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Material Properties

Mechanical properties of polypropylene/natural fiber composites: Comparison of wood fiber and cotton fiber

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ABSTRACT

In this study, the mechanical properties of polypropylene (PP)/natural fiber composites were studied. For the natural fiber component of the composites, cotton fiber was compared with wood fiber. The effect of the melt index of PP on the mechanical properties of the composites was also investigated. In order to improve the poor interfacial interaction between the hydrophilic natural fibers and the hydrophobic matrix PP, maleic anhydride (MAH) grafted PP (PP-*g*-MAH) was used as a compatibilizer. The tensile strength of the PP/wood fiber composites decreases with increasing wt% of the wood fibers, whereas that of the PP/cotton fiber composites displays different behavior. With the addition of 10 wt% cotton fiber, the tensile strength decreases, but with the addition of 20 and 30 wt% cotton fiber it increases because of the entanglement of the cotton fibers. For the PP/wood fiber composites, the melt flow index (MI) of PP was also found to be a key factor governing the mechanical properties (tensile and flexural strengths). The use of PP-*g*-MAH was helpful to increase the tensile and flexural strengths of the PP/cotton fiber and PP/wood fiber composites, due to the increased interaction between the fiber and PP matrix.

1. Introduction

Plastic/fiber composites are widely used in many industries such as the aircraft, automobile, leisure, electronic, and medical industries. The use of natural fibers in plastic/fiber composites has recently attracted increased attention, due to the increasingly stringent government regulations and growing environmental awareness. The potential advantages of natural fibers, apart from their environmental benefits, are the abundant availability of the raw materials from renewable resources, rather than fossil sources, and their low cost. Also, they have high specific strength due to their low density. Furthermore, it is possible to obtain a higher loading of natural fibers in plastic/fiber composites than conventional inorganic fillers because of the softer nonabrasive nature of the former.

A variety of natural fibers have been tested for use in plastic/fiber composites [1–13]. Natural fibers can be divided into materials with cellulose as a major component, such as seed fibers (cotton, kapok, etc.) and more complex materials where cellulose is associated with hemicelluloses, lignin, peptic cements, etc., such as leaf fibers, bast fibers or wood [14]. Among the various natural fibers, wood fibers have attracted considerable attention in the fields of both fundamental research and applications because PP/wood fiber composites have properties similar to those of PP/glass fiber composites [15,16]. Plastic/wood fiber composites constitute a rapidly growing industry in the United States. Although cotton fibers have very promising physical

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properties as a filler in plastic/fiber composites, most of the studies on these materials have focused on plastic/cotton fabric composites [17,18], whereas there have been few studies about plastic/cotton fiber composites.

In this study, the mechanical properties of PP/cotton fiber composites were compared with those of PP/wood fiber composites. Since the matrix polymer plays an important role in composite systems, the effect of the melt index of PP on the mechanical properties of the composites was also investigated. The main problem with PP/natural fiber composites has been the poor interfacial interaction between the hydrophilic natural fibers and the hydrophobic matrix PP. Therefore, maleic anhydride grafted PP, which is compatible with PP and can react with the hydroxyl groups of the fiber, was used as a compatibilizer in this study.

2. Experimental

2.1. Materials and composite preparation

The names and important characteristics of the materials used in this study are summarized in Table 1. The wood fiber and cotton fiber were dried in an oven before use. The PP, natural fiber, and compatibilizer were mixed in a plasticorder (Haake Rheocord 9000) using a rotor speed of 50 rpm at 170 °C for 10 min. Then, the obtained mixture was compression molded at 170 °C for 20 min.

2.2. Measurements

A Universal Testing Machine (Model 4466, Instron Co.) was used to obtain the tensile strength and flexural strength of the composites at room temperature. Crosshead speeds of 200 and 50 mm/min were used for the measurement of the tensile strength and flexural strength, respectively. All measurements were performed for five replicates of dumbbell shaped specimens and averaged to obtain the final result. To investigate the morphology of the composites, their cross-sections were cryogenically microtomed and examined with a Scanning Electron Microscope (SEM, JEOL JSM-6100).

3. Results and discussion

Figs. 1–3 show the tensile strengths of the PP/cotton fiber and PP/wood fiber composites incorporating PP with different MIs as the matrix. With increasing wt% of wood fibers, the tensile strength of the PP/wood fiber composites decreases, as would be expected. Generally the tensile strength depends on the weakest part of the composites and the interfacial interaction between PP and wood fiber is weak. Therefore, the tensile strength of the PP/wood fiber composites decreases with increasing wt% of wood fibers. However, the tensile strength of the PP/cotton fiber composites displays different behavior. With the addition of 10 wt% cotton fiber, the tensile strength decreases, but with the addition of 20 and 30 wt% cotton fiber, it increases. This behavior can be explained by the entanglement of the cotton fiber when its content is above 10 wt%. This entanglement was confirmed by the SEM micrographs (Fig. 4). Mwaikambo and Bisanda reported that for polyester/cotton fabric composites, the tensile strength of the composites decreased with increasing content of the cotton fabric, possibly because the void content increases with increasing fabric volume fraction [18]. The difference in the tensile strength depending on the kind of fiber can also be caused by other factors, such as the fiber length, hydrophilicity, etc., as well as the difference in the chemical nature of the fiber. This is why the cotton fiber shows a better reinforcement effect for PP than the wood fiber, even though the length of wood fiber is shorter than that of cotton fiber (since the reinforcement effect usually becomes larger as the length of the fibers is decreased) [18].

It is interesting to note that for the PP/cotton fiber composites with high MI PP (H360F and H380F) as the matrix, the tensile strength of the PP composites with 30 wt%

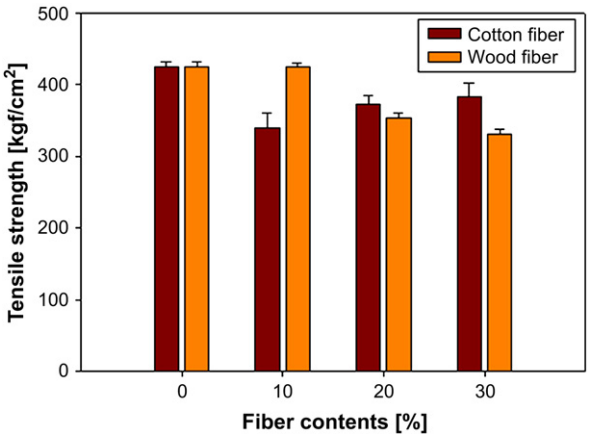

Fig. 1. Tensile strength of PP/natural fiber composites as a function of natural fiber content (PP: H720P).

Table 1
Important characteristics of the materials used in this study

Materials	Supplier	Characteristics
Polypropylene (H720P)	SK Chemical Co., Korea	MI (g/10 min): 2
Polypropylene (H360F)	SK Chemical Co., Korea	MI (g/10 min): 12
Polypropylene (H380F)	SK Chemical Co., Korea	MI (g/10 min): 25
Wood fiber	JRS GmbH, Germany	Length: 40 μm; cellulose content: >98.5%
Cotton fiber	Obtained from Korea Apparel Research Institute	Length: 1 cm; cellulose content: 87%
Maleic anhydride grafted polypropylene (Polybond 3150)	Uniroyal Chemical CO., USA	MI (g/10 min): 50; MAH content: 0.5 wt%

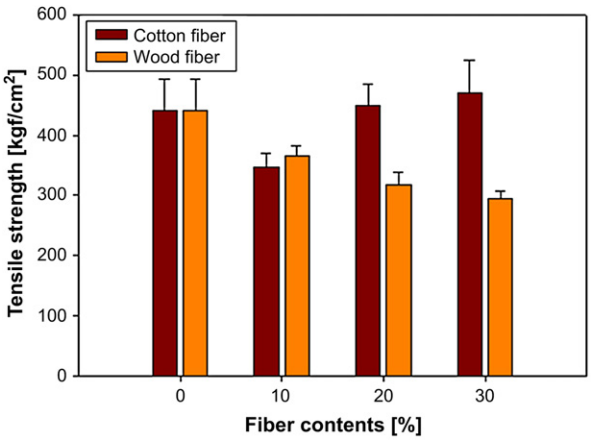

Fig. 2. Tensile strength of PP/natural fiber composites as a function of natural fiber content (PP: H360F).

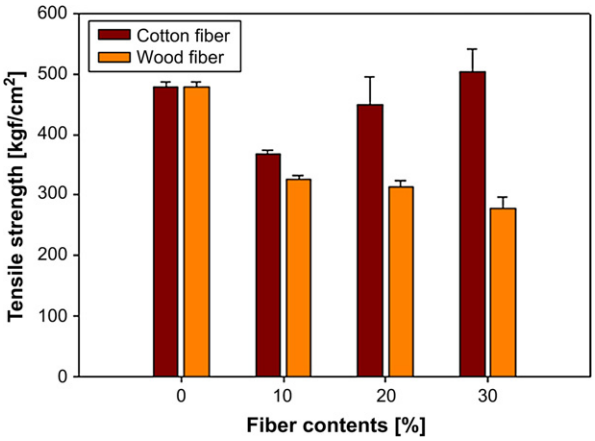

Fig. 3. Tensile strength of PP/natural fiber composites as a function of natural fiber content (PP: H380F).

cotton fiber is higher than that of PP. This implies that the better wetting behavior of PP with cotton fiber for the higher MI (i.e. lower molecular weight) PP might play a more dominant role in increasing the tensile strength of the composites than the effect of the MI of PP, since the mechanical properties of polymers or their composites are usually inversely proportional to the MI of the matrix polymer.

Figs. 5–7 show the flexural strength of the PP/cotton fiber and PP/wood fiber composites containing PP with different MIs as the matrix. The flexural strength of the composites displays different behavior depending on the MI of the PP. For the composites with H720P (MI: 2) as the matrix, the flexural strength of the composites decreases with increasing wt% of wood fiber. With the addition of 10 wt% cotton fiber, the flexural strength

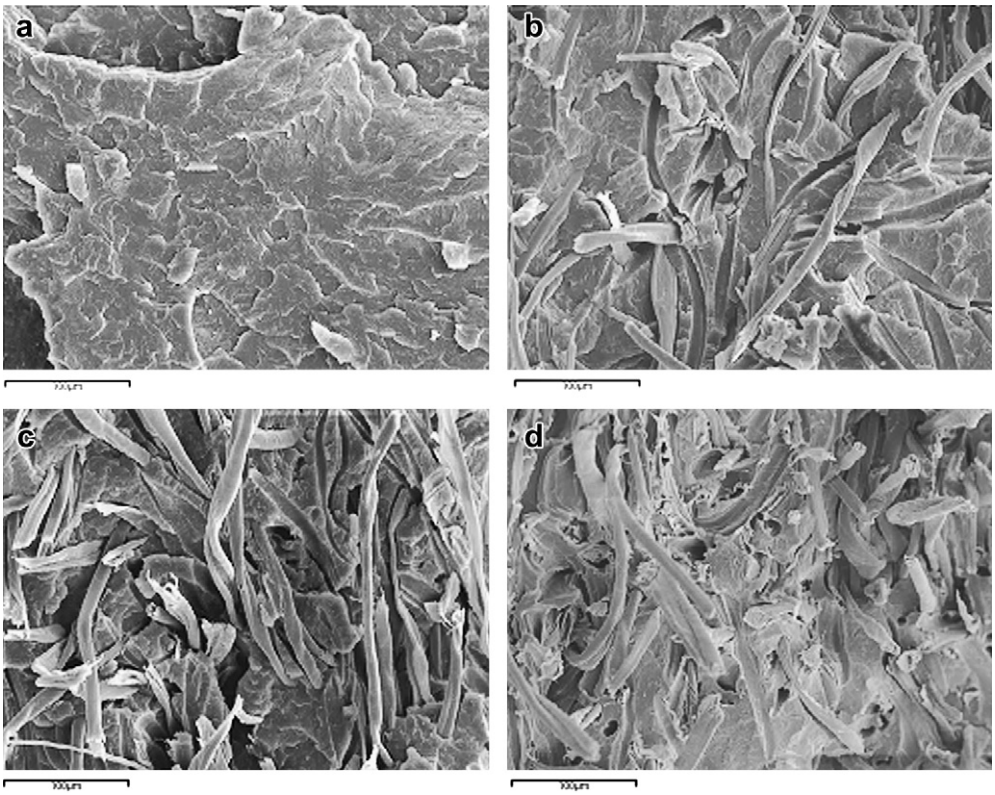

Fig. 4. SEM micrographs of PP/cotton fiber composites: (a) cotton fiber 0 wt%, (b) cotton fiber 10 wt%, (c) cotton fiber 20 wt%, and (d) cotton fiber 30 wt%.

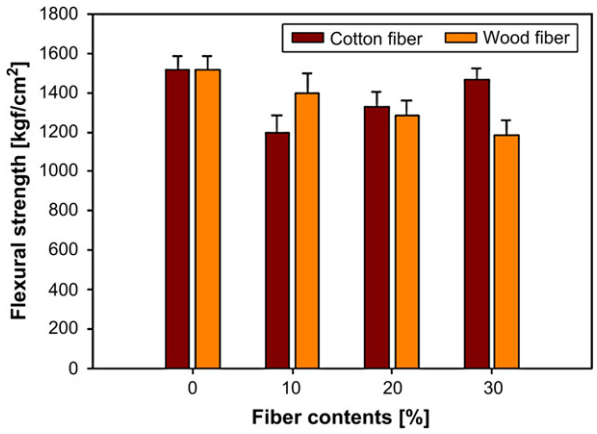

Fig. 5. Flexural strength of PP/natural fiber composites as a function of natural fiber content (PP: H720P).

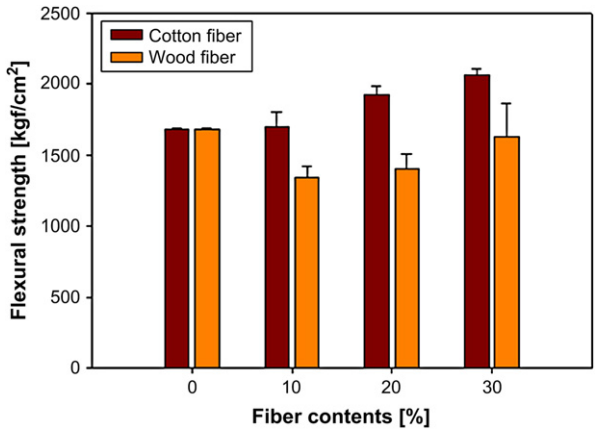

Fig. 6. Flexural strength of PP/natural fiber composites as a function of natural fiber content (PP: H360F).

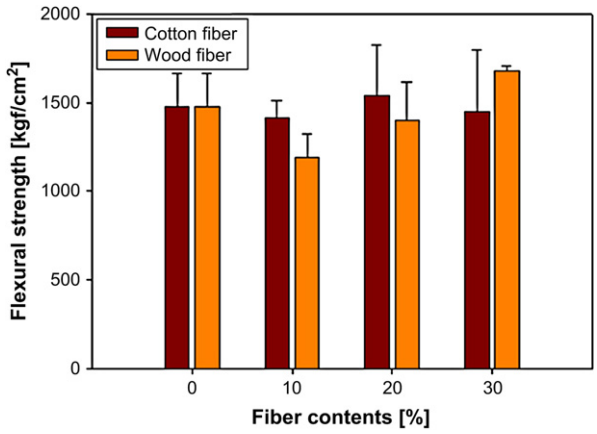

Fig. 7. Flexural strength of PP/natural fiber composites as a function of natural fiber content (PP: H380F).

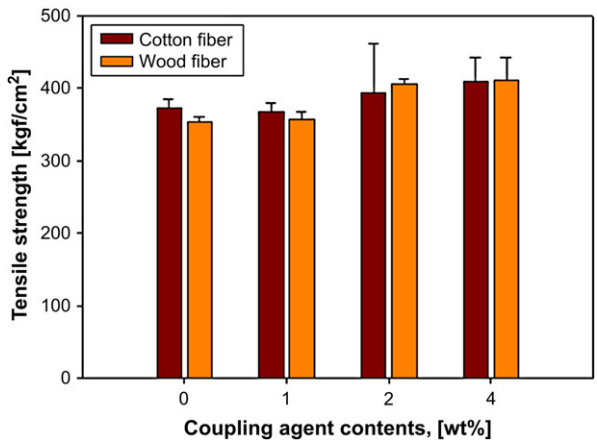

Fig. 8. Tensile strength of PP/natural fiber composites as a function of compatibilizer content (PP: H720P).

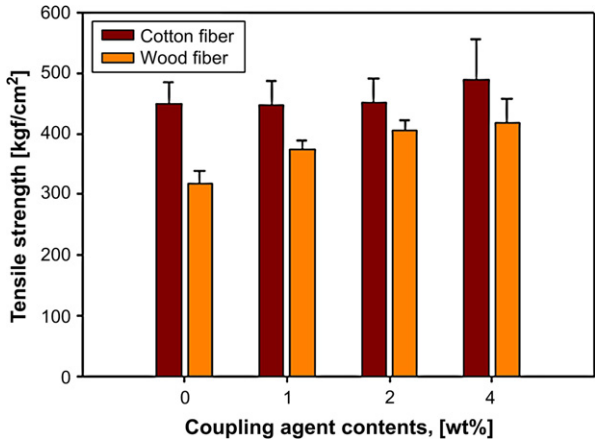

Fig. 9. Tensile strength of PP/natural fiber composites as a function of compatibilizer content (PP: H360F).

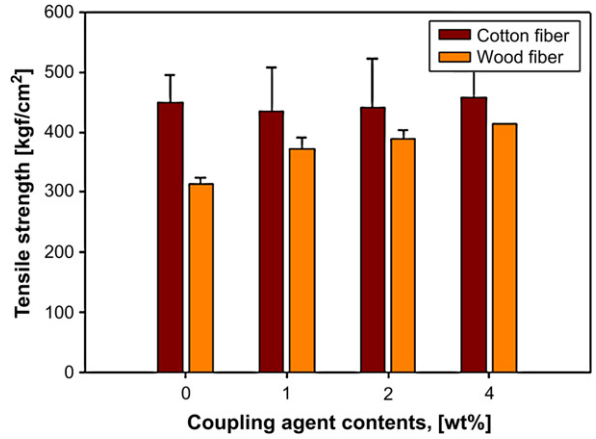

Fig. 10. Tensile strength of PP/natural fiber composites as a function of compatibilizer content (PP: H380F).

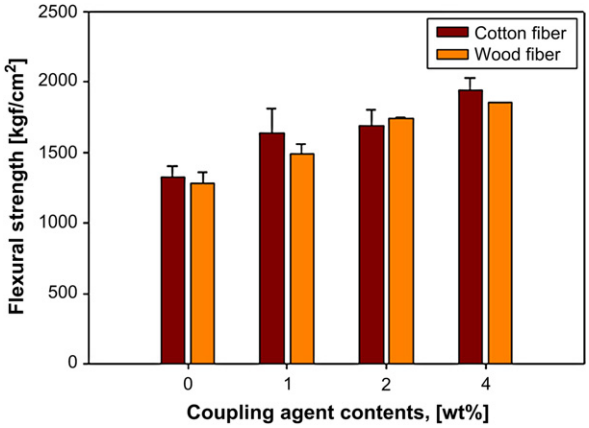

Fig. 11. Flexural strength of PP/natural fiber composites as a function of compatibilizer content (PP: H720P).

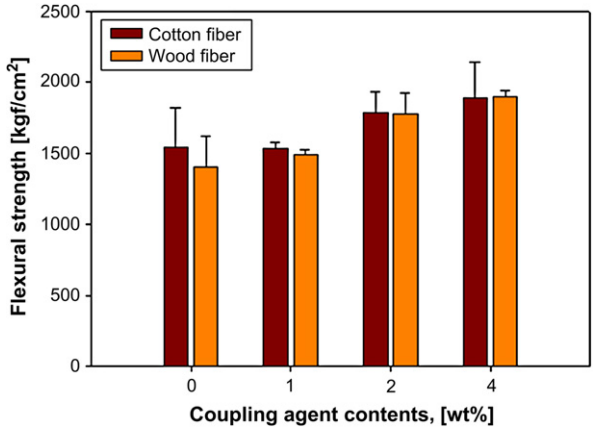

Fig. 13. Flexural strength of PP/natural fiber composites as a function of compatibilizer content (PP: H380F).

decreases, but with the addition of 20 and 30 wt% cotton fiber, it increases. This behavior is similar to that of the tensile strength. For the composites with H360F (MI: 12), with the addition of 10 wt% wood fiber, the flexural strength decreases, but with the addition of 20 and 30 wt% wood fiber it slightly increases. With increasing wt% of cotton fiber, the flexural strength of the composites continuously increases. For the composites with H380F (MI: 25), with the addition of 10 wt% wood fiber, the flexural strength decreases, but with the addition of 20 and 30 wt% wood fiber it increases. For the PP/cotton fiber composites, there is little change in the flexural strength. Based on this result for the PP/wood fiber composites, it can be inferred that PP with a higher MI is a better choice as the matrix from the viewpoint of the enhancement of the flexural strength by the wood fiber. This result again supports the speculation that was made for the tensile strength that the better wetting behavior of PP with wood or cotton fiber for the higher MI (i.e. lower molecular weight) PP plays a more dominant role in increasing the flexural strength of the composites than the MI of PP. In this sense, for PP/cotton fiber composites, H360F is the better choice as the matrix from the viewpoint of the enhancement of the flexural strength by cotton fiber. It can be concluded here that the MI of PP is a very important factor for the mechanical properties of PP/wood fiber and PP/cotton fiber composites.

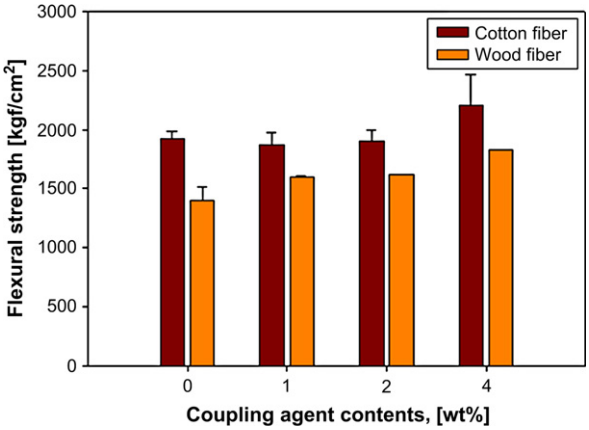

Fig. 12. Flexural strength of PP/natural fiber composites as a function of compatibilizer content (PP: H360F).

Figs. 8–10 show the effect of the compatibilizer (PP-*g*-MAH) on the tensile strength of the PP/cotton fiber (80/20 wt%) and PP/wood fiber (80/20 wt%) composites containing PP with different MIs. With increasing wt% of PP-*g*-MAH, the tensile strength of the PP/cotton fiber and PP/wood fiber composites increases. Figs. 11–13 show the effect of the compatibilizer on the flexural strength of the PP/cotton fiber (80/20 wt%) and PP/wood fiber (80/20 wt%) composites containing PP with different MIs. With increasing wt% of PP-*g*-MAH, the flexural strength of the PP/cotton fiber and PP/wood fiber composites increases.

Fig. 14 shows the SEM micrograph of the fractured surface of the PP/cotton fiber and PP/wood fiber composites without and with the compatibilizer. Because of the increased interaction between the fiber and PP matrix, fractured fibers are observed for the composites with the compatibilizer. The effect of maleic anhydride grafted PP has been reported in many studies, including the review paper by Bledzki and Gassan [1]. The acidic anhydride groups of MAH usually form hydrogen as well as chemical bonds with the hydroxyl groups of natural fibers. It was explained in these studies that the long PP chains of PP-*g*-MAH lead to the equalization of the very different surface energies of the matrix and reinforcement fiber, which allows for the good wetting of the fiber by the viscous polymer. This compatibilization effect of PP-*g*-MAH on PP/wood fiber composite was also reported by Oksman and Clemsons [6].

4. Conclusions

Since the tensile strength depends on the weakest part of the composites and the interfacial interaction between PP and wood fiber is weak, the tensile strength of the PP/wood fiber composites decreases with increasing wt% of wood fibers. However, the tensile strength of the PP/cotton fiber composites displays different behavior. With the

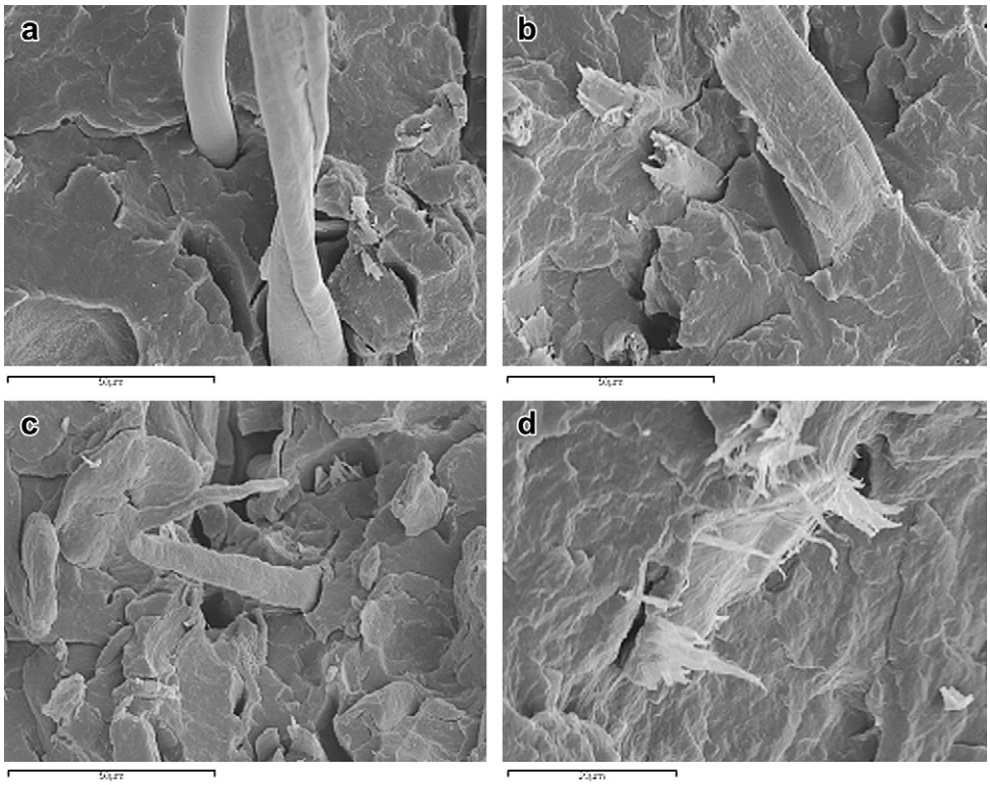

Fig. 14. SEM micrographs of: (a) PP/cotton fiber composite without a compatibilizer, (b) PP/cotton fiber composite with a compatibilizer (5 wt%), (c) PP/wood fiber composite without a compatibilizer, and (d) PP/wood fiber composite with a compatibilizer (5 wt%).

addition of 10 wt% cotton fiber, the tensile strength decreases, but with the addition of 20 and 30 wt% cotton fiber it increases because of the entanglement of the cotton fibers, as confirmed by the SEM micrographs. For the PP/wood fiber composites, PP with a higher MI is a better choice for the matrix from the viewpoint of the enhancement of the flexural strength by the wood fiber. For the PP/cotton fiber composites, H360F is the better choice as the matrix in terms of the enhancement of the flexural strength by the cotton fiber. With increasing wt% of PP-g-MAH, the tensile strength and flexural strength of the PP/cotton fiber and PP/wood fiber composites increase because of the increased interaction between the fiber and PP matrix, which is supported by the fractured fibers observed in the SEM micrograph of the composites with the compatibilizer.

Acknowledgements

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