Acetylation to Minimize Water Uptake and Deformation of High Wood Content WPC

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ABSTRACT

There is an interest in using a higher amount of the wood component in wood thermoplastic composites (WPCs) and thus using less of the thermoplastic matrix, which often is several times more expensive than the wood component. However, a high wood content in WPC will create a network of connected wood particles allowing moisture to enter not only the outer layer of the material but also the inner bulk. Depending on the size, shape and orientation of the wood component, the water uptake and resulting swelling may cause the entire material to deform (*e.g.* bend, twist and cup). Cycles of moisture uptake and release in the surface region as well as in the bulk of the composite may also create micro cracks which will accelerate the moisture uptake, causing the WPC to be more susceptible to microbiological decay. The effects of an interconnecting network of the wood fibers on the moisture and dimensional stability of WPCs may be significantly reduced if a chemically modified wood component is introduced. In this paper, the effects of water sorption in WPC made from acetylated wood and polypropylene (weight ratio 70/30) has been studied and compared with a reference WPC prepared with unmodified wood. The deformation and the water uptake were observed after cyclic soaking and drying of the composites. Optical microscopy and scanning electron microscopy (SEM) were used for detection of wood component shape and orientation in the samples and to further analyze the moisture behaviour discrepancy. In order to avoid any artefacts during sample preparation for the microscopy, a UV laser cutting technique was applied. Results indicate that the introduction of an acetylated wood component in WPC significantly reduces moisture related deformations.

INTRODUCTION

Wood plastic composites (WPCs) is in general built up by a reinforcing wood component in the shape of particles, fibres or a combination of these two, the wood component is mixed with a thermoplastic matrix. These components are put together under heat and pressure and extruded into profiles or injection moulded into final shapes. There exist an interest to increase the wood part of the composite, and thus using less amount of thermoplastic matrix which is several times more expensive than the wood component. One problem connected to the amount of wood used is that above a certain threshold an interconnecting network of touching particles/fibres are created following that the susceptibility to absorb moisture dramatically increases. This will lead to poor dimensional stability an also an increased risk for biological decay by microorganisms. To be able to use high wood content in WPCs there is a need for improvement of the moisture properties of the wood component, one way to do this is to use acetylation of the wood material. There is of course an increased cost for this but by the use of residuals from the production of acetylated solid wood boards this cost can be held to a minimum.

MATERIALS AND TEST METHODS

Preparation of composite samples

The wood material used was solid wood boards of acetylated and unmodified Scots pine (*Pinus sylvestris* L.). The acetylation was performed according to Rowell *et al.* (1986) in a pilot plant with a microwave heated reaction vessel of 0.67 m^3. The degree of acetylation was approximately 20% expressed as wood acetyl content. The boards were ground into particles in a two step process, first through a disk flaker creating thin veneer strands, the strands where then fed into a knife ring mill and chopped into fine particles. The thermoplastic matrix used was polypropylene (PP, Moplen HF 500N). The acetylated and unmodified wood material were dried to a moisture content (mc) less than 1% and mixed with the PP and compounded into pellets in a counter rotating twin screw extruder at OFK Plast AB in Karlskoga, Sweden. The pellets were fed into a conical extruder located at Conenor Oy in Tampere, Finland and extruded into square-shaped hollow profiles of acetylated and unmodified composites, the cross section of the profile measured. The wood/thermoplastic ratio was 70/30 for both types of composites.

Moisture cycling

Rectangular specimens measuring 100x10.6x3.4 mm^3 were prepared from the mid section of the flat side of the square profile, the longitudinal direction of the specimens is in line with the axial direction of the composite profile. The initial weights of all the specimens were measured, after that a 14 days leaching cycle in de-ionized water was started with water exchange 10 times followed by oven drying in 103 °C for 72 hours. After that 3 soaking cycles was performed with 4.5 days soaking in de-ionized water followed by 2.5 days of oven drying in 103 °C. Weight data was collected before and after each moment in the soaking cycles.

Specimen preparation by UV excimer laser

Cross sectional cuts as well as ablation of the flat surface were performed to create surfaces for micromorphological studies in scanning electron microscope (SEM) as well as light microscope (LM). This technique for preparing surfaces for microscopic studies without the risk of mechanically introduced artefacts by the preparation technique itself is further described in Seltman (1995) and Stehr *et al*. (1998).

SEM and LM

The two composite materials were compared in SEM and LM regarding their particle orientation, size distribution as well as the overall micromorphology.

RESULTS

The leaching procedure resulted in very high moisture contents for the WPCs with unmodified wood whereas the moisture content of the WPC with acetylated wood was very low (see Table 1). The following soaking-drying cycles demonstrated that no further absorption compared with the leaching cycle was recorded. These moisture levels are in accordance with Segerholm (2007), where water soaking was performed on the same type of materials but much smaller specimens (20x4x1 mm^3). The WPC with acetylated wood showed very small to none irreversible deformations due to the moisture cycles, whereas the WPC with unmodified wood deformed dramatically; the irreversible swelling in the width, thickness, and longitudinal directions were 5.3, 3.5, and 0.8% respectively, the WPC with unmodified wood also deformed by twisting (20 mm/m), and in flatwise bending (31 mm/m), *cf*. Figure 1.

Table 1: Moisture content during and after soaking cycles

	Unmodified	**Acetylated**
Initial	2.7	1.7
After leach	21.2	8.3
Soaked 1 time	19.8	5.7
Soaked 2 times	20.1	5.8
Soaked 3 times	20.3	5.2

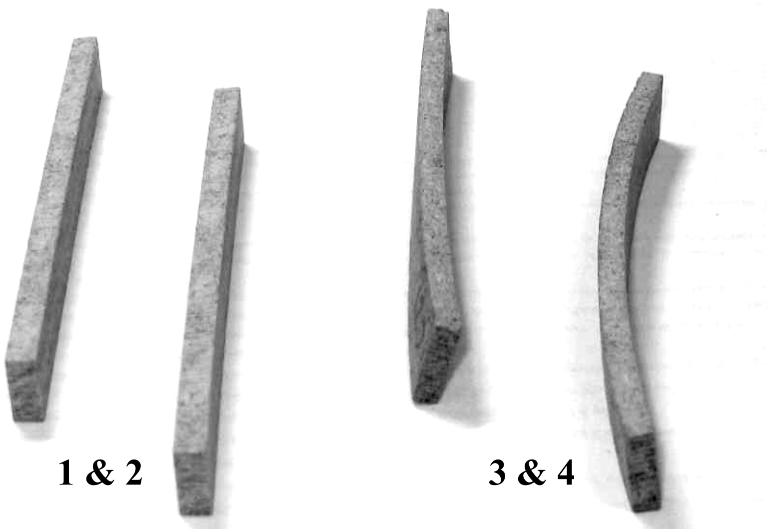

Figure 1: Specimens after moisture cycles; 1 & 2 with acetylated wood component, 3 & 4 with unmodified wood component

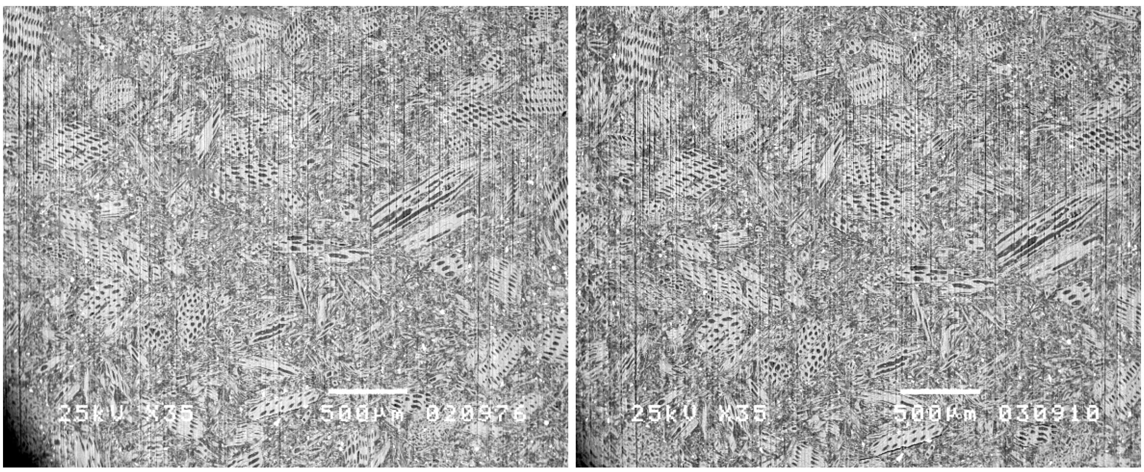

Figure 2: Specimens cross section of WPC with acetylated wood component before (left) and after (right) moisture cycles

The analysis in SEM and LM revealed that the orientation of the particles was mostly aligned slightly off the longitudinal extrusion direction. Large variations in the orientation was also recorded, which correspond with the large standard deviation of the deformation of the WPC with unmodified wood. The irreversible swelling was also observed in the SEM, where WPC specimens with unmodified wood showed cracks formed around almost every particle in the cross section after cycling in water. WPC specimens with acetylated wood showed almost no crack formation due to moisture cycles, figure 2 shows micrographs of the cross section before and after moisture cycling.

DISCUSSION

Moisture in WPCs becomes a critical issue when increasing the wood content and thus creating an interconnecting network of touching wood particles/fibres, the moisture uptake, deformations, and susceptibility to biological decay dramatically increases. These issues have shown possible to avoid by using an acetylated wood component, the amount of water absorbed is decreased by 60-75%, and the deformations caused by the moisture movements are almost entirely avoided. The orientation of the particles/fibres showed to have great influence on the deformation of WPCs with unmodified wood, where large values of twist and flatwise bending was recorded. The orientation effect on the deformation of WPCs with acetylated wood showed to have less importance due to the less moisture movements and also the original swollen state of the cell wall of the acetylated wood. To avoid problems with deformations in high wood content WPCs it is important to have control over the orientation of the particles, or using a wood component which is less susceptible to moisture.

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