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Mechanical properties of bagasse fiber filled polypropylene composites

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ABSTRACT

The bagasse is a sugarcane waste generated in high proportions in the agro-industry. In this study, bagasse fiber has been used as filler in polypropylene (PP) matrix to develop the composite from polymer and natural fiber. Bagasse fiber filled polypropylene (PP/BF) composites were prepared by using the Z-blade mixer at processing temperature of 190°C and a speed of 35rpm with different filler loading varying between 0% and 15% by weight. Maleic anhydride (MAPP) coupling agent was used to improve the adhesion between the fiber and PP matrix. The effect of coupling agent addition and fiber content on properties of PP/BF composites was studied. Tensile strength and elongation at break increased with increasing filler content while modulus of elasticity decreased for both coupled and uncoupled PP/BF composite. The addition of bagasse fiber in PP has decreased the flexural strength and flexural modulus for both coupled and uncoupled PP/BF composites. However, coupled PP/BF composites showed greater flexural properties compared to uncoupled PP/BF composites. Based on swelling behaviour, it can be observed that the coupled PP/BF composites showed lower water absorption rate compared to the uncoupled one. The presence of MAPP as coupling agent resulted in decreased water absorption level and enhanced mechanical properties for PP/BF composites.

INTRODUCTION

In recent years, studies about the utilization of lignocellulosic materials as filler or reinforcement in polymeric composites are increasing due to the improvements that natural fibers can provide to the product, such as low density and biodegradability, besides the fact that these materials are from renewable and less

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expensive sources [1-4]. Many natural fibers have been used in automobiles, trucks and railway cars [5]. Fibers and thermoplastic matrix can be mixed together by hot compression molding, where the fibers can be placed in intimate contact with the matrix [6-9]. However, the combination of lignocellulosic material with thermoplastic matrix can bring a considerable problem: incompatibility between the polar and hygroscopic fiber and the non-polar and hydrophobic matrix. The possible solution for this problem has been studied through chemical modification of fibers due to the presence of hydroxyl groups, very reactive and susceptible to chemical reactions. Non-polar groups can be inserted in the fibers, resulting in hydrophobic characteristics compatibles with thermoplastic matrices [10-12]. Other alternative to improve the compatibility between fiber and matrix is to use a coupling agent that possesses a dual functionality, enabling it to interact or react with both components [13-15].

Sugarcane is the source of the agro-based fiber that can be found abundantly in Malaysia. The bagasse is a sugarcane waste generated in high proportions in the agro-industry. In this study, bagasse fiber (BF) has been used as filler for the polypropylene (PP). The main disadvantage of using bagasse fiber in PP/BF composites is low compatibility between the hydrophilic character of the polar bagasse fiber and hydrophobic character of non polar PP polymer. Bagasse fiber does not disperse easily in the thermoplastic polymers such as polyolefin and biodegradable polymer [15]. Therefore, this study was aimed to improve the interfacial adhesion between bagasse fibers and thermoplastic (polypropylene) by using Polypropylene grafted Maleic Anhydride (MAPP) coupling agent.

EXPERIMENTAL

Materials

Polypropylene resin was supplied by Polypropylene Malaysia Sdn. Bhd. The bagasse fiber, which is used as filler was obtained from the local supplier in Kuala Perlis, Perlis, after being processed to extract juice. Polypropylene-grafted-maleic anhydride (MAPP) was used as coupling agent and supplied by Sigma-Aldrich, Inc.

Sample preparation

The bagasse fiber was dried in the oven for 24 hours. The dried bagasse fiber was separated manually then grinded. An Endecotts sieve was used to obtain 2.0 to 2.8 mm sizes of bagasse fiber. The composites were prepared by mixing PP and bagasse fiber in a Z-blade mixer with different filler loading (0wt%, 5wt%, 10wt% and 15wt %). The total weight for each sample is 300 g. PP was pre-heated for 10 minutes before bagasse fiber was added. They were mixed in the mixing chamber at 190°C and a speed of 35 rpm for 30 minutes. For the coupled composite, bagasse fiber and 3% of MAPP was mixed together before being poured into the mixing chamber containing PP melts. Then, the mixture was compression molded into sheet 1 mm and 3 mm thick by applying pressure 170 kg/cm2, temperature 180°C for 4 minutes. The composites were allowed to cool for 4 minutes.

Mechanical Testing

An Instron 5569 machine was used for tensile and flexural tests. The specimens were stretched at a speed of 50 mm/min under a load of 2500N. The gauge length was 50 mm. This test was conducted according to ASTM D638 at room temperature. Flexural test was performed at room temperature according to ASTM D790 at a speed of 2.71 mm/min and 50 mm span length.

Water Absorption Test

The samples were cut into 2.0 cm × 2.0 cm × 0.3 cm specimen and its initial weight (w0) was recorded. The samples were immersed in distilled water for a month. The weight of a wet sample (wf) was periodically measured once a week and was determined after removing the surface water by blotting with filter paper. The percent of water absorption was determined by following equation:

$$\text{Percent of water absorption (\%)} = \left(\frac{w_0 - w_f}{w_0}\right) \times 100\%$$

where;
wo = initial dry weight (in gram)
wf = weight after immersion in water (in gram)

RESULTS AND DISCUSSION

The tensile strength, tensile modulus and elongation at break for PP/BF composite are shown in Figure 1, 2 and 3 respectively.

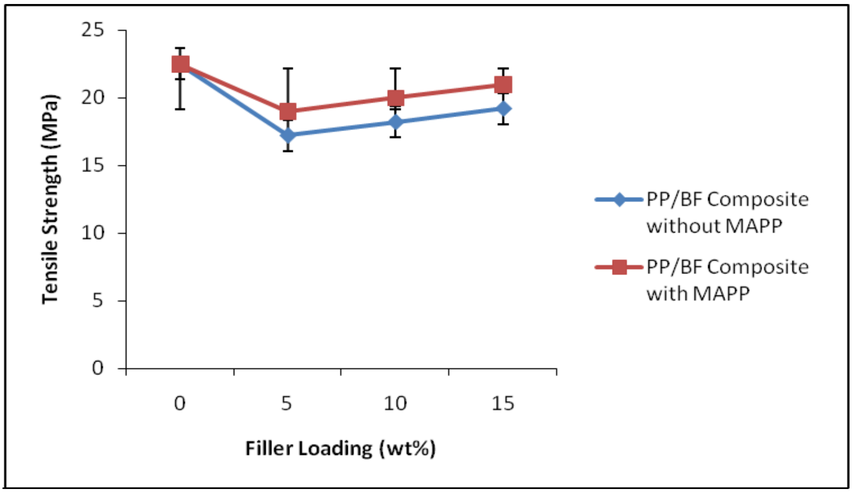


Figure 1. The effect of filler loading on tensile strength of coupled and uncoupled PP/bagasse fiber composites.

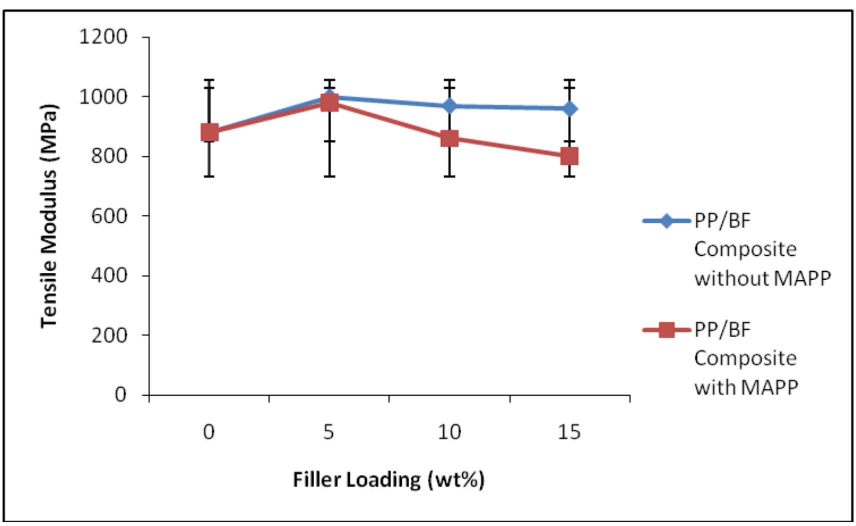


Figure 2. The effect of filler loading on tensile modulus of coupled and uncoupled PP/bagasse fiber composites.

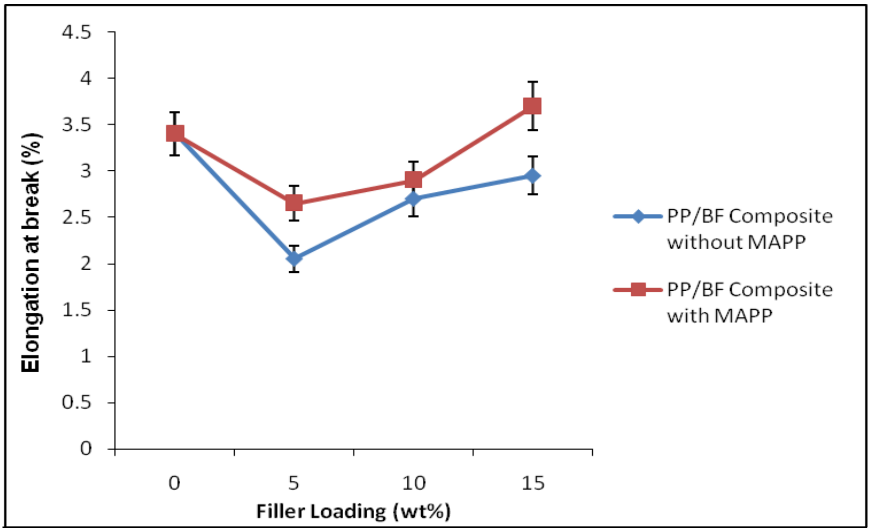
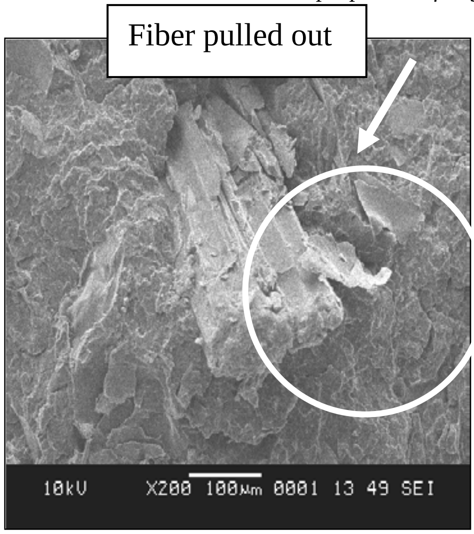
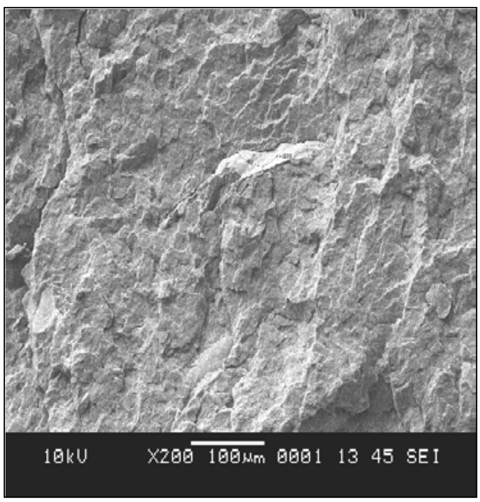


Figure 3. The effect of filler loading on elongation at break of coupled and uncoupled PP/bagasse fiber composites.

Figure 1 clearly shows the tensile strength of uncoupled and coupled composites increased with increasing bagasse fiber content. The coupled PP/BF composites showed higher tensile strength compared to uncoupled PP/BF composites. However, the tensile strength of both composite systems shows a slightly decreased in relation to the unfilled polypropylene. Filler incorporation in the polymer matrix caused an interruption in stress transferring upon the applied force. Irregularly shape fillers as in the case of bagasse fiber, were generally not be able to support stresses transferred from the polymer and thus weakened the composite material [10]. In addition, the decreasing in tensile strength causes by the poor wetting of fiber by matrix which leads to fiber-matrix debondings (see Figure 4a). PP-BF composites appeared to have slightly lower tensile strength at lower filler loading however as the filler loading was increased, the tensile strength increased. The increased strength due to the applied MAPP coupling agent are mainly based on a reduction of fiber pull-outs and less fiber-matrix debondings [1]. This should lead to less microvoids in the interphase region [18]. Furthermore, the improved fiber-matrix interface resulted in effective stress transfer [7]. Comparison between morphology of coupled and uncoupled PP/BF composite is shown in Figure 4. The morphology of 90%PP-10%BF composite without MAPP (Figure 4a) showed fiber pull-out as a result of poor wetting of fiber by matrix while the morphology of 90%PP-10%BF with MAPP (Figure 4b) shows better wetting of fiber by matrix.



(a)



(b)

Figure 4. SEM micrographs of (a) 90%PP-10%BF composite without MAPP (b) 90%PP-10%BF composite with MAPP at magnification 200x.

Tensile modulus is a measure of the stiffness of a component. The incorporation of 5wt% bagasse fiber in PP matrix resulted in a slight increment in tensile modulus. This is a common phenomenon, i.e. filler addition results in greater modulus. However, the lowering of stiffness for PP/BF composites can be observed by increasing the filler content. There are many factors affecting the modulus of the composites. Those factors are filler content, modulus of the filler, filler aspect ratio and processing. During processing, fibers move and rotate with the flow of the polymer matrix, which inevitably changes their orientation state and affects the properties of the composite material [17]. The elastic moduli of fibers, for instance are expected to increase with increasing degree of molecular orientation [10]. In addition, the higher content of fiber with fibrils structure might have induced plastic deformation in the matrix, and consequently produces the reductions in stiffness. Figure 2 also indicated the coupled PP/BF composites showed lower modulus value compared to the uncoupled composites.

The effect of bagasse fiber content on elongation at break of uncoupled and coupled bagasse fiber filled PP matrix is illustrated in Figure 3. The elongation at break for the PP/BF composites show lower value compared to unfilled PP, except for the system with 15% treated bagasse loading. Commonly, the addition of filler into the polymer matrix subsequently induces an increase of their brittleness, thus decrease the elongation at break. However, the result showed that elongation at break increases steadily with increasing bagasse fiber content in both coupled and uncoupled composites. According to Mohanty et al., in natural fiber filled polymer system, the critical load for damage initiation is not only dependent on the quality of the fiber matrix adhesion; it is also significantly affected by fiber content and fiber size. Bagasse fiber used in this research considered as short fiber (size range of 2.0 mm to 2.8 mm). In the case of short fiber, the stress on fibers may difficult to reach its breaking stress as a result of short transfer length. The propagating micro crack can be effectively deflected. Composite with low fiber loading (5%) are not assisting in increasing the ductility of the composites due to lack of short fiber distribution in the matrix but when the fiber content increased up to 15%, better distribution of fiber result in somewhat higher ductility and elongation at break. As expected, elongation at break of treated bagasse fiber composites show higher value compared to untreated composites.

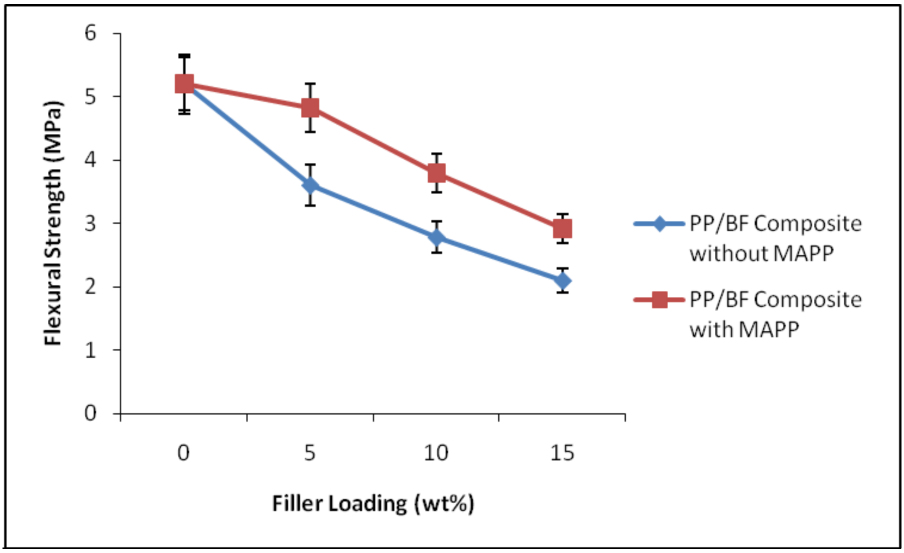


Figure 5. The effect of filler loading on flexural strength of coupled and uncoupled PP/bagasse fiber composites.

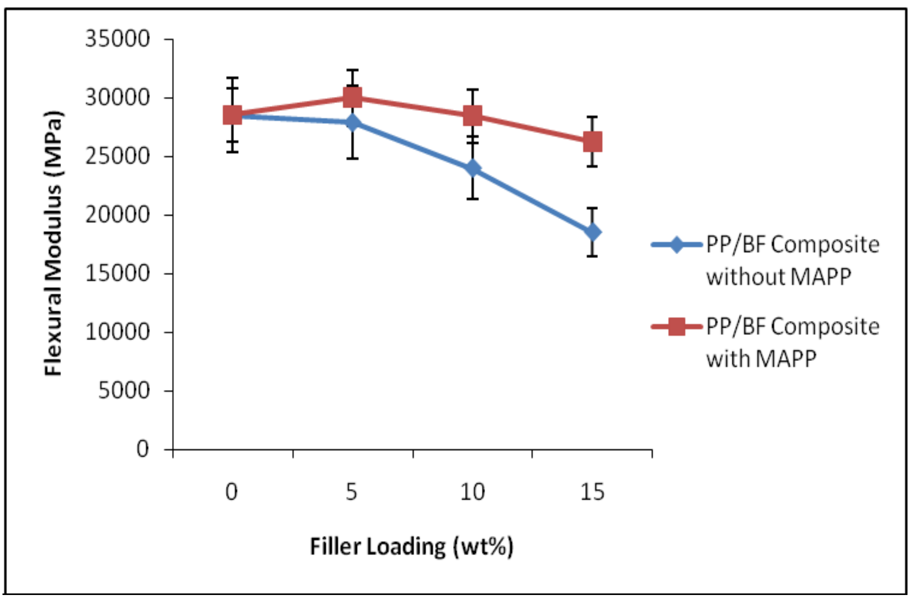


Figure 6. The effect of filler loading on flexural modulus of coupled and uncoupled PP/bagasse fiber composites.

The effect of fiber content on flexural strength of PP/BF composites is shown in Figure 5. Flexural strength decreased with an increase in filler loading, which is in contrast to the case of tensile strength where the increment can be seen. The difference is attributed to the difference in loading mode and the subsequent damage and failure modes. The brittle failure mode of this bagasse fiber under flexural load is quite different from failure mode observed in tensile tests. It is believed that splitting of fibril in the bagasse fiber under tensile loads 'adds' toughness and strength to the bagasse fiber and therefore to the composite. Result also indicates that, treated PP/BF composites performed higher flexural strength compared to untreated PP/BF composites. A stronger treated composite implies an improved interfacial adhesion between the filler and the matrix.

From Figure 6 indicates the flexural modulus for PP/bagasse fiber composites decreased in relation to the unfilled polypropylene, except for 5wt%BF-filled composite. Besides, the flexural modulus for both treated and untreated PP/BF composites decreased with increasing filler loading. However, the flexural modulus for treated PP/bagasse fiber composites much higher than untreated one. A stiffer treated composite implies an improved interfacial adhesion between the filler and the matrix.

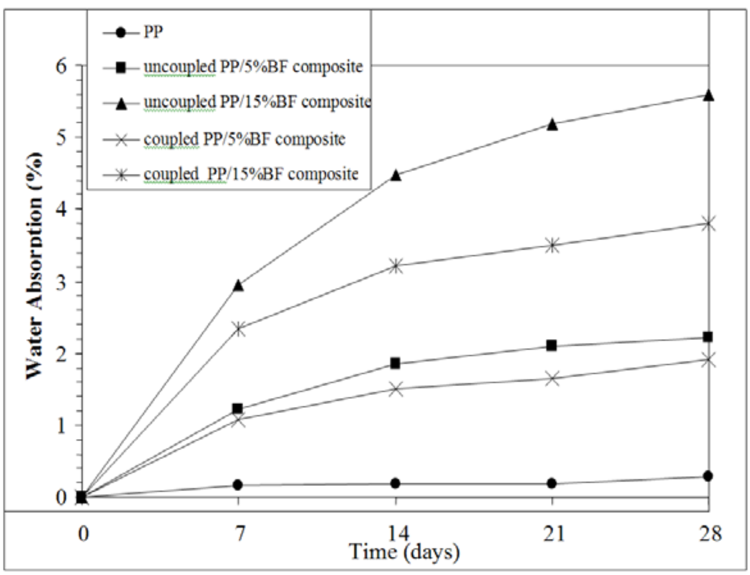


Figure 7. Percent of water absorption versus time for unfilled PP and PP/bagasse 190 fiber composites.

Figure 7 showed percent of water absorption versus immersion time curves for unfilled PP and PP/BF composites. Polypropylene resin, which is hydrophobic in nature showed lower swelling rate than the composites. The addition of hydrophilic fiber in PP matrix increased the water absorption rate for the system. Bagasse fiber, which contains cellulose, can absorb the water. Initially, water saturates the cell wall of the bagasse fiber, and next, water occupies void spaces [18]. Therefore, higher filler content may generate more possibility for water to diffuse into the composites. Overall, coupled PP/BF composites showed lower water absorption rate compared to uncoupled PP/BF composites. The presence of MAPP reduced the cellulose exposure to water, as a result of better wetting of filler by matrix, hence reduced the swelling of PP/BF composite. For uncoupled polypropylene composites, the higher percentage of water absorption means higher water uptake ability thus makes it easier to reduce the physical bonding with the matrices. In the other hand, coupled PP/BF composites keep physical bonding stronger than the uncoupled one. When subject to mechanical properties, coupled PP/BF composites are expected to show better tensile and flexural properties.

CONCLUSION

The increasing of bagasse fiber content up to 15% by weight has ability to increase the strength and toughness of the PP/BF composites. Use of 3% (by mass) MAPP in PP matrix results in moderate improvement in tensile strength and elongation at break of PP/BF composites, while substantial improvement in flexural strength and modulus of PP/BF composites are seen. The presence of MAPP also has improved water absorption resistance in the PP/BF composites.

ACKNOWLEDGEMENT

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