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EVALUATION OF MECHANICAL PROPERTIES OF POLYPROPYLENE – BAMBOO/KENAF FIBER COMPOSITES WITH NANOPARTICLE CALCIUM CARBONATE AND HINDER AMINE LIGHT STABILIZER ADDITIVES

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Abstract

This study investigated mechanical properties (tensile, flexural strength and hardness) of polypropylene composites reinforced with hybrid bamboo-kenaf fiber impregnated with calcium carbonate ($CaCO_3$). In addition to the major components, hinder amine light stabilizer (HALS) and maleic anhydride grafted (MAHgPP) were added as additives. The manufacturing of the composites was accomplished through compression molding process. In the composites preparation, bamboo and kenaf fiber ratios were varied, while part by weight of Polypropylene (PP) matrix and other additives were kept unvaried. Tensile strength of the produced bamboo/kenaf fibers reinforced PP composites ranged from 36.53 to 53.57MPa, flexural strengths ranged from 50.47 to 67.59MPa and hardness from 92.03 to 99.56 Shore A. ANOVA was used to determine the interaction between bamboo and kenaf fibers in the composites. The analysis shows Probability P value (0.000) for interaction between bamboo and kenaf fibers for tensile strength, flexural strength, hardness in the composite is less than the significant value level ($P = 0.05$). The result clearly reveals that there is significant interaction between the fibers in the composite. Composites produced using 20% bamboo and 20% kenaf fiber gave optimum mechanical properties (53.57MPa, 67.59MPa and 99.56 Shore A respectively for tensile, flexural strength and hardness) than any other percentage combination.

Keywords: Polypropylene composites reinforced with hybrid bamboo-kenaf fiber, $CaCO_3$, HALS, MAHgPP, Strength, Hardness

Introduction

Engineering materials sometimes show poor properties and would result in performance failure. The addition of additives to molecules or particles to virgin polymers can improve protection from various external agents, improve mechanical and physical properties, machinability, compatibility behaviour and performance of these materials while in service and out of service (Gatcher and Muler, 1990). However, the macroscopic structure and behavior may be changed, depending on the additive used; it may improve or reduce the basic material characteristics, its performance and durability (Bart, 2006). Notable industries like the aerospace, automobile, construction and household applications, use additive incorporation to improve polymer incorporation applicability due to their resulting changes of the polymer physical and mechanical characteristics (Prithchard, 1998). Additive incorporation in polymer matrix composites may be justify for up to 15-20 % of the total weight of a composite, to modify the mechanical or physical properties of the produced composite (www. Azom.com). Some years back the world solely depended on synthetic fiber reinforced composites, for various engineering and non-engineering applications (Yegireddi, *et al.*, 2019). Composites reinforced with artificial fibers have some short comings such as high cost, high density, and negative impact on worker's health when exposed to them and also resistant to natural decay (Carmelo *et al.*, 2006). Understanding the short comings of non-natural fibers has boasted the use of natural fibers as composite reinforcement. Natural fibers are known to have lower density when compared to artificial fibers in composites and are not resistance to natural decay, they are cheaper, easily recyclable, are richly available than artificial fibers and health friendlier to workers. Due to low cost and environmental friendliness of natural fibers, they have capability to replace artificial fibers in composites.

According to Thwe and Liao (2003), the tensile strength of bamboo fiber reinforced polypropylene composite (BFRP) and bamboo-glass fiber reinforced polypropylene hybrid composite BGRP (with or without maleic anhydride polypropylene MAPP) systems was lower than that for polypropylene PP polymer. Most mechanical properties such as (tensile and flexural strengths and stiffness) are actually improved by inclusion of materials such as MAPP that will make the matrix to be more compatible and improve the interfacial bonding between the matrix and the fiber.

According to many researchers, the kenaf bast fibers possess excellent mechanical properties that make them as a replacement to glass fibers in polymer composites as reinforcing fiber, which makes it suitable for various applications (Karim *et al*, 2014). Dashtizadeh *et al* (2019) evaluated the mechanical properties of cardanol resin reinforced with short kenaf bast fibers to produce 100% green composites, at different kenaf fibers weight percentage. The influence of weight percentage on the tensile strength, flexural strength and impact strength behaviour of composites was studied and reported. The results show that 50% untreated kenaf fiber composite has better tensile strength and impact strength than any other weight percentage in the cardanol polymer respectively. However, flexural strength of 50% for the untreated kenaf fiber composite was found to be low when compared to other weight percentage in the cardanol polymer composite. The results further reveal that composites with 50% kenaf by weight composition have maximum tensile strength of 51.72 MPa, while composite with 60% kenaf by weight composition have maximum flexural strength of 90.44 MPa and impact strength of 7.80 kJ/m^2.

Hybrid composites are either systems in which one kind of reinforcing material is incorporated in a mixture of different matrices (Thwe and Liao, 2003), or two or more reinforcing and filling materials are present in a single matrix (Karger Kocsis, 2000) or both. The behavior of hybrid composites is a weighed sum of the individual components and properties in the composites. While using a hybrid composite that contains two or more types of fiber, the advantages of one type of fiber could complement what is lacking in the other.

Ramanpreet *et al.* (2014) investigated the flexural behaviour of hybrid natural fibre reinforced composites in which composites based on recycled high density polyethylene (RHDPE) and natural fibres were developed. The results showed that the maximum flexural strength and maximum specific flexural strength were obtained from the sample having 20% Sisal fibre and 5% hemp fibre as reinforcement with HDPE as a matrix.

Atiqah *et al*. (2014) developed and produced hybrid composite by reinforcing double or triple polyester matrix with chopped kenaf and glass fibers. They also reported that 15% weight of chopped kenaf and glass fibers percentage in the composite shows higher flexural, impact and tensile properties compared to other percentage compositions.

Many researches have been carried out in recent time on the mechanical performance of hybrid natural fiber composites. Study shows that natural fiber composites compete favorably when compared with synthetic fibers in terms of strength and cost; such as tensile, flexural strength and lower densities which lead to the reason why it's used in structures where strength to density ratio is of high important. This research work is focused on influence of fiber loading on characterization of tensile strength, flexural strength and hardness of bamboo and kenaf hybrid fibers composites based on incorporation of unvaried additives.

Materials and Methods

Materials

Bamboo fibers of (2mm) were extracted from bamboo stem obtained from Idumuje Unor of Delta state of Nigeria and kenaf fibers of (3mm) were extracted from kenaf bast obtained from a local market in Girei, Girei local government area of Adamawa state of Nigeria. 99.9% pure polypropylene (PP) pellets were obtained from Indorama Petrochemical Company Ltd, Eleme, Rivers State of Nigeria, 99.8% pure Maleic anhydride grafted polypropylene (MAHgPP) granules were obtained from Qingdao Fundchem Co. Ltd, Shandong China, 99.8% pure UV stabilizer (HALS) granules were obtained from Qingdao Fundchem Co. Ltd, Shandong China, Calcium carbonate ($CaCO_3$) of 99.7/300nm long and 50µm dia was purchased from Institute of Research and Chemical Development, Zaria, Kaduna State and Sodium hydroxide (NaOH) was obtain from Northern Chemicals, Yola, Adamawa State.

Chemical Modification of the Fibers

The chemical adjustments of the fibers were done by alkaline treatment (Retting) and nanoparticle impregnation of calcium carbonate ($CaCO_3$). Alkaline treatment (retting), bamboo and kenaf fibers were soaked in 5% NaOH solution in a water bath at room temperature. The fibers were kept immersed in the alkali solution for 4 hrs and then the fibers were washed several times with fresh running water to remove any NaOH sticking to the fiber surface, the fiber was then neutralized with dilute acetic acid of 20% concentration and finally washed again with distilled water. The fibers were dried at room temperature for 48 hrs followed by oven drying at 50°C for 6 hrs. Dried fibers were then stored in nylon bags.

Nanoparticle impregnation with calcium carbonate ($CaCO_3$) was carried out at 25°C, required quantity of dry bamboo/kenaf short fibers were immersed in 2 liters deionized water for 30 minutes. Then 1.7 grams of EDTA-2Na and 2 grams of $CaCO_3$ nanoparticle according to the experimental design of fiber modification were introduced into the mixture. The system was vigorously stirred with digital overhead mechanical stirrer, at the speed of 500 rpm for 1 hours. The $CaCO_3$ treated fibers were filtered from the solution and then oven dried at 30°C for 1 hr.

Composites Fabrication

The manufacturing of the composites was accomplished through compression molding process. Calcium carbonate ($CaCO_3$) impregnated bamboo and kenaf fibers, maleic anhydride grafted polypropylene, polypropylene and UV stabilizer (HALS) were mixed and compounded into a homogenous mixture using a 2-roll mill compounding machine. Based on the experimental design process variables as shown in Table 1. Then the compounded mixture was compressed at a temperature of 180°C and a pressure of 10 MPa in an electrically heated hydraulic press to form the composite slabs. The specimens (Plate 1) were machined and tested according to American Society for Testing and Materials (ASTM), while the resultant required properties were recorded.

Experimental Design

In the experimental design, kenaf (KF) and bamboo (BAF) fiber ratios were varied, while other parameters were kept constant at 40% fiber weight, 2% concentration of calcium carbonate ($CaCO_3$) nanoparticles were used to impregnate the fibers, 3% of UV stabilizer (HALS) in the composite, 50% polypropylene and 5% MAHgPP, as shown in Table 1.

Table 1: Hybridization of Bamboo and Kenaf in Polypropylene matrix Composite

BAF %	KF %	HALS %	MAHgPP %	$CaCO_3$ %	PP %
0	40	3	5	2	50
2	38	3	5	2	50
4	36	3	5	2	50
6	34	3	5	2	50
8	32	3	5	2	50
10	30	3	5	2	50
12	28	3	5	2	50
14	26	3	5	2	50
16	24	3	5	2	50
18	22	3	5	2	50
20	20	3	5	2	50
22	18	3	5	2	50
24	16	3	5	2	
		3	5	2	50
26	14	3	5	2	
		3	5	2	50
28	12	3	5	2	50
30	10				50
					50
32	8	3	5	2	50
34	6	3	5	2	50
36	4	3	5	2	50
38	2	3	5	2	50
40	0	3	5	2	50

Plate 1: Produced Bamboo-Kenaf Hybrid Composite at a magnification of 2000x

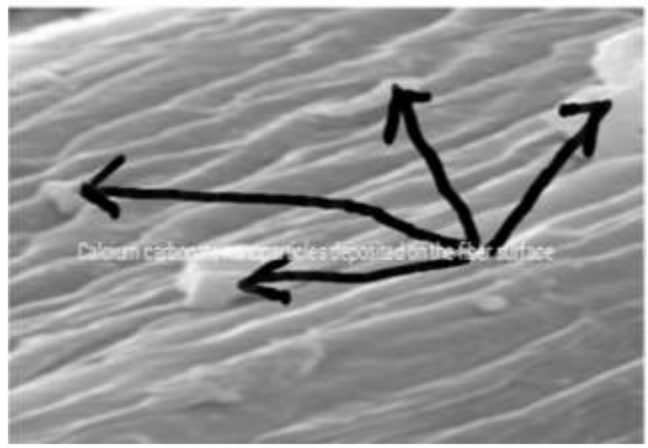

Plate 2: Fiber impregnated with $CaCO_3$ at a magnification of 3000x

Characterization of composites

Tensile test

Tensile strength is the maximum stress that a material can withstand before breaking when it is allowed to be stretched or pulled. Tensile tests were carried out according to ASTM standard test method D 3039-76 for tensile properties of polymer composites (ASTM, 2000). Three specimen of each composite were tested and average result was recorded. The Tensile strength in MPA was calculated from equation 1.

$$\sigma = \frac{P}{bh} \qquad (1)$$

Where σ represents the tensile strength, P is the basic load applied, b is the gauge width and h is the gauge thickness of the specimen.

Flexural strength test

Flexural strength was measured out using Universal testing machine with cross head speed of 2mm/min according to ASTM D790. A 3 point bending test was applied to find the flexural modulus, flexural strength and strain at break of the polypropylene composites reinforced with bamboo and kenaf fibers, the samples were machined into 127mm×13mm×3mm. Span length of 100mm was maintained. The flexural strength (MPa) was computed by using equation 2 (Hodgkinson, 2000).

$$\text{Flexural Strength} = \frac{3PL}{2bd^2} \quad (2)$$

Where, L is the length of support span (mm), P is the load applied (N), b is the width of the specimen (mm) and d is the thickness of specimen (mm).

Hardness test

The hardness test of composites is the ability of a composite to withstand it surface niche by an indenter of a particular range under a given load. Samples of 30 mm x 30mm x 4mm were tested for shore hardness values using a direct reading Durometer. The Durometer measures the hardness of material according to ASTM D2240 and ISO 7619. Three specimen of each composite were tested and average result was recorded.

Results and Discussion

Tensile strength

Results of the tensile strength test of prepared composites are given in Figure 1. Interaction in the fibers of the hybrid was observed for the produced composites, the maximum tensile strength value (53.57 MPa) was found for 20% kenaf and 20% bamboo hybrid composite. The better tensile strength of the composite may be due to equal volume of the fibers resulting to better load sharing and better stress transfer from matrix to the fibers. The observed better tensile strength may also be due to reduced micro empty space formed between fiber and matrix in the composite as compared to any other composition (Venkateshwaran *et al.*, 2013). Comparable tensile strength result was achieved by (Mohammad, (2013).

Figure 1 shows that the 40% bamboo fiber reinforced composite (0 % kenaf to 40% bamboo) has a better tensile strength of 44.68 MPa than 40% kenaf fiber reinforced composite (40 % kenaf to 0% bamboo) with tensile strength of 36.53 MPa probably due to high cellulose in bamboo. It also meant that the reinforcing efficiency of the bamboo fiber in the polypropylene matrix is higher than that of the kenaf fiber. The bamboo fiber also has lower diameter than that of the kenaf fiber as well, thus increasing bamboo fiber mechanical properties (Ge Wang *et al*., 2011 and Ismail *et al*., 2019). Therefore, the surface area of the fiber per unit area of the composite is higher in the case of the 40% bamboo fiber-reinforced composite than that of the 40% kenaf fiber-reinforced composite.

Tensile strength analysis of variance

Meaningful effect of interplay between the two fibers (bamboo and kenaf) on tensile strength has been confirmed by the ANOVA results (Table 2), where P-values of the interplay between the two fibers is lower than the meaningful value level ($\alpha = 0.05$). It means that there is interaction between the two fibers in the composite.

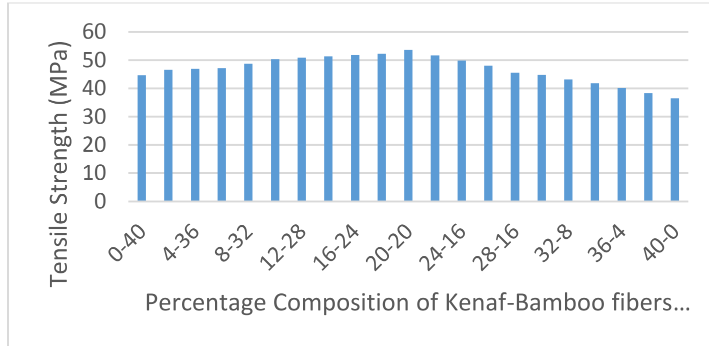

Figure 1: Tensile Strength of Kenaf-Bamboo Hybrid Composite

Table 2: ANOVA Table of Tensile Strength Hybridization of Bamboo and Kenaf Fibers at P = 0.05

Source	Degree of Freedom	Adjusted Sum of the Square	Adjusted Mean of the Square	F-Value	Probability > F
2-ways interactions of Bamboo*Kenaf	1	284.12	284.122	240.15	0.000+

+(significant)

Flexural strength

Flexural strength of the produced hybrid composites are given in Figures 2. Trend of results of flexural strength is similar to that of tensile strength, with maximum flexural strength (67.59MPa) obtained at percentage weight composition of 20:20 kenaf-bamboo. The flexural strength of hybrid with percentage weight composition of 20% kenaf and 20% bamboo composite is greater than that of 0% kenaf and 40% bamboo (58.72 MPa) and than that of 40% kenaf and 0% bamboo (50.47 MPa). The good flexural strength of 20% kenaf and 20% bamboo hybrid composite is as a result of optimal intermingling of the fibers, higher compatibility and better adhesion of fibers to matrix (Aji *et al.*, 2013) which in turn results to better bending properties compared to other percentage compositions (Aji *et al.*, 2013). Comparable flexural result was achieved by Hanan *et al*., (2018). Hanan *et al*. (2018) stated that low flexural properties of a fiber can be improved by combining it with another fiber possessing better flexural strength.

Figure 2 show that the 40% bamboo fiber reinforced composite (0 % kenaf to 40% bamboo) has a better flexural strength of 58.72 MPa than 40% kenaf fiber reinforced composite (40 % kenaf to 0% bamboo) with flexural strength of 50.47 MPa.

Flexural strength analysis of variance

Meaningful effect of interplay between the two fibers (bamboo and kenaf) on flexural strength has been confirmed by the ANOVA results (Table 3), where P-values of the interplay between the two fibers is lower than the meaningful value level (α = 0.05). It shows that there is interaction between the two fibers.

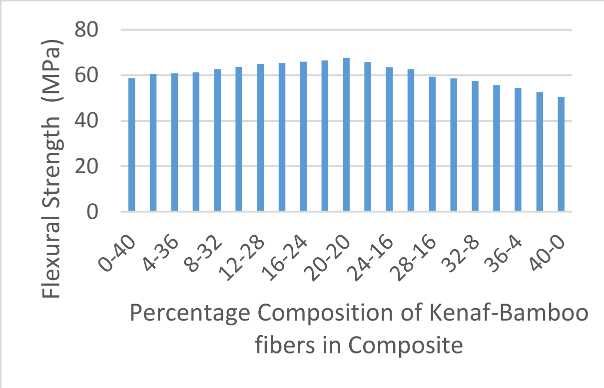

Figure 2: Flexural Strength of Bamboo-Kenaf Hybrid Composite

Table 3: ANOVA Table of Flexural Strength Hybridization of Bamboo and Kenaf Fibers at P = 0.05

Source	Degree of Freedom	Adjusted Sum of the Square	Adjusted Mean of the Square	F-Value	Probability > F
2-ways interactions of Bamboo* Kenaf	1	109.356	109.356	165.31	0.000+

+(significant)

Hardness

Hardness is the ability of a material to withstand exterior indentation. Figures 3 show the variation of hardness with percentage weight composition of bamboo-kenaf fibers in the hybrid composites. The results reveal that hardness value decreased from 99.56 to 92.03 (Shore A) with progressive growth in bamboo fiber loading from 0 to 45%, while hardness value increased from 92.03 to 97.71 (Shore A) with reduction in kenaf loading in the composite from 45% to 0%. This could be as a result of the fact that hardness of polymer composites depends on dispensation of the fiber in the matrix. Better dispersion of the fiber into the matrix minimizes the void between the matrix and the fiber, and thus enhances the hardness of the composite (Safwan *et al.*, 2019). The composite with 0% kenaf and 100% bamboo exhibited maximum value of hardness of 99.56 Shore which thus reduces the ductility of the composites thereby increasing the composite stiffness. This maximum hardness of the composite could be as a result of bamboo fiber increment. The composite with 55% kenaf and 45% bamboo had minimum value of hardness of 92.03 (Shore A). The slightly higher hardness values observed in different levels of the composites could be attributed to the good dispersion of bamboo and kenaf fibers into the polypropylene matrix. This results in minimization of void and creation of stronger surface bonding between the fibers and the matrix.

Hardness analysis of variance

Meaningful effect of interplay between the two fibers (bamboo and kenaf) on hardness has been demonstrated by the ANOVA results (Table 4), where P-values of the interplay between the two fibers is lower than the meaningful value level (α = 0.05). It shows that there is significant interaction between the two fibers.

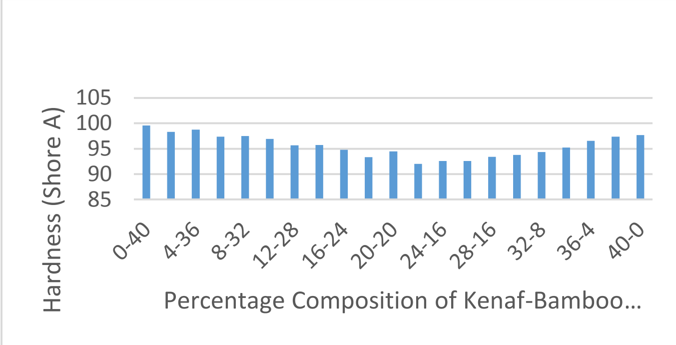

Figure 3: Hardness of Bamboo-Kenaf Hybrid Composite

Table 4: ANOVA Table of Hardness Hybridization of Bamboo and Kenaf Fibers at P = 0.05

Source	Degree of Freedom	Adjusted Sum of the Square	Adjusted Mean of the Square	F-Value	Probability > F
2-ways interactions of Bamboo*Kenaf fibers in the composite	1	65.73	65.7286	86.22	0.000+

+(Significant)

Conclusions

The conclusions drawn from this experimental investigation are as follows; Composites produced using 20% bamboo and 20% kenaf fiber shows the maximum, tensile strength and flexural strength than any other percentage combination. Composites fabricated using 40% bamboo and 0% kenaf fiber shows optimum hardness compared to any other percentage combination. Progressive growth in the percentage of bamboo fibers in the composite increases the hardness of the composite. The ANOVA tests for tensile strength, flexural strength and hardness show significant interaction between bamboo and kenaf fiber in the composite. The results reveal that bamboo fiber has a higher effect on the tensile strength, flexural strength and hardness of the produced composite.

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