Furfurylated Wood for Wooden Window Constructions

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ABSTRACT

In recent years the market share for wooden window products has continuously decreased in Europe. Plastics and aluminum have partly replaced wooden window constructions. Service life and maintenance costs lead the customer to a preferable use of other materials than wood. Additionally the use of tropical hardwoods is decreasing because the market demands sustainable alternatives. A transnational research project is initiated to evaluate the use of an alternative wood material for the production of wooden windows. This project involves both, industry and research institutes from Germany, Sweden and Norway. The objective is to establish Kebony furfurylated wood within the window market of the involved countries. Furfurylation of wood using European timbers has been a research topic for many years and is already commercially produced for different applications. The treatment improves dimensional stability, durability and some mechanical properties. This paper presents the first part of the project, where wood properties such as dimensional stability, water sorption, ecotoxicity, capillary water uptake and water vapor diffusion are evaluated.

INTRODUCTION

Background of this research is the development of the European window market. During the last decades the use of wooden window constructions in Germany is decreasing. Since 2001 the market share of wooden windows remains at approximately 20% (2.8 million produced wooden windows) (Heinze 2008). The window market is dominated by plastic (PVC) and metal (aluminum) frame materials, because such frame materials are seen to require less maintenance during service life in comparison to wooden windows. The Scandinavian window market shows a different structure. Traditionally, the windows in Scandinavia are made of pine and spruce. In 2001 the market share of wooden windows in Scandinavia was 56%, (2.2 million produced wooden windows) (Kreimeyer 2002). However, the window industry in Scandinavia is facing an increasing cost pressure by manufacturers from the Baltic countries and an increasing competition of PVC window manufacturers. Additionally, the growing internationalization in terms of legislation, technical development (*e.g.* heat insulation) requires innovative approaches in order to provide the wooden window constructions on the Scandinavian window market.

The technical requirements for wood used in the window industry are very high. Dimensional stability and durability against wood destroying fungi are important properties, which have to be fulfilled by the wood species. European wood species can hardly fulfill such requirements. Consequently, most wood windows are currently built out of tropical timbers, which exhibit good material properties. But most tropical timbers do not originate from sustainable managed forests and are also very rare. Based on these facts, it is important for the window industry in Germany as well as in Scandinavia to get the possibility to use modified European wood species for the production of high-performance windows. The decision to use furfurylated wood as an alternative wood material for the window construction is based upon the good wood properties and a high development status. The furfurylation is an extensively investigated wood modification process, which is using furfuryl alcohol, obtained from renewable resources of corn cobs or sugar cane residuals (Lande *et al.* 2008, Hill 2006).

Due to its polarity, furfuryl alcohol can penetrate into the cell wall, where it polymerizes. Furfurylation of wood provides a high protection level against bio-degradation (fungi, bacteria and marine borers) without being a biocidal treatment (Lande *et al.* 2004b). Beside the bio-resistance, wood properties like dimensional stability and hardness can be increased by the furfurylation of wood (Lande *et al.* 2004a). These wood properties depend on the amount of Furfuryl alcohol that is brought into the cell wall (Lande *et al*. 2004a). The furfurylation of wood products is industrially applied and marketed by the Norwegian company Kebony ASA.

Project description

The project “Use of furfurylated wood for the production of high-performance windows made of European timbers” is part of the ERA-Net “Wood Wisdom-Net” program. The project is a collaboration of three international research institutes (*Wood Biology and Wood Products*, University of Göttingen, Germany; *SP Technical Research Institute* of Sweden; *Norwegian Forest and Landscape Institute*, Norway), three window SMEs (*Menck Fenster*, Germany; *Tanumsfönster and Bordörren*, Sweden) and *Kebony* the Norwegian furfurylation company. The objective of the project is the industrial application of furfurylated wood in the German and Scandinavian window market. At the beginning of this project the tested species are chosen by suitability for furfurylation, regional provenance in Europe, availability on the wood market and price. The selected wood species are European beech (*Fagus sylvatica L.*), Common ash (*Fraxinus excelsior L.*), European birch (*Betula pendula L.*), Scots pine (*Pinus sylvestris L.*), Southern yellow pine and Radiata pine (*Pinus radiata D.*). These wood species are furfurylated in an industrial process at Kebony ASA, Porsgrunn, Norway. Beside the fundamental research on the furfurylated wood, window components and prototypes are going to be developed, investigated and certificated. The project is divided in the following work packages:

- Market analysis and overview of legitimate and technical requirements for wooden windows in Germany and Scandinavia. A major part of the project focuses on the requirements of the window standard DIN EN 14351-1 (Windows and external pedestrian doors) and the German directive HO.06-4 (VFF 2007). The directive HO.06-4 specifies requests on modified wood for wooden window constructions and will be an important directive to get the RAL quality mark by the "Gütegemeinschaft Fenster und Haustüren e.V."

- Evaluation of material properties. This step includes tests to reveal the material properties of furfurylated wood for a sound scientific background. Properties like dimensional stability, water sorption, coating behavior and weathering, thermal conductivity, water vapor diffusion, resistance against wood destroying fungi and mechanical properties are crucial for providing a sound scientific background for the admission of furfurylated wood as a suitable wood for window constructions.
- Investigation of component parts made of optimized material. The studies investigate the glueability of lamellas, capillary water uptake and machinability, as well as the production of window prototypes. Further studies will deal with the compatibility between wood frames and other materials, *e.g.*, metal fasteners and silicone.
- Assessment of prototypes and certification. The produced window prototypes will be tested for heat-insulation, noise-insulation, air-tightness, wind-tightness, rain-tightness, vertical load, torsion, corner joint strength, performance in continuous-operation, burglary resistance and other properties which are also required for a RAL-certification.

EXPERIMENTAL

Wood Material

The wood species named in the introduction are furfurylated by the Kebony process. Kebony's commercial treatment level for outdoor products is used. For each test, untreated control samples of each wood species are tested. Sipo mahogany (*Entandophragma utile L.*) serves as reference species of tropical wood.

Material properties

Ecotoxicity

For the ecotoxicity test furfurylated ash, southern yellow pine and beech wood samples in three different treatment levels (low, medium and high) were used together with untreated controls. As reference material, ScanImp- and CCA- treated Scots pine and beech were used. Water leachate samples were taken after 24 hours and 14 days and tested for ecotoxicity in the Microtox assay (Isenberg 1993). The water was changed according to the EN 84 standard.

All leachates were run according to the Microtox assay using the bacterium *Vibrio fischeri* as test organism. The basic test protocol was used with 45%, 22.5%, 11%, and 5.5% dilutions of the leaching water. Every test was run twice. All leachates were run for 5, 15 and 30 minutes. To avoid influence of pH, all leachates were adjusted with NaOH (0.5mol/l) to a pH between 6 and 8. The results were normalized and the EC50 values (concentration producing a 50% reduction in luminescence) were calculated from the 30 minutes data. The Toxic Unit (TU) was then calculated from the obtained EC50 values with Equation 1 (Manusadžianas *et al.* 2003). Non-toxicity was set to a TU of 2 (De Vetter *et al.* 2008).

$$TU = \frac{1}{EC_{50}(\%)} \times 100 \tag{1}$$

Water sorption

The water sorption of furfurylated wood is evaluated by calculating the sorption isotherms. The Equilibrium Moisture Content (EMC) as well as the swell rate of wood depending on relative humidity are measured concerning the method described by Krause (2006).

Capillary water uptake

The method of determining the capillary water uptake of wood has been adapted from DIN 52617 (1987), which is used for porous materials in building industry. As wood is also a porous material and water flows through capillary force in wood, this test gives information on its water resistance coefficient. The tangential water uptake is measured.

Water vapor diffusion

The determination of the water vapor transmission properties is described in EN ISO 12572 (2001). Round wood samples are positioned on glass containers, which are filled with dried silicagel.

RESULTS AND DISCUSSION

Selection of wood

The wide range of wood species was chosen to have the possibility to select the best wood species after the furfurylation process. As shown in Table 1 not all of the wood species show to be treated in a sufficient way. Difficulties based on high heart wood content of Scots pine as well as low solution uptake of European birch lead to the decision to continue the trials only with European beech, Common ash, Radiata pine and Southern yellow pine, which all show a good modification behavior.

Table 1: Furfurylated wood species, Weight-percent-gain [%] and distribution

Wood species	WPG [%]	distribution
European beech	31	Even
Common Ash	18	even/ uneven
European birch	not measured	Uneven
Scots pine	20	not in the heart wood
Southern yellow pine	41	Even
Radiata pine	42	Even

Material properties

Ecotoxicity

The ecotoxicity of the leachates from the EN84 leaching (Figure 1) show that all the furfurylated samples, except for ash, had no toxicity (TU below 2). At 24 hours, ash with a high uptake of furfuryl alcohol had a TU of 7. Ash with a medium uptake and ash with a low uptake of furfuryl alcohol had a TU between 3 and 5 at 24 hours. This can be compared to beech treated with ScanImp that had a TU of 50 and beech treated with CCA with a TU of 17 at 24 hours. *Scots pine* with a TU of 3 at 24 hours, was the only untreated sample that had a TU above 2 during the test series. The same pattern could also be seen at 14 days except that *Scots pine* treated with ScanImp had a higher TU than beech treated with ScanImp.

These results for furfurylated ash show a slightly higher toxicity in the Microtox test than what furfurylated *Scots pine* showed in earlier studies (Pilgård and Westin 2008).

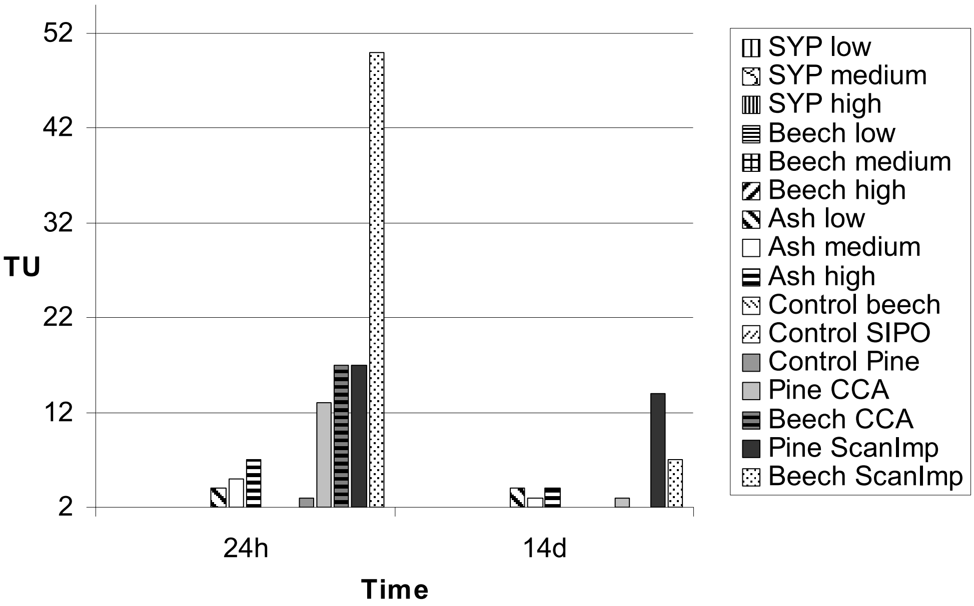

Figure 1: Ecotoxicity (TU) of the leachates from the EN84 leaching procedure

Water sorption

The calculated sorption isotherms show clearly that the wood modification via furfuryl alcohol reduces the water sorption of wood. As shown in Table 2, the furfurylated samples of Southern yellow pine (SYP), ash and beech have a lower EMC than the untreated control samples. The furfurylated wood samples show even a lower water sorption than the samples of the tropical reference Sipo mahogany.

Table 2: mean values of EMC [%] at 20 °C and different relative humidity (RH), standard deviation in brackets

RH [%]		**SYP**	**Beech**	**Ash**	**Sipo**
30	treated	3,35 [± 0,3]	3,16 [± 3,1]	2,96 [± 0,2]	
	untreated	6,36 [± 2,0]	5,31 [± 0,1]	5,12 [± 0,4]	6,20 [± 0,5]
50	treated	4,44 [± 0,1]	4,25 [± 3,4]	4,52 [± 0,4]	
	untreated	8,06 [± 0,1]	7,24 [± 0,1]	7,24 [± 0,1]	8,22 [± 0,1]
65	treated	6,52 [± 0,2]	6,48 [± 3,5]	6,90 [± 0,6]	
	untreated	11,54 [± 0,1]	10,48 [± 0,1]	10,74 [± 0,5]	12,27 [± 1,1]
85	treated	9,05 [± 0,4]	9,36 [± 3,8]	10,21 [± 1,1]	
	untreated	16,37 [± 0,1]	16,38 [± 0,1]	16,33 [± 0,1]	16,75 [± 0,1]
90	treated	10,48 [± 0,4]	10,98 [± 3,7]	12,08 [± 1,4]	
	untreated	19,55 [± 0,1]	20,45 [± 0,1]	20,02 [± 0,1]	18,99 [± 0,1]
95	treated	11,71 [± 0,5]	12,36 [± 4,0]	13,51 [± 1,6]	
	untreated	21,68 [± 0,1]	22,22 [± 0,2]	20,64 [± 0,2]	20,36 [± 0,1]

The measured dimensions during the different conditioning steps allow a statement about the dimensional stability of furfurylated wood. The furfurylated wood samples show a reduced swelling regarding their dimensions in comparison to the untreated control samples. In Table 3 the swell rates of the samples at 20 °C and 65% respectively 85% relative humidity are shown. The dimensional stability of the modified samples is even higher than the dimensional stability of Sipo mahogany. The dimensional stability is an important property for the window construction. The stability of varnishes and the influence on crack behavior depend on it.

Table 3: mean values of swell rate [%] at 20 °C and between a relative humidity (RH) of 0-65 % and 0-85 %; standard deviation in brackets

RH [%]		**SYP**	**Beech**	**Ash**	**Sipo**
0-65	**treated**	3,16 [± 0,8]	2,29 [± 1,4]	3,02 [± 1,6]	
	untreated	6,47 [± 0,4]	5,84 [± 0,5]	5,27 [± 0,6]	5,38 [± 1,6]
0-85	**treated**	4,63 [± 0,4]	4,93 [± 1,4]	5,32 [± 1,8]	
	untreated	10,10 [± 0,4]	9,80 [± 0,5]	8,89 [± 0,4]	8,26 [± 1,7]

Capillary water uptake

The reduced tangential water uptake of the modified wood samples compared with the untreated control samples is clearly visible (Table 4). The water absorption coefficient shows the water uptake in relation to time. The modified wood comprises a low coefficient. The results are comparable to Sipo mahogany. The untreated control samples however show a high water absorption coefficient. The wood modification with furfuryl alcohol results in hydrophobic wood properties. Due to the fact that furfurylated wood is planned to be used for the window construction, the reduced water uptake is very important for the behavior in outside construction. But beside of that, the reduced water uptake gives information about glue penetration into Kebony wood. It has to be considered for the further work on use of the right glue and coating systems.

Table 4: Results of capillary water uptake (tangential wood direction) depicted by water absorption coefficient [kg/m²]; standard deviation in brackets

		Beech	**Ash**	**SYP**	**Scots pine**	**Sipo**
water absorption coefficient [kg/m^2]	**treated**	0,08 [0,03]	0,082 [0,03]	0,06 [0,01]		
	untreated	0,41[0,22]	0,19 [0,08]	0,45 [0,18]	0,543 [0,09	0,10 [0,03]

Water vapor diffusion

The resistance of the furfurylated wood against water vapor diffusion is much higher than the untreated control samples (see Table 5). The furfurylated wood samples show even a higher vapor resistance than the samples of the tropical hardwood Sipo mahogany. The water vapor resistance is an important property for the window construction, because requirements concerning the insulation and the new U-value regulations of modern windows lead to high requirements regarding the frame material.

The good resistance of furfurylated wood against water vapor helps to establish furfurylated wood in the window industry.

Table 5: Water vapor diffusion resistance [µ] of furfurylated and untreated control samples

Wood species	**Water vapor diffusion resistance [µ]**	
	treated	**untreated**
SYP	112 [± 40,7]	24,65 [± 3,6]
Beech	234 [± 132,6]	30,22 [± 4,7]
Ash	248 [± 124,0]	35,48 [± 16,1]
Sipo	-	41,19 [± 4,6]

CONCLUSIONS

The results of the different experiments are important to proof the basic requirements for the use in the modern window construction. The furfurylated wood shows a satisfactory behavior against moisture, which leads to good expectations for the coating and weathering tests. The high dimensional stability, reduced water uptake as well as good water vapor resistance indicate that the furfurylated wood can be an optimized material for the production of wooden windows. The furfurylated wood also shows a low toxicity compared to CCA and ScanImp treated wood in the ecotox test. The results of the previous tests, as well as further tests like glueability and coating tests, will lead to the next project phase: the production and assessment of the window prototypes. The performance of the furfurylated wood in the construction tests of the window prototypes will have to be considered. Improvements and current requirements of the window industry have to be fulfilled by the new frame material, in order to successfully establish furfurylated wood.

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