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Recent Development of Thermal Wood Treatments: Relationship between Modification Processing, Product Properties, and the Associated Environmental Impacts

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ABSTRACT

The world’s political and economic decisions are increasingly determined by resource and energy scarcity and by climate change. In these circumstances, a balance must be achieved between economics, ecology and social welfare (sustainability), which was put forward at the end of the 20th century and has been irrevocably linked to forestry ever since.

It is essential that the forest sector is placed at the centre of the developing bio-based economy. The value of the forest for mankind and the environment is irrefutable, and the value of the multitude of products made of wood is of great importance, socially, economically and environmentally. Over the last fifty years wood, sawn timber in particular, has largely disappeared from many technological applications diminishing its contribution to sustainability in the one area where it could be most significant: as a substitute for energy-intensive materials (e.g., in the built environment). However, there is currently a resurgence of interest in timber products due to the environmental benefits they provide, a phenomenon that other industrial sectors are well aware of.

This paper discusses the role of thermally modified wood in different use of wood, environmental impacts related to maintenance, repair, refurbishment, replacement over the full life cycle. Furthermore, recycling potential of thermally modified wood at the end of a life cycle is discussed.

Thermal treatment

Thermal-treatment processes have been known for a very long time and they include several different methods. In most industrialized processes today, thermal treatment involves temperatures between 150 and 260°C, and the goal is to achieve increased dimensional stability and resistance to biological degradation. The thermal-treatment process is in most cases performed in a vacuum, in air or with an inert gas such as nitrogen. Pre-heated oil can also be used, in which case the oil acts as a heat-transfer medium and also excludes oxygen from the wood. The thermal treatment of wood above 300°C is of limited practical value due to the severe degradation of the wood material (Hill 2006). Accelerated ageing of wood is a heat-treatment process using a mild temperature, i.e. a treatment temperature in the range of 100 to 150°C, in most cases under controlled relative humidity and pressure (Sandberg *et al.* 2013).

The general discussion about the use of tropical hardwood, the toxicity of wood preservatives, and especially the willingness of sawmills and the wood industry to broaden their product range has led to the industrial development of different thermal-treatment processes and several processes have also been introduced on the market since the early 2000's. The most common processes are: the Thermowood process, the Plato process, the Retification process, le Bois Perdure, NOW (New Option Wood) process, and the OHT-process (Oil-Heat Treatment). The basic difference between these different processes is in their choice of oxygen-excluding and heat-transporting media. Most of thermal-treatment technologies have been developed in Europe. In 2011, European production reached 250,000 m^3 and global production was 350,000 m^3, which was produced at approximately 100 thermal modification plants worldwide (Tetri 2011). The thermal-treatment plants have a capacity between 1000 and 30,000 m^3/year. Several different species are used in the process, but Norway spruce is dominant. Industrial thermal-treatment processes typically aim at improving the biological durability of less durable wood species and at enhancing the dimensional stability of wood. The properties of industrially produced thermal-treated wood in general have been intensively investigated and an extensive review of the research front concerning properties of thermal-treated wood can be found in Navi and Sandberg (2012).

Thermal treatment significantly influences the properties of the wood, e.g. its hygroscopicity, decay resistance, durability, strength, and dimensional stability. Table 1 shows the main changes in wood properties that occur during thermal treatment. Wood exposed to elevated temperatures undergoes a thermal degradation process and the degradation is highly dependent on the temperature, the duration of exposure, the process pressure, the moisture content etc. The rate of thermal degradation is different for the different constituents of wood: it is highest for hemicelluloses, much lower for cellulose and lowest for lignin (Stamm 1956). It is known that during the thermal treatment of wood under moist conditions, carbonic acids, mainly acetic acid, are initially formed as a result of cleavage of the acetyl groups particularly of hemicelluloses (Kollmann and Fengel 1965, Dietrichs *et al*. 1978, Bourgois and Guyonnet 1988).

Table 1. The main changes of properties for thermal-treated wood compared to untreated wood.

Desired properties changes	Unwanted properties changes
Lower EMC	Lower density
Higher dimensional stability	Reduced MOE and MOR
Higher durability against decay	Reduced impact strength
Lower thermal conductivity	Increased brittleness
Dark brown colour	
Characteristic smell	

In the thermal treatment of wood above 150°C, the strength is reduced and the mode of failure of thermal-treated wood in mechanical tests is in most cases brittle. The density of wood is decreased by 5-15% during thermal treatment, and this of course affects the strength, but it does not explain the entire reduction in strength. The loss in strength is due to a degradation of the cell-wall matrix due to a degradation of the hemicellulose polymer. General guidelines for the reduction in strength are: hardness 5-10%, bending strength 10-20%, modulus of elasticity 5-20%, and impact bending 30-80%. This means that thermal-treated wood in its current form is not suitable for load-bearing uses. Several other investigators have shown that the reduced hygroscopicity accompanies increased dimensional stability and increased durability. It is, however, not recommended to use heat-treated wood in ground contact (Jämsä and Viitaniemi 1998). The modification also leads to colour changes and the development of an intense odour. Attempts have been made to reduce the negative effects of heat treatment at high temperatures, such reduced strength and odour, by treating wood at moderate temperatures, i.e. 100-150°C. The main task is to reach the required properties without too long a processing time (see e.g. Obataya 2009).

As sustainability becomes a greater concern, the environmental impact of construction and furnishing materials should be included in planning by considering the life cycle and embodied energy of the materials used. Therefore, Life Cycle Assessment (LCA) should be used to reveal the environmental and energy performances of the used materials throughout their whole life cycle. LCA is one of many Environmental System Analysis tools that use this approach. LCA provides a framework for measuring the inputs and outputs of an option, whether a product, a process or an activity, as well as evaluating the environmental impacts and burdens associated with its whole life cycle. Technically, LCA is a systematic approach, where the system of interest comprises the operations that collectively produce the product under examination. LCA is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying the energy and materials used and the wastes released to the environment; to assess the impact of those energy and materials used and released to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal. In the thermal-treatment process only high temperature and steam are used in the manufacturing process, and no chemicals or other extraneous constituents are added to wood in the process. Overall, thermal-treated wood has a potential of being a green building material if consideration is made to the production as well as the use and disposal at the end of its life cycle using best available techniques. The study also recognised that LCA has limitations in its methodology and is highly dependent on data quality. In consequence, recommendations for further research are made to update and produce more accurate data for energy inputs and emission outputs and thermal treated wood performance to provide innovation for cleaner production. Nevertheless, thermal-treated wood has a significant environmental potential.

For the thermal-treatment processes, a more detailed consideration reveals several issues which lead to the question: Do we really know if the global environmental impact of thermal based timber processing and further uses of the resulting products is comparable with the impact of native, untreated wood? This values new advanced wood-based materials with improved intrinsic properties that promote efficient product reuse, recycling and end-of-life use, and pave the way to a low-carbon economy. The relationship between thermal wood processing, properties of the products, and the associated environmental impact should be taken into account when developing new processes and products, as well as when optimizing the existing commercialized processes. Energy consumption considerably contributes to the environmental impact of thermally treated wood. However, the improved properties during the use phase might reduce the environmental impact of the thermally based timber processing. Interactive assessment of process parameters, product properties, and environmental impact should be used to aid development of innovative thermal processing technologies. Furthermore, product design must enable efficient product reuse, recycling and end-of-life use. However, in order to develop and optimize thermally based timber processing to minimize environmental impacts, more information of relevant process factors must be gathered.

Thermally based timber processes are already industrialized in Europe but there are still different needs with regard to further development. From a technical and industrial point of view, the following areas have been identified as focus areas for the present on-going research or industrialization projects.

- fast methods for quality and process control;
- processing techniques to withstand the thermal-treated wood brittleness and the presence of dust during e.g. mechanical processing due to its low moisture content;
- adhesive and paint systems adapted to the low moisture content of thermal-treated wood;
- new material properties of the thermal-treated wood such as UV instability, weak surface (low hardness and fibre-fibre failure), corrosion, bleeding new chemicals through the coating (phenols), low screw-withdrawal burglar resistance, cracks in annual ring orientation etc.; and
- new thermo-hydro (TH) treatments, in contrast to thermal-treated wood at high temperature, with fewer undesired effects, to produce thermal-treated wood suitable for load-bearing elements and for indoor application;

- improved methodology and data quality for environmental system analysis for the thermal-treatment processes.

Research of thermally based wood processing and the resultant products must place more emphasis on the interactive assessment of processes parameters, developed product properties, and environmental impacts. Then, thermally based wood product can contribute to mitigate climate change and promote sustainable development, by reducing energy consumption, pollution and emissions while increasing performance.

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