Effect of Oxidized Polypropylene as a New Compatibilizer on the Water Absorption and Mechanical Properties of Wood Flour–Polypropylene Composites

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ABSTRACT: The effect of oxidized polypropylene (OPP) as new compatibilizer on the water absorption and mechanical properties of wood flour–polypropylene (PP) composites were studied and compared with maleic anhydride grafted polypropylene (MAPP). The oxidation of PP was performed in the molten state in the presence of air. Wood flour, PP, and the compatibilizers (OPP and MAPP) were mixed in an internal mixer at temperature of 190°C. The amorphous composites removed from the mixer were then pressed into plates that had a nominal thickness of 2 mm and nominal dimensions of 15×15 cm^2 with a laboratory hydraulic hot press at 190°C. Physical and mechanical tests showed that the wood flour–PP composites with OPP exhibited higher flexural and impact properties but lower water absorption than MAPP. All of the composites with 2% compatibilizers (OPP and MAPP) gave higher flexural and impact properties and lower water absorption compared to those with 4% compatibilizers. J Appl Polym Sci 119: 438–442, 2011

Key words: composites; mechanical properties; poly(propylene) (PP)

INTRODUCTION

The incompatibility of hydrophilic wood filler and the hydrophobic polypropylene (PP) matrix is the principle problem in wood–PP composites, which have poor properties (mechanical strength and moisture absorption). To overcome this problem, extensive research has been carried out to improve the interfacial adhesion in wood-filled PP.[1–7] Among all of the studies, maleic anhydride grafted polypropylene (MAPP) has been well established as a compatibilizer for wood–PP composites.[1,6,8–10] MAPP improves the interfacial bonding between the polymer and wood; this improves the physical and mechanical properties of the wood–polymer composites. The addition of MAPP increases the tensile, flexural, and impact strengths and decreases the water absorption and thickness swelling of the wood–PP composites. The chemical structure and molecular weight of MAPP have important impacts on the mechanical properties of the resulting composites.[11,12]

Although most researchers have noted that MAPP gives the best adhesion between wood and thermoplastic, finding new compatibilizers that improve the interfacial adhesion as well as MAPP and can be used at lower cost and content is one of the major tasks of researchers.

Oxidized polyolefins as compatibilizers have been used in some polymer blends in very limited studies. Abdouss et al.[13] used oxidized polypropylene (OPP) as a compatibilizer between nonpolar PP and nonpolar talc and polar polyamide. The results show that the addition of OPP modified the properties of PP/talc and PP/polyamide blends. The use of oxidized polyethylene (OPE) with different molecular weights and acid numbers in low-density polyethylene/organo–clay nanocomposite preparation was examined by Durmus et al.[14] It was found that low-molecular-weight OPE created a strong interfacial interaction between the clay layers and polyethylene chains.

Only one study has been published on the effects of oxidized polyolefins as interfacial agents in wood–plastic composites. Lu et al.[15] used OPE as a coupling agent in wood fiber/high-density polyethylene composites and concluded that maleic anhydride grafted polyethylene (MAPE) coupling agents were more effective in improving the interfacial adhesion with respect to OPE coupling agents. The objective of this study was to determine the influence of OPP as a new compatibilizer on the water absorption and mechanical properties of wood flour–PP composites.

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TABLE I
Composition of the Evaluated Formulations (wt %)

Formulation	Code	Wood flour (wt %)	PP (wt %)	MAPP (%)	OPP (%)
1	Control	60	40	0	0
2	MAPP2	60	38	2	0
3	MAPP4	60	36	4	0
4	OPP2	60	38	0	2
5	OPP4	60	36	0	4

EXPERIMENTAL

Materials

We obtained wood flour by screening industrial sawdust of Iranian beech (*Fagus orientalis*) collected from local mills to a +60/−40 mesh particle size. The material was dried in an oven for 24 h at 100 ± 2°C. The PP was grade PI0800 from BIP Co. (Bandar Imam, Iran). MAPP produced by Kimia Javid Factory (Isfahan, Iran) with a melt flow index of 100 g/10 min (temperature = 230°C, load = 2.16 kg) and 1.1% coupled maleic anhydride were used as compatibilizers.

Oxidation of PP

The oxidation of PP was performed according the method described by Abdouss and Sharifi-Sanjani.[16] According to this method, first PP and dodecanol-1 were mixed in an internal mixer (Brabender, Duisburg, Germany). Dried, filtered air was then put in contact with the molten mass at a flow rate of 1 L/min. The reaction was conducted at temperature between 180 and 200°C for 2 h. OPP was used as a compatibilizer.

Fourier transform infrared (FTIR) spectroscopy

PP and OPP were hot-pressed (temperature = 190°C and ram force = 15 ton) into PP films, which were cooled under pressure. The FTIR spectra of these films were recorded with a Nicolet FTIR-710 instrument (Madison, WI) in the region 4000–400 cm^{-1} to identify the functional groups of OPP.

Mixing process

Wood flour, PP, and the compatibilizers were weighed for each formulation according to Table I and were mixed in a Brabender plasticorder (Duisburg, Germany) at 30 rpm and 190°C. First, the PP was added to the mixer, and the wood flour was added after the PP had reached its melting temperature. The mixing process took 11 min on average.

Preparation of the specimens

The amorphous composites removed from the mixer were then pressed into plates with a nominal thickness of 2 mm and nominal dimensions of 15 × 15 cm^2 with a laboratory hydraulic hot press at 190°C. The plates were conditioned for at least 2 weeks at 20 ± 2°C and 60 ± 5% relative humidity, and then, the specimens for physical and mechanical testing were cut out of these plates.

Mechanical tests

The mechanical properties of the wood flour–PP composites were assessed through their flexural and impact properties. The flexural properties of the wood flour–PP composites were determined according to ASTM D 790-90[17] specifications with an Instron-4486 testing machine (Norwood, MA). The crosshead speed was set to 5 mm/min. Unnotched impact tests were also carried out according to ASTM D 256-90[18] with a Santam Izod testing machine (Tehran, Iran). Six replicates for each test were performed.

Water absorption test

The water absorption of the composites was determined according to ASTM D 570-98.[19] The oven-dried composite samples were immersed in distilled water at room temperature. The weight of the samples was measured to a precision of 0.001 g at different time intervals during the long-time immersion. The values of the water absorption in percentage were calculated with the following equation:

$$\mathrm{WA}(t) = \frac{W(t) - W_0}{W_0} \times 100 \qquad (1)$$

where WA(t) is the water absorption at time t (%), W_0 is the oven-dried weight, and $W(t)$ is the weight of the sample at a given immersion time t.

RESULTS AND DISCUSSION

PP oxidation

The FTIR spectra of the original PP and OPP after 2 h are presented in Figures 1 and 2, respectively. Two additional peaks at 1700–1780 and 3457 cm^{-1} in the OPP after oxidation confirmed the progress of the oxidation reaction. These two peaks did not exist in the original PP, and all of the other peaks were

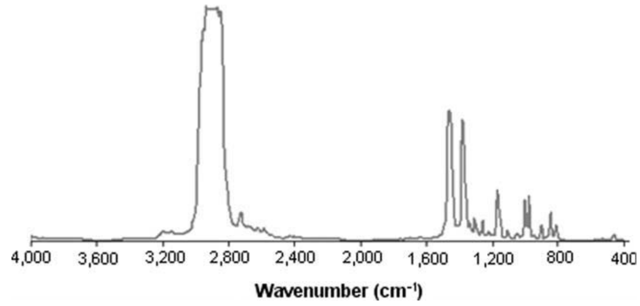

Figure 1 FTIR spectrum of the original PP.

similarly repeated. The absorbance at 1700–1780 cm^{-1} was related to the stretching mode of ketone, aldehyde, and anhydride carbonyl groups, and the peak at 3457 cm^{-1} was attributed to the stretching mode of OH groups in the alcohols.[16] So, we concluded that the oxidation reaction proceeded through the formation of carbonyl and also alcohol functional groups.

Flexural properties

Figure 3 illustrates the flexural modulus of the wood flour–PP composites. At similar compatibilizer contents, the composites with OPP exhibited a higher flexural modulus than those containing MAPP. The addition of 2% MAPP increased the flexural modulus by about 15%, whereas the addition of 2% OPP significantly increased the flexural modulus by about 36% compared to that of the control. With the increase in the compatibilizer content (MAPP and OPP) from 2 to 4%, the flexural modulus decreased slightly.

Figure 4 shows the flexural strength of the wood flour–PP composites. The composites containing MAPP and OPP exhibited significantly higher flexural strengths than those without compatibilizer. When we considered the effect of the type of coupling agent, we observed that the flexural strength of the composites with 2% OPP was significantly higher than those with 2% MAPP.

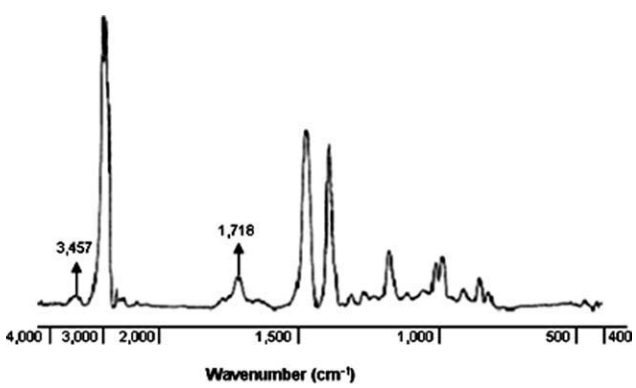

Figure 2 FTIR spectrum of OPP.

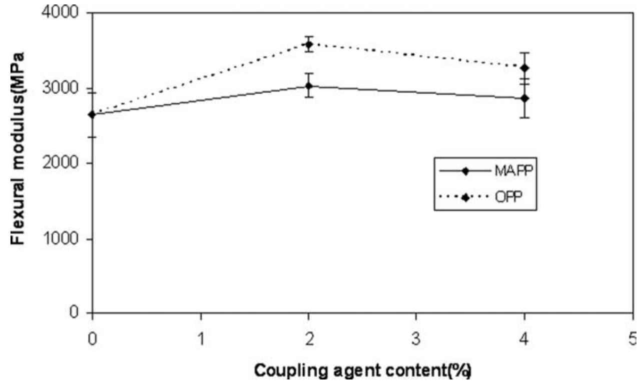

Figure 3 Effect of OPP and MAPP on the flexural modulus of the wood flour–PP composites.

Generally, the flexural strength is strongly affected by the bonding strength between wood flour/fibers and PP. The principal function of MAPP as a compatibilizer is to improve the interfacial adhesion between the polar natural fiber/flour and nonpolar PP. This interfacial adhesion improvement was associated with the formation of covalent bonds (ester linkages) between the wood flour/fiber and PP.[20–22] Also, MAPP caused uniform dispersion and better wetting of the wood filler/fiber in the PP matrix, which led to efficient stress transfer from the matrix to the fiber.

From the previous discussion, the higher bending strength of the composites containing OPP was evidence of improved interfacial adhesion and the formation of chemical bonding between the wood flour and PP with addition of OPP, and we even concluded that OPP had more chances to form chemical bonds between the wood flour and PP.

With a further increase in the concentration of MAPP from 2 to 4%, there was a significant decrease in the flexural strength. Similar results were reported by Mohanty et al.[23] and Dieu et al.[24] for jute–PP composites. The results of earlier studies indicate that the optimum mechanical properties of

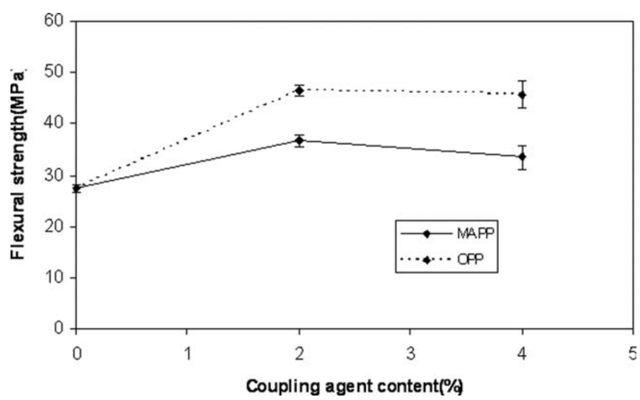

Figure 4 Effect of OPP and MAPP on the flexural strength of the wood flour–PP composites.

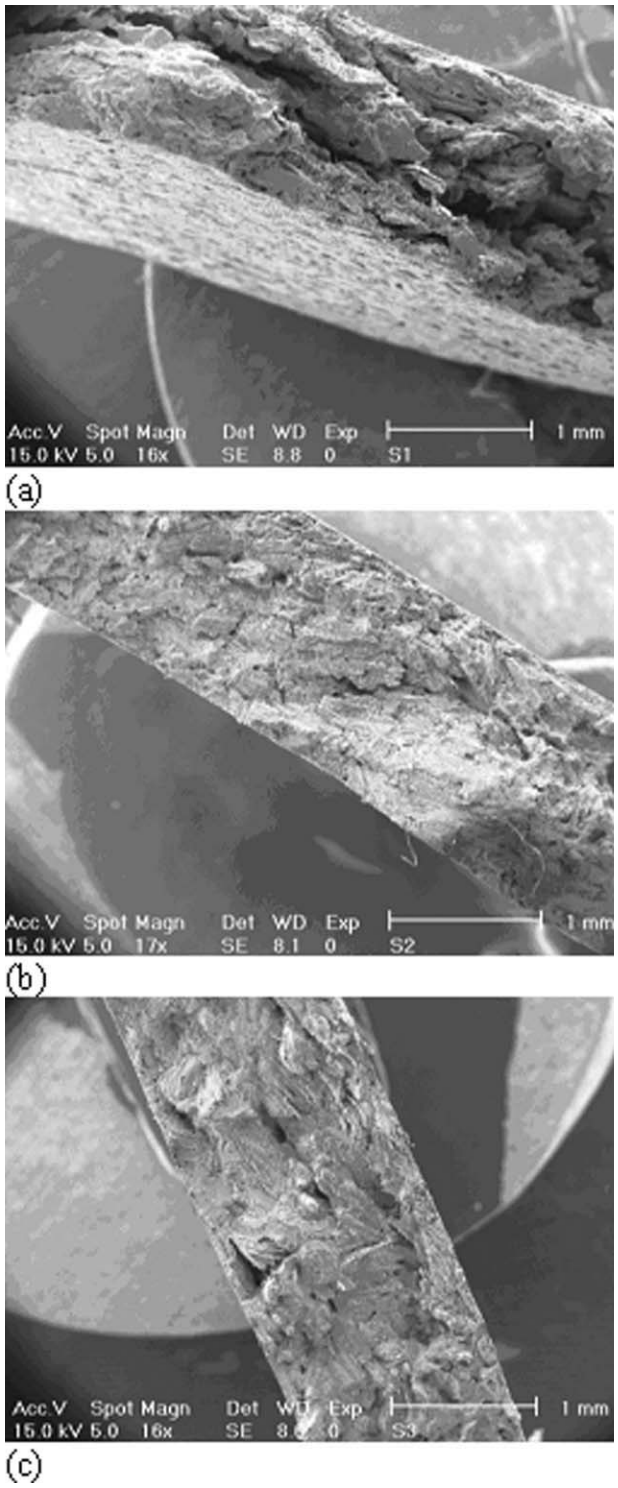

Figure 5 SEM micrographs of the fracture surfaces of the wood flour–PP composites: (a) without compatibilizer, (b) with 2% MAPP, and (c) with 2% OPP.

lingocellulosic fiber (or filler)–PP composites was obtained around 2.0 wt % MAPP.[25,26] An excessive concentration of MAPP, higher than 2.0 wt %, in the composites played a minor part as a polymer in the bulk materials and did not participate any further in the interfacial adhesion between the PP and wood sawdust in the composites.[6] MAPP had a lower molecular weight compared to the matrix PP, which seemed to be responsible for the plasticizing effect and decreasing mechanical properties.[26]

The SEM micrographs of the impact fracture surfaces of the wood flour–PP composites are shown in Figure 5. These micrographs indicate the type of fracture in the samples without compatibilizer [Fig. 5(a)] and with 2% MAPP [Fig. 5(b)] and 2% OPP [Fig. 5(c)]. Better interactions were observed for the MAPP and OPP formulations.

Impact strength

The impact strength of the wood flour–PP composites is shown in Figure 6. The addition of 2% MAPP and OPP increased the impact strength of the composites by about 67 and 74%, respectively, compared to that of the control (composites without coupling agents). The explanation for this was similar to that given for the flexural strength, as discussed earlier.

With increasing MAPP content from 2 to 4%, the impact strength was decreased by about 30%, but the composites containing 4% OPP exhibited about a 7% lower impact strength than those containing 2% OPP.

Water absorption

Figure 7 shows typical water absorption versus time curves for wood flour–PP composites with different types and contents of compatibilizer. All of the composites showed a similar pattern of water absorption, that is, an initial sharp water uptake followed by gradual increase until it reached a certain value at the saturation point (after about 1350 h) where no more water was absorbed.

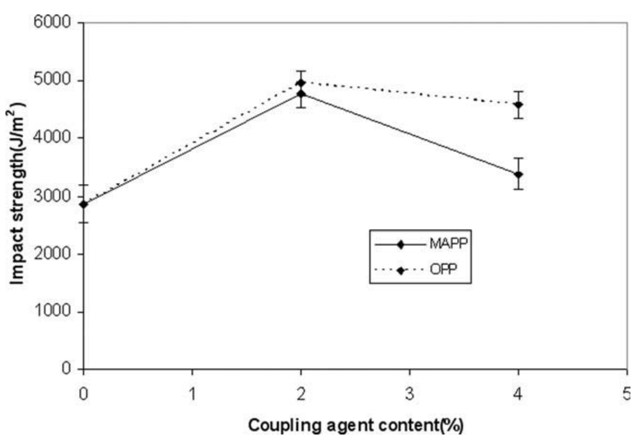

Figure 6 Effect of OPP and MAPP on the impact strength of the wood flour–PP composites.

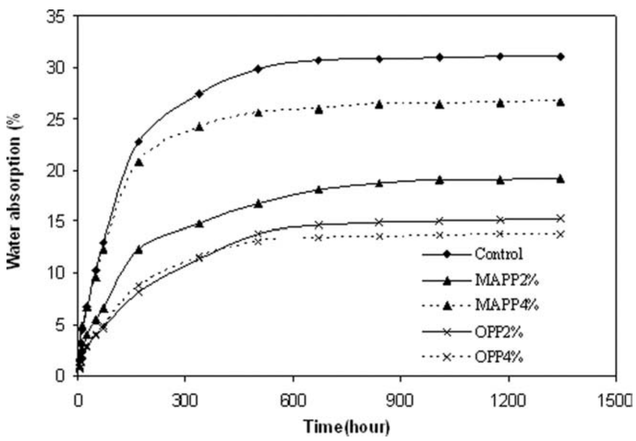

Figure 7 Effect of OPP and MAPP on the long-term water absorption of the wood flour–PP composites.

With a similar content of compatibilizer, the composites with MAPP exhibited a higher water absorption than those containing OPP. This may have been due to the better interaction of the wood flour–PP composites with OPP over MAPP. With a further increase in the MAPP content from 2 to 4%, the water absorption considerably increased. As mentioned before, an excessive concentration of MAPP, higher than 2.0 wt %, in the composites played a minor part as a polymer in the bulk materials. Therefore, the presence of nonreacted polar functional groups may have increased the water absorption in the composite with higher contents of MAPP. A slight decrease was observed for composites containing OPP with an increase in the OPP content from 2 to 4%.

CONCLUSIONS

The effects of OPP as a new compatibilizer on the water absorption and mechanical properties of wood flour–PP composites were studied. The following conclusions were drawn from the results and discussions presented previously:

- Wood flour–PP composites with OPP showed a higher flexural and impact properties but lower water absorption than MAPP.
- All of the composites with 2% compatibilizer (OPP or MAPP) gave higher flexural and impact properties and lower water absorption compared to those with 4% compatibilizers
- With regard to significant effects of the chemical structure and the molecular weight of the compatibilizers on the physical and mechanical properties of the resulting composites, it is obvious that the effects of OPP properties as a compatibilizer on the physical and mechanical performance of wood-filled PP composites should be investigated in detail.

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