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Assessment of Mechanical Properties of Hybrid Composites Based on Polypropylene and Vegetable Fibers

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A B S T R A C T

This research aim at developing hybrid composites from natural fibers with improved mechanical properties targeted in applications where high strength to weight ratio is required. In this work, Homopolymer Polypropylene (PP) was used as matrix material while coconut (cocos nucifera) and sponge (luffa cylindrica) fibers were used as reinforcing material to produce hybrid composites and to evaluate their mechanical properties such as tensile and flexural properties. Selected fibers were locally sourced and extracted. Composites was developed by initially treating the fibers in one molar concentration of sodium hydroxide (NaOH) before mixing in predetermined proportion with polypropylene matrix using coconut/sponge fibers of 2/8, 4/6, 6/4 and 8/2 wt %. The development of hybrid composites was carried out by heating compression moulding technique. From the result of the mechanical properties that were performed on the samples, hybrid composite samples show the highest flexural and tensile strength when compared to monolithic composite samples. Furthermore, all the composites gave better results when compared to the unreinforced PP sample.

1. Introduction

Hybrid composites are made by combining two or more dissimilar fibers in a common matrix to givesuperior properties that are not exhibited by the single fiber reinforced composites. Hybridization of two types of short fibers having different lengths and diameters offers some advantages over the use of either of the fibers alone in a particular polymer matrix (Madhukiran et al., 2013). Recently, hybrid composites produced by combining two or more different natural fibers demonstrate good mechanical performance (Critistiane et al., 2009;Chandramoha et al., 2011;Ahmed et al., 2007).

Polymer composites consisting hybrid reinforcement of different natural fibers are less common, but are also prospective useful materials with respect to environmental issues (Idicula et al., 2006). The mixture of fibers like core, sponge, sisal, kenaf, flax, oil palm, industrial hemp, jute and pineapple leaf fiber with polymer matrix to produce composite materials that can replace conventional synthetic composites is gaining attention of researcher all over the world (Agbabiaka et al., 2014;Saira et al., 2007). The key parameters that affect the mechanical properties of composites are fiber length, weight ratio, fiber orientation and interfacial adhesion between fiber and matrix (Madhukiran et al., 2013;Brahim et al., 2006). In search for new materials, coconut and sponge fibers were reinforced with polypropylene to produce hybrid and monolithic composites with the intention of comparing their mechanical properties.

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Coconut and sponge fibers are thick and coarse but durable fibers. They are relatively water-proof and has resistant to damage by salt water and microbial degradation (Jochen et al., 1999;Saw et al.,2013;Ray et al., 2001;Mukherjee et al., 1984). However, investigating the mechanical properties of the natural fiber is of the essence. This is why fiber reinforced composites are useful for certain applications that satisfy their characteristic requirements such as strong, rigid, light weight, environmental friendly materials. For this reason, a lot of effort has been targeted to improve the performance of the fiber reinforced composites (Joshi et al., 2004;Jarukumjorn et al., 2004; Jacob et al., 2004;Maries et al., 2005).

Natural fibers used in this work are coconut and sponge fibers and were treated with sodium hydroxide (NaOH) to modify fiber surfaces so as to improve the adhesion between the fibers and polymer matrix and also to enhance fiber strength. The treatment also eliminates fiber intramatrix (lignin and hemicelluloses) (Agbabiaka et al., 2014;Ghali et al., 2011). Tensile and flexural properties of hybrid and monolithic composites developed were investigated using universal testing machine.

2. Materials and Method

2.1 *Fiber and Matrix*

Sponge (luffa cylindrica) was gotten from the stem of the plant obtained from farm plantation after which the fiber was extracted by mechanical decortication. The inherent properties of the sponge fiber are given in Table 1. Coconut (cocosnucifera) fiber is a fruit fiber extracted from its husk by mechanical decortications after the edible part has been removed.

The chemical used for modifying fiber surface was sodium hydroxide (1 M NaOH) supplied by Pascal scientific limited, Akure, Nigeria. The matrix used for this work was homopolymer polypropylene supplied by Eurochemicals, Lagos, Nigeria. The typical properties of the polymer are shown in Table 2.

2.2. Fiber Preparation and Treatment

Selected fibers were cut into 10 mm length with the aid of scissors before treatment was carried out. The fibers weighed 60 g and were immersed in beaker that contains 1 M NaOH solution and was conditioned for 4 hours at 50 0C in a shaker water bath (DKZ series), produced for Pascal scientific limited. Afterwards, the treated fibers were removed and washed with tap and distilled water to obtain pH 7.0 followed by sun drying for 5 days.

2.3. Development of Composites

The composites were developed by random distribution of short fibers in the polymer matrix. The fibers were mixed with polypropylene in the moulds in predetermined proportions as shown in Table 3 before taking to compression moulding machine operated at 160°C maintained for 10 minutes to produce hybrid and monolithic composites. The composites developed in flexural and tensile moulds were allowed to cool before detaching them from the moulds. The flexural mould has a thickness of 150 x 50 x 3 mm while the tensile mould has a dog-bone shape of 3 mm thick. Three samples each were produced and tested for the various compositions developed.

2.4. Mechanical Testing

Flexural and tensile tests were examined using testometric universal testing machine in accordance with ASTM D790 and ASTM D412 standards. Flexural test was performed at the speed of 100 mm min-1 while tensile test was carried out at a fixed crosshead speed of 10 mm min-1.

3. Results and Discussion

3.1 Fleural Test

The flexural strength at peak results for the developed composites and the control sample (CS), as shown in Figure 1. It was observed from the graph that the composites possess better strength than the control sample. While the single fiber composites seem to have marginally performed better than the control sample, the hybrid was seen to possess the highest strength. This was made possible due to the synergetic effect of the combination of sponge and coconut fibers in the hybrid composites.

Though, the single fiber reinforced PP composite show that coconut fiber reinforced composite possess better strength property than sponge reinforced composites but it was observed that, as the amount of coconut fiber content increases in the hybrid composites, the strength tends to reduces. This means that sample with the optimum flexural strength result (4 wt % of the coconut fiber + 6 wt % sponge) is the best mixing ratio above which there will be reduction in the efficiency of the inherent potential in the combination of these fibers. It can be said that the strength of the hybrid composites increases from 2- 4 wt % followed by a decrease from 6-8 wt %.

Table 1. Physical properties of sponge (luffa cylindrica) fiber (Saw et al, 2013).

Chemical Constituents (%)		**Physical Properties of Sponge Fibers**	
Cellulose	63.0±2.5	Density (gm/cc)	0.92±0.10
Hemicellulose	20.88±1.4	Diameter (μm)	270±20
Ash	0.4±0.10	Aspect ratio	340±5
Lignin	11.69±1.2	Microfibrillar angle (^{0})	12±2

Table 2. Typical Properties of Homopolymer Polypropylene - 12MFR

Physical Properties	**ASTM Methods**	**Values**
Melt Flow (Condition) (g/10 min)	D1238	12.00 (230/2.16)
Tensile Strength @ Yield (PSI)	D638	$5.30x10^3$
Density(g/cm^3)	D1505	0.9
Elongation @ Yield (%)	D638	14
Flexural Modulus (PSI)	D790	$2.40x10^5$
Notched Izod (ft-lb/in)	D256	0.5
Vicat Softening Point (degrees F)		305
Heat Deflection Temperature	D648	219
Features:		
Excellent color, process stability, low odor, good flow & set - up		
Processing Method: Injection		

Table 3. Composition of the developed composites and control samples.

	CS	C_2SN	C_4SN	C_6SN	C_8SN	$C_{10}N$	$S_{10}N$
Coconut fibre (%)	-	2	4	6	8	10	-
Sponge fibre (%)	-	8	6	4	2	-	10
Polypropylene (%)	100	90	90	90	90	90	90

Where; C - Coconut fiber; S - Sponge fiber; N – NaOH; CS - Control Sample; CSN - Hybrid

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The flexural strength at peak for the best two samples was from hybrid sample C4SN which has the highest value of 62.78 N/mm^2 followed by hybrid sample C2SN whose value is 47.68 N/mm^2. From the analysis, it was observed that hybrid sample with coconut/sponge fibers of 4/6 wt% has a reinforcement efficiency of about 68% compared to the control sample. The response of the flexural modulus for the developed composites followed similar trend with the flexural strength at peak results with a slight difference as shown in Figure 2. It was observed that, the hybrid followed by the single fiber reinforced composites possess the best modulus compared to the control sample. Contrary to the response of the single fiber reinforced composites with the flexural strength at peak, the flexural modulus of sponge fiber reinforced composite was higher than that of coconut fiber reinforced composite.

This show that sponge fiber reinforced composite is stiffer than coconut fiber reinforced PP composite which may be part of the reasons why in both flexural strengths at peak and modulus responses, the properties tend todecrease as the sponge fiber content decreases. Though optimum results were obtained at 4/6 ratio of coconut/sponge in both cases. The results were in agreement with previous findings where hybrid usually gave better output than the single fiber reinforced composites from single fibers (Jacob et al., 2004;Mudhukiran et al., 2013). From the result, it was observed that C4SN hybrid samplegave the best result with a value of 2617.01N/mm^2 followed by C2SN hybrid sample which has a value of 2171.11N/mm2. Hence, hybridization has enhanced the flexural properties of the composites compared to single fiber reinforced composites and control sample.

Tensile Strength at peak results for the composites and control samples were shown in Figure 3. From the results, it was observed that, only the hybrid composites gave better enhancement in tensile strength at peak while the single fiber reinforced composites possess less tensile strength at peak than the control. The result showed that, tensile strength at peak reduces as the sponge content decreases. This may likely be as a result of the good stiffness potential of the sponge that was observed in both flexural and tensile moduli responses of the developed composites. The best tensile strength at peak was obtained from C2SN hybrid sample which has the highest value of 29.62 N/mm^{2}followed byC4SN hybrid sample which has a value of 24.67 N/mm^2. Although, the result shows that control sample is better than single fiber sample but the hybridization of the fibers has made the hybrid composites superior to control sample and single fiber reinforcement. For this reason, the hybridization has brought about enhancement in the mechanical properties of the composite.

Figure 4 revealed the tensile modulus results of the various samples. From the results, it was observed that the modulus tends to decreases as the sponge fiber decreases from 2/8 - 6/4 wt % ratio of coconut/sponge after which there is an increase at 8/2 wt % of coconut/sponge fibers ratio.

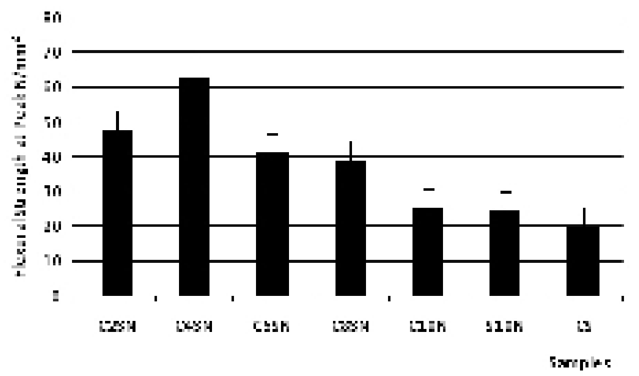

Figure 1: Plots of Variation of Flexural Strength at Peak with the developed Composites and Control Sample

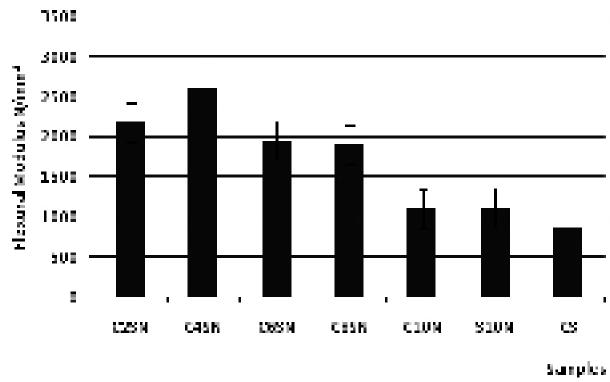

Figure 2: Plots of Variation of Flexural Modulus with the developed Composites

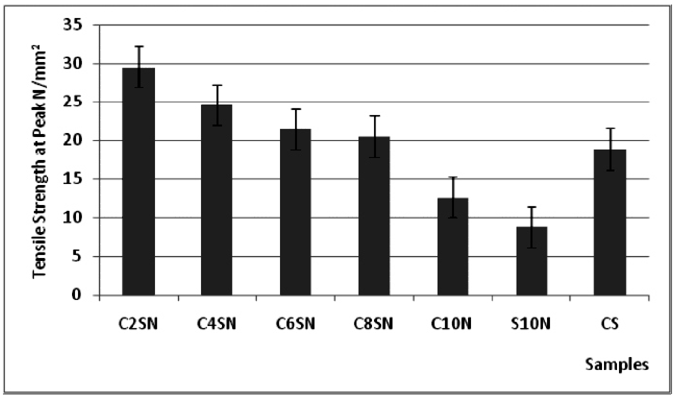

Figure 3: Plots of Variation of Tensile Strength at Peak with the developedComposites and Control Sample

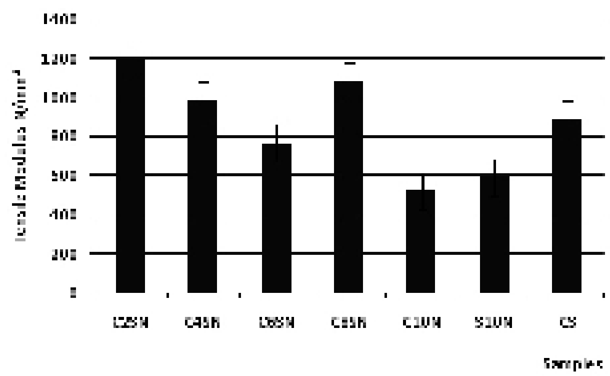

Figure 4: Plots of Variation of Tensile Modulus with the developed Composites and Control Sample.

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The reason for this may be due to either the effect of weight fraction variation, production defects or both. Production defects can occur if there is no proper bonding at the fiber/matrix interface, thereby reducing the bonding strength and the overall strength of the developed composites. The outcomes showed that C2SN hybrid sample has the best tensile modulus value of 1196.80N/mm^2 followed by C8SN with a value of 1080 N/mm^2. From the analysis, though control sample result was better than single fiber reinforced samples but hybrid sample gave the best result that culminate to reinforcement efficiency of about 50%.

4. Conclusion

Experimental studies of tensile and flexural properties of the developed monolithic and hybrid composites show that composite developed from hybrid natural fibers are potential reinforcement that can substitute synthetic fibers that are expensive and hazardous. The following conclusions can be drawn from the research conducted:

1. Flexural and tensile properties of hybrid composites based on polypropylene matrix as well as sponge and coconut fibers were highly enhanced compared to single fiber reinforced composites and control samples. Hence, hybrid composites from the combination of these selected materials are potential candidate for high strength and stiffness applications.
2. The best flexural properties was obtained from the hybrid composites with 4/6 wt % coconut/sponge ratio while best tensile properties were obtained at 2/8 wt % coconut/sponge ratio. It was observed that high content of sponge fiber enhanced composites mechanical properties.
3. Coconut fiber possesses higher flexural and tensile strength while sponge fiber possesses higher stiffness. As a result of this, higher amount of sponge fiber was observed to be present in the hybrid composite samples with the most enhanced flexural and tensile properties.

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