller waviness amplitude occurred.

In conclusion, planed beech surfaces had a processing roughness lower than that of anatomical features of wood. Heat treating beech at 200 °C for 1 h and 2 h had a negligible effect on the processing roughness measured across the grain by *Rk*, but any further increase of the heat treatment gradually increased the surface roughness, while surface waviness after planing tends to decrease. This information is useful for finishing operations.

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EFFECT OF SILVER FIR FOREST MANAGEMENT ON RADIAL DENSITY DISTRIBUTION, THERMAL BEHAVIOUR AND FINAL QUALITY OF THE HEAT TREATED WOOD

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Keywords: density, earlywood, heartwood, latewood, juvenile wood, sapwood, silver fir, thermal degradation

Until recently, most of the defects affecting heat treated wood quality were attributed to a bad implementation of the heat treatment process due to heterogeneous thermal conditions in the oven or to the nature of the wood used. The effect of some intra-specific wood properties (density, chemical composition) on wood thermal behavior during the treatment is weakly reported in the literature. Tree growth variations throughout the stem, as well as their correlation with wood properties, have been extensively studied. Variation in the wood structure from the pith to bark has been reported to affect the physicochemical and mechanical properties of numerous wood species [1-4]. Thus, the aim of this work was to study the effect of intra-specific variability of silver fir (*Abies alba* Mill.) on its thermal stability in order to evaluate the effect of natural variability on thermal modification processes and predict the final quality of the heat treated wood. For this purpose, wood samples were taken along radii of cross-sections to estimate the effect of radial position on thermal degradation kinetics. This study was performed on 4 trees, 2 resulting from a dynamic growth stand (massive thinning policy) and 2 from a standard growth stand (no thinning at all). Wood samples were ground to sawdust and subjected to thermo-gravimetric analysis. Juvenile heartwood was shown to be more sensitive to thermal degradation than other parts of the stem. The thermal behavior of sapwood was not particularly different from that of heartwood. Earlywood was more affected by thermal treatments than latewood. This result is in agreement with previous observation on *Quercus petraea* L. [5]. Forest management involving the formation of wood with larger annual rings due to the production of higher quantities of earlywood appears therefore as a factor able to influence thermal degradation of wood during its thermal modification processes. Within the same tree, boards obtained from different parts of the trunk may present different thermal properties according to the proportion of the different wood compartment explaining one part of the difficulties encountered on industrial kilns to obtain products of constant quality.

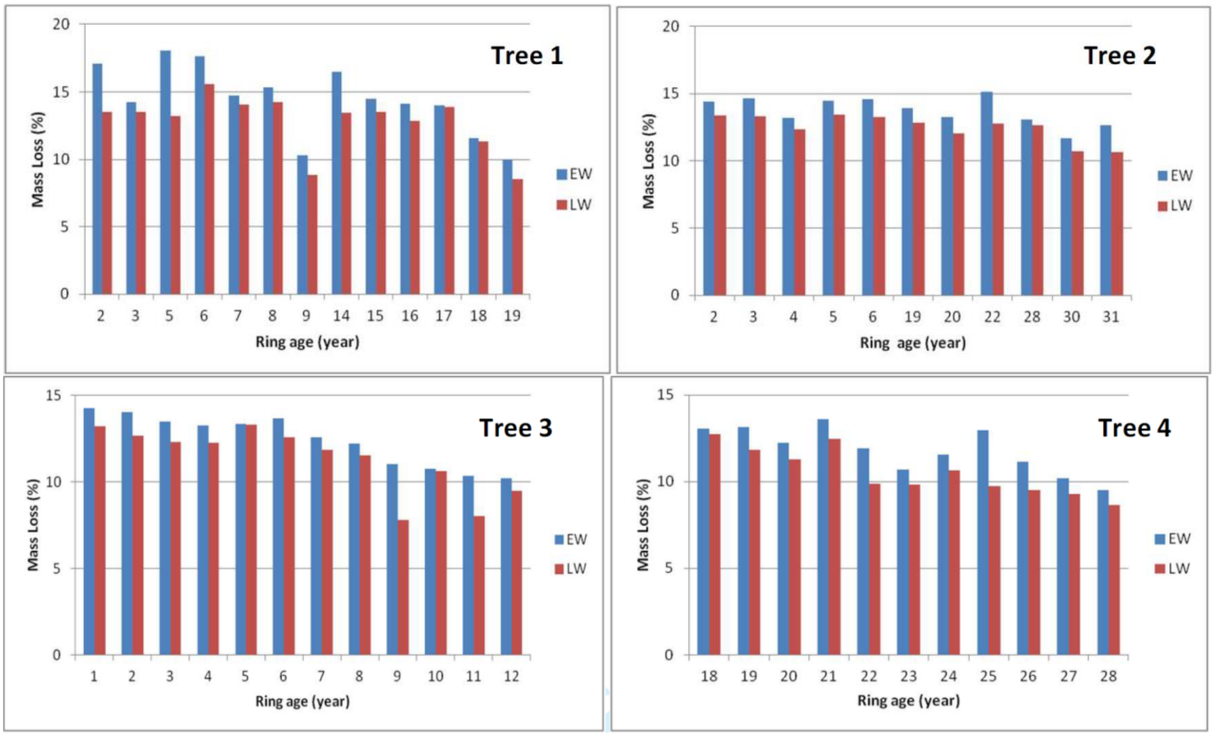

Figure 1: Intra-ring variations of thermal stability of earlywood (EW) and latewood (LW) samples treated at 230 °C for 2 hours of different trees grown under dynamic stand (trees 1 and 2) or control stand (trees 3 and 4)

Acknowledgments

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ESTERIFIED LIGNIN AS HYDROPHOBIC AGENT FOR USE ON WOOD PRODUCTS

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Keywords: organosolv lignin, coating, impregnation, artificial aging, optical properties

Lignin from spruce and eucalyptus wood was isolated using the organosolv process and was subsequently chemically modified using a long aliphatic chain (12C) of lauroyl chloride as a reagent [1, 2]. This process was used to obtain a hydrophobic lignin derivative to be used as a protective agent on wood products (Figure 1). Each esterified lignin was applied on wood veneers by two different methods. The first method was to apply it as a coating using a press moulding (current industrial processing technology) at two different conditions [3]. The second method consisted of impregnation using acetone as a solvent and immersing the samples for different periods of time [4]. The chemical modification of lignin was confirmed by FTIR, GPC, and DSC resulting in an increase of its molecular weight and a great reduction in glass transition temperature, allowing lignin to be processed by press moulding and improving the solubility in acetone.

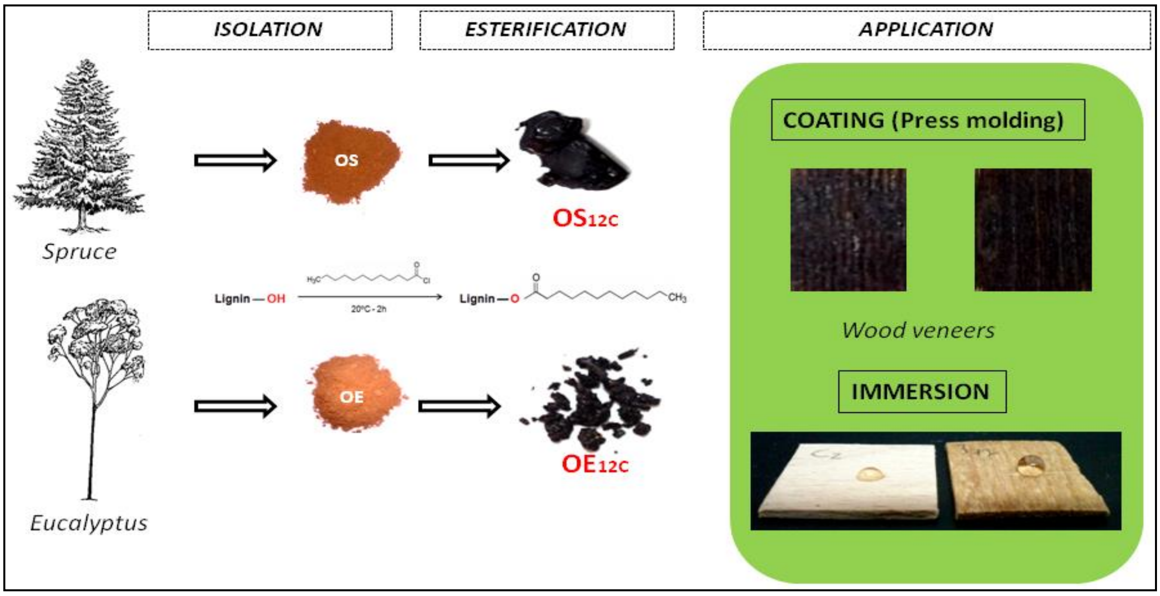

Figure 1: Graphical abstract of process.

The wood hydrophobicity (water contact angle≈140º), oleophobicity (oil contact angle≈120º), and stability against water and oil dramatically increased after treatments as observed by dynamic contact angle analysis. Furthermore, the efficiency of treatments over time was confirmed by accelerated aging testing. Aesthetic assessments by means of colour analysis (CIEL*a*b* system) showed significant differences between application methods, being more pronounced in the case of coating treatments (Figure 2). After the aging test the colour was quite stable.

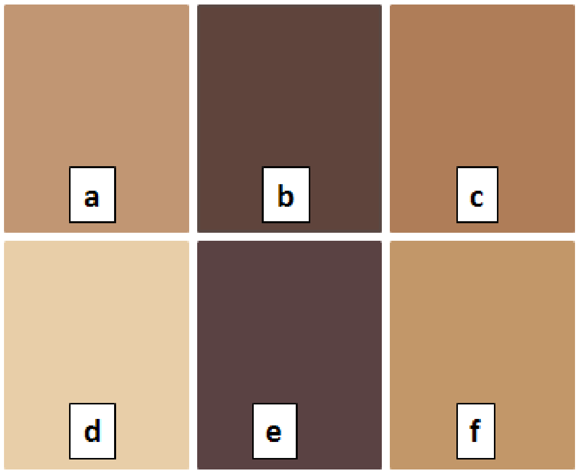

Figure 2: RGB colour space calculated for wood samples (a) untreated beech, (b) beech coated with OE12C at 90ºC/100Ba, (c) impregnated beech d with OS12C (72h), (d) untreated poplar, (e) poplar coated with OS12C at 90ºC/100Ba and (f) impregnated poplar with OS12C (72h).

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MODE I FRACTURE OF TROPICAL SPECIES USING THE GRID METHOD IN CONSTANT ENVIRONMENTS: EXPERIMENTAL RESULTS

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Keywords: Fracture, Tropical species, MMCG specimen, Grid method

Abstract

The aim of this work is to study the cracking appearance and propagation in various tropical wood of. In this paper, only the results obtained with Gabon padouk (*Pterocarpus soyauxii*) are presented. An experimental methodology comprised of wood in the form of a mixed mode crack growth (MMCG) specimen, an Arcan system, and a Zwick press are described. Results are presented as force-displacement and force-crack opening curves. Crack growth is obtained with images recorded by a camera during the test. Tests performed in the Mode I crack opening mode in the RL plane are posted. The critical energy release rate is obtained versus crack by the compliance method.

Introduction

Gabon's forests play an important role in the regulation of climate change and global warming with 85 % of the land area covered by forest. However, despite the importance of climate change and high rainfall, tropical woods are mainly used by locals. Their mechanical properties still remain unknown today and their use in timber structures is negligible. The purpose of this study is to characterize the mechanical behavior of these species and guide local populations in choosing their building materials, which are usually concrete and steel. This work is focused on the crack growth process in the opening mode of padouk using MMCG specimens [1]. Specimens are mounted in an Arcan system and placed in an electromechanical testing machine. A CCD camera records images during the test. Pictures are processed by the grid method [2]. They enable us to measure the opening and the length of crack during the tests.

Materials and methods

Wood specimens with dimensions of 105 mm x 70 mm x 15 mm were tested (Fig. 1a). The initial crack, with length a_i = 20 mm is placed along the longitudinal direction (Fig. 1b). On one face of the specimen, a grid of pitch 200 µm is deposited as seen in Fig. 1b and 1c. The density and the moisture content of the specimen are equal to 0.79 and 7.29 %, respectively. The room temperature was 21 °C and the relative humidity was about 35 %.

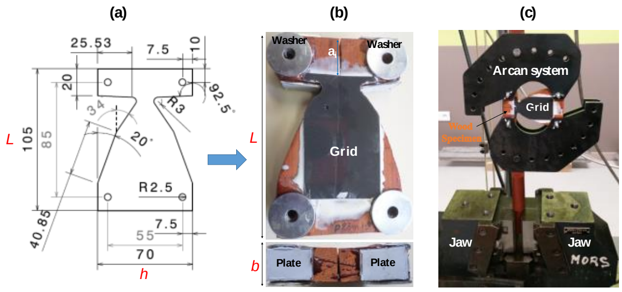

Figure 1: dimensions of specimen (a), Wood specimen (b); experimental device (c)

Four washers in galvanized steel of a diameter of 6 mm were used to reinforce the holes, through which the load was applied, as shown if Fig. 1b. The lower and upper parts of the specimen have also been reinforced by thin aluminum plates Fig. 1b. The camera was placed 675 mm away from the specimen in order to record pictures. Displacement was measured and strain fields were calculated from the images using the grid method. The MMCG specimen and the experimental device are presented in Fig. 1c.

Results and discussion

Typical results obtained with two specimens for padouk (Specimen 1 and Specimen 2) are shown in Fig. 2. The displacement maps obtained with the grid method are presented in Fig. 2a. In both tropical specimens, the crack progress followed the fiber orientation.

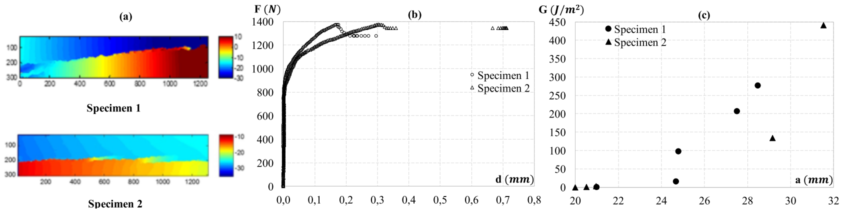

Figure 2: displacement maps (a), force-displacement curves (b), critical energy release rate (c)

The force-displacement curves of two specimens are depicted in Fig. 2b. It is worth noting that the maximum peak of the padouk curve is reached when the force at failure is 1373 N for both specimens. However, the corresponding displacement is 0.308 mm for Specimen 2 and 0.175 mm for Specimen 1. The breaking point of the specimen occurs quickly in the case of Specimen 1. This is a consequence of the heterogeneity of this species. According to the failure load, the thickness and the crack length, the critical energy release rate is computed with the compliance method with imposed displacement by the following equation:

$$G_c = \frac{F_C^2}{2 \cdot b} \cdot \left(\frac{\Delta C}{\Delta a}\right) \quad (1)$$

We note that during the crack growth process, the critical energy release rate G_c increases until the total collapse of both specimens, see Fig. 2c. The fracture toughness of Specimen 2, 445 J/m^2, is significantly higher compared with Specimen 1, at 140 J/m^2. The low value of G_c in Specimen 1 can be explained by the heterogeneities of padouk such as the orientation of fibers, the presence of nodes, and its density. This type of observation is already reported by some authors [3] in the case of non-tropical species.

Conclusion

In this study, the crack growth process in opening mode of two tropical species of padouk has been investigated with the grid method. The displacement maps, force-displacement curves, and the crack length are obtained. The results illustrate the heterogeneity and the strength of this species. The evolutions of the critical energy release rate G_c have been calculated with the compliance method. We note that the fracture toughness is significant in padouk due to the high value of G_c despite the material heterogeneity. In upcoming work, tests will be performed in mixed mode configuration with different moisture content levels in order to study the environmental impact of this parameter on the fracture process of such tropical species.

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A PRELIMINARY STUDY ON THE DELIGNIFICATION OF THE WOOD BLOCKS VIA MICROWAVE ASSISTED ATMOSPHERIC ORGANOSOLV METHOD FOR THE PRODUCTION OF HEMICELLULOSIC SCAFFOLDS

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Keywords: Delignification, microwave, atmospheric pressure, organosolv, holocellulosic scaffold

The traditional kraft, soda, and sulfite processes have long been used for delignification of wood in the pulp and paper industry. However, these methods have some important drawbacks such as air and water pollution due to organic sulphur and chlorine bleaching compounds. Due to these environmental concerns, organosolv delignification has attracted much interest as an alternative, environmental-friendly method since the 1970s [1]. However, the organosolv process requires high temperatures, long reaction times, and high pressures. Due to these challenges, some scientists have proposed and conducted microwave energy to enhance the lignin extraction yield from lignocellulosic biomass due to the efficient internal heating [2]. Most recently, two innovative studies take delignification processes a step further with the exception of pulp production and pre-treatment for the bio-fuel production. For the first time, transparent wood composites were produced by removing the lignin and filling the holocellulose structure with a polymer or epoxy resin to obtain high optical transparency. Furthermore, structural hierarchy, oriented cell structure, and the nanoscale cellulose fibre network of wood tissue were well preserved [3, 4].

The objective of this study was to evaluate the effects of the microwave enhanced organosolv delignification of wood blocks on some properties of holocellulosic template/scaffold without dissolving or degrading cellulose for potential wood/polymer composite applications. Poplar (Pop) and beech (Bch) wood blocks were obtained by longitudinally (L) cutting the wood. The poplar wood blocks were also prepared by radially (R) cutting to investigate the effect of fibre direction on the delignification process. Delignification of wood samples was carried out with different solvents (water, ethanol, glycerin) in the presence of $NaOH/Na_2S$ as a catalyst in different sulfidity percentages. The samples were immersed in the aqueous solution of ethanol (75 %, v/v) with a sulfidity of 20 % and 50 %, and glycerin (85 %, v/v) with a sulfidity of 20 % along with a water solution of $NaOH/Na_2S$ with a sulfidity of 40 %. The samples were then extracted in a microwave oven (NEOS) at the power level of 350 W for 2 h under reflux and continuous stirring. At the end of the reaction, samples were separated from extraction solution and washed with the aqueous ethanol. The wood blocks were then placed in a bleaching solution of H_2O_2 and treated in the microwave oven at the power level of 150 W for 1.5 h. Finally, samples were rinsed with aqueous ethanol and dried in an oven between glass blocks to preserve the structure until constant weight. The weight loss (WL) percentage of the wood blocks was calculated as a degree of delignification for different experiments. In order to investigate the chemical alterations of samples FT-IR/ATR spectroscopy analysis were carried out. Furthermore, the changes in the surface hardness of samples after delignification were determined by using a digital durometer.

The visual appearance of the wood blocks after the delignification indicated that the lignin, colored polymer of the wood, was removed and wood blocks turned into a yellowish color. After that with the effect of bleaching process the color of the wood blocks becomes lighter and whiter due to the colorless cellulose template. According to WL percentages (Table 1), the highest delignification was obtained via aqueous ethanol solution with the sulfidity of 20 for L-wood samples. WL of beech samples was more than poplar. When the WL in the R-wood and L-wood of poplar was compared, it was very critical that degree of delignification substantially increased. The difference in fiber directions led to different mass transfer behaviour, where lignin could be extracted out much more easily in R-wood due to the cell lumina perpendicular to the plane with a short depth same as the thickness of the wood block. The lignin polymer fills the spaces in the cell wall between cellulose, hemicellulose and pectin, and supplies the mechanical strength and rigidity of plant walls. The importance of this phenomenon was proven with the results of hardness tests (Table 1). The Shore D surface hardness values of the samples diminished correlatively with the delignification degree of samples. Finally, FTIR spectrum of the samples showed that some alterations occurred in the chemical structure of wood. Especially, it was noticed that the peaks of C-O stretching and syringly ring of lignin at the wavenumber of 1230 cm^{-1} and C=O stretching of ketones, carbonyl and ester groups at the wavenumber of 1730 cm^{-1} disappeared after delignification.

Table 1. Weight loss percentage and surface hardness value of the wood samples

Sample	WL (%)	Sample	WL (%)	Sample	Shore D	Sample	Shore D
Pop-W	8.81	Bch-W	14.87	Pop	46.7 ±3.9	Bch	59.7 ±4.5
Pop-E50	11.1	Bch-E50	17.98	Pop/R	42.1 ±3.6	Bch-W	54.8 ±3.1
Pop-E20	14.35	Bch-E20	21.7	Pop-W	43.7 ±2.7	Bch-E50	50.1 ±3.7
Pop-Gly	12.55	Bch-Gly	15.78	Pop-E50	36.2 ±4.2	Bch-E20	52.1 ±3.6
Pop/R-E50	19.73			Pop-E20	37.8 ±2.2	Bch-Gly	49.3 ±5.2
Pop/R-Gly	17.72			Pop-Gly	38.7 ±3.3	Pop/R-Gly	36.5 ±2.5
				Pop/R-E50	34.2 ±3.1		

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EVALUATION OF HARDNESS OF HEAT TREATED YELLOW POPLAR WOOD

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Keywords: hardness, heat treatment, yellow poplar

Yellow poplar (*Liriodendron tulipifera*) also known as the tulip tree or tulip poplar is a popular tree in the Southern United States. Wood from this fast-grown species is extensively used for many indoor and outdoor applications, such as for siding, moulding, millwork, cabinetry, and decking. It was reported that yellow poplar represents 9 % of the timber products in eastern hardwood forests in the USA [4]. Regarding outdoor applications of this species, the wood needs improved properties, such as enhanced durability [5] and dimensional stability [1]. Heat treatment is one of the options used to improve wood properties of this species. The hardness of the samples was adversley influenced by the treatment. Scanning electron microscopy (SEM) analysis revealed that the cross section of heat treated wood samples had a smoother surface than that of non-treated samples [1,3]. However heat treatment reduced overall mechanical properties of the samples [6]. This study aims to evaluate the influence of heat treatment on hardness of yellow poplar specimens.

Material and methods

Defect free samples were cut from boards supplied by a local sawmill in Oklahoma. Samples were exposed to heat treatment in a laboratory oven at a temperature of 190°C for 3 h and 6 h. A universal testing machine was employed to measure the Janka hardness of the samples. Measurements were performed before and after the heat treatment. SEM micrographs were also taken both from treated and control samples to observe the anatomical structure of the samples (Fig.1).

Results

As expected, the colour of samples turned dark as the heat treatment exposure increased. Such discolorations are produced by the chemical changes and degradation of hemicelluloses, lignin, and some extractive compounds [2]. It was found that the hardness of heat treated wood was lower than that of the control samples, but the results were found to be sufficient for different uses of yellow poplar. Similar results in terms of hardness values for the same wood species after heat treatment were found in literature [6]. It appeared that the reduction in hardness was greater when increasing the exposure time to 6 h. This can be explained by the deterioration occurring in the cell wall structure after the heat treatment.

The findings of this work showed that heat treatments could give new potential to fast-growing species of relatively low-grade, like yellow poplar, for a higher performance and value added use in furniture manufacturing and outdoor applications.

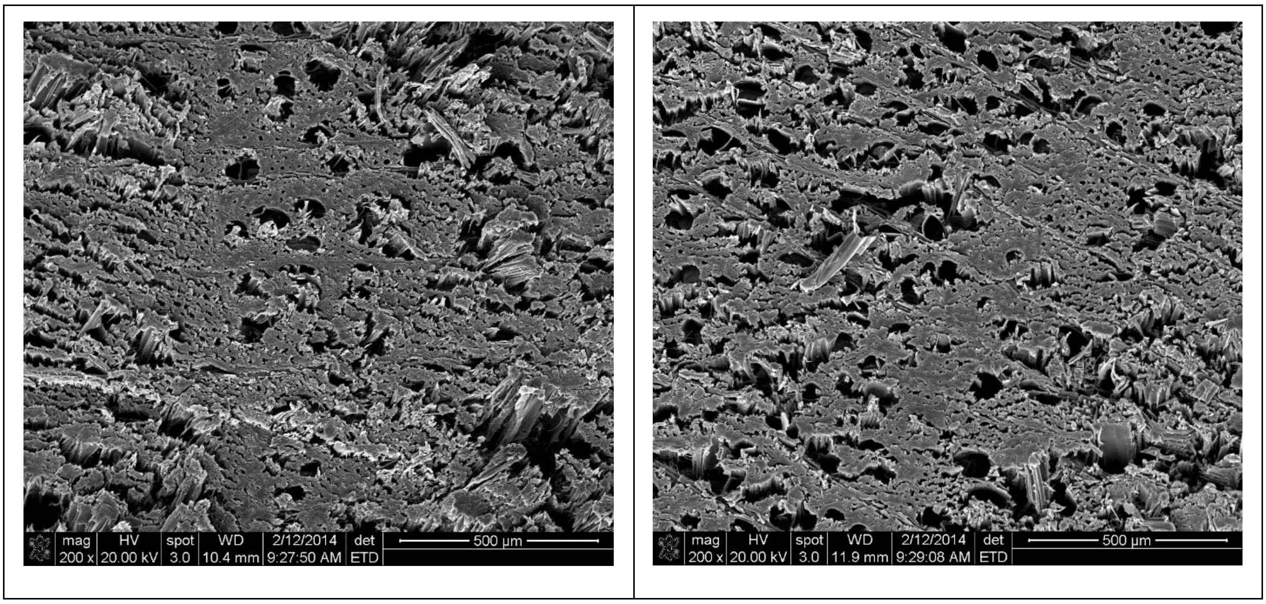

Figure 1: SEM micrographs of yellow poplar wood:
control (left) and heat treated samples at 190°C for 6 h (right)

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SURFACE MODIFICATION USING INFRARED RADIATION

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Keywords: beech, colour measurement, FT-IR spectroscopy, spruce

Surface modification is an upcoming issue of wood modification and has gained some interest in the last ten years [1-3]. New modification methods were focused on the surface layers with respect to ecological and economic reasons [2]. Particularly, the focus was placed on the surface properties of wood (e.g. wettability, weathering resistance, colour stability).

One approach may be the use of infrared radiation (IR) to alter the polymers of the wood surface. This kind of irradiation may change the properties (e.g. colour) of wood surfaces.

In this study, samples from beech (*Fagus sylvatica L.)* Norway spruce wood (*Picea abies L. [Karst.]*) were cut to dimensions of 20 mm x 20 mm x 50 mm. The preparation of the surfaces was performed with a planer. All samples were stored in a climatic chamber (20 °C and 65 % relative humidity) before and after the IR radiation as well as before and after the various analyses. The IR treatment was performed under environmental conditions at different temperatures ranging from 150 °C to 290 °C (Figure 1).

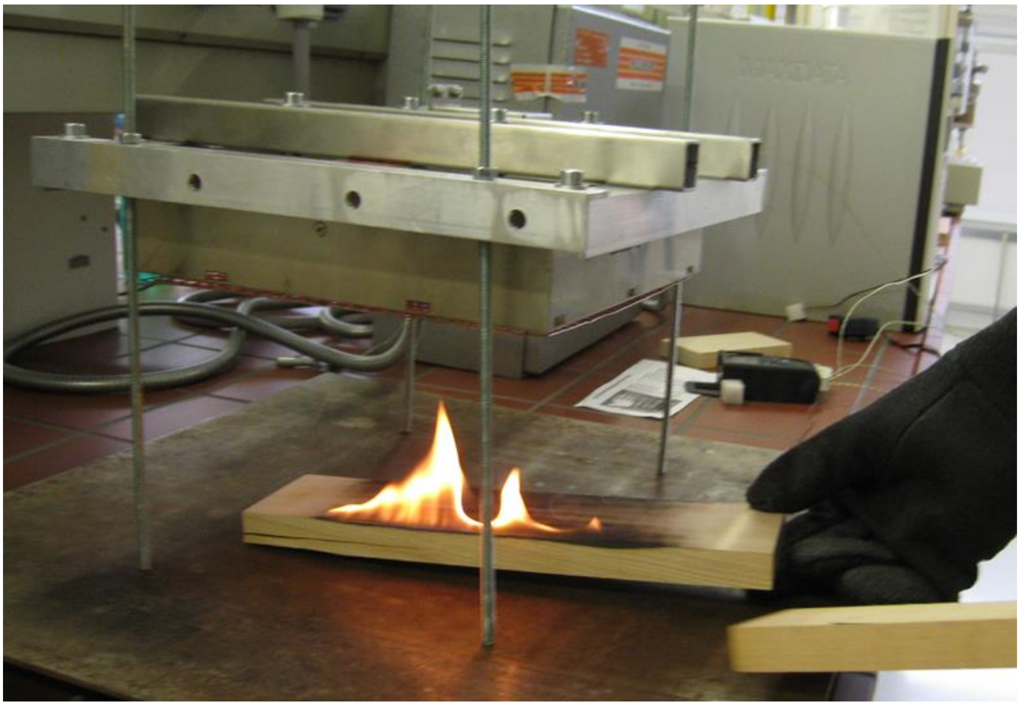

Figure 1 Ignition of one beech sample during pre-studies

The spectra were recorded in the range between 4000 cm^{-1} and 600 cm^{-1}, as an average of 32 scans and with a resolution of 4 cm^{-1} using a Frontier FT-IR spectrometer (Perkin-Elmer) equipped with a Miracle diamond ATR accessory with a 1.8 mm round crystal surface. All spectra were ATR corrected. The colour of the samples with a 2.5 mm diameter was measured with a Mercury 2000 spectrophotometer (Datacolor). The known *CIE L*a*b** system was applied with a standard illuminant D65 and a 10° standard observer. The mean of three measurements per sample is presented.

The results lead to different colouration of the wood surface depending on the treatment temperature and duration (Figure 2). Differences between the FT-IR spectra of IR treated and untreated beech and spruce samples were observed.

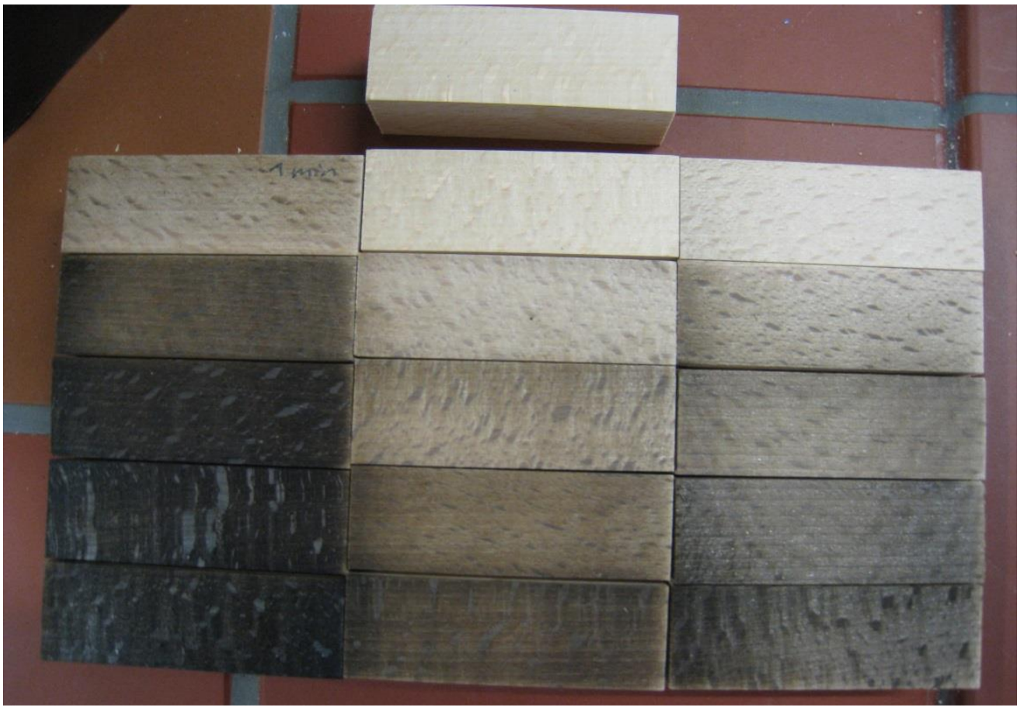

Figure 2 Comparisons of the different treatments by surface colour.

Based on these findings pre-treatment of wood surfaces for industrial use can be a potential application of this technology. Further studies on the effects of radiation doses on wood materials are needed to analyse if and how coating and gluing properties of wood are influenced by IR radiation.

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WOOD THERMAL DEGRADATION: PREDICTION OF PROCESS PARAMETERS, SOLID MASS YIELD, BY TWO MATHEMATICAL MODELS

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Keywords: Mass Solid Yield, Mathematical Model, Thermal Degradation, Wood

The properties of non-durable European species can be improved using different thermal treatments. Different configurations of treatments allow distinct wood components to be chemically modified and improve dimensional stability and biological performance against decay fungi. Torrefaction is a thermochemical conversion process which improves biomass properties and is characterized by relatively low temperatures and essentially endothermic reactions.

While experimental work on torrefaction remains active, few models exist that comprehensively describe the evolution of the volatile products or solid composition and energy balance over a range of conditions. Di Blasi and Lanzetta, [1] and Prins [2] propose and validate a kinetics model that describes the solid mass loss of willow during torrefaction. Ranzi et al. [3] developed a detailed multi-step chemical kinetic pyrolysis model. Based on eucalyptus torrefaction experiments, Almeida et al. [4] showed that solid mass loss can be used as a quantitative indicator of the extent of torrefaction. Neves et al. [5] developed an empirical model for biomass pyrolysis products based on fitting the trends of experimental data. Pétrissans et al. [6] studied the mass loss kinetics for torrefaction of wood samples using equipment specially conceived to measure mass losses during thermal treatment. Bates and Ghoniem [7,8] developed a one-dimensional model accounting for the effects of heat and mass transfer, chemical kinetics, and drying to describe the torrefaction of wood biomass particles.

The aim of this work is the development of a two-step solid mass loss and volatile release kinetics mechanism model during torrefaction, under conditions based on experimental results from Prins [2] and numerical results from Bates and Ghoniem [7,8]. The model developed in finite element software, estimates the solid product composition by mass conservation and describes their thermal, chemical, and physical properties as well as the energy yield, energy densification, and heat release rates.

Comparisons from experimental and numerical results for five different experimental configurations are made with the results from Prins [2] and Bates and Ghoniem [7] and are illustrated in Fig. 1. The results show a good agreement for the solid conservation species and most of the volatiles were released during the first stage of torrefaction, such as water, acetic acid, and carbon dioxide. Volatiles released during the second step were primarily lactic acid, methanol, and acetic acid. The higher temperatures increase the mass loss rate and heat release during the thermal treatment. The energy densification ratio increases with the degree of torrefaction quantified by the mass loss. The comparison results validate the reproduction of the Bates and Ghoniem [7,8] model and will be used in the development of a new approach to predict torrefaction process parameters under different torrefaction atmosphere configurations.

Table 1: Torrefaction experimental conditions for the five different experiments [2].

Experiment	Units	1	2	3	4	5
$T_{initial}$	(°C)	200	200	200	200	200
T_{final}	(°C)	230	250	270	280	300
Heating Rate	(°C/min)	10	10	10	10	10
Heat up period	(min)	3	5	7	8	10
Isothermal Period	(min)	50	30	15	10	10
Total Time	(min)	53	35	22	18	20

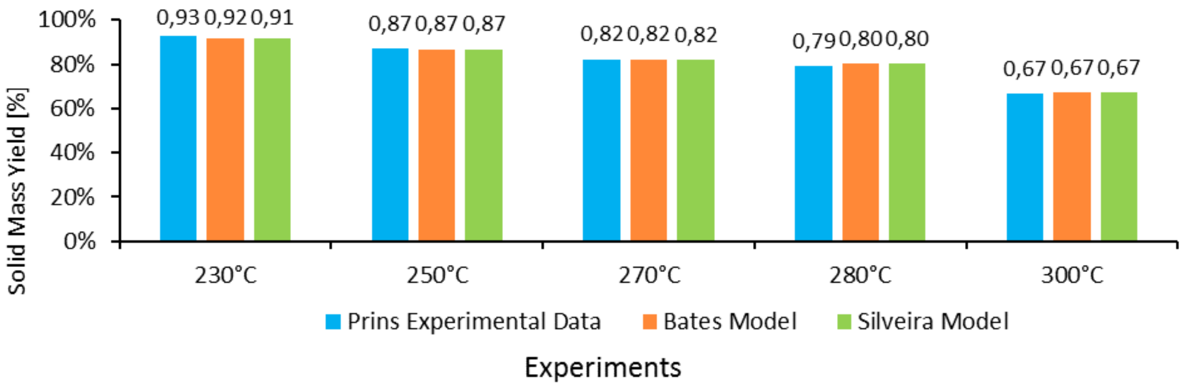

Figure 1: Comparison between numerical results, experimental solid mass yield from Prins, 2005 [2], and kinetic simulation results for solid mass yield from Bates and Ghoniem, 2012 [7].

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ABRASIVE WATER JET CUTTING (AJWC): WOOD MATERIAL – JET INTERACTION

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Keywords: abrasive water jet cutting, particleboard, OSB, oak wood, multifactoral experiment, electronic microscopy, mathematical model

Abrasive water jet cutting-(AWJC) technology presents a highly efficient machining method for wood and wood-based composites. A very important property of AWJC is the reduced trim waste produced during the process (in this paper expressed as longitudinal mass loss) and an unchanged wood tissue structure. The aim of this paper was primarily to establish a relationship between processing parameters and material characteristics. These parameters include the feeding rate (u), nozzle distance from the upper surface (h) of material and jet pressure (p). The materials characteristics include the material (oak wood, particleboard and OSB) mass loss (Δm) as measure of wood or wood-based material waste and the condition of the cutting surface after machining. The last characteristic mentioned is of extreme importance for quantitative yield in the case of cutting standard dimensional boards as well as solid wood in the final phases of wood processing. This paper focussed on 18 mm thick particle board, 16 mm thick OSB and 20mm thick oak specimens. This was considered a triple parameter test. The magnitude level of the selected parameters was set to three: zero or referent level, lower and upper level, denoted as 0, -1, and 1, respectively. A multifactor experimental plan was applied for the purpose of establishing a relationship between selected parameters and experimental output presented as longitudinal mass loss. Moisture content of the specimens was determined before and after AWJC was applied and throughout the drying and conditioning phase. After samples reached the initial moisture content it was possible to determine the difference in the mass. According to these results and by applying the orthogonal plan matrix (Box-Wilson matrix) the mathematical model has been established for all three observed materials. Presumed mathematical model was in exponential form:

$$R = C \cdot f_1^{p_1} \cdot f_2^{p_2} \cdot f_3^{p_3}$$

Other correlated investigations were conducted simultaneously, such as electronic microscope abrasive detection and wood tissue examination with SUPER EYE digital USB microscope.

Results obtained showed that the proposed mathematical model is adequate in the case of all investigated materials. However, none of the influences of processing parameters were significant, except for the nozzle distance (*h*) in the case of wood-based panels (particleboard and OSB). Detailed microscopic examination of the surface showed the presence of abrasive particles originating from the garnet mineral and its alterations, but did not show a significant amount of mass deposed on the cutting surfaces. Calculations showed small changes in the mass, but not enough to be considered as an influential factor for final results.

In the case of oak, pictures of the cutting surface made by AJWC compared to those made by conventional cutting by band saw, showed wide opened vessels in the wood tissue. No presence of deposed abrasive particles was detected by means of optical microscopy.

Results and analysis gave the following mathematical models for particleboard, OSB, and oak, respectively in equations 1, 2, and 3:

$$\Delta m = 0,767 \cdot p^{0,057} \cdot h^{1,309} \cdot u^{0,316} \quad (1)$$

$$\Delta m = 2,826 \cdot p^{-0,662} \cdot h^{0,874} \cdot u^{0,601} \quad (2)$$

$$\Delta m = 1,657 \cdot p^{0,0482} \cdot h^{0,0903} \cdot u^{0,3125} \quad (3)$$

Images from an electron microscope show an insignificant presence of abrasive particles are presented in figure 1:

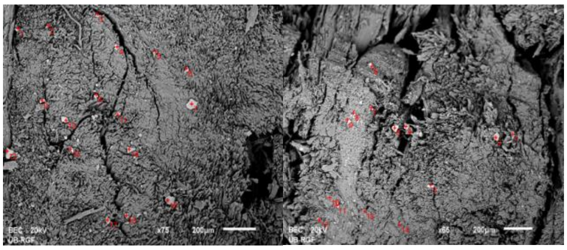

Figure 1: Deposed garnet particles on the cutting surfaces.

Comparison of the oak machined conventionally (with band saw) and by AWJC is shown in figure 2:

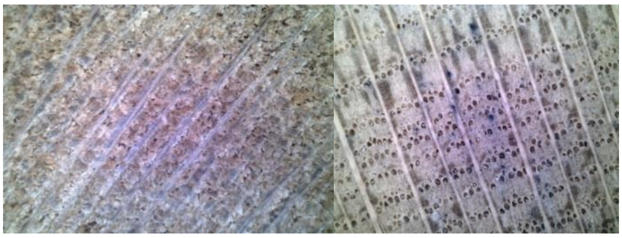

Figure 2: Left: conventionally machined; Right: *AJWC* machined surfaceoak wood surface

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PHENOLATION OF WOOD AND ITS APPLICATIONS FOR THE PRODUCTION OF ENGINEERED POLYMERIC MATERIALS

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Keywords: Phenolation, liquefaction, wood polyol, phenolic resin, moldings

In order to achieve complete utilization of wood wastes, a variety of studies are being intensively promoted on wood chemicals, modified natural polymers, energy, and new pulping methods. Apart from those, other utilization methods of wood wastes are the plasticization of wood by conventional chemical processing such as etherification, esterification, and solvolysis of wood or "liquefaction of wood", for making wood waste-based plastic sheets, molded products, foams, etc. Solvolysis liquefaction, one of the thermochemical methods, dissolves wood in an organic solvent with an acidic or alkaline catalyst at moderate temperatures (80-150 ˚C) or without catalyst at elevated temperatures (240-270 ˚C) and atmospheric pressure. A large number of organic solvents have been used for solvolysis liquefaction of biomass or its components, such as phenol, polyhydric alcohols (e.g. ethylene glycol, glycerol, polyethylene glycol), ethylene carbonate, dioxane, ethanol, etc. [1, 2]. So far, the pasty solutions obtained after liquefaction of wood have been applied for preparation of novolak and resol type phenolic resins such as adhesives [3], polyurethane foams [4], resol type phenolic resin foam [5], molding materials [6], carbon fibers [7], polyesters [8], and epoxy resins [9].

Wood liquefaction using phenol as a reagent solvent and an acid catalyst has long been studied as a technique to utilize biomass as an alternative to petroleum-based products. A variety of general studies have been conducted on wood liquefaction with phenol. The effects of water, catalyst type, catalyst concentration, liquefaction temperature and time, and phenol to wood ratio have been investigated. The molecular weight and flow properties of the liquefied wood have also been characterized [1, 2]. In an early work, Mceihinney [10] patented a method for the conversion of different lignocellulosic feedstocks into phenolic resin with an acidic catalyst at high pressure. Moreover, Hesse and Jung [11] patented a wood liquefaction technique in the presence of sulfuric acid for the production of molding and coating resins with hexamethylenetetramine (HMT). Apart from these, many attempts have been made to phenolate wood wastes in the presence of various acidic, e.g. hydrochloric, sulfuric, oxalic acid and phosphoric acid and alkaline e.g. NaOH, MgSO4, etc., as catalysts to make bakelite-type molding materials [1-4].

The properties of the phenolated wood, prepared by using acidic catalysts, except for oxalic acid, and the phenolated wood-based molded materials from it were found to be quite comparable to those of commercial novolak resin. The studies showed that among these catalysts, sulfuric acid appeared to be the most effective catalyst on the phenolation of unmodified wood at a moderate temperature [1]. Moreover, NaOH used as a catalyst in the phenolation of wood at elevated temperatures resulted in the good dissolution of wood into phenol, but with large amounts of phenol remaining unreacted. Moreover, the properties of NaOH-catalyzed phenolated wood and molded materials prepared from it, e.g. thermofluidity and mechanical properties, were determined to be evidently lower than those of commercial novolak resin due to insufficient amounts of phenol reacted with wood components [4].

As results of these, it was necessary to find a way to diminish the amount of un-reacted phenol, which led to many problems when compared with commercial novolak resin. It was found that almost all the lignocellulosic biomass could be successfully liquefied into the solvents. Specifically, phenol formaldehyde-type moldings from the wood liquefied into phenol by using inorganic and organic acidic catalysts had physical and mechanical properties comparable to commercial phenol-formaldehyde-type moldings [2].

With the increasing impetus for a more extensive utilization of abundant and renewable biomass resources, phenolation of wood and its application to thermosetting materials is a promising technique. Until now, phenolated wood resins with good processibility and reactivity have been successfully prepared by various methods. On the other hand, it has been also found that the liquefaction efficiency of wood, the thermoflow properties and reactivity of the resulting resins were remarkably dependent on the liquefaction conditions such as the kind of catalyst, temperature, etc. Therefore, for a more comprehensive understanding of the liquefaction, and for the further development of its application, more extensive studies on the fundamental phenomena of liquefaction should be accomplished. Thus, this study focuses on reviewing the studies about phenolation of wood for the production of engineered polymeric materials. This study aimed to explain the principles of the wood phenolation method, properties of molding materials, and pay attention to the importance of wood-derived materials for the better understanding of the subject.

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DEVELEPOMENT OF WOOD MODIFICATION – HIGH MELTING POINT WAX AND HOT OIL TREATMENTS

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Keywords: wood modification, impregnation, high melting point wax

Introduction

The aim of this study is to find out promising process parameters and suitable high melting point waxes and oils to modify products made out of common Nordic timber species, *Pinus Sylvestris* and *Picea abies*. To be able to reach this goal, a modern wood modification research facility was established at the Mikkeli University of Applied Sciences (Mamk).

The most common way to treat wood products are surface treatments, impregnations, thermal modifications, and chemical modifications [1]. Treatments are used to improve properties of wood products like better dimensional stability and increased weather and biological durability. Good weather and decay resistance are one of the main issues when trying to increase the use of wood and wood-based materials and create new business opportunities.

The properties of different wax/oil impregnated wood products and penetrations of the impregnation products have been investigated in several studies [2, 3]. There are companies, like those found in Central Europe that manufacture wax and hot oil mixture modified wood products. The studies and commercial products support that these kind of modifications are good methods to improve properties of wood products.

In the first phase of this study, pilot modification equipment was designed by Mamk. In the second phase, ongoing ready-made products and components were modified, evaluated, and tested. For the product components, the aim is that all the needed machining would have been done before the treatments. This reduces loss of the expensive waxes and oils and leaves all the surfaces of the products treated. The modification research is done in co-operation by Mamk and participating industrial companies who represent the whole value chain of the wood product industry, from sawn timber to ready-made component manufacturing. This co-operative research is helping companies create higher value wood products to market that are treated with high melting point waxes and hot oils.

Pilot manufacturing and testing

The new modification equipment provides a possibility to conduct small scale pilot manufacturing. The diameter of the impregnation chamber is 380 mm and 2200 mm in length. These dimensions enable modification of full size components used in the wood product industry. Maximum operating temperature is 200 °C and maximum pressure with nitrogen gas is 11 bar with air pressure at 15,5 bar. Temperature and pressure conditions in impregnation - and storage cylinders can be controlled separately. Heating and cooling is managed with a separate temperature control unit. This versatile equipment enables various modification methods for impregnations and heat treatments.

The usability of different waxes, oils, and processing parameters are evaluated after the test runs. Colours and pigments are going to be tested to increase the protective effect of the waxes and oils and to enhance the aesthetic appearance of the products. Various impregnation process parameters are going to be run to find the most promising combinations to treat different kinds of products.

After the modification treatment, properties of the products are going to be tested according to EN standards and applying EN standards. The tests are focused on mechanical properties, weather durability, and biological resistance which are the main issues when talking about the usability of wooden products. Of those scheduled to be tested are: mechanical properties, dimensional stability, gluing and coating properties, biological resistance, and weather durability. Untreated wood and commercially modified wood products are going to be used as reference materials.

Production processes together with product service life are playing an important role when life cycle impacts are assessed. The life cycle assessment program – VTT Sulca is going to be used for guidance in process development and valuing waxes, oils, and finally the treated products.

Tests run with high melting point waxes were started in March. The first runs were made with clarified Montan wax that has a drop point of 99 °C to 105 °C. These test runs show that the equipment functions as planned. Still, some process parameters need more work to have decent, smooth surfaces on all surfaces of the products.

Conclusion

This research aims to create valuable information for the companies which are working in the wood product and related industries. The results improve the understanding about the long-term durability of modern modified wood products and the environmental impacts of these methods and products. In the best case scenario, durable products with low environmental impact will be launched to the market.

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ENHANCEMENT OF LOW GRADE TIMBER WITH SYNTHETIC MATERIALS

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Keywords: FRPs, reinforcement, bending strength

In the wood building industry the provision of high safety enforcement and high-quality materials as well as the availability of timber elements conform to standards are important issues. It is estimated that in a typical pine log only 15% of the volume can be sawn into high-quality knotless lumber. The remaining 85% of the volume is loaded with various structural defects, which decrease the strength of the lumber. The limited availability of high-quality raw material, virtual trends to protect the forests and needs to keep low production costs demand an efficient utilization of wood in structural applications. In this context, the reinforcement of timber beams using CFRP strip (Carbon Fibre Reinforced Polymer) can be of a great interest.

CFRP started to be used in the construction in the 60s, with the development of the usage of resins. Composites have specific qualities that differentiate them from traditional construction materials, that is: low specific weight that goes together with very good physical parameters and high resistance [2, 3]. Table 1 shows the basic properties of chosen fibre types and steel.

Table 1: Chosen properties of fibres and steel [1]

Parameter	Fibre type					
	steel	E-glass	S-glass	graphite	kevlar 49	boron
Diameter [μm]	-	16	16	7-8	12	100-200
Specific weight ρ [kN/m^3]	78	25-25.5	24.5	13.8-18.6	14.1	25.5
Tensile strength R [GPa]	0.5	1.7-3.5	2.5-4.8	1.7-2.8	2.3-3.6	3.5
Specific strength R/ρ [km]	**6.4**	**68-136**	**102-196**	**123-163**	**163-255**	**137**
Young's Modulus E [GPa]	210	72	86	230-250	120-125	400-410
Specific modulus E/ρ [km·10^3]	**2.7**	**2.8**	**3.5**	**12.4-18.1**	**8.5**	**16**

The objective of this study was to investigate the possibility to upgrade low grade timber weakened with knots by introduction of reinforcement material. Innovative method of local strengthening was developed, which aimed at lower material costs while maintaining high reinforcement efficiency.

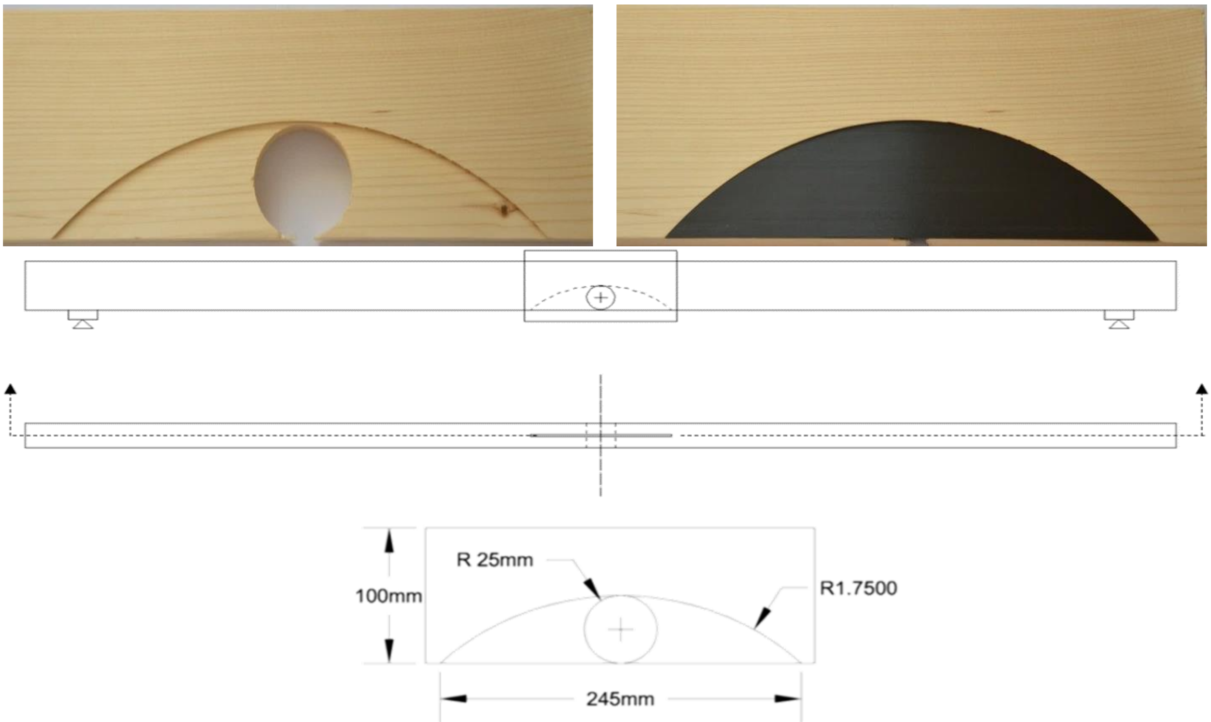

Figure 1: Reinforcement method and test arrangement

Samples were divided into 2 groups (A – non-reinforced, B – reinforced with D-shape CFRP) and then tested in four point bending according to EN 408:2012 standard.

On the basis of obtained data, flexural stiffness and bending strength were determined. Application of local reinforcement did not cause a statistically significant increase in stiffness compared to the samples of group A. No significant effect of strengthening on a flexural stiffness is related to the limited length of reinforcement, which was only about 10% of total material length. Therefore, if the criterion includes stiffness gain, it is necessary to extend the reinforcement length.

Statistical analysis showed that strengthening resulted in a significant increase of bending strength (71%). Typically, destruction of the B group of samples was caused by exceeding the shear strength of timber, then followed by a crack propagation along the fibers. In a view of the destruction occurring typically in wood, especially at high load values it may be noted that the shape, placement and characteristics of the reinforcing material are properly selected and optimized.

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MOBILITY AND TOXICITY OF HEAVY METAL(LOID)S ARISING FROM CONTAMINATED WOOD ASH APPLICATION TO SOILS

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Keywords: heavy metal toxicity, bioavailability, wood ash, arsenic, chromium

Introduction

Some compounds used to modify wood products can contain heavy metal(loid)s, such as Chromated Copper Arsenate (CCA), which was widely used to protect wood from weathering. After combustion of these modified woods for heat and power, and loss of more volatile organic compounds (VOC), the final ash can be highly concentrated in both nutrients from the biomass and heavy metal(loid)s arising from the additive treatments [1]. One way to dispose of wood ash without dumping/landfilling is by application to soil, which has a number of benefits and potential concerns associated with it. For example, it has been demonstrated that the addition of wood ash to soils increases pH [2] and improves crop biomass and yields [3]. Studies that have used wood ash generated from reclaimed waste (contaminated) feedstocks however, report that heavy metals derived from the ash are bioavailable and potentially phytotoxic, negatively impacting crop yields [4] and introducing potential environmental risks.

Materials and methods

We conducted laboratory and greenhouse trials to investigate the fate of metal(loid)s derived from contaminated ash (≤ 10000 mg kg^{-1} As, Cr, Cu, and Zn; Table 1) in terms of 1) leaching of metal[loid]s from columns filled with ash; and 2) added to agricultural soils from Scotland (UK), replicating a common disposal route for on-farm generated ash. Metal(loid) concentrations were measured in column leachates at intervals during a 2000 min^{-1} leaching procedure using de-ionised water, and after 9 weeks in pore water and ryegrass grown on the soil/manure-ash mixtures (0.1-3.0% vol. ash). Toxicity evaluation was performed on pore waters by means of a bacterial luminescence assay.

Table 1. Metal(loid) concentrations (pseudo-total) of soil, manure and ash; values are the mean of replicates (n=5) ± s.e.m.

mg kg^{-1}	As	Cr	Cu	Zn
Soil	4.5 ± 0.2	23.9 ± 2.1	8.8 ± 0.6	23.2 ± 1.4
Ash	9259.4 ± 649.3	9914.1 ± 714.9	8793.4 ± 632.0	4666.7 ± 373.5

Results

The leaching column test demonstrated that ~1% of total (measured by acid-digestion) As and Cr could be removed from the ash within the first 100 $mins^{-1}$ of leaching, whilst Cu and Zn were weakly soluble. In the greenhouse pot trials, both pore water and ryegrass tissue concentrations of As, Cu, and Cr were elevated by ash applications compared to soils receiving no ash. Applying ash to manure amended soil buffered some phyto-toxicity effects associated with ash application to non-manure treated soil, by regulating pH regardless of ash application volume. This was evident from improved ryegrass biomass and bacterial luminosity concomitant to soil without ash addition (Figure 1). Pore water concentrations of As and Cu significantly correlated with ryegrass uptake, indicating that these elements were the most bioavailable of those investigated. Cr uptake was influenced by the volume of ash addition but ash had no impact on either pore water or ryegrass accumulation of Zn.

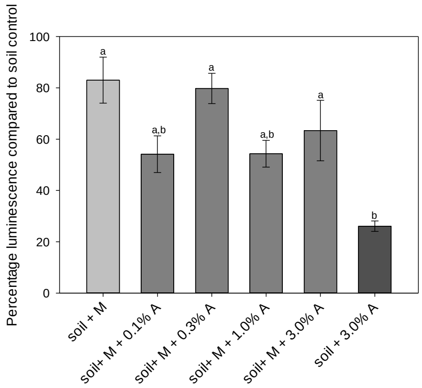

Figure 1. Bacterial biosensor toxicity tests of pore water for the different treatments (+M = with manure; + A = with ash); control was de-ionised water. Bar represent the average of the replicates and the bar is the s.e.m (n=5). Means that share the same letter are not significantly different.

Discussion and conclusions

There are potential environmental pollution issues associated with the application of metal(loid) contaminated wood ash to soils. The particular ash used in this study had high total concentrations of As, Cu, Cr, and Zn as well as highly leachable As and Cr. The immediate concern is that soil metal loadings will dramatically increase with high or repeat doses of ash application. Manuring soil before adding ash can buffer pH and reduce the solubility of metals from the alkaline ash, providing binding sites for Cu and As and reducing phyto-toxicity. Ash addition to soil appeared to have no effect on the concentration of Zn both in the pore water and in the plants. In this respect, the application of Zn rich ash will only serve to raise total Zn concentrations of soil, especially if the process is repeated, with no benefits to plant nutrition. This effect may be plant species and soil specific and it remains to be seen if Zn would accumulate and re-fractionate to more soluble forms and become bioavailable. If this were the case there could be some benefits regarding fortification of crops with Zn from the ash. It is unlikely that justification for repeated application of even moderately contaminated ash could be gained by an increase in available Zn seeing as the risks of As and Cr leaching would prove too great.

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MAINTAINING WOOD NATURALNESS: PRODUCTION OF BIOCOMPATIBLE WOODEN FLOORS AND MONITORING OF HEAVY METALS, VOC, AND RADIATION

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Keywords: Wooden floors, heavy metals, VOC, radiation, ED-XRF, SPME, geiger

Wood is a natural, renewable, biodegradable, and carbon neutral product. Wood-based materials used for construction, furniture, panels, poles, etc. are normally engineered with preservatives, glues, or coatings which dramatically increase the wood performance, but often have some disadvantages. These wood-based products may no longer be biodegradable or disposed with the same neutral footprint on environment. Furthermore, they may have an impact on human health during their use due to volatile emissions coming from Volatile Organic Compounds (VOC). Health impacts may also originate from heavy metals which may prevent ecological disposal and recycling methods at the end of their life. Another hazard in wood may derive from radiation emitted by radioactive isotopes. Following the Chernobyl nuclear disaster in 1986 the contamination from radioactive isotopes (Cs-137, I-131, Sr-90, and others) has been observed in air, land, and vegetation. Although very few cases of contaminated wood have been spotted during the last decades, matching the Chernobyl fallout zones (UNEP/GRID, 1998) with the European wood producing countries indicates that extra care may be taken when dealing with wood produced in some areas in Austria, Slovenia, Germany, Belarus, Ukraine, Norway, Romania, Sweden, and Finland.

In order to reduce the human health impact of these possible hazards and to maintain the naturalness of wood-based products, the production system and final outputs of wooden floor production has been characterized within the "Project Alfapinene". The partner enterprise claims the complete naturalness of their products, a 3-crossed-layer all-wood flooring oiled with citrus tree based finishing. More than 100 specimens were sampled from this enterprise and 30 specimens from other similar floors available on the market.

The VOC emitted from wood floorings has been determined using Head Space - Solid Phase Micro Extraction (SPME) gas chromatography. The stabilization of the headspace in the vial was reached by equilibration for 15 min at (30.0 °C ± 0.1 °C). Extraction occurred at 30.0 °C ± 0.1 °C for 40 min. After extraction, the fiber was thermally desorbed into the GC-MS. The identification of the molecules has been performed matching the spectra against the commercial NIST library. An example of results is reported in Tab. 1, where the biocompatible floor is compared with another floor.

The heavy metals elementary analysis has been performed using an X-Ray Fluorescence Energy Dispersion (ED-XRF) device mounted on a custom made robotized stage. The instrument was an X-MET 5100 Oxford Instruments in-deep tested and optimized for use on wooden materials. The X-ray tube was energized with voltage of 45 kV and current of 40 μA. The measurement time of 600 s allowed very precise and accurate measurements with the lowest possible minimum detection limit. Results (Fig. 1) showed no evidence of contamination in both groups.

The emitted radiation has been measured using a new generation of low-cost, fast response device named "pocket geiger", which is capable of detecting gamma and beta radiation as low as natural background radiation. The floors and the geiger were placed in a 5 mm thick lead case for the attenuation of natural background. One hundred measurements on biocompatible wood floors were compared to 30 other floors, and to 70 measurements of background radiation (all meas. lasting 600 s). There were no significant differences among groups and no evidence of radioactive contamination (Fig. 2). The described methodology was successfully applied in monitoring wood naturalness.

Table 1: A comparison of VOC emitted from biocompatible and other wooden floor.

Other floor			**Biocompatible floor**		
Compound name	CAS number	**Area (%)**	**Compound name**	CAS number	**Area (%)**
Acetic acid	64-19-7	24.58	**α-Pinene**	80-56-8	32,54
Pentane	109-66-0	11.97	**β-Pinene**	127-91-3	16,12
Ethyl ether	60-29-7	6.58	**γ-Terpinene**	99-85-4	11,02
Plinol C	4028-60-8	5.38	**Limonene**	138-86-3	10,56
Limonene	138-86-3	4.97	**Terpinolene**	586-62-9	7,32
Silane, trichlorodecyl-	13829-21-5	4.29	**α-Terpinene**	99-86-5	3,39
Lilac alcohol B	33081-35-5	2.64	**o-Cymene**	527-84-4	3,11
1R-α-Pinene	7785-70-8	2.47	**Camphene**	79-92-5	2,74
1,3-Cyclohexanediol, 2-...	114454-84-1	2.31	**α-Thujene**	2867-05-2	2,02
p-Trimethylsilyloxyphenyl-...	79081	1.97	**(-)-Terpinen-4-ol**	20126-76-5	1,53
Hexanal	66-25-1	1.89	**Terpineol**	98-55-5	1,11
Vinyl acetate	108-05-4	1.76	**3-Carene**	13466-78-9	0,66
Octane	111-65-9	1.66	Acetic acid	64-19-7	0,60
2-Furanmethanol, 5-...-	34995-77-2	1.65	Hexanal	66-25-1	0,59
Cyclohexanol, 1-methyl-4-...	3901-95-9	1.17	**Fenchol**	1632-73-1	0,45
Propylene Carbonate	108-32-7	0.97	**Dehydro-p-cymene**	1195-32-0	0,45
Toluene	108-88-3	0.93	**δ-Elemene**	20307-84-0	0,42
1-Pentanol	71-41-0	0.84	**α-Fellandrene**	99-83-2	0,30
Nonane	111-84-2	0.82	**Borneol**	10385-78-1	0,25
1,6-Anhydro-2,4-dideoxy...	14059-74-6	0.70	Benzene, 2-methoxy-4...	1076-56-8	0,25
β-Pinene	127-91-3	0.64	**Cadinene**	523-47-7	0,22
3-Octen-2-ol	76649-14-4	0.59	**Isoledene**	156108	0,19
Furfural	98-01-1	0.54	**α-Longipinene**	5989-08-2	0,18

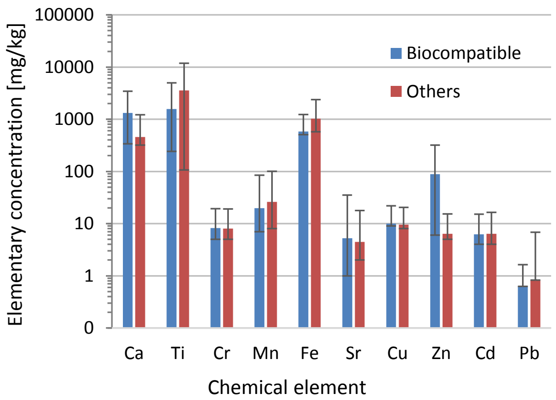

Figure 1: Elementary concentration on wooden floors.

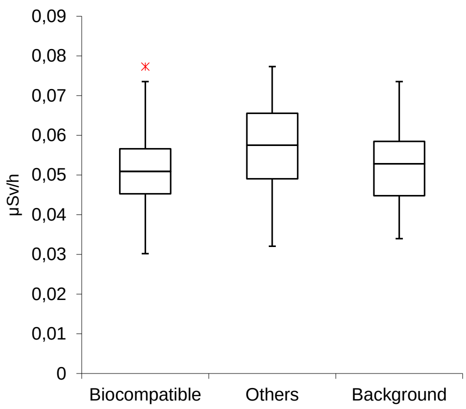

Figure 2: Radiation from wooden floors compared to background radiation.

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BIO-CASCADING OF HEAT TREATED WOOD AFTER SERVICE LIFE TO OBTAIN LIGNOCELLULOSIC DERIVATIVES

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Keywords: heat-treatment, lignin, cellulose, wood products cascading

The use of wood-based products in Europe is projected to increase threefold worldwide between 2010 and 2050. The need for innovative products from fewer resources to help reduce pressure on forests is attracting the attention of scientific community in order to provide value-added products from wood-based products after service life. In this sense, cascading of wood is an efficient use of these resources from the point of view of natural resource higher value uses that allow the reuse and recycling of products and raw materials. In this work, heat-treated wood (*Pinus radiata* L., 212 ºC) which was subjected to 40 cycles (1060 hours) of weathering, through which samples were exposed to accelerated aging cycles based on a modified version of EN 927-6:2006 [1]. Samples were submerged in distilled water at approximately 20 kPa for 15 hours and then placed in a convection oven at 75 ºC for 9 hours followed by intervals of 2.5 hours of UV-A radiation. Samples were conditioned (20 ºC; 65% RH) and measured.

To extract lignocellulosic derivatives, samples were treated with an organosolv process with ethanol-water solution (1:10 ratio) at 200 ºC for 120 min (O_P). After the separation of the solid fraction from the black liquor a total chlorine free (TCF) bleaching process was performed on the delignified wood as reported by this group [2,3]. This sequence consisted in a double Oxygen stage (O) a Peroxide stage (P) with secondary chelating reaction (Q) and an alkaline peroxide stage (PO) using a 3 M H_2O_2 solution, this sequence will be referred as O-O-PQPO. Bleached pulp was washed several times until neutral pH after each stage and then oven dried at 50 ºC for 24 h. Lignin from the pulping black liquor as well as from the spent bleaching liquors was isolated by selective precipitation in order to be valorized. Figure 1 shows visual aspect of the wood after each treatment. Pulping and bleaching were carried out in a 4 L stainless steel reactor with electronically controlled stirring, pressure and temperature. Such process represents a cost-effective and green source of lignin and cellulose derivatives.

Figure 1: Visual aspect of the different woods, from left to right: untreated wood, heat-treated wood, weathered heat-treated wood, organosolv extracted wood and bleached wood.

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A NOVEL WOOD IMPREGNATING AGENT

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Keywords: Wood impregnation, silicates, borates

Wood is one of the most popular materials used by man since ancient times despite its disadvantages in construction due to little durability and high inflammability. However, these negative characteristics are accentuated in the case of fast-growing Pinus radiata D. Don, which is the main tree species in Chile. This species has low density and low concentration of extractives, some of which provide a resistance to wood pathogens.

Various products and impregnation techniques have been developed for the protection of wood and increasing its durability. However, considering the environmental constraints of international markets, traditional impregnation products have several problems, the most important being the toxicity of their components.

In this context, the Technological Development Unit of the Universidad de Concepción, Chile, has developed a new wood impregnation product (1 under the leadership of Prof. Burkhard Seeger). The product is composed of BS borates and a sodium silicate based liquor, which is introduced into wood products via a vacuum-pressure process, similar to traditional impregnation processes.

After the impregnation, salts in the treatment solution are precipitated by a pH swing, thus creating a protective film at the interstices of the wood, increasing its resistance to microorganisms and fire. The new product is applicable both to raw and sawn wood, which not only makes it applicable in existing treatment facilities but also provides natural color, good mechanical properties, and low toxicity to the wood.

The work being presented describes the developed process and the characteristics of the treated wood. Moreover, the performance of the wood in various applications after 10 years of use has been evaluated.

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CO_2 THE UNTAPPED RESOURCE. LIFE CYCLE ASSESSMENT OF GLUE-LAMINATED WOOD SOLUTIONS FOR HOUSING IN THE PHILIPPINES

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Keywords: CO_2, LCA, Glue laminated wood

The rapid population growth and urbanization had created an unprecedented need for housing solutions worldwide[1]. It has been estimated that more than one hundred thousand housing units are needed every year[2]. The housing demand in the Philippines is further increased by the severity and amount of natural distress afflicting the country every year[3]. Many organizations work on the country supporting the development of reconstruction and social housing projects. The most common constructive systems used on these kind of projects use concrete in form of blocks and/or structural elements[4]. These systems are energy intensive and have high levels of greenhouse emissions. It has been proposed that those emissions can be reduced with the used of bio-based constructive systems, due to the fact that they are able to capture CO_2 during their growth and potentially store it during the building's life span [5]. These factors open the doors for new approaches to sustainability in which the human activity do not depletes resources from the environment but on in which a partnership is established to generates benefits for both humans and the environment [6]. The present research aims to assess the potential benefits from the use of glue-laminated wood solutions, in housing projects by assessing its environmental impacts of their production in terms of CO_2 emissions; and potential CO_2 credits that could be associated to this activity.

The methodology used a three-step approach. First a mass-flow analysis was carried out to better understand the flows of material from forest to buildings as presented on **figure 1**. The second step a Life Cycle Assessment for the production of the Glue-Laminated-Wood (GWL) was developed using the software SIMAprov7.3[7] and the environmental impact was evaluated using the evaluation method IPCC2011[8]. These results showed the emissions related to each step on the production of GWL.

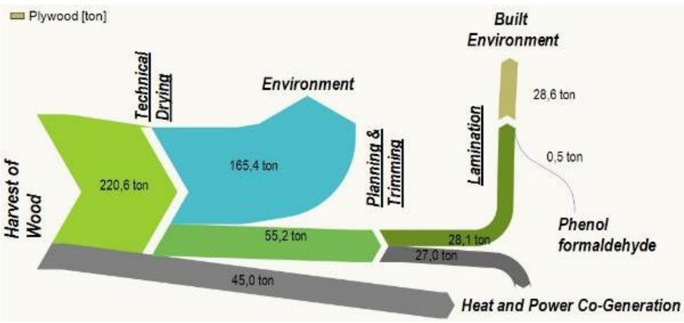

Figure 9 Mass-flow Glue-Laminated wood

Finally, a dynamic emissions model was developed using the mass-flow model and the results from the LCA. This model considered the production of 2500 housing units per year over a period of 90 years as presented on **figure 2.**The results showed that a significant amount of CO_2 can not only be captured but also emission avoided when using GLW. In a best cases scenario the levels of CO_2 avoided can offset the emissions related to the production of concrete based housing solutions. It was proposed that these emission could be potentially monetized in form of credits. The results showed over 700000CHF per year could be potentially generated. It is important to highlight that these models are very sensitive to the end of life of the GWL and the type of electricity used during their production. Based on these result it is possible to conclude that bio-based construction materials withhold an untapped potential not only to improve the environment but also to generate extra revenue for producers and end users.

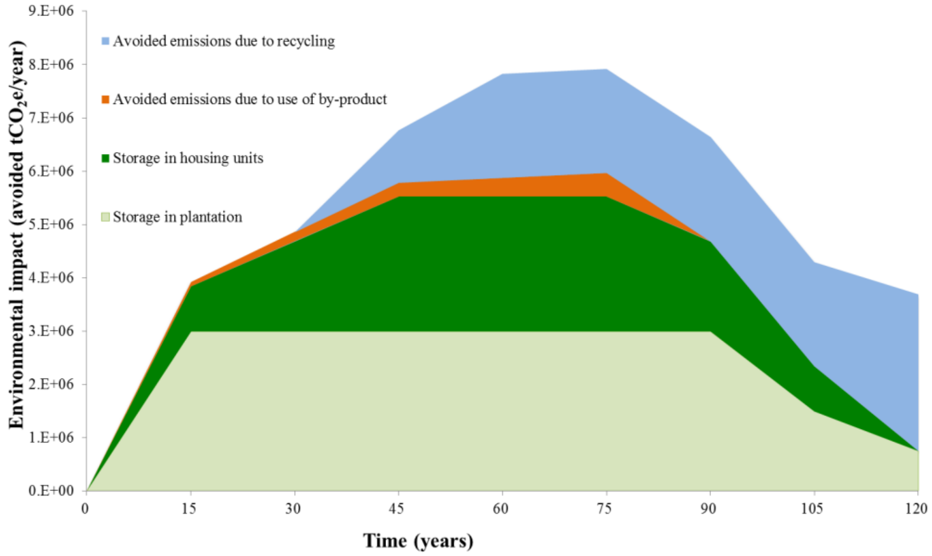

Figure 10 Dynamic CO2 model

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AUTHOR´S ALPHABETICAL INDEX

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