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Characterization of Palm Kernel Shell and Luffa Cylindrica Composite used for Car Bumper Production

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Abstract: *A car bumper is a vital component that is carefully designed and integrated to the front and rear of automotives to ensure low and high speeds impact absorptions. It protects the passengers, pedestrians and automotive components, such as headlights, parking lights and taillights from damages during impacts. The development of bumper using composites-based materials could ensure weight reduction, improved impacts absorption at low and high speeds, fuel economy, easy of vehicle handling and safer environment for all. In this paper, the tensile, impact and compression strengths of palm kernel shell and luffa cylindrical composite for use as car bumper is investigated. The composite was formulated by 5% NaOH for 24 hours and molded using a wooden mold before characterization. The obtained results revealed that for same percentage loading of luffa cylindrical and palm kernel shell, the tensile strength of the NaOH-treated specimens were better than their counterpart untreated specimens. Also, for the same percentage loading of luffa cylindrical and palm kernel shell, the impact strength of the NaOH-treated specimens was higher, while the highest resistance to compression of 59·10 MPa is obtained at 25% loading of the NaOH-treated luffa cylindrica and palm kernel.*

Keywords: *Car Bumper, Composite, Tensile Testing, Palm-Kernel, Luffa Cylindrica*

INTRODUCTION

A car bumper is a critical component that is usually integrated carefully to the front and rear of automobiles to ensure impacts absorption at low and high speeds (Helps, 2001; Kumar *et al.,* 2014; and Kiranmai *et al.,* 2016). The careful design and integration of this component to any automotive are to ensure it protects the passengers, pedestrians and vehicles' components from damages in low and high-speed collision. Bumper system should be flexible enough to prevent injury to people and the vehicles' components at low speed, and must be stiff enough in order to absorb impact energy (or dissipate kinetic energy) at high speed (Kumar *et al.,* 2014).

It is a critical component in which its size (weight) and the aerodynamic features help in lowering the drag coefficient, thereby lowering fuel consumption and easy of the vehicle handling. Car bumper are carefully designed to ensure that their failure do not occur during front or rear collisions. Hence, bumper systems usually ensure vehicles crash worthiness, while be able to protects the occupants, pedestrians and vehicles' vital components such as parking lights, taillight, fuel systems, exhaust and cooling systems, during front and rear impacts (Helps, 2001; Davoodi, *et al.,* 2012; Kumar *et al.,* 2014; and Kiranmai *et al.,* 2016).

The car bumper development using composites-based materials could ensure weight reduction, better impact absorption at low speed, improved vehicle performance (due to weight reduction), fuel economy, ease of vehicle handling (due to overall weight reduction), easy compliance with emissions standard due to fuel economy. It cannot, therefore, be overstressed that natural composites fibre bumper system could ensure a safer environment for all due to eco-friendly automobile component that is bio-degradable recyclable, cheap, available and not harmful to human health. Thus, there is a constant need for researches in academia to replace plastics and other polymers which are less competitive in terms of strength, corrosion affinity and lightweight (Kleisner, *et al.,* 2009; Abdullah *et al.,* 2011; Cigasova, *et al.,* 2013; Kumar *et al.,* 2014; and Kiranmai *et al.,* 2016; Fogorasi and Bardu, 2017).

Fogorasi *et al.,* (2017) study on natural fibres for the automotive sector revealed that India and China produced and consumed a vast variety of palm kernel shells and luffa cylindrical products, such as automotive interior and exterior (door panels, seatbacks, and dashboard), ropes, and floor furnishing materials. Hence, the utilization of environmentally friendly natural fibres like palm kernel shell and luffa cylindrica in automotive and related industries is vital for developing countries such as Nigeria. Also, Safwan *et al.,* (2013), Bernard *et al.,* (2014) and Kumar *et al.,* (2014), studies respectively revealed that increasing vehicle weight reduction demand, higher impact energy absorption in bumper systems during low impact, controllable fracture behaviour at high speed and environmental pollution issues, are among the increasing reasons for natural fibres composites. Thus, this research examines the tensile, impact, and compressive strengths of palm kernel shell and luffa cylindrical for use in car bumper development.

MATERIALS AND METHODS

This section discusses the materials and methods used for determining the mechanical properties of palm kernel shell and Luffa cylindrica composite proposed for producing a car bumper.

2.1 Materials

The materials characterized are:

2.1.1 The Reinforcement Material

Luffa cylindrica usually called a vegetable sponge, bath sponge, sponge-gourd, dish gourd, running okra, and luffa, which is a member of the cucurbitaceous family, is used as a reinforcement material. The reinforcement material was locally sourced in Minna (Niger State, Nigeria). Oboh et al., 2009 studied luffa cylindrica as an emerging cash crop and its applications, his study revealed that luffa cylindrica has wide applications that cut-across medicine, biotechnology, science, engineering, and the possibility for luffa to be used in shock absorbers components and as a reinforcement material. Thus, luffa cylindrical with a bulk density of 0.53 g/cm^3 provides the needed mechanical strength to the developed composite for use in a car bumper.

2.1.2 The Filler Material

Palm kernel shell used as a filler material is one of the lignin, cellulose, and hemicellulose materials that is environmentally friendly and is attracting the attention of material engineers (Safwan *et al.,* 2013). The Palm Kernel shell has a density of 0.68 g/cm^3 on average and is being used as the filler material in the development of composite for use in car bumpers and was locally sourced from Abab Oil Palm Mill in Kaduna (Nigeria). Safwan *et al.,* (2013) study on preparation and characterization of palm kernel shell/polypropylene biocomposites with nano-silica revealed that palm kernel shell could be used as a filler material, and to improve manufacturability of a composite.

2.1.3 The Binder Material

The epoxy resin used as a binder in this study on the development of palm kernel shell and luffa cylindrica composite for car bumper was sourced from Steve More Chemicals, Kwangila, Zaria (Nigeria). It was chosen because of its excellent adhesive strength to different materials, high resistance to corrosion, minimum internal stresses. It is also odourless, has high mechanical properties and tastelessness.

2.2 Specimens (Composite) Preparation

Palm kernel shell and luffa cylindrica composite preparation for the development of Palm Kernel shell and Luffa cylindrical composite for car bumper is as follows.

2.2.1 Preparation and Treatment of Palm Kernel Shell and Luffa Cylindrica

The dried, handpicked Luffa cylindrica fruits were peeled and washed after the seeds were removed. It was then followed by rinsing in water until they become clean. Fig. 1 shows the seedless and sun-dried Luffa cylindrica. On the other hand, the sourced Palm Kernel shell was thoroughly washed using a liquid detergent, rinsed with water and then, sun-dried as shown in Fig. 2.

Fig. 1. The Luffa Cylindrica

Fig. 2. The Palm Kernel Shell

The cleaned and dried palm kernel shell and luffa cylindrical were separately shared into two equal parts. One half of Palm Kernel shell and Luffa cylindrica treated was separately sucked in 5% NaOH for 24 hours. Thus, two separate containers, each containing 40 grams of NaOH, dissolved in 800 grams of water were prepared. Then, the palm kernel shell and luffa cylindrica treated with 5% NaOH were soaked in these solutions for 24 hours. Although this treatment could enhance the mechanical properties of palm kernel shell and luffa cylindrica fibres, they should not be soaked for more than 24 hours because of the corrosive nature of NaOH. Plate III shows the treated and untreated crushed palm kernel shell.

Fig. 3. Treated and Untreated Crushed Palm Kernel Shell

2.2.2 Composites (Specimens) Mouldings

The technique used for the preparation of the Palm Kernel shell and Luffa cylindrica composite with epoxy resin as the binder is hand lay-up. The composites were prepared with a wooden mould of size 190 mm x 150 mm x 5 mm dimensions as shown in Fig. 4. The crushed Palm Kernel shell and Luffa cylindrica (both treated and treated) were separately premixed thoroughly before the specimens were prepared with the epoxy resin at room temperature. The two composites and the binder were separately produced by gently mixing them in their respective moulds. Five specimen formulations for both treated and untreated were made, as shown in Table-1. The formulated specimens were allowed to harden at room temperature and were prepared for tensile, impact and compression tests.

Fig. 4. The Composite Moulding Technique

Table-1. Five specimens Formulations (same for treated and untreated)

Specimens	**A**	**B**	**C**	**D**	**F**
PKS/Luffa	5%	15%	25%	35%	45%
Epoxy Resin	95%	85%	75%	65%	55%

2.3 Characterization Procedure

The following procedures were followed in the characterization.

2.3.1 Tensile Test

A tensile test was carried out using Monsanto Tensometer (type 'w', Serial Number: 9875), shown in Fig. 5, located at the Strength of Material Laboratory of Mechanical Engineering department at Ahmadu Bello University Zaria (Nigeria). Three tests piece were produced according to ASTM D3039 as reported by Aloze *et al.*, (2020), and tested from each of the five formulations, and an average of the three tests was used as a mean value. Specimens (of gauge length 40 mm) were firmly gripped by the jaws of the tensometer, while loads that induce tension in the specimens was manually applied on one hand, and the extensions (due to applied) for treated and untreated specimens were noted. Vernier caliper was used to measure the specimens' width and thickness, while the Ultimate Tensile Strength was determined using equation 1, as stated by Safwan *et al.*, (2013).

$$\text{UTS } (\text{N}/\text{m}^2) = = \frac{\text{Applied Load (N)}}{\text{Area (m2)}} \quad (1)$$

Fig. 5. Monsanto Tensometer

2.3.2 Impact Test

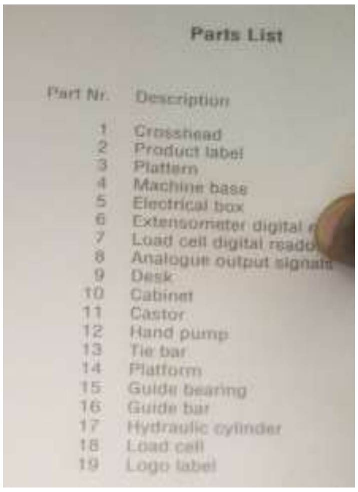
Impact test was carried out on the treated and untreated specimens based on ASTM D716, using Charpy impact testing machine (Fig. 6) at the Materials Testing Laboratory, Mechanical Engineering Department, Ahmadu Bello University Zaria (Nigeria). The testing machine has a capacity of 15 and 25 Joules (J), however, 15 J (dead oscillator weight) was appropriate for these test specimens. The specimens were mounted on the tester, while the machine handle was pulled, a pendulum swung around to impact (thereby breaking) the specimens. The impact energy was noted for each test after readings were taken from the tester's dial gauge. Three tests were performed for each of the five formulations, and an average of the three tests was used as the mean value.

Fig. 6. Charpy Impact Testing Machine

2.3.3 Compression Test

Compression test (according to ASTM D3410) was also carried out using a compression testing machine (Fig. 7) located at the same location as Tensile and impact testers. Three tests piece were used for compression tests from the five formulations, and an average value from the three tests was recorded. Specimens were mounted on the machine's plattern. Load is then applied the mounted specimens through a hand pump. Readings were obtained through a load cell digital displayer. Vernier caliper was used to measure the specimens' width and thickness, while the compression strength was calculated using Equation 2, (Safwan *et al.,* 2013).

$$\text{Compression Strength } (\mathrm{N/m^2}) = \frac{\text{Applied Load (N)}}{\text{Area (m2)}} \tag{2}$$



Parts List

Part Nr.	Description
1	Crosshead
2	Product label
3	Plattern
4	Machine base
5	Electrical box
6	Extensometer digital
7	Load cell digital
8	Analogue output signals
9	Desk
10	Cabinet
11	Castor
12	Hand pump
13	Tie bar
14	Platform
15	Guide bearing
16	Guide bar
17	Hydraulic cylinder
18	Load cell
19	Logo label

Fig. 7. Compression Testing Machine

RESULTS AND DISCUSSION

3.1 Tensile Test Results

The stable average mean values obtained when tensile test was carried on the NaOH-treated and untreated specimens are presented in Table-2.

Table-2. Tensile Test Results for NaOH-treated Specimens

Fibre content (%wt)	Area (mm^2)	Force (N)	UTS (MPa)	Extension (mm)	Strain	Percentage elongation (%)	Modulus of Elasticity (E in MPa)
5	52.46	1183.33	22.56	6.8	0.17	17	132.71
15	49.76	1166.67	23.45	6.0	0.15	15	156.33
25	64.16	1883.33	29.35	7.6	0.19	19	154.47

35	66.53	1283.33	19.29	6.0	0.15	15	128.6
45	75.35	1483.33	19.69	6.4	0.16	16	123.06

Table-2 shows that the highest tensile strength of the NaOH-treated was 29.35 MPa, and occurred at the 25% luffa cylindrica and palm kernel loading. Also, the table shows a steady increase in the specimen tensile strength as the luffa cylindrica and palm kernel loading increases from 5% to 25%. After, the tensile strength decline steadily as the luffa cylindrica and palm kernel loading increases, as evident in Table-3 and Fig. 8 respectively.

Table-3. Tensile Test Results for Untreated Specimens

Fibre content (%wt)	Area (mm²)	Force (N)	UTS (MPa)	Extension (mm)	Strain	Percentage elongation (%)	Modulus of Elasticity (E in GPa)
5	50.30	1116.33	22.19	6.0	0.15	15	147.93
15	53.86	1033.33	19.19	5.6	0.14	14	137.07
25	63.85	750.00	11.75	5.2	0.13	13	90.33
35	71.35	875.12	12.26	5.6	0.14	14	87.57
45	64.56	1366.67	21.17	6.8	0.17	17	124.53

Table-3, shows that the tensile strength of the untreated specimens was highest at the lowest luffa cylindrica and palm kernel loading. Also, unlike its counterpart NaOH-treated specimens, Table 3 shows that untreated tensile strength of the untreated specimens was lowest at the 25% luffa cylindrica and palm kernel loading, and then, increased steadily as the luffa cylindrica and palm kernel loading increases, as evident in Table-3 and Fig. 8 respectively.

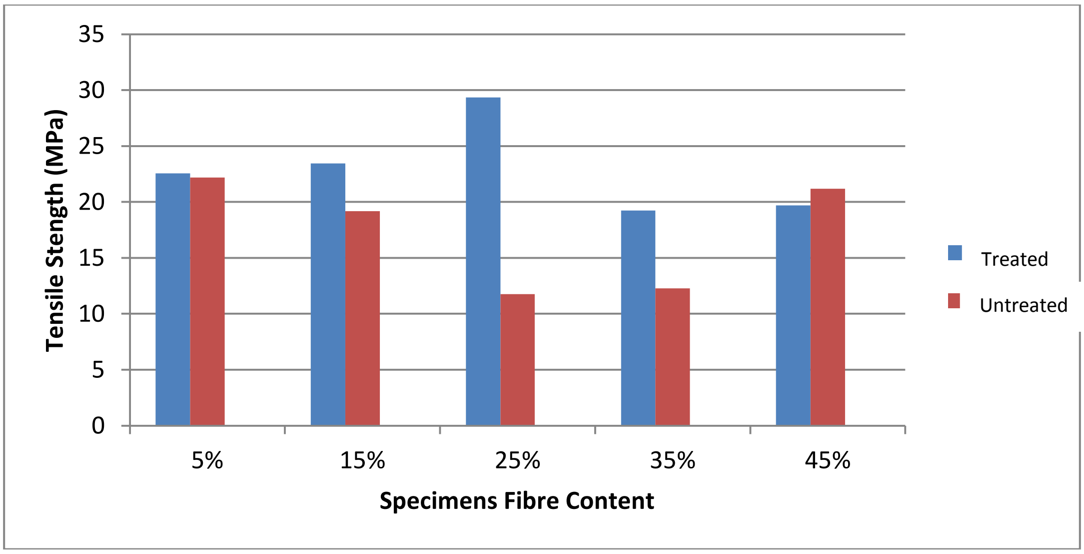


Fig. 8. Tensile Strength of the NaOH-treated and Untreated Composites

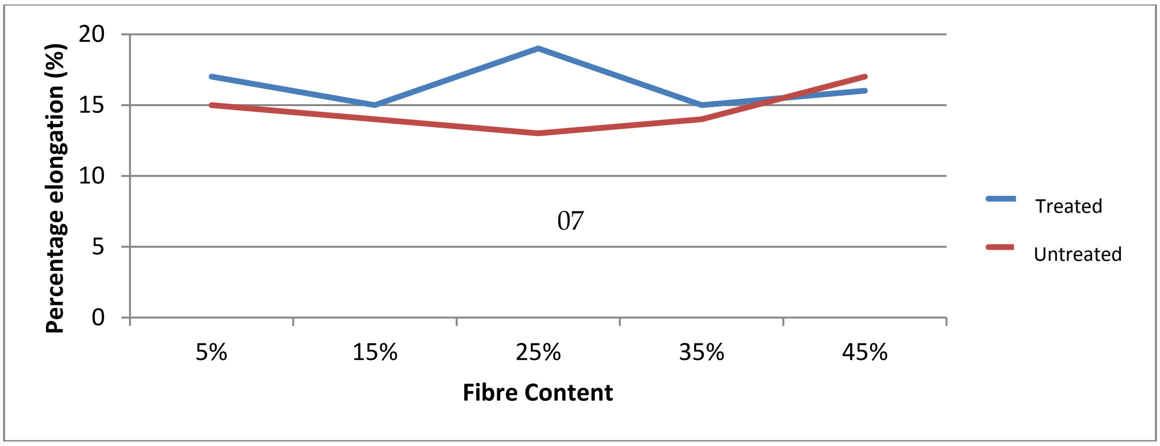


Fig. 9. Percentage Elongation of the NaOH-treated and Untreated Specimens

Fig. 8 and Fig. 9, clearly show that for the same percentage loading of luffa cylindrical and palm kernel shell, the tensile strength of the NaOH-treated specimens were better than their counterpart untreated specimens. Thus, the enhanced tensile strength may be due to the enhanced mechanical properties of the NaOH-treated composites, which results in better interfacial adhesion of the premixed fibres and the binder. This is in agreement with the respective published studies of Gassan, (1999), Rowell *et al.,* (2002), Ashori *et al.,* (2010), Safwan *et al.,* (2013), Kidalova, *et al.,* (2012b), and Fogorasi *et al.,* (2017). The percentage elongation of the treated specimens was higher, except for the 45% loading of the luffa cylindrica and palm kernel. However, at 25% loading of the NaOH-treated luffa cylindrica and palm kernel, the percentage elongation, as well as Modulus of Elasticity were the highest among both the NaOH-treated and untreated composites. This may imply that the 25% loading of the NaOH-treated luffa cylindrica and palm kernel gives the highest stiffness, which enhances the composite failing resistance (Nabi, *et al.*, 1999; Cigasova *et al.*, 2013; Gonzalez *et al.*, 1999; and Safwan *et al.*, 2013).

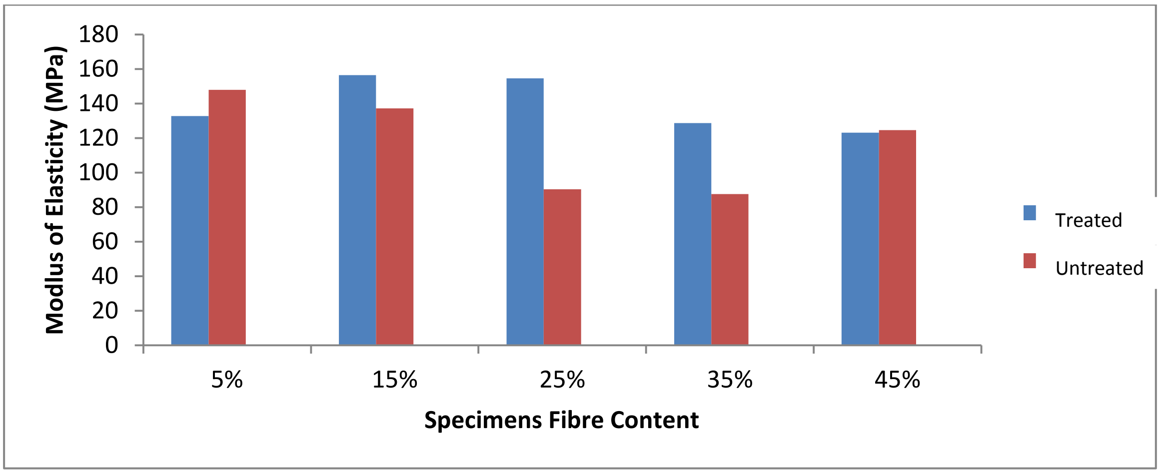


Fig. 10. Effect of the Fibres Content Loading on Modulus of Elasticity of the NaOH-treated and Untreated Composites

3.2 Impact Test

The results of the impact test, conducted on both treated and untreated test specimen are presented in Tables-4 and Table-5 respectively.

Table-4. **Impact Test Result of the NaOH-treated Specimens**

Fibre content (%wt)	Impact (J)
5	0.26
15	0.37
25	0.51
35	0.55
45	1.21

Table-5. **Impact Test Result of the Untreated Specimens**

Fibre content (%wt)	Impact (J/mm)
5	0.25
15	0.28
25	0.45
35	0.38
45	0.52

It could be seen that the impact strength of the NaOH-treated and untreated specimens was highest at 45% fibres content loading. While, on the other hand, these tables show that, the lowest percentage of the fibres content loading of the NaOH-treated and untreated specimens recorded the minimum impact strength. The corresponding graph in Fig. 11 shows the effect of fibres content loading on the specimens' impact strength.

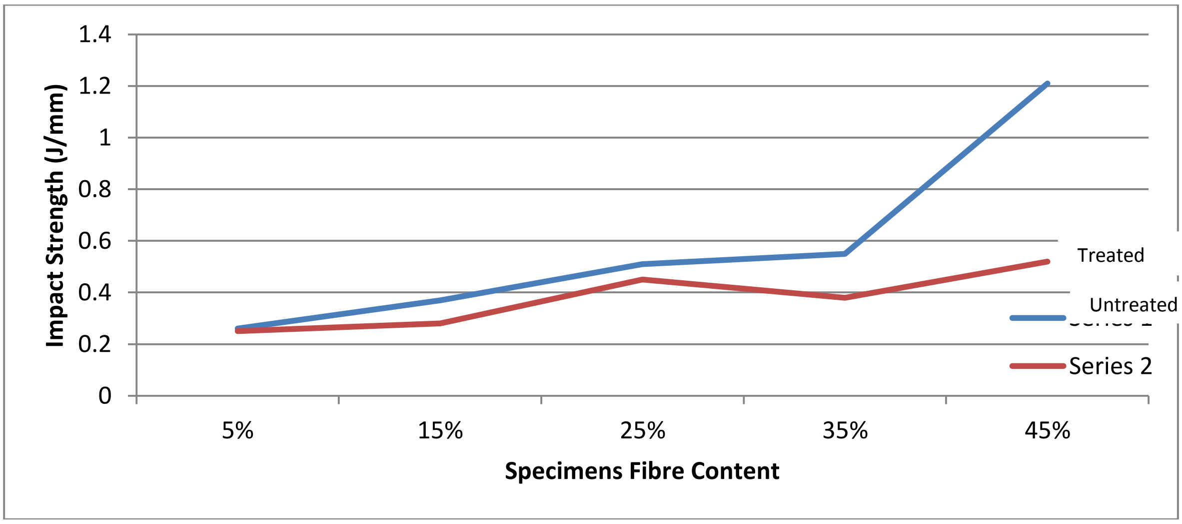


Fig. 11. Fibres Content Loading Effect on the Impact Strength of the NaOH-treated and Untreated Composites

Table-4, shows that the lowest and highest impact strength of the NaOH-treated were 0.26 and 1.21 J/mm respectively. And graphically presented in Fig. 11, it could be observed that the increase in luffa cylindrica and palm kernel loading increased the impact strength of the composites. Similar pattern was shown in Table-5, where impact strength was lowest at 5% loading of the untreated luffa cylindrica and palm kernel; and highest impact strength value was at 45% loading of the untreated luffa cylindrica and palm kernel.

However, unlike it counterpart NaOH-treated specimens, Table-5 shows that the impact strength of the untreated specimens increase from 5% to 25%, after, which the impact strength decline steadily from 0.45 to 0.38 J/mm, before it continued increased at 45% luffa cylindrica and palm kernel loading, as evident in Fig. 11. Thus, the increased impact strength due to the increase in luffa cylindrica and palm kernel loading may be caused by filler and reinforcement materials rigidity in the binder, due to which the composites (NaOH-treated and untreated) stiffness were increased (Rowell *et al.*, 2002; Mueller, 2004; Aziz, 2004; Chi Truong, 2006; Abdullahi, 2011; Safwan *et al.*, 2013; and Fogorasi *et al.*, 2017). From Fig. 11, it can be observed that for the same percentage loading of luffa cylindrical and palm kernel shell, the impact strength of the NaOH-treated specimens were higher, which could be attributed to the enhanced mechanical properties of the treated composites (Jang, 1990; Jacob, 2004; Ozturk, 2010; Rowell, 1998; and Safwan *et al.*, 2013).

3.3 Compression Test

The results of the compression strength test carried out at Strength of Material Laboratory of Mechanical Engineering Department at Ahmadu Bello University Zaria (Nigeria), for the NaOH-treated are presented in Tables-6. Similarly, Table-7 shows the results of the impact strength test that was carried out on the untreated specimens at the same Material Laboratory of Mechanical Engineering Department, at Ahmadu Bello University Zaria.

Table-6 Compression Strength Test Results for Treated Specimens

Fibre content (%wt)	Area (mm²)	Force (N)	Compression strength (MPa)
5	872.9	36320	41.61
15	891.58	48750	54.68
25	860.25	50810	59.10
35	992.55	51850	52.24
45	981.00	56547	57.64

Table-7 Compression Strength Test Results for Untreated Specimens

Fibre content (%wt)	Area (mm²)	Force (N)	Compression strength (MPa)
5	867.97	48810	56.23
15	927.68	34743	37.45
25	480.00	29030	60.48
35	541.78	33645	62.10
45	958.75	47295	49.33

It could be seen that the compression strength of the NaOH-treated specimens was highest at 45% fibres content loading, and lowest at minimum fibres content loading. While, on the other hand, it could be seen that the compression strength of the untreated specimens was highest and lowest at 35 and 45% fibres content loadings. The corresponding graph in Fig. 12 shows the effect of the fibres content loading on the compression strength of the NaOH-treated and untreated specimens.

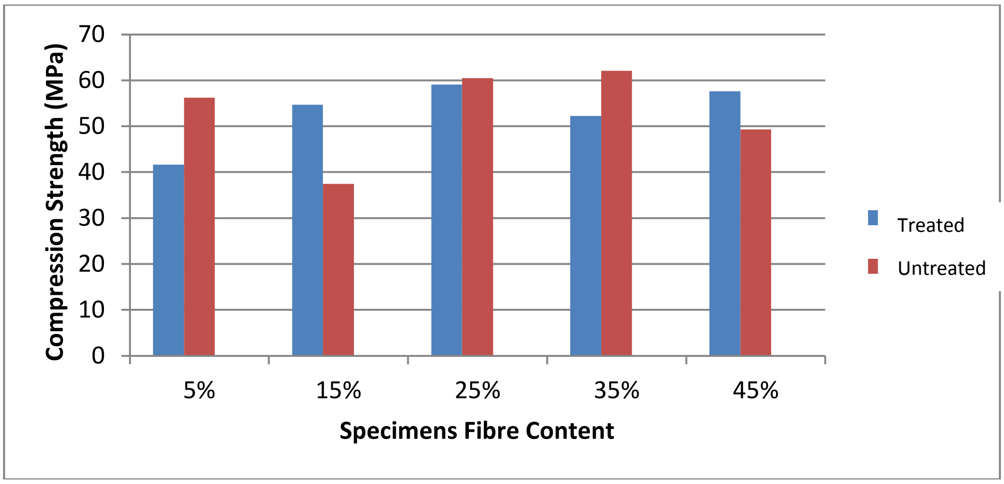


Fig. 12. Effect of the Fibres Content Loading on the Compression Strength of the NaOH-treated and Untreated Composites

Table-6 shows that the maximum compression strength of the NaOH-treated was 59.10 MPa, and obtained at the 25% luffa cylindrica and palm kernel loading. Also, the table shows a steady increase in the specimen compression strength as the luffa cylindrica and palm kernel loading increases from 5%, until it reaches its peak value at 25% fibres content loading. Then, the compression strength declined from its peak value to 52.24 MPa, at 35% luffa cylindrica and palm kernel loading, after, which it was increased from 52.24 to 57.64 MPa as evidence in Fig.12. Table-7 shows that the compression strength of the untreated specimens was highest at 35% luffa cylindrica and palm kernel loading, and it was lowest at the 15% luffa cylindrica and palm kernel loading. Also, Table-4, Table-5, and Fig. 11 clearly show that for the same percentage loading of luffa cylindrical and palm kernel shell, the compression strength of the NaOH-treated specimens was better than their counterpart untreated specimens, except at 15 and 35% luffa cylindrica and palm kernel loadings. However, unlike it, counterpart NaOH-treated specimens. It could also be seen from the compression strengths of the NaOH-treated and untreated tables that the highest compression strength was obtained at 25% loading of the NaOH-treated luffa cylindrica and palm kernel. This may imply that the 25% loading of the NaOH-treated luffa cylindrica and palm kernel gives the highest resistance to compression (Rowell *et al.,* 2002; Juwaid, 2011; Safwan *et al.,* 2013; and Fogorasi *et al.,* 2017).

3.4 The Specimens Viability for Car Bumper

The tensile, impact, and compression strengths results for the NaOH-treated specimens revealed that its mechanical properties are superior to its counterpart untreated specimens. Although, both NaOH-treated and untreated specimens proved to be light in their respective weights, the high values of tensile (154.47 MPa), impact (0.51 J/mm), and compression (59.06 MPa) strengths obtained at the 25% weight loading of NaOH-treated specimen shows a very good standing when compared to impact analysis carried out on the existing car bumpers. Bohra *et al.,* (2015) study on the comparative analysis of frontal car bumper during impact revealed that an existing ABS plastic Maruti Suzuki Alto car bumper material could resist the stress of 53.109 MPa and 60.027 MPa at Federal Motor Vehicle Safety Standard (208) speeds of 75 km/hr and 120 km/hr respectively. Also, Uddandapu's (2013) study on the impact analysis on car bumper by varying speeds using materials ABS plastic and Poly Ether Imide by finite element analysis software solid works revealed that car bumper (frontal facia) made of ABS plastic material can withstand the stress of 24.4296 MPa and 33.6692 MPa at speeds of 75 km/hr and 120 km/hr (based on Federal Motor Vehicle Safety Standards 208).

Thus, the palm kernel shell and luffa cylindrica composites' excellent lightweight (and even overall density, when compared to other car bumper materials such as steel, Poly Ether Imide, and ABS plastic), as well as good mechanical properties is an indication that it could be carefully and optimally combined to further enhance its crashworthiness during the collision.

CONTRIBUTION TO KNOWLEDGE

A sustainable material for the production of a bumper for future vehicle has been enveloped and characterized for application, which is in line with the motor vehicle safety standard 208. The results of the analysis shows that the developed composite is sufficient to be used for motor vehicle bumper.

CONCLUSION

The results obtained in this study clearly show that the mechanical properties of the NaOH-treated luffa cylindrica and palm kernel shell specimens were superior, which may be due to better interfacial adhesion in the treated specimens, when compared to the untreated specimens at the same percentage weight of fibre loading (Gassan, 1999; Rowell *et al.,* 2002; Ashori *et al.,* 2010; Safwan *et al.,* 2013; Kidalova, *et al.,* 2012b; and Fogorasi *et al.,* 2017). The tensile strength of the NaOH-treated specimens was higher than that of their untreated counterparts. Thus, the tensile strength of the developed composites (NaOH-treated and untreated) was found to be at its peak value of 29.35 MPa, at the 25% weight fibre loading of the NaOH-treated crushed luffa cylindrica and palm kernel shell powder in the binder. Also, the percentage elongation and modulus of elasticity of the NaOH-treated and untreated composites were all at peak values of 19 MPa and 154.47 GPa, during the 25% weight fibre loading of the NaOH-treated luffa cylindrica and palm kernel shell specimen in the binder. The impact strength increases for both the NaOH-treated and untreated specimens, and it was found to be at its peak value of 1.21 J/mm, at the 45% weight fibre loading of the NaOH-treated specimen. Also, it was observed that the impact strength at all percentage weight of the fibre content loading of the NaOH-treated specimens was superior to their counterparts untreated specimens. On the other hand, the compression strength of the NaOH-treated specimens was at highest at the 25% weight fibre loading, while the untreated composites' compression strength was highest at 35% weight fibre loading. Thus, this study shows that maximum tensile, impact and compression strengths can be achieved simultaneously at 25% weight loading of NaOH-treated fibre content. Also, the excellent lightweight quality of NaOH-treated composites, as well as its tensile, impact and compression strengths could be carefully and optimally combined for car bumper development.

CONFLICT OF INTEREST

I wish to state here that, the research present/reported here is an original work of the authors and have not been present to any publishing house before now and therefore there is no conflict of interest with this manuscript to the best of my knowledge.

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