WOOD/POLYPROPYLENE COMPOSITES WITH IMPROVED PERFORMANCE

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1 Introduction

In recent years, thermoplastics reinforced with various natural fillers have received considerable attention because they have several advantages. Wood plastic composites (WPCs) have lightweight, low cost, reasonable strength and stiffness, high filling levels, recyclability, biodegradability, renewable nature, and flexibility during the processing with no harm to the processing equipment. Moreover, WPCs can be readily processed by conventional plastic processing techniques such as extrusion, injection and compression molding. In addition, surface appearances can be controlled by adding different wood species and pigments. The most common thermoplastics used in WPCs are high and low density polyethylene (HDPE and LDPE), poly(vinyl chloride) (PVC), and polypropylene (PP).

When non-polar PP was used as a matrix for WPCs, the incompatibility between the polymer and hydrophilic wood fillers has been a big problem, and there have been many studies on improving interfacial interactions between the polymer and wood fillers. According to the previous studies, the best solution to the problem was using a proper coupling agent such as maleic anhydride functionalized polypropylene (MAPP). MAPP could bridge the interface and improve the stress transfer between the polymer matrix and wood fillers at low concentrations.

Polymer/clay nanocomposites are a new class of polymeric materials that show improved properties at very low loading levels of a nanosize filler. The improved properties include mechanical, dimensional and thermal stability and flame retardancy. It has been suggested that the presence of clay in a polymer matrix can enhance the char formation providing a transient protective barrier and hence slowing down the degradation of the matrix. Therefore, it was considered that a WPC with a polymer/clay nanocomposite matrix would improve the performance of the WPC. It was not easy to find previous studies on WPCs with a polymer nanocomposite matrix.

In this study, to improve the mechanical properties of wood/PP composites, nanoclay was incorporated. Furthermore, to improve chemically as well as physically the weathering resistance of the WPCs, the effect of adding different UV stabilizers as well as the effect of mechanical surface brushing with sandpaper on the color change of the WPCs was investigated. WPCs were prepared by melt-blending followed by compression molding, and their performance was investigated by UTM, izod impact tester, DMA, TMA, DSC, and TGA.

2 Experimental

2.1 Preparation of WPCs

Wood flour/PP/organoclay nanocomposites were compounded in a Haake Rheomix 600 equipped with a roller blades rotor at 170 °C, 60 rpm for 15 min. The organoclay was loaded when PP granules melted down enough to give a steady torque value. The WPC samples with the coupling agent of 0, 2, 3, and 5 wt% were denoted as W40P60, W40P58C2, W40P57C3, and W40P55C5 at a fixed wood content of 40 wt%, respectively, and the WPC sample with the organoclay 1 phr was denoted as W40P57C3M1. WPCs panels were prepared by compression molding in a Carver hydraulic hot press at 180 °C, 1000 psi for 6 min. Specimens for thermo-mechanical testing were prepared by tailoring the panels into desired sizes.

2.2 Mechanical tests

Tensile properties of the WPCs were measured using a universal testing machine (UTM, Lloyd LR-
30K, Hampshire, UK) with a 1 kN load cell according to ASTM D882 at a crosshead speed of 5 mm/min. Izod impact tests were performed with unnotched WPC specimens at room temperature using an impact tester (SJI-103, Sungjin Co., South Korea) according to ASTM D256.

2.3 Thermal analysis

TGA measurements for the WPCs were carried out using a thermo-gravimetric analyzer (SDT 2960, TA instruments, New Castle, DE, USA). Each TGA scan was performed under nitrogen purging from room temperature to 700 °C at a heating rate of 10 °C/min. Dynamic mechanical properties of the WPCs were measured using a dynamic mechanical analyzer (DMA 2980, TA instruments). The melting and glass transition as well as crystallinity of the WPCs were measured using a differential scanning calorimeter (DSC 2910, TA instruments) under nitrogen purging from -65 to 200 °C at a heating rate of 5 °C/min.

2.4 Weathering resistance

Weathering resistance of WPCs with different type and amount of UV stabilizers were tested using a UV chamber equipped with a high pressure mercury UV lamp (UV intensity = 1.76mW/cm²). Color changes of the WPCs after exposing them to UV light for 400 h were measured. The effect of mechanical surface brushing of the WPCs with sand paper on the weathering resistance was also investigated.

3 Results

3.1 Mechanical properties of the WPCs

MAPPs are widely used to enhance the compatibility between wood flour and PP matrix. Incorporating just a small amount of MAPP into a WPC system resulted in a drastic increase in the tensile properties and impact strength. Fig. 1 and Fig. 2 show the effect of loading the MAPP coupling agent and/or organoclay on the mechanical properties of the WPCs at a fixed wood content 40wt%. The mechanical properties of the WPCs increased with increasing the amount of the coupling agent. W40P55C5 showed almost the same mechanical properties as W40P57C3 even though it had 5 wt% of the coupling agent. Therefore, the coupling agent content of 3 wt% was considered an optimum value. Adding organoclay 1 phr was not effective in improving tensile properties of the WPCs.

These results are expected that the nanometer scale dispersion of silicate layer in a polymer matrix act as efficient nucleating agents and generally leads to improved modulus and strength because of the stiffness of the inorganic layers.

3.2 Thermal properties of the WPCs

To further understand the effect of loading the MAPP and/or organoclay TGA, DMA, DSC, and TMA were employed. The thermal degradation behavior of the WPCs was analyzed by TGA as shown in Fig. 3. All the WPCs decomposed in two decomposition steps.

![Fig. 1. Impact strength of the WPCs.](image1)

![Fig. 2. Tensile strength of the WPCs.](image2)
In terms of retarding thermal degradation, thermal stability of the W40P57C3M1 was slightly higher than that of the W40P57C3. It was expected that the presence of clay in a polymer could enhance the char formation providing a transient protective barrier and hence slowing down the degradation of the matrix. But W40P60 composite showed a little bit better thermal stability than the other WPCs. This result in the thermal stability could be attributed to the low thermal stability of the MAPP.

The storage modulus of the WPCs is shown in Fig. 4. The storage modulus of the W40P57C3M1 was higher than that of the other WPCs. This increase in modulus can be attributed to a uniform distribution and to a good interfacial adhesion between the clays and polymer matrix. Well dispersed clay particles with good interactions with polymer matrix can improve the modulus considerably because they constrain the segmental motions of the polymer chains. Consequently, it could contribute to better mechanical properties of the WPCs.

The crystallinity of the clay and MAPP filled WPCs was higher than that of PP and WPCs without MAPP. This result can be explained by the assumption that the silicate layers act as efficient nucleating agents for the crystallization of PP matrix. These results are presented in Table 1, which lists $T_m$, $\Delta H_f$, and $X_c$ for various WPCs. The specimens’ relative percentage of crystallinity ($X_c$) was calculated according to the following equation:

$$X_c = \frac{\Delta H_f}{{\Delta H_f}^0W} \times 100$$

Table 2. The thermal expansion coefficients and dimension change of the WPCs.

<table>
<thead>
<tr>
<th>Sample types</th>
<th>$\alpha_1$ [μm/m °C]</th>
<th>$\alpha_2$ [μm/m °C]</th>
<th>ΔL [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>W40P60</td>
<td>103</td>
<td>194</td>
<td>0.69</td>
</tr>
<tr>
<td>W40P57C3</td>
<td>69</td>
<td>156</td>
<td>0.59</td>
</tr>
<tr>
<td>W40P57C3M1</td>
<td>74</td>
<td>153</td>
<td>0.54</td>
</tr>
</tbody>
</table>

*Expansion coefficient measured at 50 °C

**Expansion coefficient measured at 100 °C

†Dimension change between 50 °C and 100 °C
Where, $\Delta H_f$ is the heat of fusion of the PP, MAPP, and various WPCs, $\Delta H_f^0$ is the heat of fusion for 100% crystalline PP ($\Delta H_f^0 = 138 \text{ J/g}$) and $\omega$ is the weight fraction of the PP in the WPCs.

Thermo-mechanical analysis measures linear or volumetric changes in the dimensions of a sample as a function of time, temperature and force. To obtain the thermal expansion coefficients ($\alpha$) under the uniform condition using a single point on the TMA curves, certain two temperatures were used. The thermal expansion coefficients and dimension changes of various WPCs are listed in Table 2. As shown in the table, the dimensional stability of the W40P57C3M1 was higher than that of the other WPCs because well dispersed clay particles with good interactions with polymer matrix can improve the interfacial adhesion considerably.

**Fig. 5.** Effect of surface brushing on the color changes of the wood/PP composites with different UV stabilizer contents.

### 3.3. Weathering resistance of the WPCs

The effects of UV stabilizer content and brushing can be found in Fig. 5. The addition of UV stabilizers improved the discoloration resistance of wood/PP composites even though the effect of increasing the content of UV stabilizer was negligible.

The surface brushing of the WPCs with sandpaper could improve the weathering resistance significantly as shown in Fig. 5. The surface brushing could remove PP rich thin skin layer as well as make the surface reflect most UV lights, and resulted in improving weathering resistance.

### 4 Conclusion

The maleic anhydride functionalized polypropylene was useful in increasing compatibility between the PP matrix and wood particles as well as improving the dispersion and exfoliation of nanoclay in the PP matrix, and resulted in improving the impact strength of the WPCs considerably. The nanoclay promoted the mechanical strength and dimensional stability. The interaction between well dispersed clay nanoparticles and the PP matrix could improve mechanical properties because they constrain the segmental motions of the polymer chains. The weathering resistance of the WPCs was slightly improved when both HALS and UV absorbing stabilizers were added. The mechanical surface brushing of the WPCs with sandpaper improved considerably the weathering resistance of the WPCs by reflecting most UV lights at the rougher surfaces.

### References