Think outside of the wooden box!

Proceedings

PhD Workshop Hamburg
COST Action FP1407

Editors
Oliver Mertens
Martin Nopens
Julius Gurr
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THÜNEN

FP1407
ModWoodLife

Universität Hamburg
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Think outside of the wooden box!
PhD workshop Hamburg – COST Action FP1407

Proceedings of the "Think outside of the wooden box!" PhD workshop Hamburg within COST Action FP1407 STSM.

July 3 - 6, 2017, Hamburg Bergedorf-Campus

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Our thanks go first to Andreja Kutnar, Gus Verhaeghe, Johannes Welling and Jörg Ressel for helping us cross the first hurdles. Their support on a pragmatic and direct way has contributed greatly to our sessions.

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Thank you all for your significant efforts!

Oliver Mertens, Julius Gurr, Martin Nopens, Goran Schmidt

Preface

The Thünen Institute of Wood Research welcomes the participants of the workshop "Think outside the wooden box" within the COST Action FP1407. Thünen has got a long record in proposing, leading and being partner in COST Actions. Information exchange between scientists and knowledge transfer to other countries and especially to young researchers is a key element of our work. Therefore, the Thünen Institute of Wood Research and its cooperation partner, the Center for Wood Science at University Hamburg are happy to host you here in our jointly used premises. The members of the organizing team, all of them are PhD candidates conducting their research here on the campus, are very proud that they could convince quite a number of well-known European experts and leading scientists to support this workshop. You can expect an interesting program. Now it depends on you and on your active participation that the workshop will be a success and that we all can have benefit from it.

Dr. Johannes Welling

Head (acting) Thünen Institute of Wood Research

Introduction

Wood as a porous, three dimensional, hygroscopic, viscoelastic and anisotropic bio-polymer composite is not yet understood completely. The gap in fundamental understanding of the highly complex anatomical, chemical and physical structure of lignocellulosic materials constrain the development of innovative wood-based products.

The European wood-based panel and composite sector is composed of cost-driven industries, which lack the high-performance products that are required by an emerging bio-economy. Young researchers in independent research institutions are urged to generate, deliver and connect knowledge, which then drives real innovation in the industry. Environmental friendly building materials require elevated resistance to physical and chemical factors as well as biodegrading agents. Especially wood modification and bio-composite design aim at enhancing product performance. Extending the life span of these products enables the European market to strengthen cascade utilization, hence broadening the resource base, storing carbon dioxide and saving process energy in the long-term.

The PhD workshop in Hamburg aimed at connecting ideas of young researchers, active in adjacent topics such as process engineering, building physics, wood and material science. The programme involved specialists from wood biology, chemistry, physics, industry and politics.

This shall yield an advanced knowledge on how wood structure influences behaviour of renewable high-performance biomaterials. The results of the workshop may lead to ideas outside of the “wooden box”, benefiting each partner institution as well as our sector.

Workshop program

Monday, 3rd July 2017

8:00 – 12:00 **Reception & basic session:** The essentials of wood physics, anatomy, chemistry and processing technologies

- Wood physics and material science: Jump into the wooden box (Prof. Dr. Andreas Krause - UHH)
- Brief introduction to Wood Components (Prof. Dr. Bodo Saake - UHH)
- The woody cell wall: Cellulose and lignin deposition (Dr. Dr. h. c. Uwe Schmitt - Thünen)

12:00 – 13:00 **Lunch**

14:00 – 18:00 **1st Session:** Wood-water relations - Is water a main component of lignocellulosic materials?

- Wood water relations (Dr. Emil Engelund Thybring- University of Copenhagen)
- Water in Nanopores (Prof. Dr. Michael Fröba - UHH)

18:00 – open **Get together & dinner**

Tuesday, 4th July 2017

8:00 – 12:00 **2nd Session:** Performance of wood products - What are the theoretical potentials and how do they translate into practical values?

- Bio-inspired wood materials (Prof. Dr. Ingo Burgert - ETH Zurich)
- Performance of NFR plastics (Prof. Dr. Jörg Müssig - Bremen University of Applied Sciences)

12:00 – 13:00 **Lunch**

14:00 – 18:00 **3rd Session:** How do wood based products impact the environment?

- How can we measure environmental impacts? (Prof. Dr. Callum Hill - JCH Industrial Ecology Limited)
- Reducing GHG emissions by using wood products (Dr. Stefan Diederichs – Department of Environment and Energy)

18:00 – open **Guide through the institute & dinner**

Wednesday, 5th July 2017

8:00 – 12:00 **4th Session:** Advanced processing of lignocellulosic materials: Where to find higher added value?

- Advanced processing of lignocellulosic materials (Prof. Dr. Mark Irle - Ecole Supérieure du Bois, Nantes)
- NFC & Ligneos by Faurecia (Hugo Piccin - Faurecia)

12:00 – 13:00 **Lunch**

14:00 – 18:00 **5th Session:** The 10 big questions of wood science - Which high-value products are currently being researched or produced?
(Univ. Prof. Dipl.-Ing. Dr. nat. techn. Dr. h.c. Alfred Teischinger)

18:00 – open **Dinner & discussion**

Thursday, 6th July 2017

Complementary InnovaWood event (voluntary)

8:00 – 10:00 Departure from Bergedorf campus

10:00 – 11:15 Visit to Ilim Timber (sawmill) or Huetteman (gluelam)

11:30 – 13:00 Both groups visit Egger

13:00 – 13:45 Lunch at Egger cantine

13:45 – 15:30 Workshop (seminar room at Egger)

Moderator: Prof. Dr. Alfred Teischinger, Boku, Wien, Austria

15:30 – 17:30 Departure to Hamburg city

17:30 – 18:00 Drop-off at Hamburg airport

18:00 – 18:30 Drop-off at main station

18:30 - open Return to Bergedorf campus

Session schedule

	Description	Speaker
0. Basic	**The essentials of wood physics, anatomy, chemistry and processing technologies.** It is an explicit intention to host participants from different backgrounds, e.g. biotechnology, process engineering, material science etc. The basic session aimed to ensure a successful communication by introducing a common terminology and a similar level of understanding. The participants teamed up into heterogeneous assignment groups to strengthen the social cohesion and prepare for the upcoming sessions.	**Prof. Dr. A. Krause** (University Hamburg) **Prof. Dr. B. Saake** (University Hamburg) **Dr. Dr. h.c. U. Schmitt** (Thünen)
1.	**Wood-water relations: Is water a main component of lignocellulosic materials?** Lignocellulosic plant parts are designed and optimized to function in water-saturated conditions. Our understanding of how the three main biopolymers interact with water is based on theoretical assumptions. Alternative concepts and recent analytical methods raise new questions. The session shifted the perspective towards the key component water and its role in wood.	**Dr. Emil E. Thybring** (University of Copenhagen) **Prof. Dr. M. Fröba** (University Hamburg)
2.	**Performance of wood products: What are the theoretical potentials and how do they translate into practical values?** Wood and natural fibre modification and functionalization can lead to wood products and composites with improved performances or novel properties. However, it is a challenging task to develop and implement processes, which are environmentally friendly, cheap and can be easily up-scaled. An intense discussion about the underlying concepts and existing limitations encouraged the participants to think out of the „wooden box“. Together, they identified and elaborated the current progress, potentials, and challenges. The session aimed to generate blueprints for high-performance products.	**Prof. Dr. I. Burgert** (ETH Zurich) **Prof. Dr.-Ing. Jörg Müssig** (Bremen University of Applied Sciences)

3.	**How do wood based products impact the environment?** In this session, the environmental assessment approach to modified wood products showed the participants how life cycle concepts are applied. The session based on a general introduction to problems of LCA, followed by a demonstration of current practical measures of implementation on Hamburg policy level. After that the participants got the chance to apply the knowledge with a following group debate.	**Dr. Stefan Diederichs** (Ministry of Environment and Energy, Hamburg) **Prof. Dr. Callum Hill** (CoE InnoRenew)
4.	**Advanced processing of lignocellulosic materials: Where to find higher added value?** The European wood, wood-based panel and composite sector is to its largest part a cost-driven industry which, in consequence, lacks high performance products required by a competitive bio-economy. In this session, the key speakers will provide a general overview on markets and product classes as well as on scientific knowledge transfer to push innovative technologies from research into the industry.	**Prof. Dr. M. Irle** (Ecole Supérieure du Bois, Nantes) **Hugo Piccin** (Faurecia)
5.	**Best-practice examples of wood/lignocellulosic utilization: Which high-value products are currently being researched or produced?** Within recent decades, various wood composite categories and wood modification methods have been subject of intensive research. However, only relatively few of the scientifically proven concepts have been converted into a marketed product. Wood plastic composite resp. natural fibre reinforced composites or acetylated and thermally modified wood are some of the rare examples of successful market introduction. Other topics such as the industrial utilization of hardwood and increased use of secondary wood resources, despite being subject of extensive research and interest, have shown less dynamic development. In this session, we aim to disclose factors that may foster or restrain the market success of innovative wood products.	**Prof. Dr. Dr. h.c. A. Teischinger** (University of Natural Resources and Life Sciences, Vienna)

Session reports

Basic session: The essentials of wood physics, anatomy, chemistry and processing technologies

Chairs: Goran Schmidt, Oliver Mertens
Speakers: Uwe Schmitt, Bodo Saake, Andreas Krause
Authors: Rene Diaz, Wen Jiang
Keywords: Woody cell wall formation, lignification, water interaction, wood-based composites, lignocellulose

Part 1: Wood Biology

Cellulose and lignin amount up to 65 – 80 % of the cell wall composition. They represent a total global biomass of more than 200 billion tons (cellulose) and 100 billion tons (lignin). Wood formation is strongly influenced by climate factors; thus, this process is shorter in North Europe than in South Europe [1].

Wood formation happens in the cambium, which is a secondary meristem (Figure 1). The typical seasonal cycle of trees involves cytoplasmic changes, where the cambial cells are divided by a large vacuole, which is subsequently fragmented to begin the cell wall thickening [2].

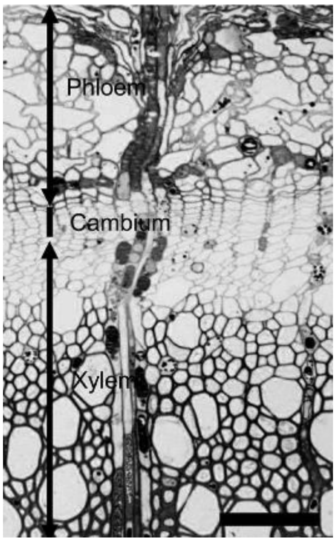

Figure 1 *Cambium (Prislan et al. 2013)*

The cell wall models of wood were designed in the 1950s. It was initially based on light microscopy and early electron microscopy. The terminology varied at that time. The structure of the wood cell wall with secondary layers (S1, S2, S3), primary wall (P) and the middle lamella (ML) was proposed, see Figure 2 [3].

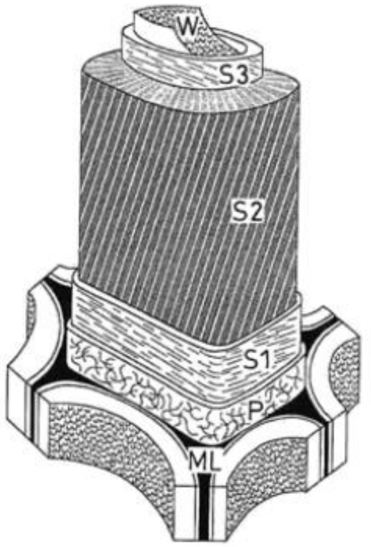

Figure 2 *Cell wall model (after Cote 1965 from Core at al. 1979)*

The cellulose formation: a membrane – bound process starts first, then the lignin formation. One of the most accepted hypotheses of the cellulose formation states that cellulose synthase complexes (CSC) are moving in the plasma membrane in a given orientation with parallel elongation of fibrils [4]. The direction is determined by underlying cortical microtubules. There are two differentiated cellulose regions: the amorphous and the crystalline region which are formed by cellulose aggregates, bundles of beta-1,4-glucan chains [4,5].

There are direct and indirect methods to localize the wood lignin. The most common practices for a direct localization of the lignin compounds are the light microscopy, using various staining techniques (e.g. safranin/astra-blue) as well as fluorescence microscopy, and electron microscopy [6]. On the other hand, indirect methods use the enzymes present in the lignification process (such as peroxidases), and measure with a transmission electron microscope or with a UV-microscope: Cellular UV-Micro spectrophotometry (UMSP) (Figure 3) [7].

Figure 3 *Universal-Microscope-Spectrophotometer (UMSP 80) (ZEISS 1992)*

An interesting aspect about wood formation is the so-called reaction wood, which is formed as a response to local tensions (slope, branches, etc.). The orientation of cambial cells is adapted to the load direction. In gymnosperms it is called compression wood, whereas in angiosperms reaction wood is called tension wood [8].

Part 2: Wood Chemistry

This session covers the basic knowledge in wood chemistry. The main chemical components of wood (cellulose, hemicellulose, and lignin), their structure and bonding types as well as the interaction between them and water will be represented here. As wood is composed of small molecular lignocelluloses, understanding those main components can help with wood study and utilization.

The micro-structure of wood cell walls has been updated in the last 60 years with the development of electron microscope technology. Wood is a lignocellulosic material, which mainly consists of cellulose, hemicellulose, and lignin. Cellulose molecules are oriented in straight chains (Figure 4); glucose residues in the cellulose chains, enables them to form intra- and inter-molecular hydrogen bonds in the presence of hydroxyl groups, so that the microfibrillar cellulose is largely crystallized by bundles of cellulose molecules along with a small proportion of amorphous regions [9,10]. Cellulose with the fibrillated structure and hydrophobic methyl groups make it none water soluble.

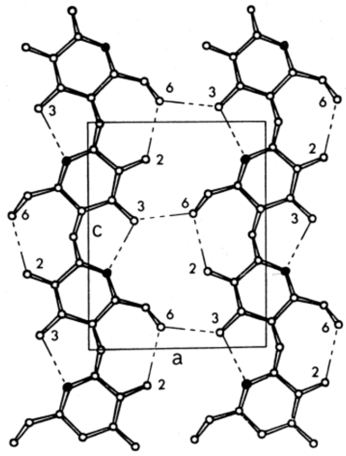

Figure 4 *Hydrogen bonding pattern in cellulose I (Sjöström 1981)*

Hemicellulose is recognized as a polysaccharide polymer composed of sugar monomers, such as glucomannan in softwood and xylan in hardwood. Since hemicellulose has a lower crystallinity, it is soluble in aqueous alkali and is easily hydrolyzed by water, acid and base [9, 11]. Lignin is an amorphous aromatic heteropolymer of phenylpropane building blocks held by C-C and C-O-C linkages. The lignin models have been updated in the last 15 years, which is an important change in the study of wood chemistry. In wood, lignin is associated with xylan hemicellulose in the form of ester, ether and glycosidic linkages. Water solubility of lignin is influenced by the xylan, as to know that solubility and water interaction is not only governed by chemical structure but as well about aggregation and interaction of the various wood components [12].

In conclusion, the behavior and properties of components in wood is determined by both their interaction and chemical structure. By understanding these, technologies can be used to change the wood cell wall structure, and apply chemical or enzymatic conversion of wood.

Part 3: Wood Physics

A complete comprehension of wood and wood composites requires an insight in chemistry, biology, and physics as well as knowledge of the environment. The global trends demand an increase in amount, quality and diversity of wood and wood composites; besides, the process should accept the diversity of raw materials, size reduction of pieces, less variability and diversification of processes.

Regarding the mechanical properties of wood, it is important to maintain the balance between load and strength. If the load is larger than strength, it causes the mechanical destruction (Figure 6) [13].

Figure 6 *Mechanical destruction of a tree (Čeština 2014)*

On the other hand, material deformation is induced by a greater strength (Figure 7) [14]. Changes in load are due to external and internal forces, moisture changes and dynamic of sorption.

Figure 7 *Deformation of trees (Anonymous 2013)*

Another important characteristic of wood is its anisotropy, which affects the shrinking hierarchically depending on the direction (X, Y, Z) and the scale (tree, cell, micro fibril). The wood strength is influenced by the wood species, density, anatomy, moisture content, anisotropy, and degradation process.

The general mechanical properties measured are the modulus of elasticity, shear modulus, tensile strength, tensile strain and compression strength. Additionally, other properties needed for measurement in construction timber are the bending strength, tensile parallel, tensile perpendicular, compression parallel, compression perpendicular, modulus of elasticity parallel, and modulus of elasticity perpendicular.

Another topic in this session is the wood composites, which usually consist of a matrix (elastic or viscoelastic), and the fiber joined with high or low glue content. Material distribution is an important aspect of wood composites, and spots, respectively specific locations where the composite could decline. The principal mechanical properties are the bending strength, tensile perpendicular and modulus of elasticity [15, 16].

The future challenges for the wood-based composite materials are optimizing their mechanical properties, achieving lower weight, lower variability and lower environmental impact, understanding the material on the molecular level, knowing the differences between species and managing the material service life.

Discussion

This session gives us a good picture of what wood is made from with three main components: cellulose, hemicellulose, and lignin. As we discussed and agreed, that it is a good arrangement to have this session ahead of other sessions. Wood biology shows the formation of wood cell walls, influences of wood chemical components on its properties as well as their interaction with water and other solvents. In wood physics we study the mechanical and physical properties of wood as a construction material. Hence, when we consider utilizing wood and think outside the wooden box, it is always important to understand the fundamental knowledge of the material.

Three impressive views from this session brought in lots of discussion through the whole workshop. One is the lignification process: how it takes place and the formation time during the wood growth is still mysterious and remains under-researched. The second aspect is the interaction between water and wood components, which have significant meanings for wood modifications and applications. The question of whether lignin is biosynthesized via simple combinatorial chemistry, or proteinaceous control and template replication, is still not answered. In our opinion, once the lignification is fully understood, it can give instructions to delignification to the pulp and bio-energy industry. Study and utilization of wood in wood-based composites nowadays has turned to a molecular level. Therefore, more and more researchers focus on micro/nano-cellulose studies. In comparison to other materials such as metal and plastics, wood does not only have advantages of the environmental benefits but it also gives more possibility for derived timber products with added values.

Conclusions

The purpose of this session is to introduce the fundamental knowledge of wood. This session leads us to jump into the wooden box and then possibly to think outside of it. Wood has been utilized and exploited for over thousands of years, the current trend of studying it is on the molecular level. The molecular world gives chances but also more challenges for us as researchers working in the wood science.

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Session 1: Wood-water relations - Is water a main component of lignocellulosic materials?

Chair: Martin Nopens
Speakers: Dr. Emil E. Thybring, Prof. Dr. Michael Fröba
Moderator: Callum Hill
Authors: Agnieszka Jankowska, Tinh Sjökvist, Jure Žigon
Keywords: Nanopores, physio-mechanical properties, wood-water-relations

Part 1: Wood-Water relations

Wood as a natural material with its hygroscopic nature possesses different properties and behaviors in relation to water. Beside all three main structural components (cellulose, hemicelluloses and lignin) water can occupy a huge amount of wood volume by defined moisture content. Therefore, the mechanical properties, durability, dimensions, thermal conductivity, and heat capacity of wood depend on the water content in its structure.

Water in wood can be partitioned into water within cell walls and void water outside cell walls. There are different definitions and expressions regarding water content in wood, which are based on proportions between the mass of the wood and the mass of the water.

The equilibrium state depends on the relative humidity; meaning that the number of molecules leaving the wood is equal to the ones entering it. Pressure is a very important factor, which influences and adjusts the relative humidity (RH).

Depending on the size of the largest openings between water-filled cavities and surroundings, wood species will have different equilibrium moisture contents (MC) in desorption (drying) when they are dried from a RH slightly below 100 % (< 98 %) to 0 % . During the drying process, liquid water goes out of cell lumens. By further drying, the moisture loss is caused by drying of cell walls. If RH is increased from 0 %, the moisture contents in absorption (uptake) are lower than in desorption. Sorption hysteresis: Desorption isotherm is always above adsorption isotherm (Figure 1) [1].

These two isotherms intercept only by 0 % and 100 % of RH. If we want to make a hysteresis curve, we must start with measurements in fully-saturated state and then decrease the wood MC to the dry state. At higher RH (98 % through 100 %), the sorption hysteresis is enormous compared with the one with RH < 98 %. The lumens, voids and pits become filled with water.

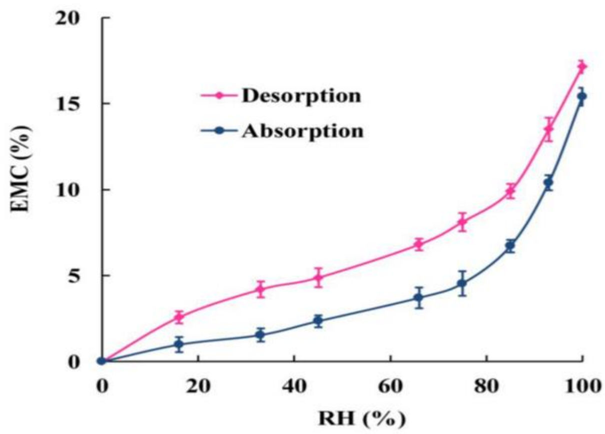

Figure 1 *Typical wood sorption and desorption isotherms (Liu et al., 2015)*

In hygroscopic conditions (0-98 % RH), the equilibrium MC can be determined in different climates generated by saturated salt solutions, climate chambers and sorption balances. However, those methods require extreme temperature stability to avoid condensation and changes in RH. But the most precise method for determining the wood MC is by mass measurements (gravimetric techniques). In range of over-hygroscopic conditions (> 98 % RH), the mass of a wood sample at equilibrium can be determined very accurately after conditioning in special pressure plate (membrane) equipment, see Figure 2 [2].

Figure 2 *Pressure plate extractor – 15 bar (Hoskin Scientific LTD.)*

However, this method is designed for desorption experiments and modifications are necessary to perform absorption experiments [3]. The pressure plate method is therefore commonly used in the high moisture range. Determination of melting enthalpy can be done by using different techniques, two of which are differential scanning calorimetry (DSC) and nuclear magnetic resonance (NMR) (Figure 3, 4) [4,5].

Figure 3 *DSC 2500 (TA Instruments)*

Figure 4 *TD-NMR The minispec mq20 (Bruker Corporation)*

By determination of fiber saturated point (FSP), we rather speak about cell wall water capacity. Among the other factors, water absorption into cell wall also depends on mechanical stresses in wood cells.

Part 2: Water in nanopores - Phase behavior of confined water in ordered nanoporous organosilica hybrid materials with periodically modulated surface polarities

Water (H_2O) forms four hydrogen bonds, resulting in tetrahedral geometry and a three-dimensional network of hydrogen bonds. Water is a special molecule, exhibiting more than 60 anomalies.

Nanoparticles are between 1 to 100 nm in size, and their properties are strongly size-dependent. They have a good relation between size (volume) and the surface area, and tend to conglomerate. Nanoparticles can form pores with different geometries and diameters or different morphologies. These porous materials, depending on the pore diameters (micro-, meso- or macropores) hold many functions.

One of those materials is mesoporous silica with crystal-like pore walls. A mesoporous silica structure can be in a range from 2-50 nm in pore size. Depending on the diameter and constituents (chemical composition) of such pores, confined water molecules exhibit different properties and interactions: melting point, thickness of liquid-like layer (non-freezing water) etc. (Figure 5) [6].

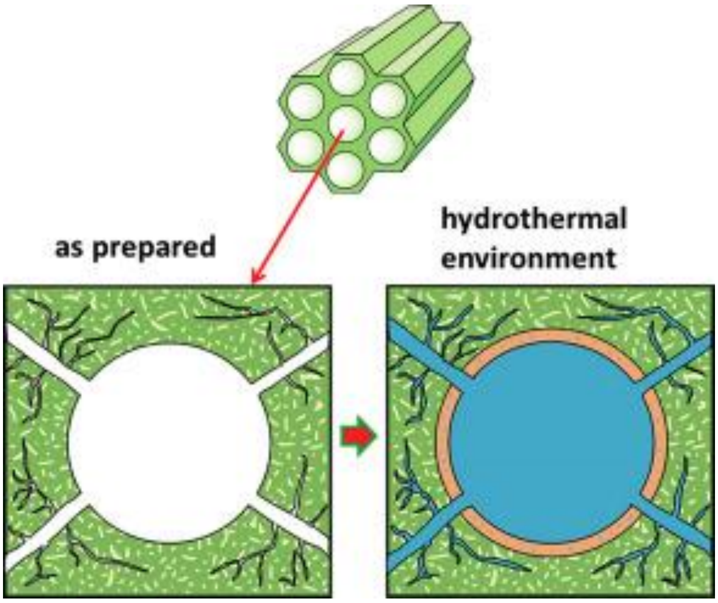

Figure 5 *Mesoporous silica with crystal-like pore walls as prepared (left) and containing confined water (right) (Kizzire et al. 2017)*

Synthesis of the silica structure is made by adding silica precursors into surfactants that are organized in different 2D or 3D shapes. The structure made by the surfactants shapes the final pore structure of the silica component. The cavities emerge when the surfactants are removed, leaving a porous silica structure. Several types of silica precursors define the surface chemistry of the structure.

Discussion

Both sessions cover the movement of water in porous materials. The first session by Dr. Thybring describes the water transport in wood while the second session by Prof. Dr. Fröba studies the behavior of water in a well-defined pore structure made of silica. New perspective was given, e.g. regarding the fiber saturation point even relative humidities slightly below 100 % will lead to a drying process in the cell wall. Another additional information is that there are lots of desorption curves in literatures initiated from non-saturated condition; which in fact might be a little misleading.

It is also interesting to learn that the melting point of water decreases and can be as low as -70 ˚C in a silica pore structure below 4 nm. The presentation made by Prof. Dr. Fröba was very advanced from a chemical point of view. Still, the message is quite clear. A better understanding of water behavior can be achieved by using these advanced and well-defined surface and structures made of silica. This can further on be used to understand water transport in wood since wood itself is a porous material.

Do not believe in everything what the professor says!

Conclusions

Wood-water relation is a complex area and still needs to be studied further. Moreover, water in fact could be considered as the fourth component in wood beside cellulose, hemicellulose and lignin.

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Session 2: Performance of wood products - What are the theoretical potentials and how do they translate into practical values?

Chair: Oliver Mertens
Speakers: Ingo Burgert, Jörg Müssig
Moderator: Callum Hill
Authors: Francesco Negro, Greeley Beck
Keywords: biomimicry, natural fibers, fiber wetting, functionalization

Part 1: Bio-inspired wood materials

Biomimetics can be defined as the study of formation, structure or function of natural substances, materials and processes with the main aim of copying and realizing them through artificial methods [1]. Nature has developed and perfected countless systems for millions of years, finding excellent solutions and developing highly efficient processes. Therefore, humans have always tried to copy nature for their purposes. For instance, the anatomy of flying animals inspired the flight of several artificial objects; Velcro®, a worldwide-known industrial product, was developed by copying hooked seeds that attach to animal furs for being transported at wide distances; more recently, molecular composition of non-wettable surfaces of self-cleaning plants inspired the development of water-repellent nanoparticles.

Wood is produced by nature and has many values that encourage taking it as a model for bio-inspiration. To mention some, wood has a porous structure that confers lightness and mechanical strength at the same time; in many parts of the world, timber is available and relatively cheap compared to other raw materials. Its capacity to store high quantities of carbon dioxide has recently began to be recognized. Or solid wood has a high energetic content. In addition, wood can provide high performance with artificially embedded functionalities. Acetylated wood has enhanced properties in terms of dimensional stability and natural durability [2], and is a typical example of modified wood that achieved an established position on the market.

Wood is constituted by cellulose, lignin and hemicelluloses, where cellulose represents the reinforcing element and lignin and hemicelluloses constitute the joining matrix. The structure of wood can be exploited as a scaffold for the incorporation of additional materials to create improved hybrid materials. Since the available volume in cell walls is limited, various strategies for removing the matrix components and creating free spaces in the hierarchical structure of the cell wall are currently being studied. Delignification processes are an example: in the nano-porous structure of delignified cell walls, lignin can be replaced by the desired materials.

Functionalization of wooden cell walls can also be obtained starting from the processes of heartwood formation, through an in-situ polymerization of cell walls. Incorporating biominerals into the cell walls of wood enables development of inorganic-wood materials with enhanced properties. Wood can for instance be bio-mineralized through distribution of calcium carbonate in wood for fire-retardancy purposes. Similarly, it is possible to depose magnetic particles for decorating cell walls and producing magnetic wood. Such new wood-based materials can be used for new applications that in many cases are still to be determined.

Taking as a model the stiffness control of trees, wood can be used as a smart material since it is able to move in predictable ways depending on the environmental conditions. For instance, this enables production of wooden shading systems that vary their orientations depending on the level of incoming solar radiation.

Many other examples of innovative, bio-inspired wooden materials can be cited regarding different properties: liquid repellency of wooden surfaces, surface modification for UV resistance, oil absorption (Figure 1) [3], self-reporting proteins for obtaining specific responses, etc.

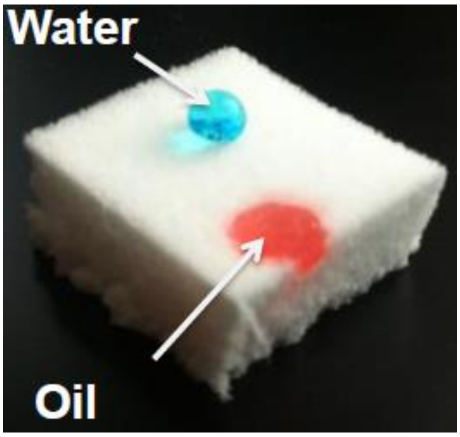

Figure 1 *Oil absorbing cellulose composite (Empa 2014)*

In conclusion, purpose of the presentation 1 was to illustrate how wood is suitable for developing innovative and high-performing products. In this view, the presentation provided a wide overview on various researches that are currently undergoing. A relevant outcome is that wood must be considered the main material for creating a renewable society not only for its intrinsic values but also for its high potential for realizing innovative and high-performing products.

Part 2: Performance of natural fiber-reinforced plastics

Besides wood, other natural materials can also be used to construct fiber reinforced products. A large amount of natural fibers is available, ranging from plant fibers like hemp, and flax (Figure 2) [4] to animal fiber, for example silk. Beside the renewability aspect, these fibers also possess good mechanical properties. In natural fiber composites, mostly fiber bundles are used as the reinforcing fibers. These are built up out of several fiber cells. In the other literature this might be referred to as technical fiber and elementary fiber respectively [5].

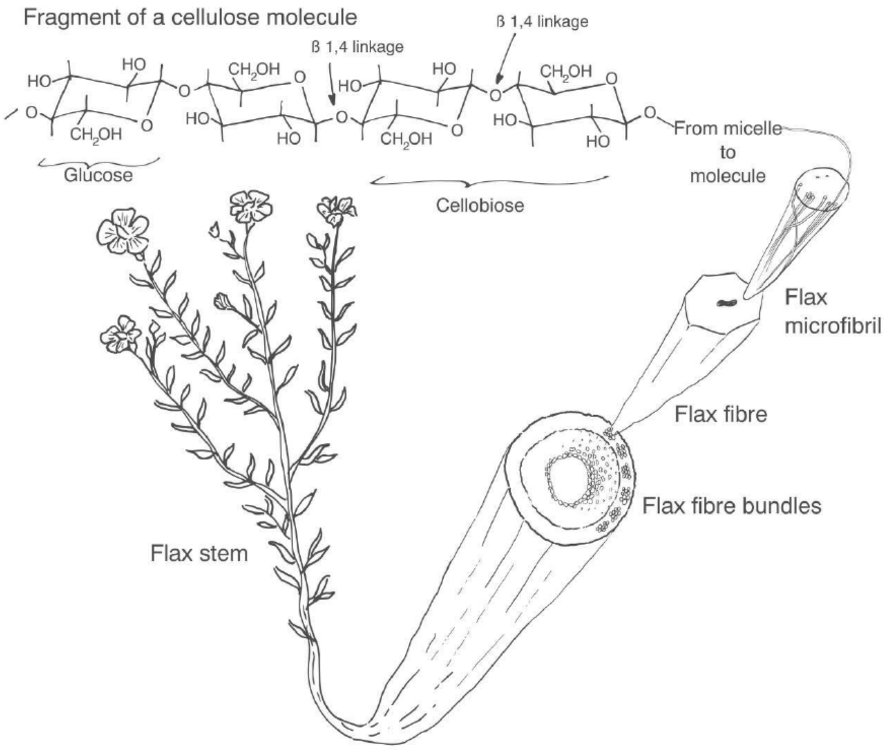

Figure 2 *Schematic representation of the hierarchical structure of flax - from plant to cellulose (Müssig & Hughes 2012)*

Comparing natural fibers with traditional synthetic fibers like glass fibers is mostly done by comparing the specific mechanical properties. The strength and stiffness are weighted by the density of the fiber. However, depending on the load case one might want to optimize a different relationship. Based on the Ashby model, a material's indices can be defined depending on the load case that we want to optimize with minimal weight. For a bar under tension we want to maximize the specific stiffness: E/ρ. For a clamped bar under bending: $E^{1/2}/\rho$ and for a plate under bending the material indices changes to $E^{1/3}/\rho$. Other load cases and more depth explanation are given in the book by Ashby: "Material selection in mechanical design". Considering this connection, it becomes clear that natural fibers can even outperform steel and aluminum for specific load cases, see Figure 3 [6].

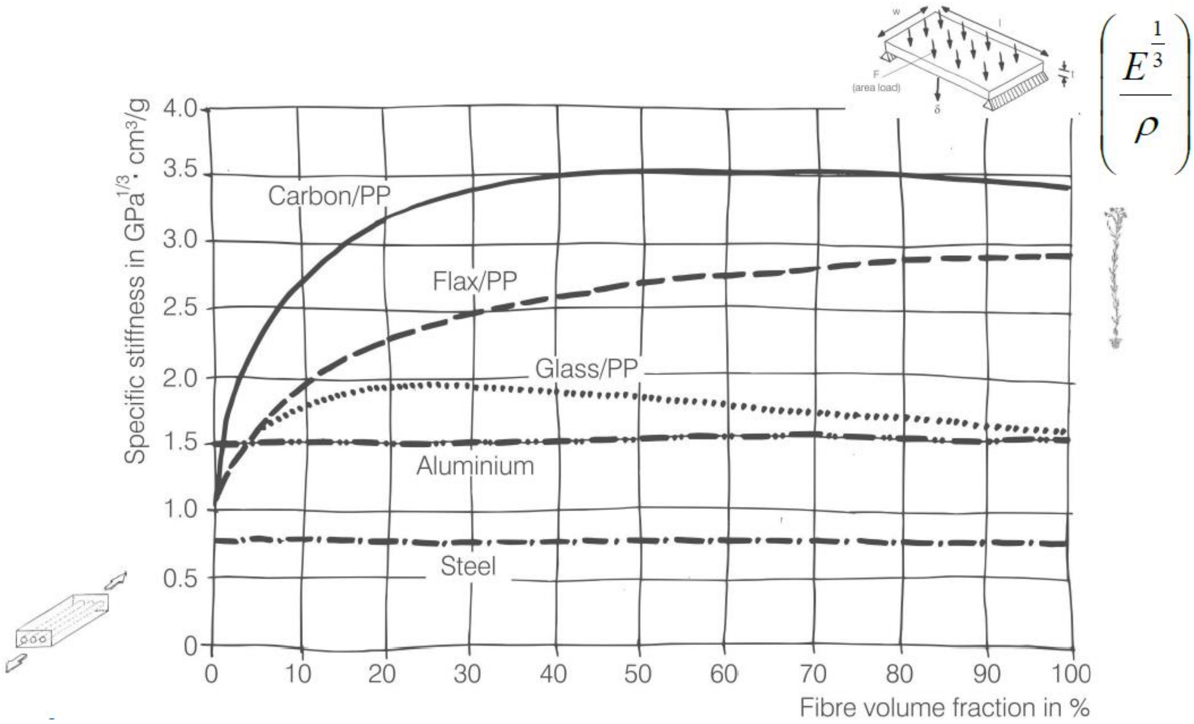

Figure 3 *Fiber volume fraction dependent longitudinal specific stiffness values of composites compared to metals (adapted from Verpoest & Baets 2012)*

A few new elements are introduced when working with natural fibers. Many of the fibers find their origin in the textile industry. The process of making a yarn from a fiber is based on entangling (spinning) multiple fibers to a yarn. This spinning introduces twist to the fiber. The more twist that is applied on the fiber the higher the strength of the dry yarn, but the lower the properties of the composite, represented in Figure 4 [6]. This twist causes a misalignment of the fibers which for a few percentage of misalignment drops the modulus significantly.

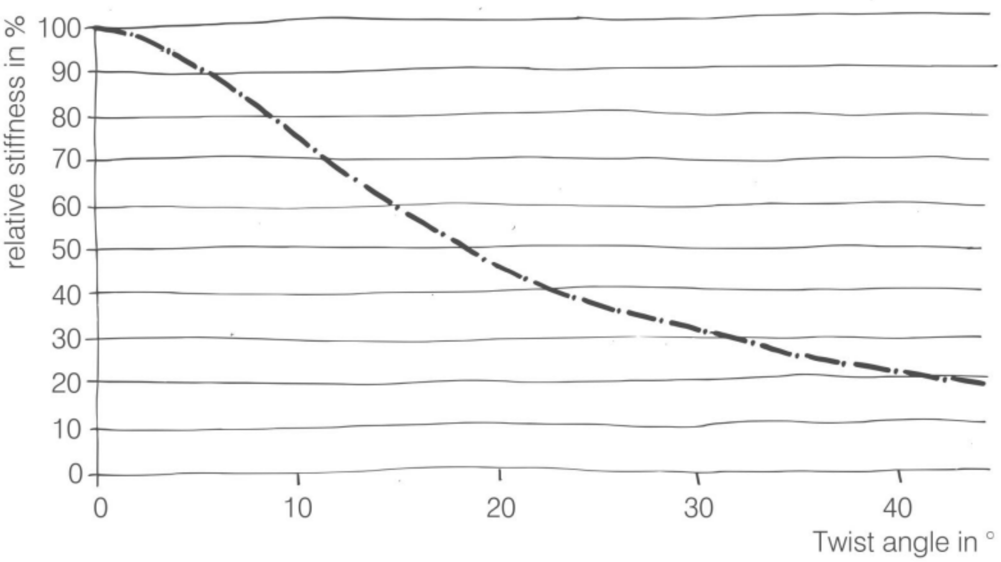

Figure 4 *Yarn twist angle dependent stiffness values of composites (adapted from Verpoest & Baets 2012)*

Understanding the mechanics of composites is one thing, but determining the mechanical properties experimentally requires some other insights. In literature, a huge spread is found on the reported mechanical properties of natural fibers. This spread is only partly due to the natural variability of the plant, the other part can be assigned to the testing method. First of all, a fiber bundle consists of different fiber cells. When testing a fiber bundle, the gauge length will have an influence on the measured properties. If a single cell gets clamped from one end to another, the evaluated strength and stiffness will increase. This shows the necessity of effective communication on the procedure used. Another influencing factor for a tensile test is the procedure of determining the fiber diameter [7] analyzed some different techniques to measure the diameter and this already leaded to big variation of the results (quantify). Another interesting literature on the influence of the method was performed by Shah and his colleagues [8]. Considering all these influencing parameters regarding the test method, the need becomes clear for a new standard for testing of natural fibers.

The presentation a few interesting applications/ research projects inspired by nature (biomimicry) were highlighted during the workshop.

Research on the impact resistance of a coconut revealed that the properties of the fibers surrounding the coconut showed a gradient towards the nut. Composites were assembled layering hemp, ramy and lyocell to get the same gradient and an increase in impact behavior could be seen.

Discussion

The discussion of the session was structured with four questions to which we responded in small groups and examined together afterwards. First, we were asked what information was new for us in the session. Because of the diverse backgrounds of the workshop participants, answers to this question varied. For those coming from a wood science background, most of the content of the second presentation about other natural fibers was new. Particularly surprising was the lack of standardized methods for the testing of natural fibers, whereas, for wood, standardized testing of the material is well established. With regard to the first presentation, many of the applications of wood were novel, such as functional wood modification, wood mineralization and using wood as a smart material.

With the second prompt, we were asked to identify what remained unclear after the talks. Because the first talk was meant to briefly present many novel applications of wood, some of the applications were not presented very thoroughly or the details were summarized too quickly. There was specifically some confusion around what was meant by “self-reporting” proteins in wood. This was clarified in the discussion by Professor Burgert. The idea was to modify wood with proteins that would respond in some detectable way when they are exposed to specific environmental conditions.

The third question asked was to figure out the connections and similarities or contrasts we saw between the talks. One strong connection between the two talks was their use of biomimicry. The sensing material in spider legs inspired Professor Burgert to use wood as a smart material through functional wood modification. He also mentioned studying the natural deposition of extractives in trees to provide insights for impregnating wood cell walls with other chemicals. Professor Müssig drew inspiration from nature with his layered composite material modelled on the impact resistant fibers in coconut husks. Professor Müssig also drew a parallel between his talk and the previous one when he compared the twist angle in fiber spinning to the microfibril angle in wood cell walls. The main difference between the two presentations was their approach to natural materials. Professor Müssig focused on using natural fibers in composites, where functionality can be easily customized by selecting the correct ratio of components. Professor Burgert on the other hand preferred using the structure of wood itself as a scaffold, and to impart functionality by chemically modifying the polymers in-situ.

Lastly, we were asked if we had any remaining questions or ideas. A variety of topics were discussed at this point. Regarding the first presentation, many were left wondering about heartwood formation and the natural deposition of extractives in the wood cell wall. Somehow, the tree can get these hydrophobic molecules into the water saturated cell wall at room temperature. No explanation was made, but this led to an interesting discussion regarding the biochemistry of extractive synthesis. For the fiber topic, most questions were about fiber spinning – how spinning affects fiber properties and how new spinning methods could be developed. Someone thought of using the electrostatic properties of wood fibers in composite formation. Professor Irle pointed out that Japanese researchers had looked into this application, but nothing came of it due to the risk of fire. To develop new spinning methods, many suggestions were proposed. Some thought of using synthetic nonporous material to guide fiber spinning. Or perhaps dipping the fibers in some solution that would dissolve them and then, when pulled out of solution, the fibers would reassemble in a more desirable way.

Conclusions

Both speakers in this session did an excellent job of highlighting the potential of wood and natural fibers for future applications. As early-stage researchers, the workshop participants found this session to be very valuable because it provided ideas and directions for future research projects. The topics discussed will certainly prove useful as we develop our scientific careers.

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Session 3: How do wood based products impact the environment?

Chairs: Goran Schmidt
Speakers: Callum Hill, Stefan Diederichs
Moderator: Philipp Sommerhuber
Authors: Arianna Lucia, Carolina Gonçalves, Eija-Katriina Uusi-Tarkka
Keywords: LCA, environmental impact, midpoint/endpoint, GHG, emissions, standards

Part 1: How can we measure environmental impacts?

Ideally, the environmental impact of a product should be evaluated by a standard that everybody can reproduce and use. However, this is far from reality. The European Standards EN 15643, 15804, 15942 and 15978 can be used for such an evaluation, but every country has its own standards and rating system which makes it difficult to compare.

According to LEED (Leadership in Energy and Environmental Design), a protocol for the classification of energy efficiency and ecological footprint of buildings, there are many categories, through which one can evaluate the impact of a human construction on the environment. Building materials and natural resources are only a small aspect of this evaluation with 4 out of 110 possible points on the rating ladder. This is problematic because buildings can score a high overall rating without paying regard to building materials and natural resources. To put this into perspective, the category "Innovation in Design" can yield six additional points.

The Life Cycle Assessment (LCA) is a widely used concept. The main idea of a LCA is to assess the impact of a product in all contexts, from the cradle (production) to grave (disposal). The Life Cycle Impact Assessment (LCIA) is a vital phase of any LCA. The LCIA helps interpret emissions and resource consumption data that are associated with a product's life cycle in terms of environmental burdens, human health and resources. However, the model is not complete because there are more aspects that affect the calculation. Also, there could be some uncertainties associated with data, which might make the assessment unreliable.

Additionally, the impact categories (midpoint / endpoint) must be defined and parties must have mutually agreed upon those. Midpoint models reflect the potency of stressors within a cause-effect chain, and endpoint categories report on the consequences of the release of stressors into the environment. Midpoint categories include global warming potential, stratospheric ozone layer depletion, codification of soil and water, eutrophication, tropospheric photochemical ozone creation, abiotic resource depletion of both elements and fossil fuels. For endpoint categories, the uncertainty is higher. The consequences, such as skin cancer, species loss, flooding and reduced life expectancy, are often taken more seriously by decision makers.

A commonly used standard is the Environmental Product Declaration (EPD). The weakness of this assessment tool is that the gathering of data is not standardized, which complicates comparisons and reliability. To fulfil the EPD, there are certain Product Category Rules (PCR) that define the standard for each material. A main standard problem is the multitude of information and parameters that are highly-specialized and hence, difficult to be understood even for experts. An example for misunderstandings is the intended use of units, e.g. kilogram. It is useful as a declaration unit, but completely useless as functional unit.

Time is a factor to be considered when assessing the impact of building materials. If we compare timber and PVC in windows, even though the use of timber causes less CO_2 release in the environment, the life stage of timber might be shorter than that of a PVC window frame (which is more durable). Comparison between standards and materials must always be made with caution.

Part 2: Reducing GHG emissions by using wood products

The second session focused on the use of Environmental Product Declaration (EPD) on a practical level. Here, wood substitutes to building materials in construction in Hamburg were assessed.

EPD can be used on buildings, even though the results might vary depending on the parameters and standards used. There are, as mentioned in session 1, also difficulties involved with databases that can be an obstacle when it comes to correct interpretations and utilizations of data regarding certain types of materials.

There can be many problems regarding the use of data. It can be difficult to obtain data on factors like the by-product or the energy used during the machinery or fabrication process. Also, there are imprecise data like electricity consumption or heat consumption, and sometimes this kind of data is not collected at all. In these cases, projections about the impact of a product cannot be performed correctly. It can be challenging for policy makers and companies to use the standards for assessing environmental impacts and carbon footprint of a product.

In spite of the complications involved with using the EPD, it can still be a useful tool when it comes to assessing energy consumption, water consumption and recycling (which can have several impacts because of the various recycling potentials of different materials). The effect of substituting building materials with wood showed advantages regarding CO_2 emissions.

An example of applying this sort of LCA knowledge on a policy level is found in Hamburg. Here, the municipality inclines construction companies to use wood products by subsidizing 2 % of the construction cost.

Discussion

It was clear in the group discussion that there is a lot of room for improvement when it comes to assessing the environmental impacts of materials. A thorough improvement of data collection is needed, as well as a common standardized measurement system. Awareness on methods of data collection is as important as the results themselves. Without transparency, data can easily be misused and misinterpreted, whether intentionally or not. On the other hand, the standardized measurement and assessment systems should be simplified, to make them more accessible and understandable. This will also improve comparisons across both products and borders.

An agreed upon standard for assessment and a revision of existing ones could be a solution to this problem. For example, one issue that should be addressed is that companies can report a negative value for CO_2 emission if they recycle materials or burn them to collect energy.

In addition to the definition of different parameters and the use of standards, the topic of scientific interests versus economic realities was discussed. Despite the scientific interest, the further development shall be accompanied by an economic interest from stakeholders. The political framework is not yet able to incentivize the above-mentioned steps.

Conclusions

- Rating systems must be standardized;
- Data collection must become transparent and easy to understand;
- Timber products are always superior when the sequestered carbon is considered (GWP);
- Especially reasonable diligence is needed when comparing different building materials by descriptive parameters and (functional) units.

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Session 4: Advanced processing of lignocellulosic materials: Where to find higher added value?

Chairs: Julius Gurr
Speakers: Mark Irle , Hugo Piccin
Moderator: Andreas Krause
Authors: Axel Rindler , Liselotte De Ligne
Keywords: lignocellulosic materials, added value, innovation, value proposition

Part 1: Advanced processing of lignocellulosic materials: Where to find higher added value?

There are 3 types of wood-based panels: solid wood / veneer-based, particle-based and fiber-based. Wood as a raw material originates either from forests (round wood – € 65 per m³), wood residues aka "by-products" (thinning in the forests, sawmills, plywood mills and timber processing residues) or recycled wood (pallets, boxes and demolition timbers). The driving factors in the raw material economics are costs and availability. In general, the "classical" wood-based panel is a "low tech" product.

Particle Board

Since the 1980s, the recycling of lignocellulosic materials and their implementation into new materials began to gain interest. The key issues when dealing with recycling material are the availability (spread of material), and its quality (prior application). Normally, the most interesting panel type to implement recovered wood is the particle board (Figure 1) [1], since the chipping of material is possible in most cases. Nowadays, especially in Italy, a high proportion of recovered wood is used in particleboard cores.

When comparing particle board production over the different European countries, one can see that types of principle raw material differ greatly. For instance, in Greece, 87 % of the particle boards are produced from round wood and 13 % by-products; while in Belgium 65 % of the particle boards are produced from recycled wood [2].

Due to high spread of material, the recycling of wood is not done by the panel producers themselves. They buy the material from the recycling yards were the material is often already chipped.

The first step in particle board making is also the most expensive step, namely the drying. Reducing the particle moisture content to 2-8 % requires 66 % of the total energy input. (1 t of wet wood = 500 kg of wood and 500 kg of water). Two thirds of the energy consumption during the particleboard manufacturing is due to the drum dryer. One of the major advantages of recycled wood is that it has a lower moisture content compared to green wood, thus, drying is less energy intensive. The second step requires hot pressing of wood chips, sawmill shavings, or even sawdust with resin. The temperature goes up to 210 °C with a pressure of 3 MPa. There are three types of presses: multi-daylight presses, single daylight presses and continuous presses. Nowadays, the continuous presses are the most common ones. Afterwards, several finishing steps are performed: cooling, trimming, sanding (for calibration of the panel thickness), cutting to size and laminating (55 % of chipboards are laminated). These last two steps provide added values since it comes closer to the customers final requirement / need [3,4].

Figure 1 *A particle board (HORNBACH)*

MDF

MDF (Medium-Density Fiberboard) (Figure 2) [5] consists of individual fibers, late wood fibers and early wood fiber bundles, combined with wax and a resin binder. Different densities are created in MDF by pressing. Current researches are focused on reducing panel density while maintaining mechanical properties (ultra-low-density panels for different uses) and finding alternative fibers.

Figure 2 *MDF boards with different thicknesses (EXPRESSZUSCHNITT®)*

Plywood

Plywood is the oldest wood based product, and is a sheet material manufactured from thin layers of wood veneer that are glued together, with adjacent layers having their wood grain rotated up to 90 degrees to one another (Figure 3) [6]. Plywood makes up the largest volume of wood products over the world. Current trends are reducing density, testing distinct species and glues, making use of advanced technologies to automate the manufacturing processes (purging of knots, lay-up etc. is still done by manual labor) and increasing the range of niche products.

In the wood-based panel sector, researchers mainly focus on improvements of the existing products and processes but not on substantial innovations that can turn the sector around. The improvements are all about reducing production costs, as there is not much room for changes because of strict EU regulations. The EU has harmonized standards, which facilitate free trade but limit the development of new products because of legislation.

Figure 3 *Birch plywood (HORNBACH)*

Business and innovation canvas

Innovation in the wood sector is necessary to provide added values. New products can be imagined by making use of the CANVAS system. The segments of interests when imagining a new product are mainly the “customer segment” (understanding your market), the “key resources” (wood: advantages, disadvantages, available quantity, shape, etc.) and the “value propositions” (how to create a need for your product).

Part 2: Natural fiber reinforced composites & Ligneos

Faurecia is one of the largest automotive interior parts producers. There are around 15 % of all car cockpits made by Faurecia.

Innovation is very important in the automotive sector, which is mainly driven by the engine manufacturers, consumers, regulators and trends. New developments are strongly related to the customer requirements and needs, which is why Faurecia usually pitches ideas to the customers that are related to trends first. Generally, they do not launch an idea without using CANVAS.

The company is divided into three business groups, where the vision of "Clean Mobility" is dealt with. This sector is primarily focusing on technologies for air quality, energy efficiency and thermal management, light weight and acoustic performance [7].

Two product examples based on lignocellulosic material are:

1. NFC (natural fiber composites) for door panels
    - Pine wood chips formed into premium car doors with good insulating performances
    - Flax fibers for premium light weight car doors with good insulating performances and crash resistance
2. WSC (wood sheet complex) for wood surface
    - Veneer for premium car surfaces with good crash resistance

NFC

- Flax fibers perform better during a crash, because of the long fibers
- Pine wood fibers (crash test not as good) → could not pass new crash standards
- Flax fiber composites are produced 20 min before assembly → "just in time plants".

The bottleneck for door panel manufacturing with natural composites is assembly of various parts made of different materials; see Figure 5 [7]. Therefore, co-injection of Polypropylene (PP) is performed within the pressing process and makes the assembly quite fast. Also, clips for mechanical fixation are getting implemented during the pressing. A big advantage of doors made from natural fibers (flax fiber) compared to "pure" plastic ones is the weight reduction of around 30 %. The pressing / injecting process is fully automatized and lasts for 90 sec. Plastics based on natural resources like the bio-plastic Polylactic Acid (PLA) are also applicable for this process, but for now there are no advantages of using PLA over PP. PLA would become more interesting if PP price is increased due to rising petrol prices. The reason why Toyota is using PLA for its cars is that Japan is a PLA supplier and has no petrol fields available.

A reinforcement of PP with fibers would be too brittle for the application. Car doors generally are a simple product, but with co-injection a lot value can be added. Faurecia is a leader in this technology, which means that they deliver fiber mats to their competitors. Unique selling point: 30 % lighter materials and crash proof.

Figure 5 *NFC / DP VW Golf (Faurecia)*

WSC (Ligneos)

The intention is to create the comfort of a living room in a car by implementing veneer surfaces. Large visible veneer surfaces are applied in premium cars (saloon drive), represents in Figure 6 [7]. Veneer is made by micro fractures (not chemically) and bleached. After bleaching, the surface gets recolored (dyed) to achieve a homogenous surface appearance. In the last step, the surface gets treated with an antioxidant.

For further interior uses, veneer gets stabilized with a laminated textile membrane, which is glued to the wood surface by mechanical and thermal methods. That way, it is possible to increase the formability of the wood fiber structure. Finally, the veneer surface is treated with a high gloss PUR casting for a perfect surface appearance.

Every customer is provided the copyright for its own pattern recipe to protect their type of wood veneer being used by competitors. That way, Faurecia can sell exclusive wood that appeals to customers' wishes. Designs are changed and modified every year to stay unique and competitive, so new value is added every year. Unique selling point: real wood surface is premium and exclusive wood (150-300 €/m² added value)

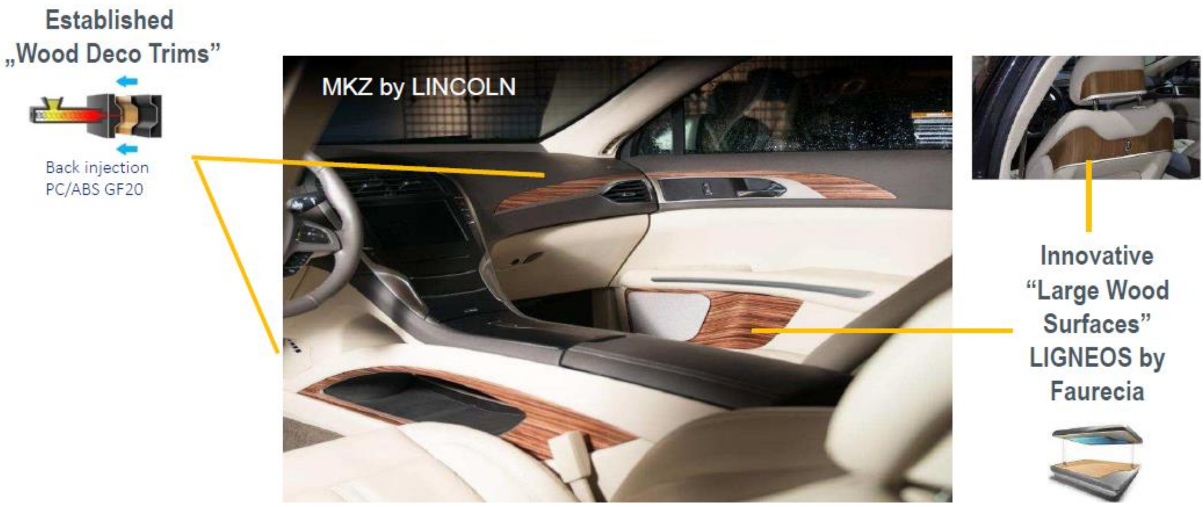

Figure 5 *Car interiors with "Wood Deco Trims" and "Large Wood Surfaces" LIGNEOS (Faurecia)*

General information

Faurecia is trying to add as much value to the product as possible to set unique selling points. Major regulations such as crash resistance need to be fulfilled. The manufacturing of interior parts out of natural materials should be competitive to materials based on fossil fuels. Behavior of the material due to specific climatic conditions is very important to be aware of. Faurecia only acts on a global scale. Therefore, decisions and new product ideas do not differ locally. Faurecia is interested and focusing on innovations dealing with natural materials. Wood certification is also very important to them (PEFC). In manufacturing, compromises must be made on how much chemistry should be involved in the process.

Discussion

The discussion is divided into three main questions:

1. Why make wood-based panels?
2. What are the advantages and disadvantaged of wood?
3. What can be done to accentuate the advantages and minimize the disadvantages of wood?

Discussion participants	Overview Prof. Dr. Mark Irle
▪ To reduce the material anisotropy (both for mechanical as dimensional properties) ▪ More efficient utilization of wood ▪ To customize performance and engineer properties (within limits) ▪ Lower costs ▪ High volumes ▪ Low value material can be used	▪ Economic reasons ▪ Use of low grade logs ▪ Use of waste material ▪ Ecological reasons ▪ Efficient use of wood ▪ Performance reasons ▪ Size → wide ▪ Consistency in dimensional stability and strength ▪ Decay resistance (e.g. cement bonded particle board is very decay resistant) ▪ Fire resistance ▪ Insulation (WBP often more isolating than wood panels) ▪ Easy machining (cutting and shaping, molding) ▪ Good surface quality (flat, smoot and uniform in color) ▪ Decoration
Advantages	**Disadvantages**
+ Natural product + Aesthetics + Renewable + Light weight + Easy machining + Biodegradable (end of service) + Recyclable + CO_2 sequestration + High caloric fiber (burning) + Some resistance to fire + Can be used in different forms (solid wood, fibers, etc.) + Cheap + Ecosystem services	– Variability (dimensional stability, mechanical properties) – Not color stable – Hygroscopic – VOC emissions – Biodegradable (in service) – Size effect (characterizations of small wood sample cannot compared easily to larger wooden beams in practice) – Dimensionally unstable – Long growing cycle (emotional link)
General ideas	**Specific ideas**
• Homogenize and stabilize color • Wood veneer is bleached away and recolored to make Ligneos (wood sheet complex), to have uniform wood decoration in cars. • Improve the marketing of wood • Promote wood through education: technical universities, civil engineers, architects, etc. • Increase link between wood research and other sectors	• Self-forming products E.g. thermoplastic MDF or plywood (using thermoplastic polymers) → warm it up and bend it into any shape • Shape memory Wood products that can be flattened for transportation and turn back into their original shape when at destination • Change the mind-set of suppliers Suppliers should provide more detailed information about the characteristics of wood-based panels to increase confidence in the building sector • Flexible walls with flexible wood surfaces; e.g. veneer on Velcro as wall paper

Conclusions

Every single piece of wood is unique, which makes it interesting for designing exclusive products. On the other hand, this uniqueness reflects the high variability of the material concerning its mechanical and physical behaviors. Wood is a growing material what makes it sustainable and cheap compared to other materials.

By looking at these facts, wood reveals a lot of potentials but also the need for innovation to compete with other materials. In future, engineers should become more confident to work with wood and start seeing it as a reliable material. Therefore, the enormous variability of the material needs to be better understood for a better predictability of the material behavior. Parallel to this, wood scientists should further focus on their knowledge and awareness from different material disciplines to compare possible similarities and gain new ideas for "their" material. By following this path and intensifying the academic exchange with other sectors, possibilities to add high value to already established products or potential future products could emerge. To achieve this, also the "wood education" of potential users such as engineers and architects is of significant importance and should be focused on.

The two talks showed different approaches to add value to wood based materials and underlined the potentials of wood.

One approach was to add value to waste materials and enhance their value by elongating their life cycle and reusing them for further material production. Another approach was to eliminate disadvantages of products based on natural fibers like the production time to a negligible stage and focus on the advantages the materials offer like the reduced weight.

In case of "Ligneos", adding really high value to the products was possible by combining its uniqueness and ensuring its applicability as premium surface material.

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Session 5: The 10 big questions of wood science - Which high-value products are currently being researched or produced?

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Wrap-up

Wood has been one of the most extensively used natural resources in the history of human evolution, from the very beginning when mankind used wood as tools and weapons to the wide variety of modern wood-based products. Undoubtedly, wood is a key to our civilization. Today we see highly sophisticated primary and secondary wood processing chains, in which established material flow process concepts are constantly approved and new products are developed.

First, wood as a raw material is abundant, relatively easy to exploit, and has a wide range of valuable properties for merging material fabrication. However, a better understanding of wood in terms of e.g. its structure, properties, genetics and potential value is of immense importance in order to promote further development of wood utilization. In the following, some state of the art examples of wood utilization as well as promising areas of research are presented.

From freshly cut green softwood and hardwood to the final product, wood undergoes several processing steps. More specifically, the raw material wood is firstly divided into several classes based on its quality, which includes saw logs, industrial round wood and forest residues. Each class will be processed into their own product categories, implementing primary and secondary material flows. Starting from saw logs, which are primarily used for solid wood products on account of their size and structural integrity. The residues of the saw mills provide raw material for further process chains as a secondary material flow. Industrial round wood is mainly processed into wood-based panels such as plies, particles and fibers, pulp, paper and fine chemicals. Forest residues are mostly used for energy generation. In addition, the recycling of wood has become a substantial part in the process chains. Wood products can be recycled at the end of their lifetime, serving as a recovered raw material from final products to produce wood based panels like particleboard, pulp, paper and fine chemicals [1].

The wood industry has been growing faster than the average economy, caused by the inclining usage of wood. For example, the utilization of saw wood, starting from just under 6 x 107 m^3 in the early 1950s has nearly doubled within half century. Despite the increasing competition for raw materials in central Europe due to growing energetic usage (approx. 50 % volume), the use of wood also increased, fostered by the development of successful new products. Two recent examples in Europe are laminate flooring and Glulam. Nonetheless, Particleboard remains one of the most successful wood-based panels. Up to now, there is no other competitive material available, which can compete in price or properties, etc. [1].

Meanwhile, research in wood science followed a similar trend with an increasing number of topics over time, e.g. investigation of wood durability, new processes and improved performances of wood-based panels just to name a few. However, the challenges of further research and development are based on a growing population and consumption. Although wood is a renewable resource, it is limited in its availability. Looking at a steady growing of global population and emerging countries developing more wealth with growing consumption, shortage of wood can be predicted. Even today, after decades of intensive research and development, not to mention a great expansion of production capacities, we witness a lack of raw material for some mills all over the world. The question for further research and development should therefore be: how can we make more out of the same amount of material? The transfer and utilization of new knowledge from research and scientific literacy can be advantageous for creating new technology.

Compared to the short development intervals in other science areas, such as chemistry, physics and computer science, the development time scale in wood technology is relatively long. In the wood industry, the typical development time of actual innovative technologies is about 14 years. It usually takes about seven years in the university, and government laboratory based development to prove the feasibility of a new product or technology, and to reach the development limit. After that, it takes another seven years to implement all of them and to let corporate based development take over [2].

Interestingly in many cases when a new technology has been launched, for example, wood modification, WPC, Nanocellulose and biofuels, its popularity is extremely high at the initial stage due to inflated expectations. This is then followed by a high drop as a result of disillusionment. After a better understanding is gained and some knowledge of how to exploit this new technology exists, its “visibility” tends to recover and reaches its maximum over time.

There are many good examples of wood-based products arising from the transfer and utilization of knowledge. In addition, innovative wood-based products often use a combination of parts from technologies that preceded them. One example for this kind of development is cross-laminated timber (CLT), which uses the same principle as plywood; a wood-based panel that has been in use for over a century. The major difference of CLT is its significant higher thickness of each board layer, i.e. utilizing layers of solid-sawn lumber instead of veneers. By gluing these boards perpendicular to each other, several disadvantages of solid wood are avoided. Because of the perpendicular orientation of the different layers, directional dependent properties like warping and shrinking are minimized. Furthermore, due to the cross gluing CLT can be used with two span directions, e.g. in walls or ceilings. The practice of the implementation of CLT is also a good example for technology development in the wood industry. The very first university chair based on CLT was in Austria in 1985. About 13 years later in 1998, CLT achieved its first technical approval as a building component [3]. Nowadays, CLT as building material has become an attractive alternative for brick, concrete and steel. Another reason for this success story is, that it extends, not competes timber engineering. Over the past 20 years, the amount of CLT produced has increased over 30 times [4].

Another example is Viscose, which is a world-leading man-made cellulose fiber. The viscose process dissolves pulp with aqueous sodium hydroxide and carbon disulphide. This produces a viscous solution. This solution was the first thing to bear the name "viscose". The cellulose solution is used to spin the viscose rayon fiber, which may also be called viscose. The technology was based on the already established wood refinery. In the past 40 years, synthetic fiber has been used intensively to more than 70 % over the entire fiber industry. Viscose provides the highest added value in forest based industries [5].

Research in wood science has been examined worldwide with an average growth rate every year. Noticeably, North America and Europe are the main contributors to the research in wood science, with 45 % and 43 % respectively. On the other hand, China has the highest growth rate in wood science research with over 30 %. Major research topics include engineering, construction, energy and fuels. One of the highlighted topics is the interaction of wood properties and product properties due to a high demand of wood-based products with optimized properties. Researchers must devote tremendous amount of effort to manipulate wood properties, including wood density, growth ring width, cell wall thickness, etc. This is achieved by several important aspects. Firstly, genetics, the source of the seed and seeding material are important for the growth of the tree. Also, environmental factors play a key role, such as light condition, temperature, water, nutrients etc. Lastly, silviculture - the way to plant trees is equally important. As a result, wood material is produced with different properties, which have a critical influence towards the final product. The mechanical properties of wood material have been compared to other materials. At unit density, wood has very impressive tensile properties. In other words, for those materials that have similar tensile properties, like polymers, metals or other composite materials, wood is much lighter, which makes it a superb material of utilization [1].

Discussion

The focus of the discussion, respectively of the workshop, was rather on the content of the presentation than on personal research preferences of the participants. Prof. Teischinger asked the audience to think about what they would really like to research with given budget and infrastructure. The topic did not have to be related to wood. From there on a lively brainstorming of different ideas came up, with topics reaching from the genetic modification of trees for specific product properties to deep space exploration.

Conclusions

Starting from wood as a raw material, multiple value chains in different branches of the wood industry exist, meeting various needs and applications. Wood is a versatile raw material of which a wide range of products with high values can be created. It is used as a construction material, for furniture making, for paper, cardboard and hygiene products, for textiles and finally for energy generation. Overall, Wood has always been and will continue to be a major resource in our civilization. In fact, in the face of the ever-growing world population and emerging economies the renewable resource wood will become even more limited. Wood research can offer solutions to face these current and upcoming challenges, in order for wood to remain sustainable and an ever-present part of our lives.

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