THE EFFECT OF WOOD FLOUR FRACTION SIZE ON THE PROPERTIES OF WOOD-PLASTIC COMPOSITES


Abstract: Wood-plastic composites are developing way of thought, sustainable and efficient. Most important question is how to enable recycling and to extend life-cycle of products. Plastic waste has long decomposition cycle. Wood particles in plastic matrix absorb water and enable more rapid decomposition. In this study different fractions of wood flour made from alder (Alnus) chips were used in composites with polypropylene and linear low-density polyethylene. Mechanical properties of composites were tested and additionally industrial experiments were carried out with the same mixture. Injection moulded forks were prepared and mechanical tests were performed.

Key words: disintegrator, binding agent, mechanical properties, composites.

1. INTRODUCTION

Wood plastic composites (WPC) are composite materials that consist of either wood fibers or wood flour and different thermoplastic polymer matrix. Wood plastic composites are the materials that combine the best performance and cost properties of both wood and thermoplastics. These composites are gathering bigger market share with every year because of their favorable properties, such as lower cost, improved stiffness, lower density, lower abrasiveness and better process ability compared to other fillers, for example inorganic fibers. \(^{[1-3]}\)

Wood plastic composites mechanical properties depend on the properties of their components and the ratio of these components. Wood component properties are affected largely by wood particle size. Previous studies have investigated wood particle size effects on WPC mechanical properties. These studies have examined the effects of small wood particles or fibers. The results of these studies showed that wood particle size influence on WPC mechanical properties was substantial. However, some studies showed that there was only slight effect to the WPC mechanical properties. Majority of the tested WPCs showed that increasing the wood fraction size also increases WPC mechanical properties. However, some of the tested WPCs, showed the reverse effect. \(^{[2-3]}\)

It is difficult to give general explanations because there are many factors that are influencing the test results in these studies. For example, thermoplastic type, wood content, wood particle geometry, coupling agent type and content, and processing method influenced the results of the these studies. In conclusion, based on the previous studies, the influence of the wood particle size on WPC mechanical properties is not completely evident. More studies are needed to understand wood particle size importance on WPCs. Wood particle dimensions can influence the strength properties in wood fiber based products. \(^{[4]}\) Small wood particles (wood flour) are often used for manufacturing commercial WPCs. It is due that small particles are easy to use with manufacturing equipment. Small particles can be integrated easily into the process.
However, low length to diameter ratio can cause stress concentrations and therefore strength of the WPC is reduced lower than pure polymer. \(^{5-6}\) Some reports have stated, that when WPCs are formed with injection molding the using of longer wood fibers also increases the mechanical properties of WPCs. \(^{7-8}\) Very few studies have shown beneficial influence of fiber length on mechanical properties when extrusion method was used. Other studies have stated that there was slight to none influence on mechanical properties. Therefore the effect of wood particle size on WPC strength properties varies with composites forming process. There are very few studies yet that explain the wood fiber size and their influence on the mechanical properties of WPC. \(^{9-12}\)

The objective of this study was therefore to investigate the influence of wood component size to the WPC structure and mechanical properties. Three different wood particle sizes was used to find out what is the optimal wood particle size to be used in WPCs. Bending tests were done to investigate mechanical properties of WPCs. Also industrial products of WPCs were tested to investigate the influence of wood component size in industrially made forks of WPC.

2. MATERIALS AND METHODS

2.1 Wood particles

Alder chips were used as wood raw material for manufacturing WPCs. Wood chips were brought from sawmill and chips were undried and there were different sizes of wood particles: very small (smaller than 1 mm) and too big (ca 8 mm) particles. The moisture content of undried wood chips was 32 wt.%. The wood chips were dried in oven at 50 °C for 24 h. Then wood chips were mechanically refined with disintegrator DS – A into three fiber length classes. Particle length and distribution were measured using analytical sieve shaker method with Fritsch Analysette 3. Used sieve sizes were from 25 to 0.025 mm. Dimensions were measured and particle bulk density was also determined. Screening of the particles into three fiber length classes was done with screening mechanism SM-1.

The basic process consists of several steps:
- The material is placed from batcher to the boot.
- The material from the boot is sprinkled in different sieve sets.
- A large fraction is separated from the first sieve where then material goes into the collector.
- The rest of the small particle size fractions go to the sieves according to the particle size sieves.
- The process lasts until there are no more small particles in the bottom of the mechanism.

Three particle sizes were experimentally obtained, details are show in Table 1.

2.2 Polymers

For composite preparation pelletized polypropylene (PP) from Borealis Polymers and linear low-density polyethylene (LLDPE) Icorene 2550 were used. Polyethylene (PE) with maleic anhydride MAH was DuPont Fusabond M603 12% MAH and PE copolymer. Most important properties of polymers are shown in Table 2.
2.3 Binding agents
For improving the adhesion between matrix and filler three different binding agent were used: triethoxyvinylsilane (TEVS), polyvinyl alcohol (PVA) and MAH. MAH was derivatised with PE pellets, DuPont Fusabond M603 12% MAH and polyethylene copolymer was used. TEVS and PVA were added to wood flour. TEVS was mixed with ethanol-water 9:1 solution and sprayed over wood flour while mixing thoroughly. After mixing wood flour was kept at room temperature for 2h and then dried in oven at 110 °C. From PVA a water solution was made and sprayed over wood flour while mixing thoroughly. After mixing wood flour was dried in oven at 110 °C.

2.4 Preparation of test specimens
All test specimens contained 65% polymer and 35% wood flour (WF). Properties of WPCs are shown in Table 3. Polymer and wood flour coupling agents amounts are weight% from wood flour. Wood flour and polymer were compounded in twin-screw extruder Brabender Plasti-Conder PLE 651 at 190 °C and 70-80 rpm. Test specimens for bending testing were made according to ISO 178:2003. Injection moulding was done at Battenfeld BA 230 E device. Test specimen measurements were 60x10x4mm, cross-section area was 40 mm².

2.5 Bending testing
Three-point bending tests were carried out according to ISO 178:2003. For testing Instron 5866 tensile tester was used, testing temperature was 20 °C, test span 60 mm and speed 20 mm/min. From every mixture 10 test specimens were used.

3. RESULTS AND DISCUSSION
3.1 Mechanical testing
The results from the mechanical testing are shown in Table 4. Results show that the addition of wood flour makes the material more brittle - a deflection of test pieces was largest with pure polymers. From Table 3 and 4 it can be seen that the chemical pre-treatment affected the flexural properties positively: the composites with pretreated wood chips had better bending strength values than composites with untreated wood chips.

Table 3. Properties of compounds

<table>
<thead>
<tr>
<th>Sample</th>
<th>Polymer</th>
<th>Polymer coupling agent</th>
<th>Polymer coupling agent, wt%</th>
<th>WF fraction</th>
<th>WF coupling agent</th>
<th>WF coupling agent, wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>II</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>PP</td>
<td>MA</td>
<td>5</td>
<td>III TEVS</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>PP</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>LLDPE</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>LLDPE</td>
<td>-</td>
<td>-</td>
<td>II</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>LLDPE</td>
<td>MA</td>
<td>5</td>
<td>II</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>LLDPE</td>
<td>MA</td>
<td>0.6</td>
<td>I TEVS</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>LLDPE</td>
<td>-</td>
<td>-</td>
<td>I PVA</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4. Results from mechanical testing

<table>
<thead>
<tr>
<th>Sample</th>
<th>Deflection (mm)</th>
<th>Bending strength (MPa)</th>
<th>Deformation (%)</th>
<th>Modulus of elasticity (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.5</td>
<td>33.0</td>
<td>7.7</td>
<td>4.3</td>
</tr>
<tr>
<td>2</td>
<td>5.0</td>
<td>32.0</td>
<td>3.4</td>
<td>9.5</td>
</tr>
<tr>
<td>3</td>
<td>8.0</td>
<td>34.1</td>
<td>5.3</td>
<td>6.4</td>
</tr>
<tr>
<td>4</td>
<td>6.3</td>
<td>37.2</td>
<td>4.2</td>
<td>8.9</td>
</tr>
<tr>
<td>5</td>
<td>16.7</td>
<td>8.8</td>
<td>11.1</td>
<td>0.8</td>
</tr>
<tr>
<td>6</td>
<td>10.7</td>
<td>20.4</td>
<td>7.1</td>
<td>2.9</td>
</tr>
<tr>
<td>7</td>
<td>12.6</td>
<td>22.9</td>
<td>8.4</td>
<td>2.7</td>
</tr>
<tr>
<td>8</td>
<td>12.4</td>
<td>20.7</td>
<td>8.3</td>
<td>2.5</td>
</tr>
<tr>
<td>9</td>
<td>10.3</td>
<td>16.4</td>
<td>6.9</td>
<td>2.4</td>
</tr>
</tbody>
</table>
It is a noticeable increase in the bending strength of PP without additives transition to PP composite with additives, from 33.0 (pure PP) to 37.2 MPa (PP+WF+PVA). In a view of bending strength and influence of additives, the wood flour processed with polyvinyl alcohol gives WPC the best physical resistance values. However, test results for specimens based on PP also showed that flexural properties increase gradually with increasing particle size from wood flour (less than 0.63 mm) to fraction (0.63-1.25 mm). These results correlate with other studies from the literature which show that increasing the fiber length and L/D ratio also increases the bending strength values. [13-15, 17] This can be explained as the fine powder acts more like a filler but larger wood particles show some mechanical strength and by choosing the right coupling agent the adhesion between filler and matrix is very good. For the PE, best adhesion is achieved by adding maleic anhydride. Adding maleic anhydride gives WPCs good strength values as shown in Table 4. (PE+WF bending strength is 20.4 MPa compared to PE+WF+MA is 22.9 MPa) and also composites have smooth surface, material is tough and well workable. Compared to pure LLDPE samples the bending strength of composites is more than twice higher. Comparing the bending results with other study [17] we see the difference in results: flexural strength differs in 8-24 % and modulus of elasticity differs in 47-79 % [13, 17]. Variation of the results may be due differences in dimensions of the test specimens, various polymers, using different manufacturing technologies and equipment and using different wood species. Also results from the other studies have been revised with series of experiments and test conditions were different from this work. WPCs are anisotropic materials and therefore large differences may occur in test results. [16, 18-19]

3.2 Industrial product testing
Forks were made with injection molding technology in the production test to explore the products made from low quality waste wood filler for use in the manufacture of the WPC product. The other interest was also to find out what fraction of wood particles is best to carry out injection molding technology experiments and compare the bending strength properties. Forks were made of WPC using PP as matrix polymer in granule form and same wood flour made from Alder wood chips as filler material in laboratory tests. Composites were prepared with wood flour and polymer ratio of 1:1. Four different mixtures were used to prepare test forks for bending testing. Bending testing of PP+WF composites was performed with three-point bending test using an Instron 5866 machine. A minimum of 3 specimens of each material were tested. Impact properties of the prepared composites were measured with a falling weight impact testing machine with the crosshead speed of 10 mm/min. Forks made of WPC were tested to analyze if the forks made of WPC are competitive with pure PP forks, because the addition of wood flour can provide the cost reduction and combination of properties. To obtain high performance PP+WF composites, the influence of wood flour content on mechanical properties was investigated. Table 5 shows the effect of wood flour content on the mechanical properties of forks made of WPC. Based on the results in Table 5, it is evident that flexural strength values of PP+WF composites are lower than those of pure PP which decrease with increased WF size. This may simply show that there is a poor interfacial interaction between reinforcing wood particles and polymer matrix because of the poor stress transformation across interphase. Another reason can be the design of a fork. Compared to laboratory test specimens which were made according to standard and have rectangular cross section the
<table>
<thead>
<tr>
<th>Sample</th>
<th>Distance between supports (mm)</th>
<th>Crosshead speed (mm/min)</th>
<th>Flexural strength (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure PP</td>
<td>32.00</td>
<td>10.00</td>
<td>40.1</td>
</tr>
<tr>
<td>PP+WF fr.III</td>
<td>32.00</td>
<td>10.00</td>
<td>37.32</td>
</tr>
<tr>
<td>PP+WF fr.II</td>
<td>32.00</td>
<td>10.00</td>
<td>35.4</td>
</tr>
<tr>
<td>PP+WF fr.I</td>
<td>32.00</td>
<td>10.00</td>
<td>32.61</td>
</tr>
</tbody>
</table>

Table 5. The effect of wood flour content on the mechanical properties.

Forks have much thinner and more complicated cross section. This may explain why in forks the best results after pure PP were with finest wood flour. External inspection revealed that failures occurred near the location of the wood particle as the particles were mainly parallel next to each other and perpendicular to the longitudinal axis of the fork stem. Tests showed that in these places were also fractures of bending forces.

4. CONCLUSION

In conclusion it can be said that alder wood is worth considering as source for wood fibers and particles for using in WPC. Most important is choosing the right binding agents as wood fibers are not compatible with polymers. Another important result of this study was that mixtures that gave good result in laboratory test were not working in industrial experiments as the design and area of a cross-section seem to have important role. With right ratios, particle size and processing parameters wood flour can be used in producing commodity products like forks and spoons and thus enabling faster degradation.

5. REFERENCES


