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Properties of an industrial extruded HDPE-WPC: The effect of the size distribution of wood flour particles

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HIGHLIGHTS

- WPC performance depends on the particles size distribution of the wood floor.
- Finer wood floor improves the mechanical performances in the transverse direction.
- Broader wood floor improves the mechanical performances in the extrusion direction.

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ABSTRACT

This work aims understanding the influence of the size distribution of wood flour particles on the physical and mechanical properties of an extruded wood plastic composite (WPC). A industrial-scaled process has been tested for both the wood flour production and the composite forming. Three size distributions of wood flour have been produced from the same batch of wood chips. The analyses of the particle size and form for the three wood flours were carried out by sieve column and by image analysis, revealing the limits of sieving in the case of particles with a high aspect ratio. The present study investigates the influence of the wood flour size distribution on the tensile and flexural behavior of WPC. The Charpy impact behavior of HDPE-WPC is also studied. In addition to the industrial process, the originality of this work lies in relating the microstructure to the mechanical performances of the extruded WPC; especially the orientation of the wood particles that differs according to the size distribution of the wood flour used. In general, mechanical performances of composites are improved by adding large particles. However, in the transverse direction to the extrusion, fine wood flour allows better performances.

1. Introduction

The use of wood plastic composites (WPC) has grown over the last few years. There are many advantages of associating polymer and wood. The polymer matrix reduces the water uptake of the wood. It creates greater durability, in particular preventing the development of mold and rot [1]. On the other hand, the wood flour acts as a filler and improves the elastic modulus and the flexural strength of the composite [2]. However, the mechanical performances of WPC differ from those of wood. For example, even if the flexural strengths of both WPC and wood are close, the elastic properties of wood are four times higher. This statement is based on the comparison of data from [2,3].

The mechanical properties of WPC depend on the interface between the wood particles and the polymer matrix. Different methods have been developed to improve the adhesions between wood particles and polymer and then to improve the macroscopic mechanical behavior of the composites. For example, the use of maleic anhydride grafted onto the polymer has been shown to be efficient to improve the mechanical strength of the composites [4–8]. Also, other methods have been developed to improve the wood – polymer affinity [9–12]. Those chemical methods increase the chemical affinity by the addition of a bonding agent between the wood and polymer. Another way to improve the mechanical behavior of the composites is to use wood treatment such as mercerizing [13,14] and corona and plasma treatments [15–17]. Those treatments allow to chemically modify the wood surface and to improve the wood-matrix interface. However, these methods are difficult to industrialize due to their cost and additional induced processing.

The wood particles size distribution is important for the properties of WPC. The effect of wood particles size distribution has been already discussed in many works [2,4,18–32].

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However, the conclusions of these different studies conflict. Using injection-molding, Julson et al. [18] did not observe significant changes of mechanical properties with fiber lengths while others have shown significant improvement of the mechanical performance with increased fiber lengths [2,19–21]. Some of these studies advise an optimum fiber length in order to obtain the best mechanical properties [24–26,33]. Stark and Berger [24] observed an optimum fiber length of 250 μm within a range of 50–600 μm. Other studies deal with the geometry of the wood particles. They showed that the length-to-diameter L/D (often called aspect ratio) is a decisive factor that influences more the mechanical performances than the particles length [2,21,26,34,35]: A high aspect ratio of the wood flour induces a higher performance of the composite.

Also, it appears that the damage of the wood fiber induced by the grinding process [22] and WPC forming process impacts the composite mechanical behavior [4,23].

Wood flour is the most common natural fiber used in industry; it can be produced from post-industrial sources such as sawmill chips. Stark and Rowlands [2] demonstrated that commercial pine flour particles have L/D ratios ranging from 3.3 to 4.5. The mesh size is conventionally used to characterize the wood flour distribution. Commercial wood flours have a broad size distribution because screening out fines to narrow the particle size distribution raises the costs. In this context, it was decided to investigate the broad distribution sizes of wood flour, which are more representative of their use in industrial production; this differs from many other studies in which only some size classes of wood particles are chosen [19–21,24,28,33]. In addition, all wood flours studied have a common portion in their size distributions that are the finest particles, similar to dust.

The aim of this study is to investigate the effect of a range of industrial wood flour on the mechanical properties of an extruded HDPE-WPC. The specificity of this work is that a single batch of wood was used to produce the different wood flour size ranges and all the processes were carried out on industrial machines. The aspect ratios were measured by image analysis. The quasi-static mechanical behavior of the composite was characterized both in the extrusion direction and in the transverse direction, to evaluate the mechanical anisotropy and the flour range influence on this anisotropy. Charpy tests were also carried out to question the influence of flour size distribution and granular shape on the composite impact strength.

2. Materials and methods

2.1. Materials

2.1.1. Wood flour (WF)

Three wood flours have been produced from the same batch of wood chips, composed of a mixture of *Pinus pinaster* and *Picea sitchensis*, from a sawmill production residue. The final particle size distributions of the wood flours ranges from 0 to 200 μm, 0 to 500 μm and 0 to 800 μm. The chips were reduced in size by a hammer-mill using a 1 mm screen. At the mill outlet, an industrial sieve separated wood particles as its mesh size. Three sieve sizes of respectively 800 μm, 500 μm and 200 μm were used to produce wood flours whose particle sizes are smaller than these three values. Wood particles that were too coarse were transported back to the industrial mill for a further milling-sieving cycle. The three batches of wood flour are denoted WF200, WF500 and WF800.

2.1.2. High density polyethylene (HDPE)

High density polyethylene (HDPE), Marlex HHM 5502BN, was provided by the Chevron Philips Chemical Company LP. Its density at room temperature was 0.955 g/cm^3 and its melting flow rate was 0.35 g/10 min (ISO1133 – 190 °C/2.16 kg).

2.1.3. Wood flour/HDPE composites (WPC)

A unique formulation of WPC was produced. This formulation has been tried and tested over many years and is known to have a useful life of more than 10 years under outdoor conditions. The WFs were oven-dried at 95 °C to reduce their moisture content to less than 5%. According to a predetermined formulation (35 wt% HDPE, 55 wt% WF, 5 wt% mineral particles and 5 wt% of other additives and constituents such as residual water, coloring agent and lubricant), the components were mixed in a low-speed mixer. After a drying step, the mixture was fed into an industrial twin-screw extruder (Battenfeld-Cincinatti) and extruded into full profile real decking of 138 × 23 mm^2 cross section at the extrusion temperature of 200 °C. Then, a water jet at 25 °C around its section cooled the extruded decking.

2.2. Mechanical tests

2.2.1. Flexural strength measurements

3-point bending tests were performed on the entire decking using a tensile testing machine (Shimadzu EZ tensile tester with a maximal load of 20 kN). The span was 350 mm and the load speed was 10 mm/min. The tests were performed on 10 samples from each composite at 20 °C.

2.2.2. Tensile tests and Charpy impact measurements

Tensile tests were performed at a test speed of 2 mm/min according to EN ISO 527 on a MTS Synergie RT1000 machine. The specimens were prepared using a digitally controlled milling machine into a dumbbell-shape specimen with overall dimensions of 90 × 10 × 4 mm^3 (Fig. 1). Samples were taken from the center of the surfaces of the extruded profiles. Tensile tests were carried out on 10 different specimens for each wood flour type. The Charpy impact strength was determined by testing 12 unnotched specimens per composite according to EN ISO 179 using a Tinius Olsen Impact 503 pendulum. The tensile and impact specimens were cut both in the extrusion direction, called Machine Direction (MD) and in the transverse direction (TD).

2.3. Water absorption and density measurements

Water absorption was measured by weighing after immersion of the WPC samples in water for 24 h at temperatures of respectively 20 °C and 60 °C. The results correspond to an average value using 10 samples of dimensions 100 × 138 × 23 mm^3. WPC densities were measured according to EN ISO 1183 (immersion method), using a density balance on 15 samples to obtain an average value and low standard deviations. The samples were cut with a saw in the following dimensions: 23 × 20 × 20 mm^3.

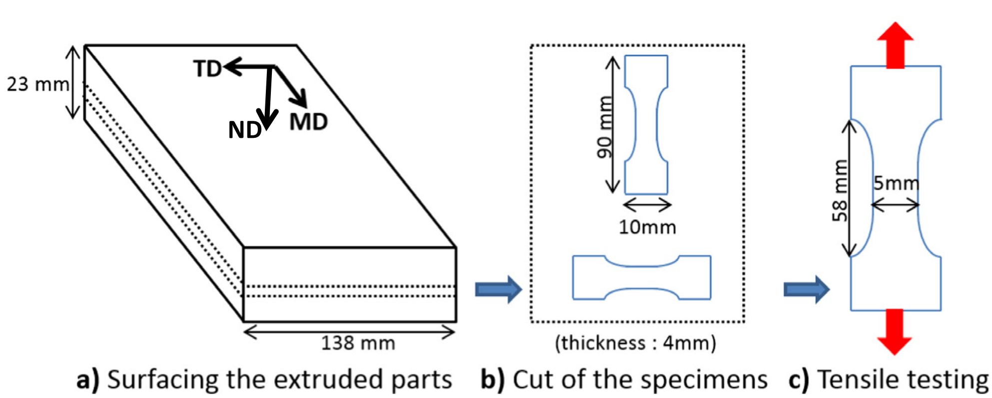

Fig. 1. Manufacturing steps of tensile specimen type 1BA (EN ISO 527).