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doi:10.4028/www.scientific.net/AMM.815.111

Mechanical Properties of Short Fiber and Non-Woven Kenaf Reinforced Polypropylene Composites: Effects of Oil Palm Shell Powder Addition

Mohd Abrar Abd Latif[1,a], Mohd Edeerozey Abd Manaf[2,b], Loganarrth Maslamany, Muhammad Syafiq Mohd Hussain and Noraiham Mohamad[3,c]

[1,2,3]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia.

[a]m051410022@student.utem.edu.my, [b]edee@utem.edu.my, [c]noraiham@utem.edu.my

Keywords: oil palm shell, kenaf fiber, polypropylene composite

Abstract: Kenaf is renowned for its renewable and environmental friendly properties. Recently, there is an interest on the application of kenaf-based material for high-end uses such as in the automotive industry. In this study, the effects of oil palm shell powder (OPSP) addition on the mechanical properties of kenaf reinforced polypropylene (PP) composites are investigated. Two types of kenaf are used in this study, i.e., non-woven and short fiber. For the former, the composites are fabricated by hot pressing a non-woven kenaf sheet sandwiched by thin PP sheets which have been mixed beforehand with OPSP by using internal mixer. For the latter, kenaf short fibers are mixed with OPSP using internal mixer, then compression molded by using hot press. In general, addition of OPSP was effective to improve the mechanical properties of non-woven kenaf reinforced PP composites, while the kenaf short fiber reinforced PP showed varied results. Composites reinforced with non-woven kenaf showed a larger increase in tensile strength, elongation at break and impact strength with the OPSP addition than those reinforced by kenaf short fibers.

Introduction

As industries attempt to minimize the dependence on petroleum-based materials and products, there is an increasing need to investigate more sustainable materials to replace the synthetic fiber reinforced materials. For example, in automotive industry natural fiber reinforced plastic composite has been considered as a potential material to decrease the vehicle weight and also improve fuel efficiency. Natural fibers such as jute, hemp and kenaf are not only renewable, cheap and degradable, but they also offer other advantages such as low density, comparable specific strength, reduction in tool wear, less energy of production and carbon dioxide (CO_2) neutrality, which make them eligible as a replacement for synthetic fibers [1].

Natural fiber reinforced thermoplastic composites have been widely studied in an attempt to obtain benefit from the cost and mechanical properties of these natural fibers. Kenaf fiber shows strength/weight ratio comparable to the traditional materials such as glass and Aramid [2]. It is shown that increasing fiber weight fraction in kenaf/PP composite increases ultimate strength, tensile modulus, and impact strength.

In non-woven kenaf/polypropylene composite, kenaf fiber become a dominant material and most load-bearing component since up to 50 wt% of kenaf can be incorporated. Hence, allows more environmentally friendly composites to be produced due to the higher content of natural fiber in the composite [3]. On the other hand, kenaf in short fiber form gives advantages such as more environmental friendly and lower cost. However, kenaf short fibers are shorter and thicker, thus creating a poor slimness proportion, which thus reduces tearing resistance drastically. This is because the short fibers do not deliver great surface contact and also fiber-to-fiber bonding [4]. In general, plant-derived fibers and fillers show poor compatibility with matrix polymer due to polarity different between hydrophilic natural fillers and hydrophobic polymers. In order to improve the compatibility

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with the matrix polymer, various methods have been applied such as filler modification through alkaline treatment [5] or silane treatment [6], as well as the use of coupling agents [7].

Oil palm shell is one of the wastes produced from palm oil mill and approximately 6.89 million tons of OPS are produced annually. [8] It has been studied as a replacement to replace conventional aggregates in structural elements and road construction utilizing its low density with the potential to remarkably reduce the cost [9]. Olumuyiwa et al. [10] studied the effect of OPS particle sizes (150, 300 and 400 μm) on the mechanical properties of recycled polyethylene composite. They reported that composites with the smallest OPS size showed the highest values of tensile strength, hardness, and impact energy. However, tensile and impact strength was found to decrease when the amount of OPS particle is above 5 wt%.

Utilization of OPSP as biofiller potentially gives an added-value to it, as well as reduces the cost of the composite. However, relatively little work has been carried out on the development of thermoplastic composites reinforced with OPSP. In this study, effects of OPSP addition on the mechanical properties of PP reinforced with kenaf fiber with two different forms, i.e., non-woven and short fiber are investigated.

Experimental

Materials

Kenaf fibers in short and non-woven form were supplied by Kenaf Natural Fiber Industries Sdn. Bhd. The non-woven sheets used in this study were made from chemically treated kenaf fibers. The oil palm shells were obtained from Jugra Oil Palm Sdn. Bhd. The polypropylene (PP) was purchased from Polypropylene Malaysia Sdn. Bhd. The coupling agent used in this experiment, maleic anhydride grafted polypropylene (MAgPP) was produced by Sigma Aldrich.

Sample Preparation and Testings

Oil palm shells were crushed and subsequently pulverized by using Variable Speed Rotor Mill Pulverisette (FRITSCH) to obtain oil palm shell powder (OPSP). The particle size for the OPSP was approximately 45 μm. The amount of OPSP was varied at 0, 5, 10, 15 per hundred compound (phc), while the composition of kenaf/PP was fixed at 30/70 wt%. The formulations for the composites used in this study are shown in Table 1. The amount of MAgPP used was 3 phc.

Table 1. Formulations of the OPSP/kenaf/PP composites.

Fiber forms	Kenaf (wt%)	PP (wt%)	OPSP (phc)	MAgPP (phc)
Non-woven, Short fiber	30	70	0	3
	30	70	5	3
	30	70	10	3
	30	70	15	3

Fabrication of composite samples was carried out through melt mixing and hot compression molding processes. The procedures used were slightly different between the composites reinforced with non-woven kenaf sheet and those reinforced with kenaf shor fibers. For the former, copression molding was performed by sandwiching kenaf non-woven sheet between two OPSP filled PP sheets. The OPSP/PP sheets were prepared by melt mixing using internal mixer at 180 °C for 10 min, followed by extrusion and lastly, compression moulding. The composites with kenaf short fibers were prepared by compression molding of palletized OPSP/kenaf/PP mixture. For compounding the OPSP, kenaf and PP, melt mixing was used followed by extrusion. The extrudites were crushed to obtain OPSP/kenaf/PP pallets, which were hot compressed to obtain the composite samples. Prior to compression, the composite was preheated for 10 minutes. Then, the composite was compressed for

10 min at 180 °C and 10 MPa. Subsequently it was let to cool at room temperatures, before being cut into standard samples.

Tensile test was performed using Universal Testing Machine according to ASTM D638. Izod impact test was performed using pendulum impact tester according to ASTM D256. For each composition, five measurements were carried out, and the average value was recorded.

Result and Discussion

Tensile Properties

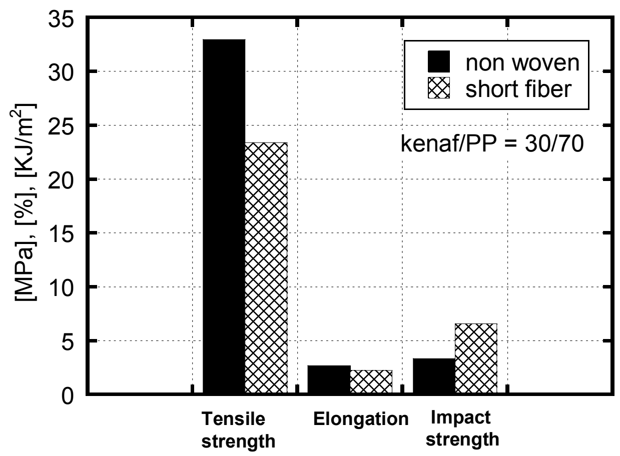

Fig. 1.Values of tensile strength, elongation at break and impact strength for kenaf/PP (30/70) composite without OPSP addition

The values of tensile strength (MPa), elongation at break (%) and impact strength (kJ/m^2) for kenaf/PP composite prior to OPSP addition are shown in **Fig. 1**. It is clear that PP reinforced with non-woven kenaf shows superior tensile strength as well as elongation at break, compared to that reinforced by kenaf short fiber. As shown in **Fig. 2(a)**, tensile strength increases with the addition of OPSP in both types of composites. The tensile strength for the non-woven composite shows an increase of up to 25% for 15 phc of OPSP, while for the short fiber composite, the increase is smaller at 5%. The result indicates that addition of OPSP is more effective to increase the value of tensile strentgh in non-woven kenaf reinforced PP composite than in kenaf short fiber reinforced PP.

This fairly good increase in tensile strength may be attributed to the better filler-matrix interaction and geometry of the OPSP fillers. As the size of OPSP used is sufficiently small, the outcomes obtained are in same reaction as other particulate filler behavior. For regularly shaped fillers, the strength of the composites increases due to the ability of the filler to support stresses transferred from the polymer matrix. A good filler distribution also could be one of the factors that contribute to the increase in tensile strength.

Kenaf short fiber reinforced PP composite shows a decrease in elongation at break with the increase of OPSP content as shown in **Fig. 2(b)**. Reduction in elongation as observed here is commonly observed in various filled polymer systems. It is due to the decreased deformability of a rigid interphase between the filler and matrix polymer [11]. As the amount of OPSP increases, the fraction of thermoplastic polymer decreases and interfacial area increases. These lead to increased brittleness as reflected in reduction of elongation. The increase of elongation at break with the increase of OPSP filler as demonstrated in non-woven kenaf/PP is rather unusual phenomenon. This is perhaps due to the strong interfacial bonding between the non-woven kenaf fiber and the matrix. The presence of MAgPP coupling agent helps the OPSP to be unified with the well-bonded non-woven kenaf/PP system. Thus, contributes to the increase in elongation at break.

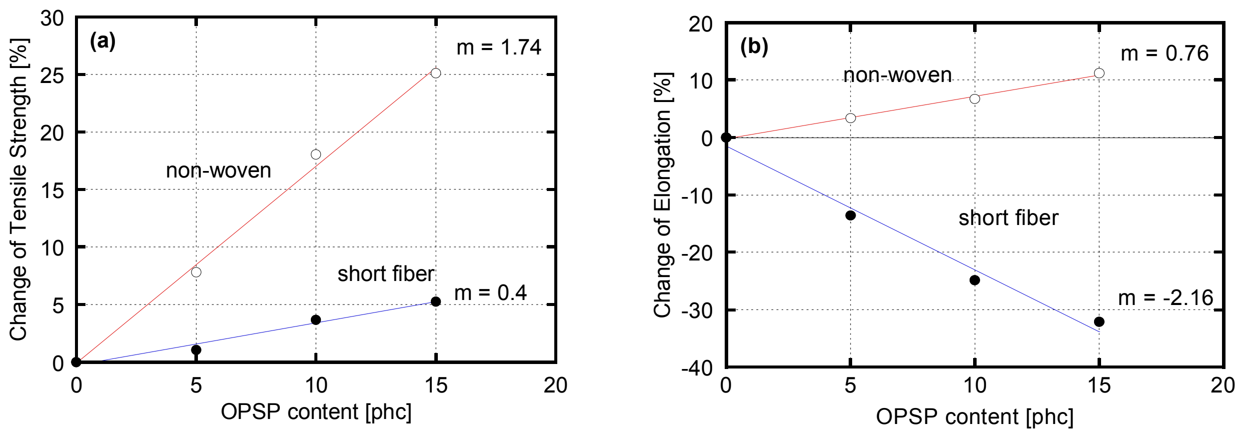

Fig. 2. Percentage of change in (a) tensile strength and (b) elongation at break with OPSP content

Impact Properties

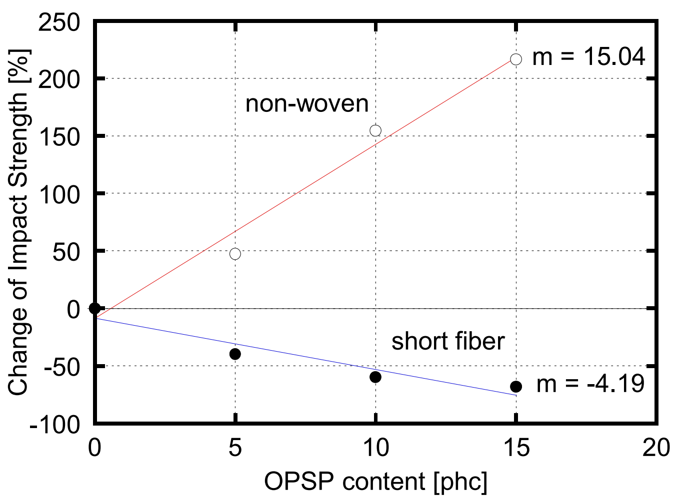

Fig. 3. Percentage of change in impact strength with OPSP content

Prior to OPSP addition, PP reinforced with kenaf short fiber shows higher impact strength than non-woven kenaf reinforced PP (refer to **Fig. 1**). However, with the OPSP addition, impact strength in non-woven composite samples demonstrates a significant increase, i.e., more than 200% at 15 phc of OPSP. This may be as the result of better bridging formed by the OPSP, PP and kenaf shape (non-woven) and its texture. On the other hand, the adverse result is observed in the short fiber composite, which shows a decrease of about 75% with 15 phc of OPSP addition as shown in **Fig. 3**.

This might be due to the irregularity in short fiber shape that may affect their capabilities to support stress transmitted from the PP matrix to the kenaf fiber. The results of impact strength reflect the results obtained for the elongation at break. In addition, effects of OPSP addition on the impact property in the short fiber composite could be due to the immobilization of the macromolecular chains by the OPSP filler, and the ability to adapt to the deformation is somewhat limited, thus it makes the material more brittle. Moreover, each OPSP particle can start a microcrack inside the composite because of bonding imperfection that exists between OPSP filler and PP matrix [12].

Conclusion

The effects of OPSP addition on the mechanical properties of two types of kenaf/PP composites are compared. Prior to OPSP addition, composites reinforced with non-woven kenaf produce higher tensile strength and elongation at break than those reinforced with kenaf short fibers. Oil palm shell powder is found to be effective as reinforcing filler in kenaf/PP composite as demonstrated by the increase in the tensile strength value. Furthermore, the effect is found to be more significant in the PP reinforced with non-woven kenaf, which demonstrates an increase in tensile strength, elongation at break as well as impact strength with OPSP addition.

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