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DETERMINATION AND COMPARISON OF SOME SELECTED PROPERTIES OF MODIFIED WOOD

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ABSTRACT

Modification of wood has become increasingly significant in recent decades due to e.g. growing environmental awareness, and a number of modified wood products are available. Some inherent qualities of wood may, however, raise questions about the durability of modified wood. This study investigates the properties of modified wood products. Three commercial modified wood products and two possible future contenders of our own production are studied and their resistance to artificial weathering, water absorption, swelling, and bending strength are analyzed. The results show that weathering caused notable and interesting differences among the tested materials. The moisture properties of the commercially available modified wood products remained on a restrained level compared to the contenders, but in the bending strength, the contender achieved equal values with the commercial products. It is concluded that each of the modified wood products had some outstanding properties.

KEYWORDS: Wood, modification, acetylation, furfurylation, sodium silicate, melamine, properties.

INTRODUCTION

Wood is a natural material which has been used in many applications for centuries. However, some of its weak inherent features, for example water susceptibility and biodegradability, reduce its quality. Wood modification is a way to advance these features to increase the usability of wood products.

Modification of wood alters its properties in such a way that during the lifetime of a product, loss of the enhanced performance of the wood should not occur. In addition, it is desirable that the modification of wood would is carried out with no release of toxic substances (Hill 2006). Although, the demand for non-toxicity has been abandoned slightly (Militz and Lande 2009), the growing environmental awareness has turned the focus on non-hazardous chemicals and processes and also natural materials (Németh et al. 2015). The first studies relating to wood modification were done in the 1930s, but the wood modification technology is still relatively new. Some methods have been introduced in the European market, such as acetylation, heat treatments, furfurylation, and use of DMDHEU (dimethyloldihyfroxyethyllenurea) (Militz and Lande 2009). In addition, wood plastic composite (WPC) products are also an alternative to modified wood in some outdoor applications (McGraw and Smith 2007; Stark and Matuana 2007; Clemons et al. 2013).

The properties of the studied materials have been investigated quite widely. Research of acetylated wood has been done since 1928. Today, the most common acetylation reaction is performed by acetic anhydride without a catalyst as a liquid phase. The reaction of acetic anhydride with wood forms acetic acid as a by-product, which must be removed from the final product. The acetylation treatment process of solid wood consist of a vacuum and a drying step before and after the anhydride processing, respectively (Rowell 2006; Rowell et al. 2009; Rowell 2013). The acetylation of wood reduces the number of hydroxyl groups, which results in a reduction of the equilibrium moisture content. Hence, dimensional stabilization increases and fungal attack decreases. The strength properties are retained almost unchanged after acetylation. (Rowell et al. 2009). The trade name Accoya is a known acetylated wood product.

Investigations of wood modification with furfuryl alcohol were started in the 1930s and 1940s, and the method is known as furfurylation (Lande et al. 2004); Kebony is the known trade name for furfurylated wood. Furfurylation is usually defined as impregnation modification (Esteves et al. 2011), the process of which is based on the full cell method with water-borne solution of furfuryl alcohol and its additives. An intermediate vacuum drying step before steam curing and drying is also possible, for example within the Kebony process (Pilgård et al. 2010). Furfurylated wood has good dimensional stability and resistance to decay and insect attack (Lande et al. 2004). The changes of the mechanical properties depend on measurable features. Some properties show insignificant change, but hardness can increase about 50 %, for instance (Esteves et al. 2011).

Water glass means potassium or sodium silicates, or solutions thereof, and it is utilized in many applications. Its beneficial properties are non-toxicity, low price and availability, inter alia (Mai and Militz 2004; Chen 2009). Water glass is soluble in water and forms an alkaline solution at elevated temperatures and pressures (Mai and Militz 2004). The strongly alkaline solution can polymerize from wood acidity when it is unable to penetrate into the cell wall layers (Chen 2009). The treatment of wood with water glass can reduce fungal growth and change of color, and in addition, it can increase the fire resistance (Mai and Militz 2004; Pfeffer et al. 2012). The number of commercially available silicate-based wood preservatives is difficult to determine (Mai and Militz 2004), but examples of commercialized wood products based on sodium silicate can be found. Such examples are the trade names TimberSil (Flynn 2006), S-Treat, and Q-Treat, of which the latter includes also thermal modification (Pynnönen et al. 2014).

From the commercial point of view, wood treatment with melamine does not have a significant role yet. However, its penetration into wood has been studied for years (Lukowsky 2002; Gindl et al. 2003). Melamine can protect wood against weathering, it reduces water uptake, and improves the strength and decay-resistance of wood on its own (Deka et al. 2002, Hansmann et al. 2006; Lahtela and Kärki 2014a) and in synergy with moderate heat treatment (Lahtela and Kärki 2014b).

The aim of this study is to compare the properties of commercial, and potential future modified wood products. There are several modified wood methods and products, but the selected products are based on treatment with a modifier agent, and possibly by the utilization of thermal modification. The comparisons of the products are done by measuring the weathering, moisture, and mechanical properties of the wood.

MATERIAL AND METHODS

The commercial modified wood products were purchased from an importer (Accoya and Kebony) and a retailer (Q-Treat). In addition to the commercial modified wood products, Scots pine (*Pinus sylvetris*) samples (20 x 95 x 1000 mm) were impregnated with melamine (Prefere 70 0592 L), at a pressure of 10 bars for 120 min. After that, the samples were dried at 90°C for 24 h, and the measured weight percent gain (WPG) that was 38.7 %. Finally, the samples were heat treated, at temperatures of 180°C (MHT180) and 212°C (MHT212) for 180 min. The densities of the tested materials are presented in Tab. 1.

Tab. 1: Average densities and standard deviations.

	MHT180	MHT212	Q-Treat	Accoya	Kebony
Density (kg.m^{-3})	599.61 (76.32)	569.45 (93.94)	420.81 (18.54)	619.26 (26.21)	626.72 (17.92)

Values in parentheses indicate standard deviations.

The weathering performance of the tested materials was evaluated by an accelerated weathering test in a test chamber (Q-Sun Xe-3 Xenon Test Chamber) with intervals of UV-light and water spray based on the standard of SFS-EN ISO 4892-2 (2006). The effect of the weathering test was analyzed through measurement of the surface color with a Minolta CM-2500d spectrophotometer (Konica Minolta Sensing Inc., Japan) with the following settings: Reflectance SCE, illumination D65, observer 2°, and illumination area 8 mm. The surface color was calculated before the test and after every 100 h up to the end of the test, 1000 h. In addition, the surface color was calculated in the beginning of the test, 24 and 48 h after test start. In the spectrophotometer measurement, the CIELAB color space was measured in L*, a*, and b* coordinates. The value of L* indicates the lightness coordinate and varies from 100 (white) to 0 (black), a* indicates the red (+a*) to green (-a*) coordinate, and b* indicates the yellow (+b*) to blue (-b*) coordinate. The color difference (ΔE*) is defined by the following equation:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (\%) \qquad (1)$$

where: ΔL*, Δa*, and Δb* illustrates the differences between the initial and measured values of L*, a*, and b*, individually. The surface color for each product was measured from six specimens, by 18 measurements in total.

The moisture properties were determined with swelling and water absorption tests for pieces with the size 20 × 20 × 30 mm (RxTxL). The test pieces were conditioned at 20°C and 65 % relative humidity for over 24 h before the test. The specimens were then weighed and the dimensions were measured before immersion into water for the duration of 28 days. The specimens were periodically taken out of the water, surface-dried with absorbent paper, re-measured, and returned to the water immediately.

Swelling (S) was determined in radial and tangential directions according to the following equation:

$$S = \frac{T_1 - T_2}{T_2} \times 100 \qquad (\%) \qquad (2)$$

where: T_1 - the thickness of the piece after immersion,
T_2 - the thickness of the piece before immersion.

The water absorption values (WA) were calculated as follows:

$$WA = \frac{W_1 - W_2}{W_2} \times 100 \tag{3}$$

where: W_1 - the mass of the specimen after immersion,
W_2 - the mass of the specimen before immersion.

Mechanical strength was determined by three-point bending strength tests with a Zwick Roell Z020 testing machine in accordance with ISO 3133 (2008). Fifteen test samples of each product, with dimensions 20 × 20 × 380 mm, were tested. The test samples were conditioned at 20°C and 65 % relative humidity for over 24 h prior to testing. The moisture and mechanical properties were determined of 15 specimens per product.

RESULTS AND DISCUSSION

Weathering

The weathering performance of the tested specimens is presented as point charts in Figs. 1-2, with an added trend line between the points. Fig. 1 shows weathering behavior based on the first three measurements, and the weathering performance of the whole test period is presented in Fig. 2.

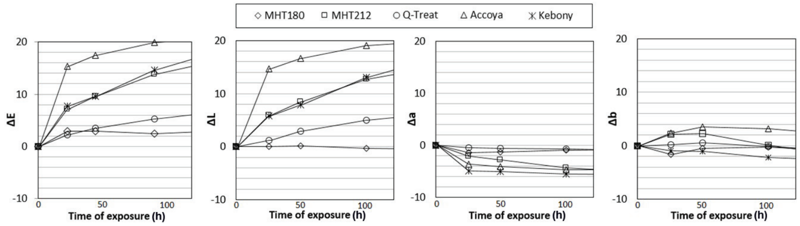
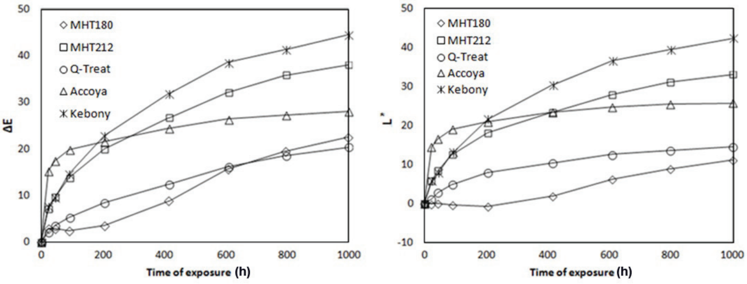


Fig. 1: Total color change (ΔE) and changes of three color parameters (L, a*, b*) of tested specimens in artificial weathering for the first 100 hours.*



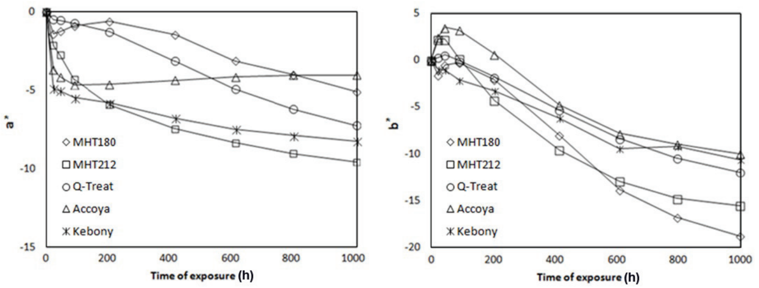


Fig. 2: Total color change (ΔE), and changes of lightness (L), and the red/green (a*) component and yellow/blue (b*) component as a function of artificial exposure of the tested materials for 1000 hours. The results are presented as spaced from 200 h forward.*

The graying of wood is the most obvious feature of weathered wood, which is due to leaching of extractives and lignin, resulting in cellulose-rich surface layers (Evans 2013). One ΔE is the smallest change in color which the human eye can detect (Sachs 2001-2003), and we could detect the color change already in the first measurement. All specimens showed a tendency to become lighter, bluer, and greener when the weathering test proceeded. The melamine-impregnated and heat-treated (MHT180) samples together with the Q-Treat samples had the lowest changes of color in the beginning of the weathering test. The MHT180 samples had the lowest color change until about halfway of the test period, after which the color change increased slightly. It has been found in previous studies that melamine treatment can reduce wood discoloration and retain its natural appearance (Hansmann et al. 2006). The weathering performance of the Q-Treat specimens was nearly linear for the whole test period. Water glass treatment can curb the decrease of lightness particularly in the case of Scots pine, but it cannot prevent discoloration during long-term weathering (Pfeffer et al. 2012). This kind of function is possible with the Q-Treat specimens. The total color change was greatest with the Kebony specimens, the lightness of which increased most, which is in agreement with a previous study (Temiz et al. 2007). Furfuryl alcohol is a colorless liquid which forms a hydrophobic dark brown polymeric gel in the presence of heat and an acidic catalyst (Thygesen et al. 2010). The color change of the melamine-impregnated specimens heat treated at 212°C (MHT212) were congruent with the Kebony specimens, only the b* color value was reversed compared to the color parameters in the beginning of test. The change of lightness was higher with the MHT212 specimens compared to the MHT180 specimens, which may be due to the color function of thermally modified wood. Generally, the darkness of thermally modified wood increases with the increasing temperature (Thermowood 2003) but fades relatively quickly at weather exposure (Jämsä et al. 2000, Bak et al. 2012). The color change of the Accoya specimens was significant in the beginning, after which it became stable. According to Rowell (2013), acetylation changes dark woods to lighter and light woods to darker. Weathering changed the color of the Accoya samples rapidly, after which the surfaces remained stable, as well as lighter and cleaner by visual review.

It has been found that the surface color alters more tangentially than radially (Huang et al. 2012). In this study, the surfaces of the Accoya and Kebony specimens were tangential, those of the Q-Treat mainly radial, and the MHT samples (MHT180 and MHT212) consisted of both kinds of surfaces. Analysis of the tangential and radial surfaces of the MHT samples showed that the tangential surfaces altered more, and the effect was highlighted in the MHT212 samples.

Moisture properties

Data on the moisture properties are presented in Figs. 3-4. The water absorption (WA) properties are presented as a point chart in Fig. 3, to which a trend line has been added. The Q-Treat specimens absorbed the most water during the test while the other specimens absorbed considerably less water, and the MHT212 absorbed the least. The Accoya specimens absorbed water slightly more in the beginning of the test but it leveled off when the test proceeded.

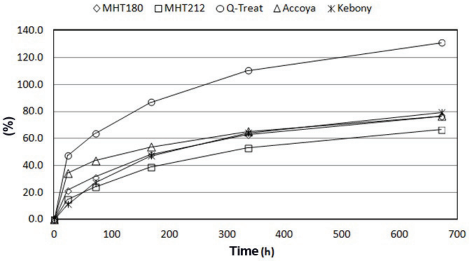


Fig. 3: Water absorption as a function of immersion time of the tested materials.

The swelling properties are presented as a bar chart in Fig. 4 for the tangential and radial directions. The swelling increased with the progressing immersion time, but part of the specimens reached quickly a status where no more swelling occurred. For example, the swelling of the Accoya specimens was diminished significantly in both directions, starting from the first measurements. Generally, the swelling of the commercial wood products was almost stabilized after a week of water immersion at the latest.

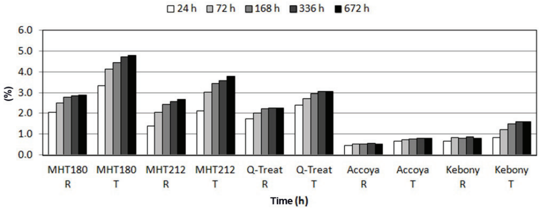


Fig. 4: Radial (R) and tangential (T) swelling with time.

The significance of moisture must not be underestimated, as it affects many properties of wood. Generally, tangential swelling is twice compared to radial swelling (Rowell 2013) but in modified wood this difference did not seem to be so notable. Further study showed that although the swelling anisotropy decreases as a result of heat treatment, it will not disappear (Bak and Németh 2012). It has been reported that the cell walls of Accoya and Kebony specimens are more hydrophobic owing to treatments, in which case swelling does not have a normal influence (Thygesen and Elder 2008). The water absorption function of the Q-Treat specimens was similar to a previous study where heat treatment had a negative effect on the water absorption of water glass-treated wood (Lahtela and Kärki 2014b). It has been stated that the high moisture content of water glass-treated specimens proceeds from hygroscopicity of unreacted solution in the lumen of the cell and on the specimen surface (Mai and Militz 2004; Pfeffer et al. 2011). It can be seen on the basis of the study that the method of wood modification has an effect on the moisture properties of wood.

Mechanical properties

The averages of bending strengths are presented in Fig. 5, as bar charts with standard deviations added as error bars. Accoya and MHT180 have the best values, 104.92 and 103.15 MPa, respectively while the bending strength of Q-Trear reached 62.5 % of the best strength.

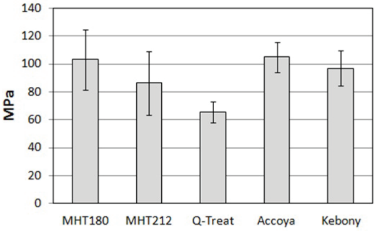


Fig. 5: Bending strength of the tested materials.

The modification affects the bending strength individually. For example, furfurylation increases to strength (Esteves et al. 2011) but the effects of acetylation is insignificant (Papadopoulos and Tountziarakis 2011; Rowell et al. 2009) or at most slightly increased (Epmeier et al. 2004). The strength property of acetylated material depends on the species and treatment processes (Bongers and Beckers 2003). It has been found that melamine can increase the strength of wood on its own (Deka and Saikia 2000) and in combination with moderate heat treatment (Lahtela and Kärki 2014b), but immoderate treatment temperature and time reduce the strength (Sun et al. 2013). Water glass treatment with elevated temperatures decreases the bending strength because a high pH produces hydrolysis of the cell wall polysaccharides (Mai and Militz 2004). Although Q-Treat achieved the weakest bending strength, its lowest standard deviation must be noted, which expresses controlled manufacture and product. It can be noted on the basis of the study that bending strength depends on the way of modification.

A high treatment temperature causes strength loss in wood (Thermowood 2003; Lekounougou and Kocaefe 2014). Therefore, the process values must be selected carefully when exploiting heat in wood modification. The bending strength depends on many properties, like specific gravity (Winandy and Rowell 2013) and it has been found that the bending strength reduction is aligned with hemicelluloses degradation (Weigl et al. 2012). For modified wood, the bending strength increases with increasing weight gain (Minato et al. 2003), but it is not always automatic (Epmeier et al. 2004).

CONCLUSIONS

In this work the effect of weathering, moisture, and mechanical properties of modified wood products were investigated. The tested products had different properties and there was variation in the results, showing that there was a need for this study. Superiority ranking between the investigated samples is challenging, but each type of modified wood has at least one excellent material property.

On the basis of the promising results of the weathering test, the color change of modified wood can be minimal or stable, especially in the beginning of weathering. The most significant changes in moisture took place quickly and the commercial modified wood products had controlled swelling. The mechanical properties were quite identical in the MHT180, Accoya, and Kebony samples.

This study has demonstrated that modified wood products have improved properties. However, none of the modified products had superior features in every test, and consequently wood modification is still a subject for further development. Modified wood products may have some other excellent properties which did not come out in this study. The choice of the modified wood product must be done according to intended use.

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