Evaluation of the Bending Strength, Impact Strength, and Morphological Properties of Wheat Straw Fiber/Paper Mill Sludge/Polypropylene Composites

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Composite production of polypropylene polymers was considered in this work as the matrix, filled with the fiber of wheat straw and paper mill sludge; different ratios were evaluated relative to their potential as reinforcement materials. Maleic anhydride polypropylene (MAAP) was used at 3% by weight. The bending modulus of elasticity of the composites significantly increased with both types of filler. The highest bending modulus of the composites was found with 40% of paper mill sludge. Using 40% wheat straw fiber decreased bending strength, but the addition of paper mill sludge increased bending strength. The highest bending strength of the composites related to polypropylene/10% of wheat straw fiber and 30% of paper mill sludge. In terms of impact strength, the use of paper mill sludge had a higher impact on strength than wheat straw fiber composites. The inclusion of MAPP improved the mechanical properties of all composites. Scanning electron micrographs showed that the composite paper mill sludge improved the adhesion and dispersion of the filler (paper mill sludge/fiber paper instead of wheat) in the matrix.

Keywords: Composite; Wheat straw; Paper mill sludge; Impact strength; *Bending strength*

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INTRODUCTION

In recent years, considerable attention has been drawn to the use of organic and inorganic substances and their mixture with thermoplastic polymer composites. The use of various organic materials (derived from plant fibers) and minerals (such as talc, calcium carbonate, silica, *etc.*) has led to the appropriate combination of suitable properties, which reduces the price of composites. In this study, wheat straw an agricultural waste and paper sludge an industrial waste were used in the production of thermoplastic composites. The application of different types of filler in composites can modify their properties. According to recent research, the use of agricultural filler products and industrial waste has increased; in fact, they are good alternatives for conventional mineral fillers (Nawang *et al*. 2000; Ismail *et al*. 2002). These materials were considered because of their low price as well as their environmental and industrial benefits (Zaini *et al*. 1996; Ismail *et al*. 2002).

Paper sludge is a waste material derived from the production of pulp and paper, and its high-volume production has led to environmental problems. The waste from most pulp and paper mills is buried and used as fertilizer for farms. This material contains short cellulose fibers and minerals such as kaolin and calcium carbonate, which could be suitable as reinforcements in composites (Qiao *et al*. 2003). Therefore sludge can be used as a reinforcing agent / filler in the manufacture of composite introduced. Natural fibers such as flax, hemp, corn stalks, and wheat straw can be used as reinforcements for thermoplastic and thermoset polymers because of their low density, low cost, non-abrasiveness, and recyclable and renewable nature (Bourmaud and Baley 2007). The aim of this study was to investigate the mechanical properties and morphology of hybrid composites using polypropylene as the continuous phase and both treated and non-treated wheat straw fiber and paper mill sludge as reinforcement materials, which were added at different ratios.

EXPERIMENTAL

Materials

In this study, polypropylene (SHAZAND Petrochemical Company, Arak, Iran) with a melt flow index (MFI) of 16 g/10, density of 0.92 gr/cm^3 and melt point of 143 °C was used as the matrix, and maleic anhydride polypropylene (MAPP; Aldrich, Germany) with a melt flow index of 64 g/10 min, composition maleic anhydride, 8 to 10wt.% of maleic anhydride grafted was applied as the binder. The wheat straw was cut into pieces of 4 to 5 cm and was made fiber under mechanical processes. It was left in water for one night and then was passed three times through a mechanical refiner in laboratory scale with a temperature of 180 °C and duration of 20 min and gap width of 2-3 mm in order to become fiber. The length of wheat straw fiber ranges from 0.04 mm to 6.29 mm with an average length of 0.30 mm. Paper mill sludge was prepared from the waste water treatment of the Latif mill (Karadj, Iran).

Methods

Sample preparation

The formulation of polypropylene/wheat straw fiber/paper mill sludge composites is depicted in Table 1. Because it is important in composite production to eliminate moisture in the materials before mixing, fiber wheat straw and paper mill sludge were heated in an oven for 24 h at 75 °C.

Table 1. Formulation of the Samples

Sample No.	Sample Code	Wheat Straw Fiber (%)	Paper Sludge (%)	PP (%)	MAPP (%)
1	PP	0	0	100	0
2	W40	40	0	60	0
3	W40/M	40	0	57	3
4	S10/W30	30	10	60	0
5	S10/W30/M	30	10	57	3
6	S20/W20	20	20	60	0
7	S20/W20/M	20	20	57	3
8	S30/W10	10	30	60	0
9	S30/W10/M	10	30	57	3
10	S40	0	40	60	0
11	S40/M	0	40	57	3

Composite preparation

A twin screw extruder was used for mixing materials with five zones at 170, 175, 180, 185, and 190 °C and at a rotor speed of 30 rpm. After leaving the extruder, the mixed molten materials were cooled in the air and then transformed into granules in a granulator machine (WIESER, WGLS 200/200 model, Germany). The resulting granules were dried at 105 °C for 12 h. Mechanical test samples were prepared by injecting molding machines in the pilot (Imen Machine, Tehran, Iran) of the Polymer and Petrochemical Institute. The cylinder injection temperature in three zones was 180 °C, and the mold temperature was 23 °C. The injection pressure was 110 bars, and the injection time was less than 20 seconds. Bending and impact strength tests (notch sample) were performed according to ASTM D790-10 (2010) and ASTM D256-10 (2010), respectively, and a loading speed of 5 mm/min was performed on the samples. For this purpose, the device (INSTRON) Model 4489 and Model 5102 (manufactured by Zwick, Ulm, Germany) was used. Furthermore, the mechanical properties of the samples were characterized by scanning electron microscopy (SEM; Philips KL 30, Netherlands).

RESULTS AND DISCUSSION

Bending Properties

With the addition of fillers (wheat straw fiber or paper mill sludge) to the PP polymer matrix, the bending modulus of elasticity increased (Fig. 1). With the addition of 40% wheat straw fiber, the PP bending modulus of elasticity increased from 1064 MPa to 1632 MPa. However, with the addition of paper mill sludge, a more noticeable increase was observed. In combined PP with 40% paper mill sludge, the bending modulus of elasticity increased to 2277 MPa. The improvement in the combined ratio to PP matrix was 114%, which showed a dramatic improvement in the bending modulus of elasticity.

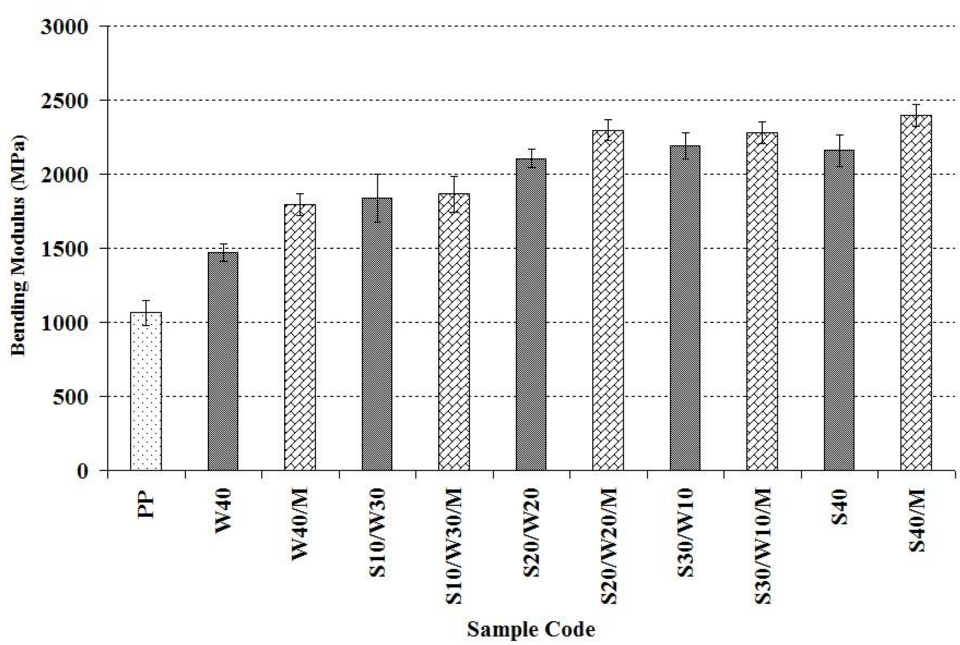

Fig. 1. The effect of wheat straw fiber and paper mill sludge on bending modulus

An increase in the bending modulus composite PP/wheat straw fiber ratio to pure PP was attributed to higher stiffness, which represents the reinforcement properties of the wheat straw fiber in the matrix to the fiber stress of their transfer (Houshyar *et al*. 2005). By adding paper mill sludge, the bending modulus of elasticity increased to higher hardness values. Due to the use of natural fiber, the modulus of elasticity increased, and it can be stated that the paper mill sludge with 52% short fiber increased the flexural properties.

Hamzeh *et al*. (2011) reported that increasing paper sludge improved the bending properties of a composite even in the absence of a binder. Son *et al*. (2001) reported that paper mill sludge filler increased the stiffness of the composite. Adding MAPP led to the formation of the interface between the PP and wheat straw fiber/paper mill sludge. The mechanical properties of all composites were improved by the addition of binder. Many studies have shown that adding binders improves the bending modulus of composites (Geng and Simonsen 2004; Zhang *et al*. 2007).

Figure 2 shows that the bending strength of the composite decreased with the addition of wheat straw fiber, whereas the addition of paper mill sludge improved the bending strength. This reduction in bending strength causes poor adhesion, aggregation, and the agglomeration of wheat straw fibers in the matrix (Yang *et al*. 2004). The hydrophilic and hydrophobic matrices prevent the weak links between the wheat straw fibers that release tension and reduce the composite strength (Yang *et al*. 2004).

The reduction in bending strength was attributed to weak compatibility between the natural fibers and the hydrophobic and hydrophilic properties of the matrix. However, by adding paper mill sludge to the composite, it has been observed that the tensile strength increased. Therefore, paper mill sludge with 48% inorganic materials, such as kaolin and calcium carbonate and 52% short cellulose fibers with hydrophobic properties can lead to a better bonding interface with the PP matrix and an increase in bending strength. Mixing 30% paper mill sludge and 10% wheat straw fiber yielded the highest bending strength. Increasing in combined ratios to pure PP to 66% showed a noticeable increase.

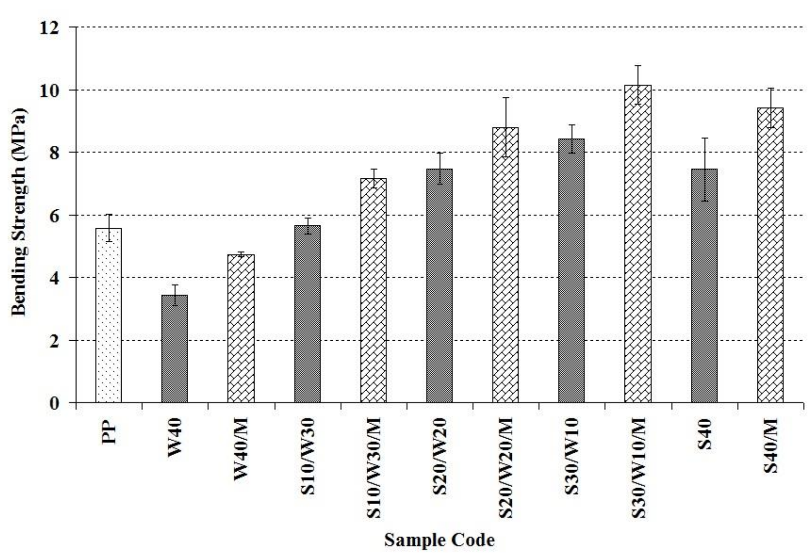

Fig. 2. The effect of wheat straw fiber and paper mill sludge on bending strength

The addition of paper mill sludge improved the bending properties of the composites. Therefore, this material more effectively transferred stress between the two phases, and higher force was needed for the failure of these materials. The enhanced composite bending properties using MAPP were attributed to better distribution and higher tension between the two phases (Son *et al*. 2001).

The highest bending strength of the PP composite was achieved with 10% wheat straw fiber, 30% paper mill sludge, and 3% MAPP (an 82% improvement). Therefore, this combination for producing composites can be introduced in order to obtain the optimal bending strength. Adding a binder to the composite also improved its bending strength. Therefore, the use of a binder can increase the interface combination of the material and eventually lead to higher bending strength. This improvement in bending strength was attributed to good stress distribution (Zhang *et al*. 2002).

The lack of interaction between the two major components of the composite (PP and wheat straw fiber) as a result of the inefficient common surface caused an ineffective transmission of the matrix reinforcement (Girones *et al*. 2010). Usually, a binder is a good solution to this problem. Among binders, MAPP has shown an excellent ability to overcome the reduction in the tensile strength of composites. Adding paper mill sludge to a combination of PP/wheat fiber straw enhances the bending strength of composites. By adding MAPP to this combination, further improvement was observed. The bending properties of the composite made with paper sludge showed that these substances are good alternatives for wood fiber composites, which reduces forest resources.

Impact Strength

Impact strength is the ability of the material to resist fracture under stress applied at high speeds. The absorbance of energy in composite strength against strike occurs by the combination of the creation and development of cracks. Cracks start in areas with high stress concentration with defects or points, such as areas where the connections between the two phases is very weak. The addition of 40% wheat straw fiber to PP composites caused a reduction in impact strength. Adding sludge mill to combined PP/wheat straw fibers improved the composite impact strength. In these compounds, the use of 40% paper mill sludge and 3% MAPP had the highest impact strength (63 J/m), compared with pure PP. The increase in the impact strength of PP/paper mill sludge on the ability of the material (paper mill sludge) to absorb the impact energy was attributed to the addition of wheat straw fibers. The addition of MAPP, which increases the impact strength in various combinations, contributed to elastic deformation (Girones *et al*. 2010).

Presence of anhydride groups in binders such as MAPP can create covalent bonds with hydroxyl groups of fiber (wheat straw fiber and short fiber in paper mill sludge). And interconnection with the PP polymer creates a strong interface between the filler and polymer. Also SEM images of the fracture surface indicates that MAPP create the better connection between the two phases.

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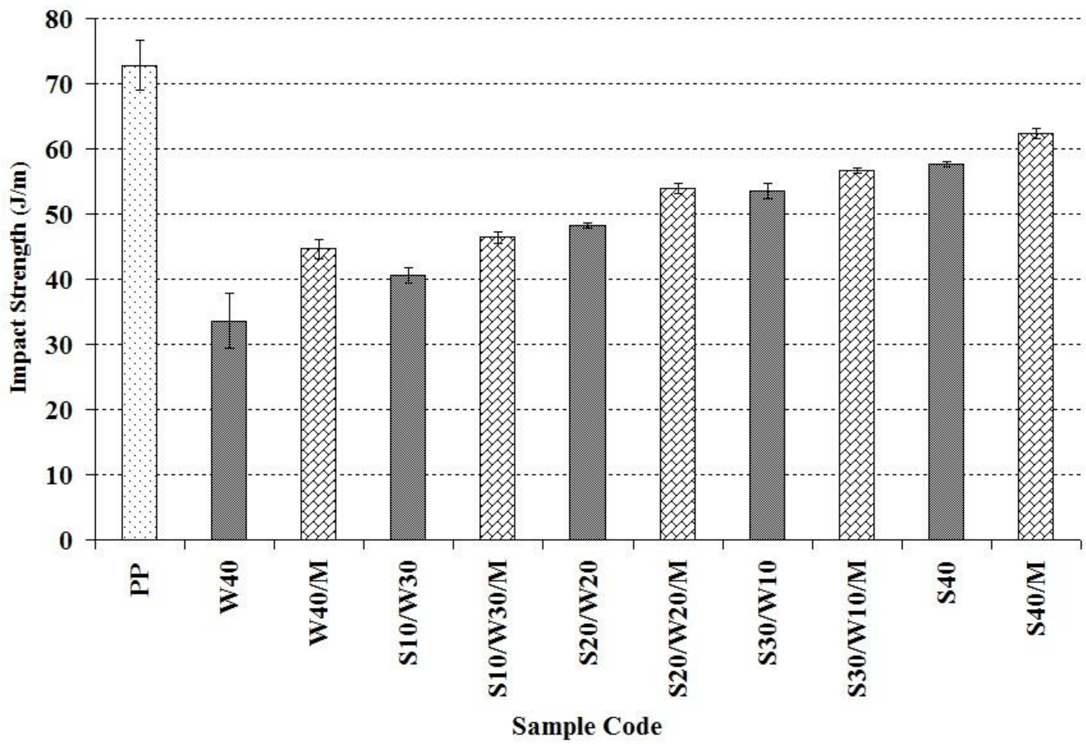

Fig. 3. The effect of wheat straw fiber and paper mill sludge on impact strength

Morphological Properties

Figure 4 shows micrographs of the fracture surface of different samples. Figure 4(a) shows that wheat straw fibers inhibited the proper connection between the structure of the polymer and the filler. In these composites, releasing wheat straw fiber and the gap between the two phases of the conflict between these two materials were indications of lower mechanical properties.

Figure 4(b) shows that the composite with 20% wheat straw fiber and 20% paper sludge had good dispersion in the phase of the filler-matrix, with no gaps in between. The paper sludge improved the dispersion of the filler in the matrix phase, and in contrast to Fig. 4(a), fiber pull-out from the matrix was not observed.

Figure 4(c) shows that the binder of MAPP in the composite caused further improvement in the distribution and adhesion between the two phases (Digabel *et al*. 2004). The use of a coupling agent reduces stress concentration and promotes this energy for the enhancement of cracks (Sain *et al*. 2004).

Figure 4(d), which shows the effect of 40% of paper mill sludge filler dispersion in the matrix, showed excellent adhesion between the two phases (paper mill sludge and polypropylene), with no cracks or crevices in the composite. By evaluating these images, the higher mechanical properties of the composites containing well-established paper mill sludge were confirmed.

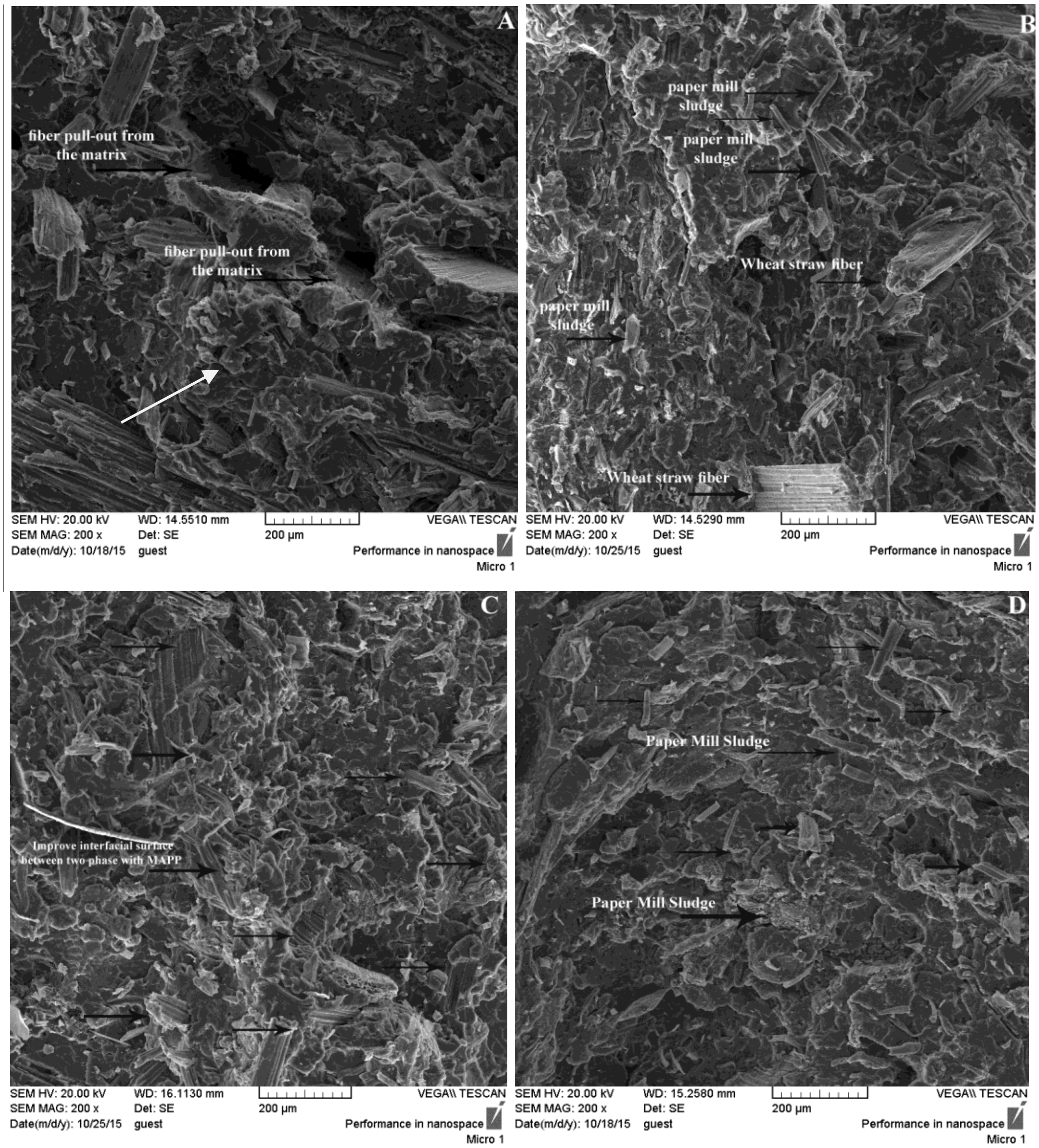

Fig. 4. SEM micrographs of fracture surfaces in composites with A) 40% wheat straw fiber; B) 20% wheat straw fiber and 20% paper mill sludge; C) 20% wheat straw fiber, 20% paper mill sludge, and 3% MAPP; and D) 40% paper mill sludge

CONCLUSIONS

1. The composite bending module elasticity considerably increased with the addition of wheat straw fiber into the matrix, while the composition of paper mill sludge showed an increasing trend.
2. The bending modulus of elasticity was 2159 MPa with 40% of paper mill sludge and increased by adding binders up to 2396 MPa, while with pure PP, the bending modulus of elasticity was 1064 MPa. The bending strength of the composite was reduced by adding 40% of fiber wheat straw into the matrix PP (4.3 MPa), while paper mill sludge noticeable improved the composition.

3. The highest bending modulus of elasticity of the PP composite was 8.4 MPa in 10% of wheat straw fiber; with 30% paper mill sludge and the addition of MAPP, it increased up to 15.10 MPa, while the bending strength of pure PP (5.5 MPa) was shown. By adding both types of fillers to the PP matrix, a dramatic reduction in impact strength was observed. Comparing the two fillers, paper mill sludge was shown to have higher impact strength in the PP matrix. The addition of the binder also improved impact strength.
4. SEM images showed that the use of paper mill sludge in wheat straw fibers with improved dispersion in the matrix led to better adhesion between the filler and the matrix.
5. The composite containing wheat straw fiber and paper mill sludge had better dispersion and adhesion of wheat straw fiber than composites containing only wheat straw fibers.

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