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Improved filler–matrix interfaces in environmentally friendly polymeric composites

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Wood-plastic composites can be optimized with the addition of waste paper fibers, coupling agents, and bioderived polymers.

Over the last few decades, environmental protection has become an important worldwide issue, especially with regards to plastic waste.[1] To reduce the detrimental impact of plastics, the use of polymeric matrix composites filled with natural waste products is becoming increasingly popular because of their potential recyclability and the chance to use waste materials in their production.[2] For example, wood-plastic composites (WPCs) can be used as a substitute for virgin wood in many applications (including automotive and nautical applications, as well as the construction of windows, door frames, and outdoor furniture). The amount of solid waste produced from the paper industry can also potentially be reduced by using waste paper as a filler in thermoplastic matrices.[3] The difference in the polarity of the natural fillers (polar) and polymer matrices (non-polar) of these composites, however, can be problematic.[4]

It has previously been demonstrated that differences in the hydrophilicity of natural fillers and a polymeric matrix gives rise to weak interfaces between the two. In addition, stronger fiber–fiber interactions than fiber–matrix interactions mean that it is difficult to achieve good dispersion of the fillers within the matrix. All together, the poor fiber distribution and weak fiber–matrix interfaces cause the composites to have weak mechanical properties.[4–6]

In our work we therefore investigated a new approach to obtain improved fiber–matrix interactions in WPCs.[7] In particular, we worked with fibers of recycled waste paper and of wood flour, and with a high-density polyethylene (HDPE) matrix (Eraclene MP90 from ENI Versalis). We also chose a starch-derived polymer matrix (Bioplast 500 from Biotec, Germany) as an additive to introduce a bioderived charge (i.e., to reduce the amount of non-recyclable charges required). In addition, we have adopted a number of steps to improve the fiber–matrix interfaces and the mechanical properties of the composites. For instance, we used a turbomixing process to improve the dispersion of the fillers,

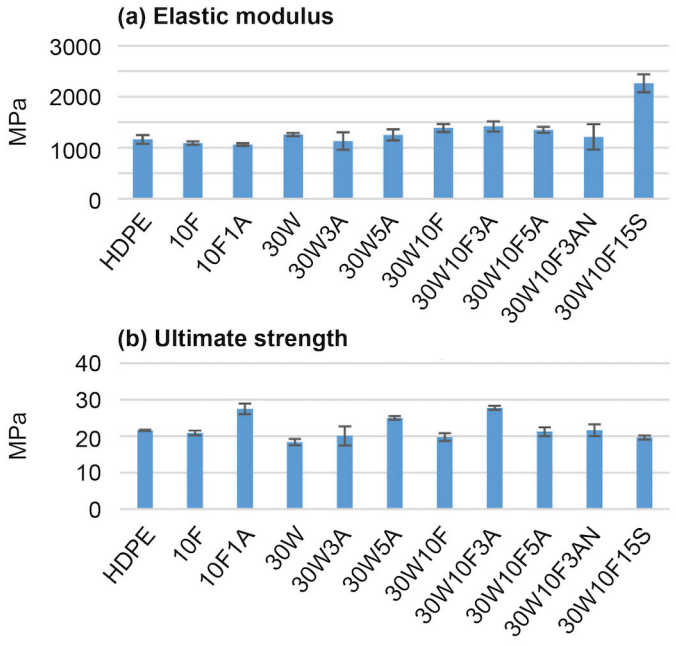

Figure 1. *The measured (a) elastic modulus and (b) ultimate strength of the 11 composite samples (listed in Table 1).*

we grafted maleic anhydride onto polyethylene (MAPE) to use as a compatibilizer,[8] and we soaked the fillers in sodium hydroxide, NaOH (a mercerization treatment).[9]

The composite samples we produced with the turbomixer are listed in Table 1. These materials include the hardwood beech wood flour fibers (with diameters of less than 0.8mm), which we obtained from La.So.Le East (Italy), and the micronized waste paper fibers (with diameters of 15–20μm and lengths of 200–250μm) in concentrations of up to 30%. After melting and compression molding, we performed a variety of tests on the samples. These measurements included tensile strength tests, scanning electron microscopy (SEM), as well as water absorption and hardness tests.

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The results of our tensile strength, ultimate strength, and water absorption tests are shown in Figure 1 and Figure 2. Our results for the 30W10F samples are evidence for a synergistic effect and good interactions between the two morphologically different filler types (i.e., this sample exhibited improved elastic modulus and superficial hardness, as well as reduced mass variation and softening with increased temperature). Furthermore, all our tests—including our SEM images (see Figure 3)—confirmed the positive effect of including MAPE in the composites (and indicated its optimum concentration).

Table 1. *Constituents of the 11 composite samples (produced through turbomixing). All the samples had a high-density polyethylene (HDPE) matrix and included fibers of recycled waste paper (fibers) and/or wood flour (wood). Maleic anhydride polyethene (MAPE) was used as a compatibilizer for some samples. The fillers for the 30W10F3AN sample were treated with sodium hydroxide (NaOH) and the 30W10F15S sample included a starch-derived polymer matrix (Bioplast)/HDPE blended matrix.*

	Wood (%)	Fibers (%)	MAPE (%)	Bioplast (%)	NaOH
HDPE	0	0	0	0	-
10F	0	10	0	0	-
10F1A	0	10	1	0	-
30W	30	0	0	0	-
30W3A	30	0	3	0	-
30W5A	30	0	5	0	-
30W10F	30	10	0	0	-
30W10F3A	30	10	3	0	-
30W10F5A	30	10	5	0	-
30W10F3AN	30	10	3	0	×
30W10F15S	30	10	0	15	-

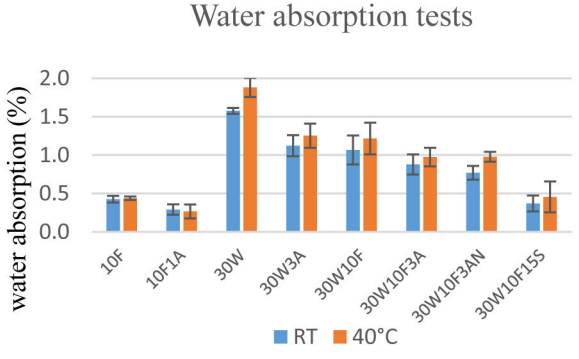

Figure 2. *Results of water absorption tests conducted on a number of the composite samples. The tests were performed at both room temperature (RT) and at 40°C*

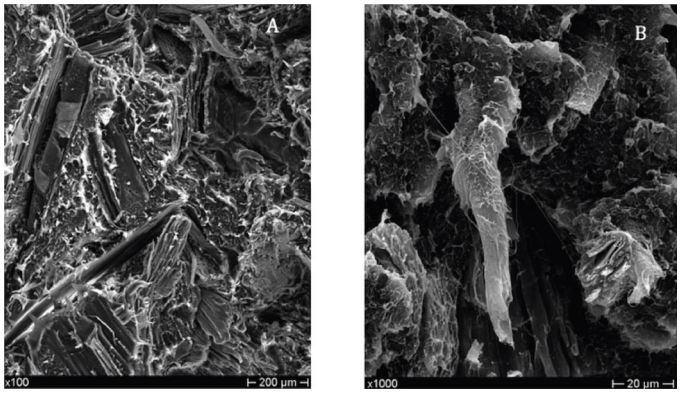

Figure 3. *Scanning electron microscope images showing (A) the weak interfaces between both wood particles and recycled paper fibers and the HDPE matrix, and (B) the improved fiber–matrix interfaces in the 30W10F3A sample (i.e., upon addition of MAPE).*

We also found that addition of the starch-derived polymer caused a significant improvement in the elastic modulus of the samples. In contrast, the addition of the Bioplast caused a reduction in ultimate strength. We attribute this result to matrix heterogeneity, as a result of the thermoplastic blend. In addition, the SEM images confirmed that our NaOH treatment was too severe for the recycled cellulosic fibers we used in this study (i.e., caused chemical damage). The best overall results we obtained were for the 30W10F3A sample.

In summary, we have successfully used a turbomixing process to introduce two different types of cellulosic fibers into WPCs and have achieved improved fiber–matrix interactions. The encouraging nature of our results so far have thus opened up a number of prospects for future improvements. For example, we would like to make modifications to the fiber–matrix interfaces and to improve the overall performance of the composites. Moreover, to reduce the damage caused by chemical treatments, we will investigate different NaOH procedures (i.e., to find optimum soaking times and soda concentrations). We also plan to focus on the addition of different bioderived polymers and optimize the resulting thermoplastic blend.

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