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Effect of Alkaline Treatment on Tensile Properties of Low Density Polyethylene/Bean Sprout Skin Composites

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ABSTRACT

This study the effect of alkaline treatment on the tensile properties of LDPE/BSS and LDPE/BSS$_{NaOH}$ composites at various loadings (5–25 phr). The composites were fabricated through a Z-blade mixer and compressed at the temperature of 160^{o}C. The tensile strength increased with filler loading up to 15 phr but decreased at 20 phr due to filler agglomeration. Alkali treatment enhanced filler-matrix adhesion, resulting in higher tensile strength and Young's modulus for LDPE/BSS$_{NaOH}$ composites. Elongation at break decreased with filler content, indicating improved stiffness but reduced ductility. The findings highlight the role of filler loading and surface treatment in optimizing mechanical performance, offering insights for developing high-performance, sustainable polymer composites.

Keywords: Low density polyethylene, Bean sprout skin, Bio-fillers, Alkaline treatment.

1. INTRODUCTION

The demand for sustainable and high-performance materials has driven extensive research into polymer composites reinforced with natural fillers. Natural fillers, such as fibers and agricultural residues, offer numerous advantages, including biodegradability, low cost, and wide availability [1]. However, natural fillers are inherently incompatible with hydrophobic polymers such as LDPE, which limits their efficiency without surface modifications. Elfaleh et al. (2023) reported that the hydroxyl groups in lignocellulose make them incompatible with hydrophobic thermoplastics and susceptible to moisture damage [2]. Therefore, the incorporation of natural fillers into polymer matrices requires careful optimization and surface treatment to achieve desired mechanical properties, such as tensile strength, Young's modulus, and elongation at break. The growing demand for sustainable materials has positioned natural fiber polymer composites as a prominent focus in research.

Surface modification of fillers, such as alkaline treatment, is one of the methods to improve the interfacial adhesion between the filler and polymer matrix. This treatment removes impurities, such as lignin, hemicellulose, and waxes, from the filler surface, resulting in better compatibility and stress transfer efficiency [3]. Previous studies have shown that alkali-treated fillers lead to composites with improved mechanical properties compared to untreated fillers [4-6]. Besides, [7] reported the alkali treatment improves fiber-matrix interfacial adhesion, therefore reducing the mobility of the polymer chains and promoting better stress transfer from the filler to the matrix in the composites.

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This study investigates the mechanical properties of LDPE composites reinforced with untreated (BSS) and alkali-treated (BSS_{NaOH}) fillers. Specifically, the tensile strength, Young's modulus, and elongation at the break of the composites were evaluated at various filler loadings (5 to 25 phr). The influence of filler loading and surface treatment on the composite's mechanical behavior is discussed in detail. The findings provide valuable insights into the role of filler-matrix interactions in optimizing the performance of natural fiber-reinforced polymer composites.

2. MATERIAL AND METHODS

2.1 Materials

In this research, low density polyethylene (LDPE) was used as the matrix of LDPE/BSS composites. LDPE pellets were purchased from Lotte Chemical Titan (M) Sdn Bhd, Johor, Malaysia. Bean sprout skin (BSS) was used as the reinforcement filler for the composites. The BSS was collected in the wet market at Kaki Bukit, Perlis, Malaysia. Sodium hydroxide, NaOH with molecular weight of 40 g/mol was purchased from HmbG Chemicals.

2.2 Preparation of LDPE/BSS Composites

In raw material preparation, some remaining BSS was separated from the bean sprouts after collecting from the wet market Kaki Bukit, Perlis, Malaysia. After that, BSS was cleaned using tap water and dried under sunlight. After fully dried under the sunlight, the BSS was placed into an oven at 105 °C for eight hours to eliminate the remaining moisture. Then, the fully dried BSS was ground and sieved to get the size of 100 µm.

2.3 Alkaline Treatment on BSS with Sodium Hydroxide

BSS was put into a beaker containing 5% of NaOH solution and soaked for one hour to remove any dirt or impurities from the BSS surface. After soaking, BSS was washed using distilled water several times until the pH of the water became 7. The BSS_{NaOH} (BSS treated with NaOH) was dried in the oven at 70 °C for 24 hours to remove moisture resulting from the soaking.

2.4 Compounding of LDPE/BSS and LDPE/BSS_{NaOH} Composites

LDPE/BSS (low density polyethylene/bean sprout skin) and LDPE/BSS_{NaOH} (low density polyethylene/NaOH treated bean sprout skin) composites were compounded using Z-blade mixer. The temperature of the Z-blade mixer was set at 160 °C with a rotor speed of 50 rpm. LDPE pellets were loaded first into the compounding chamber. After the LDPE pellets became softened, BSS was introduced into the compounding according to the formulation in Table 1. The compounding was continued for 10 minutes until the mixture became homogenous. The same steps were done on LDPE/BSS_{NaOH} composites where the BSS was replaced with BSS_{NaOH} filler.

Table 1: Formulation of LDPE/BSS and LDPE/BSS_{NaOH} Composites.

Materials	LDPE/BSS Composites	LDPE/BSS_{NaOH} Composites
LDPE (phr)	100	100
BSS (phr)	5,10,15,20	-
BSS_{NaOH} (phr)	-	5,10,15,20

2.5 Compression of LDPE/BSS and LDPE/BSS_{NaOH} Composites

After compounding, samples of LDPE/BSS and LDPE/BSS_{NaOH} composites were compressed using a Hot-Press machine at the temperature of 160 °C for 15 minutes. The preheat time was 4 minutes, fully compressed for 6 minutes, and cooled for 4 minutes to get the composites in the sheet form. Then, LDPE/BSS and LDPE/BSS_{NaOH} sheets were cut into dumbbell shaped after the compression process.

2.6 Test and Characterization

2.6.1 Tensile Properties

The tensile properties of LDPE/BSS and LDPE/BSS_{NaOH} composites were obtained from the tensile test using Shimadzu's 50 kN AG-X plus series universal testers equipped with Trapezium X software. Tensile strength, Young's modulus and elongation at break were obtained from the tensile test according to ASTM D-638 with the crosshead speed of 50 mm/min. Three tensile properties such as tensile strength, Young's modulus and elongation at break of LDPE/BSS and LDPE/BSS_{NaOH} composites were discussed.

3 RESULTS AND DISCUSSION

3.1 Tensile Properties of LDPE/BSS and LDPE/BSS_{NaOH} Composites

Figure 1 shows the tensile strength of LDPE/BSS and LDPE/BSS_{NaOH} composites. For LDPE/BSS and LDPE/BSS_{NaOH} composite, the tensile strength increased as the BSS filler was added from 5phr to 15phr filler loading, followed by a significant decrement at 20phr filler loading. The increment of tensile strength for both composites was due to the BSS fillers that resist the crack propagation in the structure of the composites. Ramesh et al. (2022) reported the tensile strength of the natural fiber reinforced composites was influenced by the filler amount. They discussed the high performance of composites was attributed to the high amount of filler where the effective distribution of stress from the matrix uniformly to filler can make the composites [8]. Erana (2024) also found out the tensile strength increased as the concentration of sisal fibre increased in the sisal fibre reinforced polypropylene [9]. However, at high filler loading particularly at 20phr, high filler loading tends to promote filler-filler interaction rather than filler-matrix interaction, therefore agglomeration tends to happen. The weak filler-matrix interaction due to agglomeration could prevent the efficiency of stress transfer from the filler to the matrix when tensile load is applied to the composites [10].

The tensile strength of LDPE/BSS_{NaOH} composites was higher due to the good adhesion and better interaction compared with LDPE/BSS composites. This was mainly caused by the removal of the dirt and impurities on the surface of the BSS filler, thus enhancing the interaction and adhesion, promoting better filler-matrix interaction, thus improving the tensile strength. Ismail et al. (2021) showed that a clean surface and no impurities were observed for kenaf fibre after the alkaline treatment [11]. Besides, Verma and Goh (2021) reported strong adhesion can be generated on alkali-treated natural fibre with matrix due to the removal of impurities like lignin, hemicellulose, pectin and waxes from the fibre, thus surface roughness and surface area increased, therefore increased the tensile strength [12].

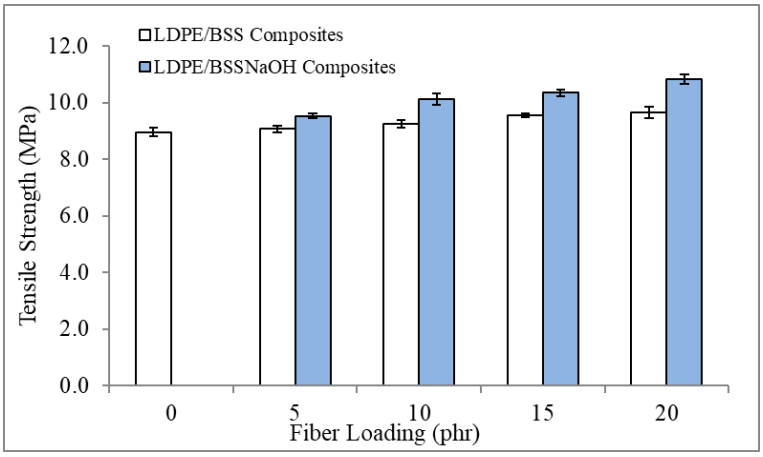

Figure 1: Tensile strength of LDPE/BSS and LDPE/BSS_{NaOH} composites at different filler loadings.

The Young's modulus of LDPE/BSS and LDPE/BSS_{NaOH} composites at different filler loading is presented in Figure 2. The tensile strength of both composites increased with the addition of BSS and BSS_{NaOH} from 5-25 phr. This was due to the BSS being stiffer and having higher rigidity compared to the LDPE matrix. Mahdi and Dean [13] found that Young's modulus was increased directly proportional to the fiber loading due to the stiffer characteristics of the filler than the matrix. In the same filler loading, LDPE/BSS_{NaOH} composites indicated higher Young's modulus in comparison to LDPE/BSS composites. The same finding was reported by Hosseini et al. (2023) alkaline treatment on natural fibre significantly improved Young's modulus of the composites due to the improvement of compatibility between filler and matrix after the removal of surface impurities [14].

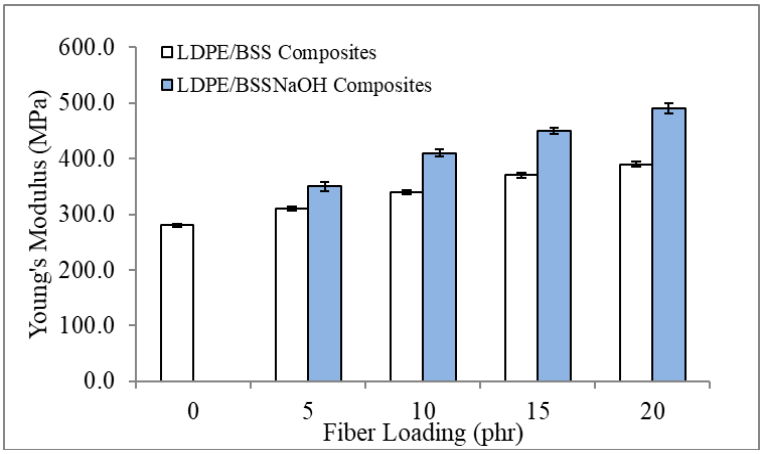

Figure 2: Young's modulus of LDPE/BSS and LDPE/BSS_{NaOH} composites at different filler loading.

Figure 3 shows the elongation at the break of LDPE/BSS and LDPE/BSS_{NaOH} composites at different filler loading. The elongation at break of alkaline treated and untreated LDPE/BSS composites reduced as the filler loading increased. The presence of BSS and BSS_{NaOH} has greatly improved stiffness and reduced the ductility of the composites. Besides, the decrement of elongation at break, was also caused by the good dispersion and interaction between BSS and BSS_{NaOH}, which led to a uniform stress distribution in the composite's structure. Yadav et al. (2023) discussed the ductility of composites was greatly influenced by the filler content [15]. As more natural fibers were added to the composites, the rigidity of the composites was improved, but the ductility of the composites was restricted by the presence of fibers. LDPE/BSS_{NaOH} composites possessed a lower percentage of elongation at break in comparison to LDPE/BSS composites at any fiber loading. BSS_{NaOH} has better surface roughness and more interaction with

LDPE as compared to BSS due to the removal of impurities. Better interaction promotes more uniform fiber distribution and adhesion between fiber and matrix, thus improving the ductility of the composites [16].

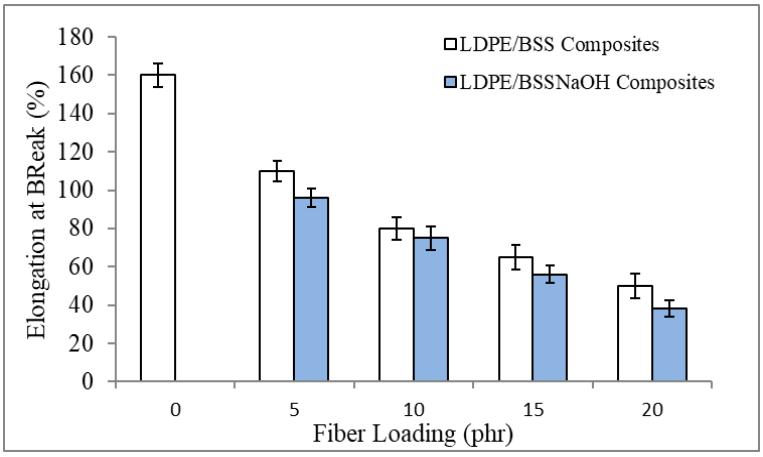

Figure 3: Elongation at break of LDPE/BSS and LDPE/BSS_{NaOH} composites at different filler loading.

4 CONCLUSION

The addition of BSS fillers significantly influenced the mechanical properties of LDPE/BSS_{NaOH} composites, with alkali-treated BSS_{NaOH} composites showing superior performance of tensile properties compared to untreated BSS composites. The tensile strength increased with filler loading up to 15 phr due to improved stress distribution and crack propagation resistance but decreased at 20 phr due to filler-filler interactions and agglomeration. The Young's modulus increased consistently with filler loading, with higher values observed for LDPE/BSS_{NaOH} composites. The increment was due to better filler-matrix adhesion and the removal of surface impurities through alkaline treatment. However, the elongation at break decreased with increasing filler content for both composites, reflecting reduced ductility as fillers increased stiffness and restricted matrix deformation. Alkaline treatment improved mechanical properties by enhancing filler dispersion, interfacial adhesion, and compatibility with the LDPE matrix, making BSS_{NaOH} composites more effective reinforcements.

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