USE OF CONSTRUCTION WASTE IN WOOD FIBRE COMPOSITES

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ABSTRACT

At the end-of-life of buildings, a large volume of demolition waste streams exists. Although a large part of these waste materials already has recycling routes, others are e.g. incinerated. B-wood that is composed of recycled wood containing glues, adhesives and paint (but not contaminated with toxic substances with which C-wood is usually categorized) is amongst this latter group of materials.
This study investigates the possibility of using renewable raw materials from construction waste streams, by manufacturing wood-fibre composites from recycled A-wood and B-wood and study the resulting mechanical properties.
Wood waste, collected at a construction recycling plant, is dried and shredded to obtain wood fibres. Particle size distribution is determined and, by adding polypropylene in different percentages and other additives to improve fibre-matrix adhesion, wood fibre composites are compounded, and subsequently compression moulded and injection moulded. Tensile and flexural properties are then investigated.
Results show that recycled wood composites can be made with competitive properties. As expected, fibre content has a great effect on the mechanical properties of the studied materials. This shows the potential of using wood from construction waste streams in making competitive wood fibre composites at an industrial scale.

Keywords: Wood composites, Recycling, Extrusion

1. INTRODUCTION

In view of sustainability, closing life cycle loops becomes increasingly important. The sustainable use of wood can lower impact on climate change and can decrease the non-renewable resource demand [1]. A better management of this helps the wood sector to ensure long-term availability of solid wood products. At the end-of-life of buildings, a large volume of demolition waste streams exists and, by a lack of viable alternatives, of which a major part is incinerated.
This paper shows the possibility of re-using these wood waste streams. Composites loaded with two different wood fibres (A-wood and B-wood) have been examined and compared. Processing is demonstrated by granulating the fibres into the proper size pellets and different ways of processing and resulting mechanical properties are studied.
Re-usable wood is classified in three different grades: A-wood, B-wood and C-wood. A-wood is composed of clean recycled wood, B-wood is an industrial feedstock grade, including grade A material plus construction and demolition waste, containing (traces of) coatings, adhesives and

fixing materials. C-wood is a fuel grade, containing all of the above material plus that from municipal collections, that includes contaminated and impregnated timber [5].
Efforts are being made to re-use solid and glued wood products instead of other "recycling" routes, like incineration. Nowadays, an important challenge is to activate the potential of the wood sector to provide new products with proper requirements. With reuse and recycling of wood products, a positive effect can be obtained which will lead to improved lifecycle assessment (LCA) indicators for wood-based products.
Wood fibre composites have been extensively studied over the last years. One of the most important features of fibre reinforced composites is that the mechanical properties of the material can be tailored to suit applications. By varying fibre content, coupling agents and process parameters (i.e., temperature, mixing time, speed) strength and modulus properties can be obtained, higher than the sole polymers, at the expense of impact strength and ductility [7]. Furthermore, the use of wood – based composites is beneficial due to their intrinsic renewability, decreased material costs, compatibility with existing cost-effective processing equipment, favourable strength/weight ratio, low hardness, etc.
Bledzki et al (2004) reported a comparison of compounding processes and wood type for wood fibre – PP composites, showing that twin – screw extruder compounded composites had higher mechanical properties than those mixed in a two-roll mill or a high-speed mixer [2,4].
A major issue in achieving true reinforcement is the incompatibility between the hydrophilic, irregular, hygroscopic, thermally sensitive, polar fibres and the hydrophobic, a-polar polymers, which results in poor adhesion and in poor ability to transfer stress from the matrix to the fibre [6]. Xanthos (1983) reported that the compounding process improves adhesion thanks to the use of a coupling agent and at the same time gives minimum degradation of the wood fibre [3].
The main envisaged applications of wood fibre thermoplastics include automotive, building industry, electric insulation, furniture and packaging materials.

2. EXPERIMENTATION

2.1 Materials

A polypropylene, with a density 0.903 g/cm^3 and melt flow index in the range between 6 - 25 g/10 min (230°C, 2.16 kg), T_m = +/-165 °C is used as a composite matrix. Two kinds of additives are used as compatibilizers: (1) maleated polypropylene (MAPP) and (2) lubricant, to reduce the viscosity, widen the processing window and lower the melt temperature.
The wood is selected from construction and demolition waste by Rouwmaat B.V., a company in the Netherlands representative for their regular waste streams and delivered in large amount. In particular, two types of recycled wood are used as filler:

1. untreated wood, not impregnated, not glued – defined as A-wood and shown in *Fig. 1*;
2. non-hazardous, treated wood, coming from cupboards, scrap wood and painted timber – defined as B-wood, shown in *Fig. 2*.

Figure 1. A-wood waste

Figure 2. B-wood waste

2.2 Chemical constituents of wood fibre

The chemical constituents of WF were previously determined by the supplier according to DIN EN 16171 [Sludge, treated biowaste and soil - Determination of elements using inductively coupled plasma mass spectrometry], DIN ISO 10382 [Soil quality — Determination of organochlorine pesticides and polychlorinated biphenyls — Gas-chromatographic method with electron capture detection] and DIN ISO 18287 [Soil quality — Determination of polycyclic aromatic hydrocarbons (PAH) — Gas chromatographic method with mass spectrometric detection (GC-MS)]. It was found that the amount of organochlorine pesticides and polychlorinated

biphenyls is less than 0.4 mg/Kg and the number of aromatic hydrocarbons is lower than 1.5 mg/Kg.
FTIR (data from the absorption spectra) was conducted to confirm the absence of chlorine groups, that can be dangerous for the processing of composites at high temperatures.

2.3 Preparation of composites and samples

A-wood and B-wood scraps were dried in a Memmert UF160 convection oven at 103 ± 2 ℃, for 4 hours in two steps. Remaining moisture content was 4-5 %. Wood fibres are produced using a 4 mm mesh screen in a rotating knife granulator. The shredding operation is repeated four times for each batch. Wood fibres were then separated with a vibratory sieve shaker Retsch AS200 Basic (combination time/amplitude = 60 min/ 2.25 mm). Fibres in the range 0.5 – 1.6 mm were sorted for the extrusion process.
WF/PP composites were prepared by two melt processes. Since B-wood fibre can contain materials different from wood (paints, adhesives and so, materials like polyurethanes, formaldehydes and PVCs), a threshold degradation temperature was defined. Polyurethanes degrade above 230 ℃, formaldehydes above 200 ℃ and PVC's can already start to degrade at 160 ℃. Between 100 ℃ and 200 ℃ wood becomes dehydrated and generates water vapor and other non-combustible gases and liquids; from 200 ℃ to 300 ℃ some wood components begin to undergo significant pyrolysis (hemicellulose above 200 ℃, lignin above 225 ℃ and cellulose above 300 ℃) [10]. Since the chemical analysis established the absence of chlorine groups, it was decided to process the composites in the range 175 – 195 ℃.
The melt processes used were:

- Extrusion on a single screw extruder (Suke SJ35X25). The barrel temperature ranged from 175 to 195 ℃, the residence time greater than 300 s. Since effective mixing is important to achieve good dispersion of wood fibre and to optimize the final properties, two types of mixing were employed utilizing similar thermal conditions: *Method I*: PP, WF and additives are previously dry-mixed and then fed into the extruder; *Method II*: PP, WF and additives are fed subsequently in the same weight percentage (50 wt%/50wt%).
- Injection moulding machine (Boston Matthews) in dumbbell shape. The barrel temperature was 185-190 ℃.

The WF content in the composites was 50 wt% and 55 wt% with 2 – 3 wt% additives. *Table 1* summarises the composites prepared. Directly after extrusion, the material coming out straight and hot was compression moulded into sheets of 3-4 mm thickness, at 20 ℃ for 2 min, under pressure of 0.7 MPa. Standard (EN ISO 14125, Class I) specimens were laser cut from the compression moulded sheets for flexural measurements.
Tensile tests specimens were prepared by above injection moulding process.

A – wood composites			**B- wood composites**		
Wood Fibre	**PP**	**Additives**	**Wood Fibre**	**PP**	**Additives**
50 wt%	48 wt%	2 wt%	50 wt%	48 wt%	2 wt%
55 wt%	43 wt%	2 wt%	55 wt%	43 wt%	2 wt%

Table 1. Weight percentage of the constituents.

2.4 Tensile and flexural test

The determination of the tensile properties of wood reinforced plastics in the form of standard dumbbell – shaped test specimen was done in accordance with EN ISO 527 – 4 [8].
The determination of the flexural properties under 3-point bending applied to a simply supported beam was done in accordance with EN ISO 14125 [9].
Tensile and flexural properties of the WF/PP composites were measured on a universal testing machine (Testometric M500-100CT), equipped with a loadcell of 100 kN. The specimens were conditioned for 24 h at 23 ± 2 °C before testing. The statistical average of the measurements of at least 5 specimens was taken to obtain a reliable average and standard deviation. The coefficients of variation for the mechanical properties are around 10 %. The tensile and flexural strength loads were measured at 5 and 2 mm/min testing speed, respectively.

3. RESULTS

3.1 Tensile properties

The introduction of 50 wt% and 55 wt% wood fibre in the PP matrix increased the tensile modulus of 54% and 70% respectively, compared to the pure PP (*Fig. 3*). In terms of tensile modulus, the composites filled with A-wood and B-wood fibres (in the same ratio) have similar values, considering the error margins. In addition, the introduction of the wood fibres reduced the tensile strength of 25% compared to the unfilled polypropylene: the fibre loading likely lead to dry spots, that can reduce the strength (*Fig. 3*).

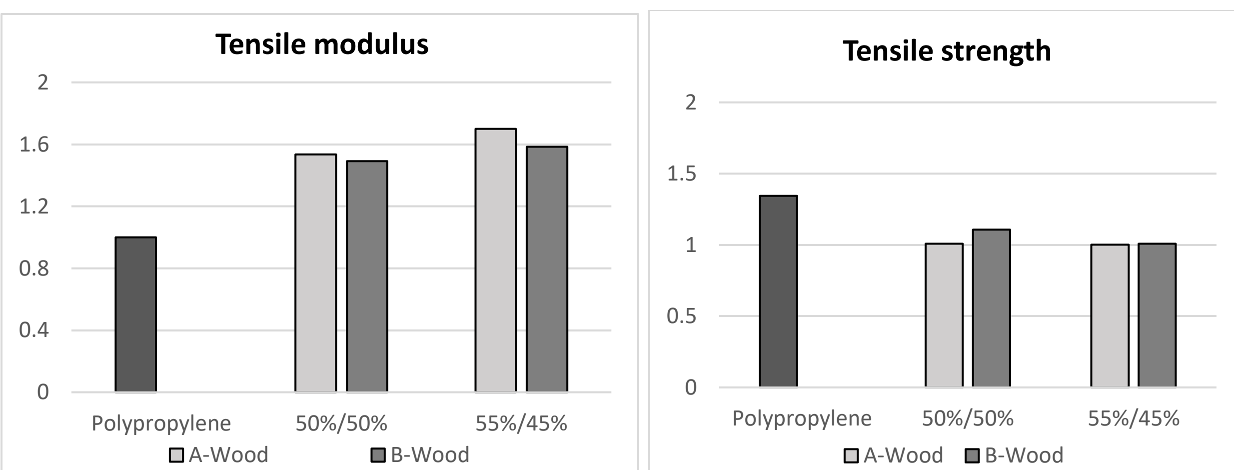
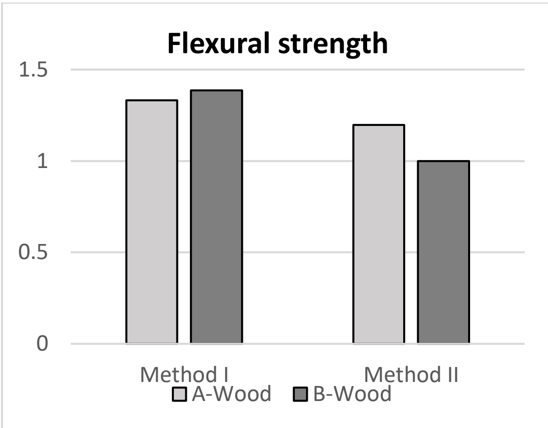


Figure 3. Tensile properties of wood fibre composites. The values are normalized with respect to the tensile modulus and strength of the matrix (PP).

3.2 Flexural properties

The effect of mixing (*Method I* and *Method II)* is studied by comparing the bending modulus of both types flexural specimens.



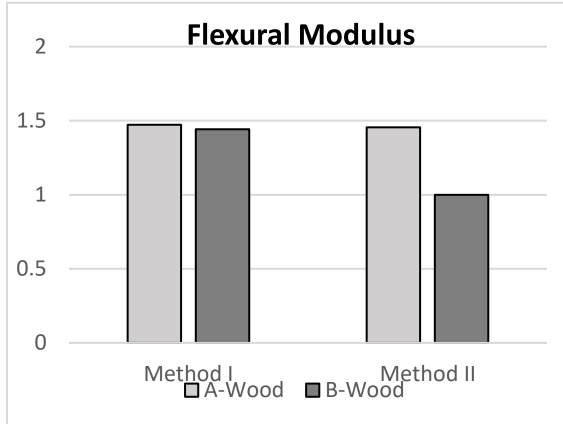
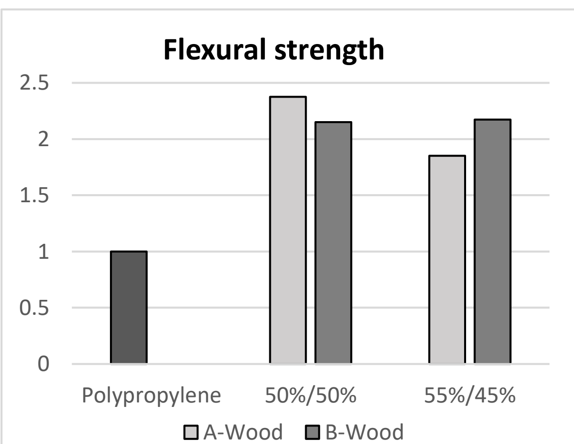


Figure 4. Effect of mixing on the flexural properties of wood fibre composites. The values are normalized with respect to the smaller value.

Results show that A-wood and B-wood flexural moduli and flexural strengths are comparable, using *Method I*; A-wood performs better, if *Method II* is applied. In general, *Method I* results in better mechanical properties (both flexural strength and flexural modulus) than *Method II*.
Thus, the 3-point bending specimens were prepared using Method I. The introduction of 50 wt% and 55 wt% wood fibre in the PP matrix increased the flexural modulus by a factor of 4 and 5 respectively, compared to the pure PP (*Fig. 5*). In general, in terms of flexural modulus, A-wood and B-wood composites have similar values and increasing the amount of fibre wt%, the stiffness of the composite increases. This is indicative of good mixing and interfacial adhesion between the fibres and the matrix by using proper additives.
Also, the mechanical test results how that the values of the flexural strength of the wood composites are higher than those of the matrix (PP), as expected.



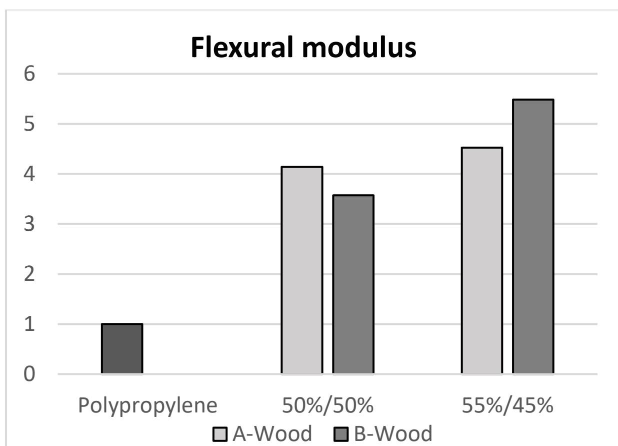


Figure 5. Flexural properties of wood fibre composites. The values are normalized with respect to the flexural modulus and strength of the matrix (PP).

4. CONCLUSIONS

The current research shows that processing of recycled wood composites (both grade A and grade B) is feasible with different processing methods, i.e., injection moulding and extrusion: wood products can be re-used in a sustainable way to lower impacts on climate change and avoid incineration.
In addition, suitable mixing methods have been determined: the fibre content has shown a significant effect on the mechanical properties of the processed wood fibre composites (composites filled with 55 wt% mechanically perform better than the composites filled with 50 wt% of fibres). Tensile and flexural moduli increased the value with respect to the unreinforced material.
Overall, when appropriate processing methods are used, only small differences are found between A- and B-wood composites. This underlines the possibility of using B-wood as a suitable material for wood fibre composites.

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