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Production and Performance Evaluation of Sisal Fibre (*Agave Sisalana*) as Composite Material for Car Bumper

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Abstract: *A bumper is one of the main automobile parts used as protection for the car and passengers against front and rear collision. The aim of this study is to carry out research on sisal fibre as a suitable reinforcement material for production of a composite car bumper. The research also evaluated the properties of the composite bumper to ascertain its improvement on crash-worthiness during car collision. Sisal fibre is a material that has properties of low weight, high strength, and low density. Considering the fact that fuel economy and efficiency is necessary in modern automobiles, the best way to increase the vehicle efficiency without sacrificing safety is to employ the use of sisal-fibre reinforced composite in the production of less weight and high strength bumpers. The research was conducted through experiment, analysis and production processes. Hand lay-up technique method was employed in the production of the mould and the composite car bumper. The results obtained from the tests are; Tensile strength; 69.51 MPa, Impact strength; 32.79kJ/m^2, Compression strength; 6.92MPa, and flexural strength: 86.81MPa. At the end of the research, better quality, light weight and high strength composite bumper was produced. The analysis of the produced car bumper showed that it conformed to National Highway Traffic Safety Administration (NHTSA), 1971 and Federal motor vehicles safety standards (FMVSS, No. 215), at 8km/hr collision speed.*

KEYWORD: Bumper, reinforcement, composite, compressive strength.

INTRODUCTION

Natural fibers reinforced composites are emerging very rapidly as the potential substitute to the metal or ceramic based materials in applications that also include automotive, aerospace, marine, sporting goods and electronic industries. Natural fiber composites exhibit good specific properties, but there is high variability in their properties. Their weakness can as well

be overcome with the development of more advanced processing of natural fiber and their composites. Their individual properties should be a solid base to generate new applications and opportunities for bio-composites or natural fiber composites in the 21st century "green" materials environment (Sanjay *et al.*, 2016). The discovery of natural fiber composites in various applications has opened up new avenues for both academicians as well as industries to manufacture a sustainable module for future application of the composites. Natural fiber is a type of renewable sources and a new generation of reinforcements and supplements for polymer-based materials. The development of natural fiber composite materials has been important due to its increasing environmental friendliness. Natural fibers are one such proficient material which replaces the synthetic materials and its related products due to its less weight and high strength. Natural fibres can be obtained in commercial quantity from the plants shown in plate 1.

The application of natural fiber- polymer reinforced composites to replace the existing synthetic or polymer- glass fiber reinforced materials is of paramount importance in modern industries. Automotive and aircrafts industries have been actively developing different kinds of natural fibers, mainly on hemp, flax, sisal and bio-resins systems for production of their interior components (Sanjay *et al.*, 2016).

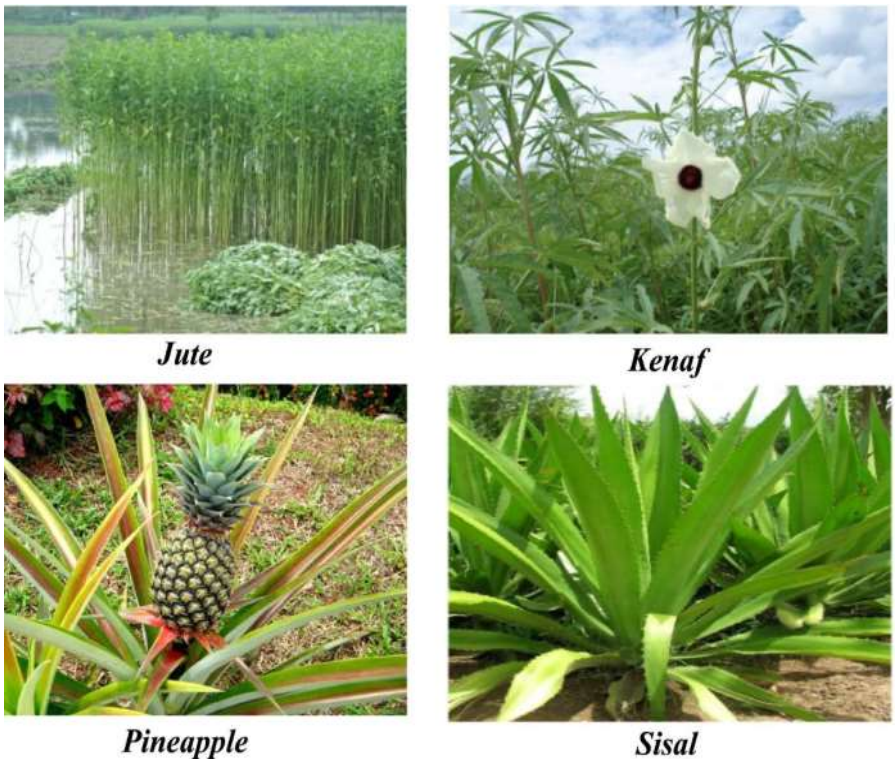

Plate 1*: Natural fibre plants.*

Natural fibers are applied in many sectors such as automobiles, furniture, packing and construction industries. Natural fibers have advantages over synthetic materials as low cost, availability, low weight and density, less damage to processing equipment, improved surface finish of moulded component, good relative mechanical properties, high strength, and better thermal insulation. Natural fibers are used in various applications such as building materials, particle boards, insulation boards, human foods animal feeds, cosmetics, and for other bio-polymers and chemicals. It is also used in high- tech applications such as composites parts for automobiles, aircraft, ships, trains, fishing rods, golf clubs, crash helmets, Helicopters, boats etc (Balakrisnan, *et al.,* 2016). Some of the few dis- advantages associated with natural fibres include high moisture sensitivity, faster fading and recycling difficulty.

#According to (Arpitha *et al*., 2016), Sisal fiber is a hard fiber extracted from the leaves of the sisal plant (*Agave- sisalana*). Though native to tropical and sub-tropical North and South America, sisal plant is now widely grown in tropical countries of Africa, the West Indies and the Far East. The plants are widely grown in Sahel and Savannah regions of Nigeria. Sisal plant can be found in large quantities in places like Adamawa, Borno, Taraba, Bauchi, Plateau, Kaduna and other states in Nigeria.

The plant is common, particularly in Mubi-North local government area, Adamawa State. Although not been cultivated in commercial quantity, but if properly harnessed in the production of automobile components the cultivation of the plant can be encouraged in the State and other neighboring communities which can serve as a source of income to the communities and the nation at large. A picture of sisal plant taken from Vimtim, Mubi-North Local Government Area, Adamawa State is as shown in plate II).

Plate II: *Agave (Sisalana). Picture taken from Vimtim, Mubi- Adamawa State.*

Composite Materials

According to science dictionary, composite is a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to

metallic alloys, each material retains its separate chemical, physical and mechanical properties. (McGraw- Hill, 2003).

Car bumper

Bumper is one of the essential exterior structure for passenger cars which are designed to have three major functions; receiving the impact, protecting against the crash that may cause more serious damage and absorbing the sufficient energy to meet the Original Equipment Manufacturers Requirement (Oksman, *et.al.*, 2003). The picture shown in plate. III is a typical Toyota corolla starlet car**.**

Plate III: *Car Bumper*.

In 1971, Federal motor vehicles safety standards No. 215 (FMVSS, 215) was enacted, and adopted as a barrier for crash tests of car bumpers. This standard prohibited functional damage to specified safety related components such as headlamps, and fuel system components when the vehicle is subjected to a collision at 8km/hr for front and 4km/hr for rear bumper systems.

It has been observed that most of the car bumpers in Nigeria are imported, hence there is need to reduce the costs due to importation. This could be done through the production of the bumper by using natural fibre which can be sourced locally.

Steel bumpers are heavy in weight compared to composite bumper which can lead to excessive fuel consumption of a car, hence, there is need to improve this through weight reduction for better efficiency and performance.

In most cases, maintenance of steel and plastic bumpers is difficult and not cost effective when compared to composite bumper.

MATERIALS AND METHODS

The materials and method are discussed under the following subheadings below:

Materials for the bumper and mould

The materials that are used for the production of bumper and mould are as follows:

- ✓ Sisal fibre as reinforcement for the bumper
- ✓ Polyester resin as the matrix,
- ✓ E- Glass fibre as the reinforcement for the mould
- ✓ Calcium carbonate as the hardener,
- ✓ Methyl Ethyl Ketone Peroxide as catalyst,
- ✓ Cobalt Napthenate as accelerator,
- ✓ Black pigment and neutral shoe polish as mould releasing agent.
- ✓ Paint

Tools and equipment

The following tools and equipment were used in carrying out the production of specimen for the research.

- ✓ Bowl for preparing the polyester
- ✓ 4” flat brush for applying the polyester unto the fibre
- ✓ Stirrer to mix the matrix constituents
- ✓ Clean piece of foam
- ✓ Mallet hammer to separate the fabricated bumper from the mould
- ✓ Scissors to cut the fibres
- ✓ Thermo-plastic bumper as pattern.
- ✓ Fabricated mould.
- ✓ YAW-200 Hydraulic compression testing machine.
- ✓ Charpy Impact testing machine
- ✓ G. Gusson universal testing machine (UTM) OKH100kN
- ✓ Tinius Olsen H10K.L9(Bi-axial) Flexural testing machine.

Classification of composite materials

Composite materials are classified into three major groups. These are; (i) Particulate (ii) Fibrous and (iii) laminate (Gandhi, 2014). The classification could be summarized in block diagram as shown in figure 1.

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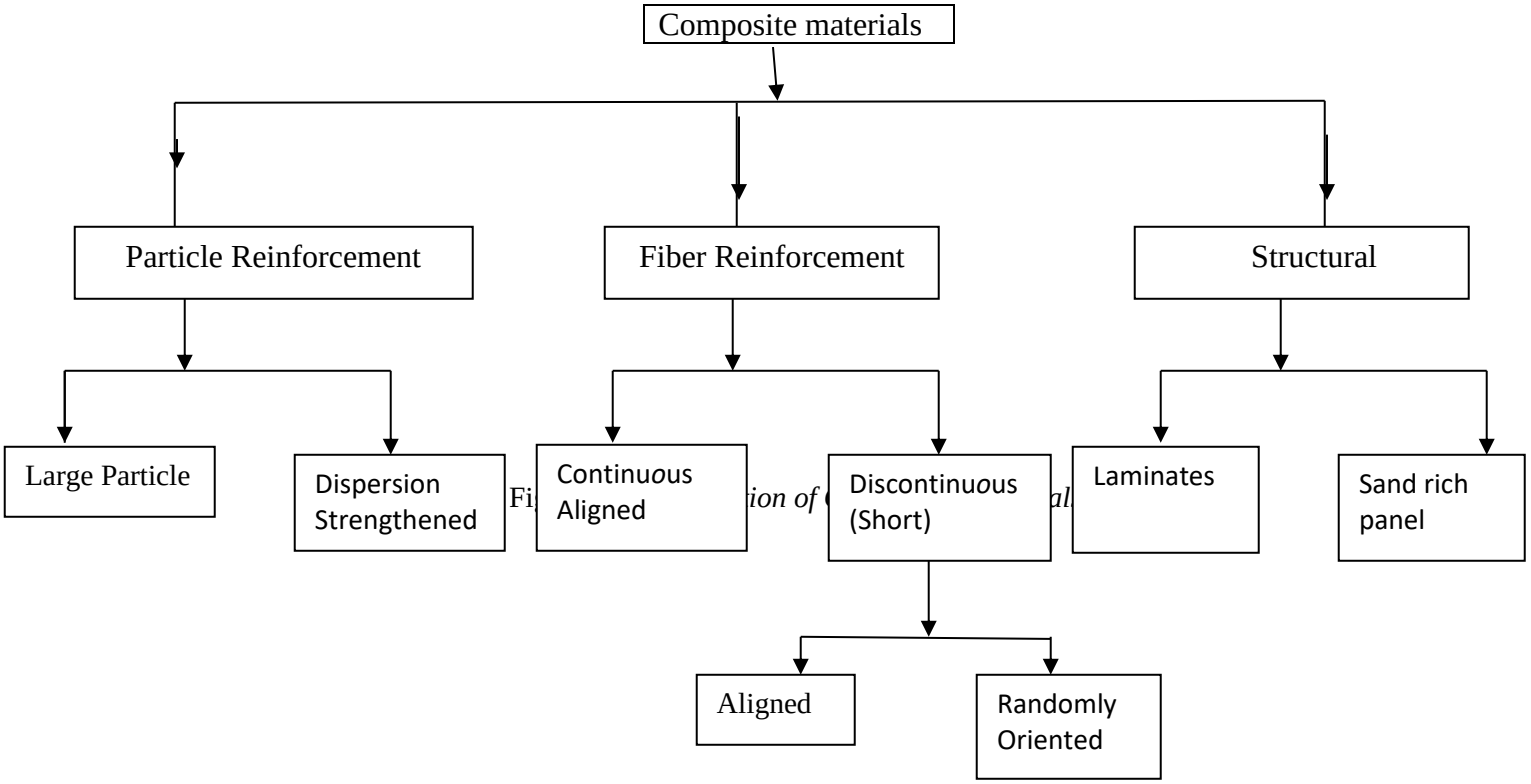

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Methods

The flowchart shown in figure 2 below illustrates the methods through which the composite bumper and the mould were produced.

Flow Chart for Production of Composite Car Bumper

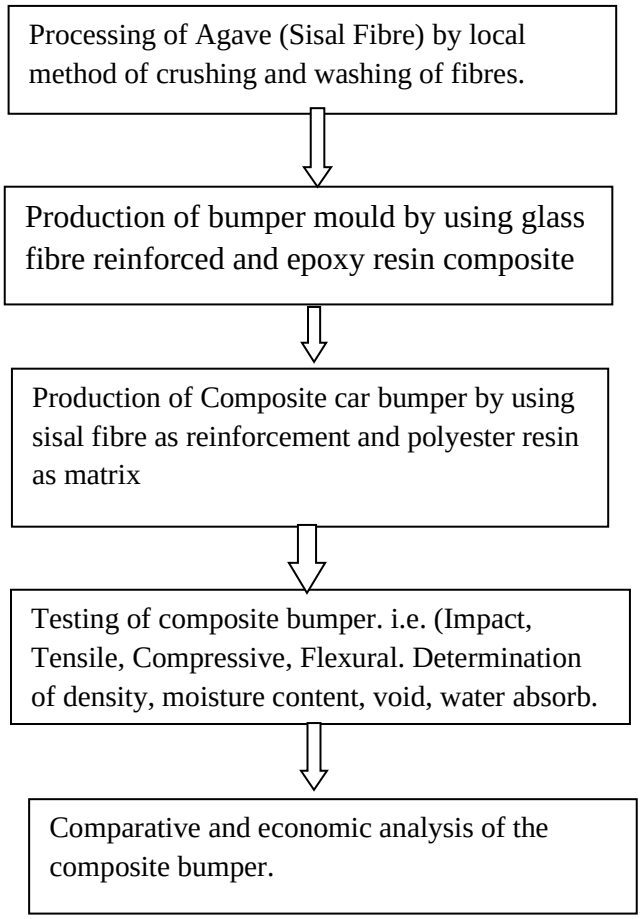

Figure 2: *Composite Bumper Production Process***.**

Design Theory

Bumpers play an important role in preventing the impact energy from being transferred to the automobile body and passengers. Saving the energy in the bumper to be released in the environment reduces the damages that can occur to the automobile and passengers. The bumper either absorbs the impact energy, transfers in perpendicular direction to the impact direction. In bumper design, a mechanism is been designed to convert about 80% of the kinetic impact energy to the spring potential energy and release it to the environment in the low impact velocity according to ASTM standard (Mortazavi and Ahmadian, 2016).

In the design of the composite bumper the following design parameters were taken into consideration.

- ✓ The type and properties of matrix used.
- ✓ The type and properties of fibre used
- ✓ The fibre orientation adopted to give the optimum composite strength.
- ✓ The volume fractions of fibres and matrix to give a qualitative strength of the car bumper.

- ✓ The availability of the fibre and matrix materials.
- ✓ The simple and cost-effective method of producing the composite car bumper.

Design of composite bumper

For designing the composite bumper an already existing steel or plastic bumper is used as a mould pattern. In this case fibre glass reinforced composite was used in design and production of the bumper mould. Dimensions were assumed to be the same as that of the steel/plastic bumper for fabrication.

In the design, the following dimensions and properties of steel bumper was used for reference purpose.

Effective length = 0.97m
Total length = 2.05m
Thickness = 0.002m
Effective breadth = 0.078m
Total breadth Weight = 0.172m
Weight = 5.16kg
Material = Mild steel (Chromium coating)
Tensile strength Density = 460MPa (Design data book)
Density = 7800kg/m^3 (Prabhakaran, 2012)

Determination of Fibre and Matrix Properties

In this bumper design, the amount of fibre and matrix volume fractions was determined by strength equivalent evaluation of the existing steel bumper. The maximum tensile strength of the existing bumper was determined to be 250MPa (Tomas, 2012).

This data was used as a basis for comparative analysis with composite bumper test results.

Table 1.0 Design computation of Composite properties.

Parameter.	Initial data	Computation	Result
Fibre and matrix Volume fractions.	From the steel bumper, σ_c= 250MPa σ_f = 530MPa from table (1) σ_m = 45MPa from table (6)	From eqn. (3) $\upsilon_f = \frac{\sigma_c - \sigma_m}{\sigma_f - \sigma_m}$ But υ_m = 1- υ_f = 1-0.3	υ_f = 0.3 υ_m = 0.7
Composite Modulus.	E_f = 17GPa from table (1) E_m = 1.3GPa from table (6)	$E_l = E_f\upsilon_f + E_m\upsilon_m$	E_l = 11.11GPa
Theoretical Density of Composite.	ρ_m = 1500kg/m^3 from table (6) ρ_f = 700kg/m^3 from table (2)	From eqn.8 $\rho_c = \rho_m\upsilon_m + \rho_f\upsilon_f$ $_{pc}$ = 1500x0.7 + 700x0.3 = 1260kg/m^3	ρ_c = 1260kg/m^3
Weight fraction of Fibre & matrix.		$W_f = \frac{\rho_f}{\rho_c} \times \upsilon_f$	W_f = 0.39

		$= \frac{700\times1000}{1260\times1000} \times 0.7$	$W_m = 0.61$
Fibre max stress.	σ_c =386MPa E_f = 17 GPa E_c = 6.481GPa	$\sigma_{fmax} = \frac{\sigma_{c\times E_f}}{E_c}$	σ_{fmax}= 664MPa
Yield stress.	σ_{fmax}= 664MPa d = 140micrometre as measured from fibre l = 0.0035m from table (6)	$\tau_y = \frac{\sigma_{fmax.}}{2l}.d$	τ_y = 13.28MPa
Ultimate fibre Strength.	E_f= 17GPa Fracture strain = 4.1%	$\sigma_{fu} = E_f.\varepsilon_f$	σ_{fu}= 697MPa
Critical fibre Length.	σ_{fu}= 697MPa d = 150micrometre τ_y = 12.60MPa	$L_c = \frac{\sigma_{fu.d}}{2\tau_y}$	0.00385m
Matrix stress at Fibre fracture Strain.	E_f = 17GPa E_m = 1.3GPa σ_{fu}= 731MPa	$\sigma_{m(\grave{\varepsilon}f)} = \frac{\sigma_{fu\times E_m}}{E_f}$	$\sigma_{m(\grave{\varepsilon}f)}$ = 55.9MPa
Matrix ultimate Strength.	E_m =1.3GPa ε_m = 4.7%	$\sigma_{um} = E_m x \varepsilon_m$	σ_{um} = 61.1MPa
Minimum fibre Volume fraction.	σ_{um} = 61.1MPa σ_{fu} = 664MPa $\sigma_{m(\grave{\varepsilon}f)}$ = 55.9MPa	From eqn. 4. $V_{crit} = \frac{\sigma_{mu}-\sigma_{\grave{\varepsilon}f}}{\sigma_{uf}+\sigma_{mu}-\sigma_{\grave{\varepsilon}f}}$	V_{min}= 0.0078

Critical Volume fraction.	σ_{um} = 61.1MPa σ_{fu}= 664MPa	From eqn.(13) $V_{min} = \frac{\sigma_{mu}-\sigma_{\dot{\varepsilon}f}}{\sigma_{uf}-\sigma_{\dot{\varepsilon}f}}$	V_{crit} =0.0085
Composite Ultimate Strength	σ_{um} = 61.1MPa σ_{fu} = 664MPa	From eqn.14 $\sigma_{cu} = \sigma_{uf}\upsilon_f + \sigma_{m(\dot{\varepsilon}f)}\upsilon_m$	σ_{cu} = 258.43MPa
Minimum load transfer length	σ_{fmax}= 664MPa d = 170micrometre, τ_y= 12.60MPa	$L_t = \frac{\sigma_{fmax}}{2\tau_y} d$	0.004m

Methodology for production of the mould and composite bumper by Hand lay-up technique.

There are several methods of fabricating composites materials. These methods were developed to meet the specific design and manufacturing challenges. Selection of a method for a particular component, therefore, depends on the materials, the part design and the end-use or application. In this research work, hand lay-up technique was chosen for the production of the mould and the composite bumper. This method is simple, less capital intensive and is the most basic method for fabricating a thermo set product.

This method typically consists of laying the dry plies of fibre by hand unto the mould to form a laminate stack. Resin is applied to the dry plies after lay-up is completed by means of resin infusion. In a variation known as wet lay-up each ply is coated with polyester- resin. Several curing methods are available. The intended basic one used was to allow the moulded product cure at room temperature for 24Hrs.

Equipment used in the production of Bumper.

The equipment used in the production of the bumper are:

- ✓ 4” flat brush
- ✓ Scissors
- ✓ Bucket
- ✓ Clean piece of foam
- ✓ Bowl
- ✓ 13mm spanner
- ✓ Bumper mould

- ✓ Hammer
- ✓ Stirrer

Table 2: Composition of the composite for Mould

Material	Quantity in (kg)
Polyester resin	4L
Fibre glass	2.5kg
Calcium carbonate	1.5kg
Catalyst	0.012kg
Accelerator	0.04g
Cobalt Napthenate	1.5ml

Processing of sisal fibre

In this process, fibre leaves collected from the plants were crushed by beating with a stick against a hard and smooth surface object to remove the cuticles from the fibres. The crushed fibres were there after soaked in water to wash the fleshy pulp completely and dried in the sun at ambient temperature as seen in Plate IV. The fibres were then soaked in sodium hydro-oxide (NaOH) solution for treatment to improve its properties.

Plate IV: *Removal of cast bumper from the mould.*

Plate V: *Processing of Sisal fibre.*

Plate VI: *Processed Sisal fibre.*

The dried fibres as shown in plate VI are those used as raw material for the production of composite bumper.

Production of the Mould.

Since there is no available mould in existence for the particular type of car bumper to be fabricated, there is need to design and construct the mould that may be required to carry out the moulding of the composite bumper. Highly precise work is required to give the correct shape and dimension of the mould. It is also important to take into account the breakeven of the mould so as to justify the cost of production within a specific cycle time of usage. In producing the mould, the shrinkage of polyester is to be taken into consideration for a desired dimensional accuracy.

Hand lay- up technique was adopted to fabricate the mould. In this process, a plastic bumper was selected as a pattern.

The surfaces of the bumper pattern were thoroughly cleaned with water and dusted. Edges were taped to give a precise shape of the mould to be fabricated.

During the production process, a gel coat was applied to the surface of the plastic bumper (pattern) to give the shape of the mould. Fibre glasses were then laid on the surface of the synthetic bumper where polyester resin was applied by a hand brush unto the mat of a glass fibre to give the reinforcement. Layers of reinforcement and polyester can continue to be added to meet the desired design thickness.

The moulding was then left for 24Hrs for curing at ambient temperature. After the mould was completely dried, the assembly was separated and finishing was then carried out with a fine emery cloth for smooth inner surface as shown in plate VII.

Plate VII: *Fabricated bumper mould, (Inner and outer surface)*

Table 3: Properties of Steel bumper

S/No.	Description	Steel bumper
1	Effective length	975mm
2	Total length (L)	2055mm
3	Thickness	2mm
4	Effective breath	78mm
5	Total breath	0.172m
6	Weight	5.16kg
7	Tensile strength	460MPa
8	Density	1.45g/cm^3
9	Cost	N17,000

Source. *(Prabhakaran, 2012)*

From table 3, the shrinkage of polyester of thickness 0.100-0.180 inches (2.54-4.572mm) which is within the range of the bumper thickness, 0.0012-0.006 inches/ inch (0.1524-0.03048) mm/25.4mm of linear shrinkage.

The longest side of the bumper is 2050mm; the shrinkage allowance for this length is;

$$\frac{2050}{25.4} X\ 0.03048 = 2.46\ mm.$$

This shrinkage allowance was considered so that the shrinkage is compensated. To compensate for the shrinkage, the mould after production was engraved to the shrinkage

value. For shorter lengths the shrinkage values were neglected due to low shrinkage value of polyester.

Production of the composite car bumper.

The following materials were used for production of composite bumper;

- ✓ 0.5kg, Sisal fibre
- ✓ 2.1kg, Polyester Resin
- ✓ 1.5kg, Calcium carbonate as the accelerator
- ✓ 0.02ml, Methyl Ethyl Ketone Peroxide as catalyst,
- ✓ 0.05ml, Cobalt Napthenate as accelerator,
- ✓ 1 Tin, black pigment and neutral shoe polish as mould releasing agent.
- ✓ 0.7kg, Paint

In the production of composite bumper, Hand lay-up technique was employed. In this process, the fabricated mould was used for laying of the sisal fibre and the polyester resin to produce the exact shape and size of the bumper. Gel coat was initially applied to the surface of the mould by using hand brush. 0.5kg of sisal was sliced into long fibres and laid randomly on the surface of the mould by hand lay- technique. The sisal fibres were placed on the top of the gel coat which stuck to it and follow the contours of the mould surfaces as shown in plate VIII.

Plate VIII: *Laying of fibre in the mould.*

A hand brush was used to impregnate the fibre with polyester resin. Further resin and reinforcement layer are applied on top of the mould until a suitable desired thickness was achieved as shown in plates IX.

Plate IX*: Application of polyester- resin to the fibre*

The moulding was left for 12 -24Hrs for curing at ambient temperature. After the product has properly dried up, the mould assembly was dismantled with 13″ flat spanner and the product was separated from each other as shown in plate X.

Plate X: *Removal of cast bumper from the mould.*

The finishing was thereafter carried out on the fabricated composite bumper with power grinder and fine emery cloth for a smooth surface texture as shown in plate XI.

Plate X1: *Finished composite bumper.*

For commercial productions, high pressure and vacuums can be used to force the plies together in the laminate thereby creating good adhesion and bonding during the curing process at room temperature. In this process, curing time can be less than 5Hrs.

A limitation of the hand lay-up technique is that it can only produce single component at a time.

RESULTS AND DISCUSSIONS

Determination of Impact Energy per Unit Area

The impact strength test was done by Charpy impact tester MT220 with a maximum capacity of 15J as per ASTM D256 standard. Four Sample specimens of composite bumper of sizes 75mm x 10mm x 10mm were selected. Each specimen was loaded in the testing machine and set at a specific reading. The pendulum or hammer was released from the rest position to swing and hit the mounted specimen in the machine jaw until it bends or fractures. Using the impact test, the energy to break the material is noted and is used to measure the toughness of the material and the yield strength. The effect of strain rate on fracture and ductility of the material is analyzed. The energy absorbed was recorded for each specimen as showed in Table 4

Table 4: Result of Impact Test

Specimen Identification	Energy absorbed (J)	Area (mm^2)	Energy absorbed (kJ/m^2) Energy/unit area
A	11.1	100	32.14
B	10.7	100	31.07
C	11.2	100	32.86
D	10.8	100	32.79
AVERAGE	10.95	100	32.215

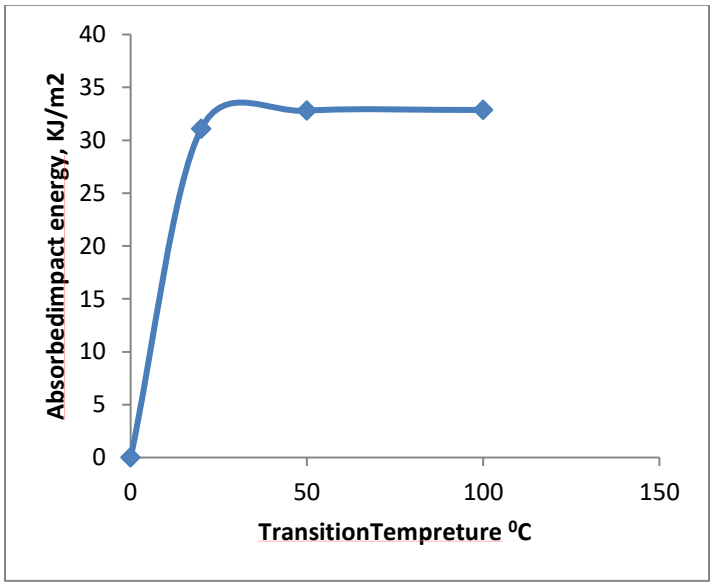

Fig. 3: *Impact strength graph of composite bumper*

Velocity of the Impact Hammer

There is need to determine the velocity of the hammer that will heat the specimen during test. To obtain the velocity of the hammer from the law of conservation of energy which said energy can neither be created nor destroyed rather it can be transformed or transferred from one form to another.

Therefore, the potential energy of the hammer at rest equals the kinetic energy of the hammer.

Hence; $Mgh = \frac{1}{2}MV^2$ 1

$V = \sqrt{2gh}$ 2

h = 0.9m as measured from the arm of the machine

$g = 9.81ms^{-2}$

$V = \sqrt{2} \times 9.81 \times 0.9$

$= 4.2ms^{-1}$

= 15.12km/hr.

Impact Energy on Toyota corolla bumper

The gross weight of Toyota corolla starlet car is 1322kg as given by the manufacturer, if the car is moving at a velocity of 8km/hr (2.22m/s) it is expected that the external structure (bumper) should be

able to withstand the impact energy as stated by the National Highway Traffic Safety Administration (NHTSA) and Federal Motor Vehicle Safety Standard (FMVSS-215).
The Kinetic energy possess by the car, K.E = $1/2mv^2$
Where:
M = mass of vehicle = 1322kg
V = velocity of vehicle = 2.22m/s
K.E = $\frac{1}{2} \times 1322 \times (2.22)^2 = 3257.67$J
The smallest area of impact on the bumper is $0.14m^2$
The energy absorbs per unit area = $\frac{3257.67}{0.14} = 23.27 kJ/m^2$

Therefore, it can safely be inferred, that the bumper can absorb the energy of the car moving at a speed of 8km/hr since the total energy absorb per unit area is $23.27kJ/m^2$ which is less than the minimum energy absorbed by bumper samples which is $32.215kJ/m^2$ shown in figure 3.

Tensile Test of a Car bumper

The Tensile test was conducted on composite bumper specimen as per ASTM D638 standard (sample dimension of 295mm x 18 x 10mm) was selected. A universal testing machine (UTM) OKH100Kn is used with the maximum load rating of 100KN. Composite specimens of sisal – polyester bumper is tested. Three samples of specimen are tested in each case and the average is determined and noted. The specimen is held in the grip and load is applied and the corresponding deflections are noted. The load is applied until the specimen breaks. The breaking load and ultimate tensile strength are recorded. Tensile stress and strain are also recorded where load verses length graph is generated as shown in figure 4. The results obtained from the tests were tabulated in tables 6, 7, 8, & 9.

Table 5: Dimensions of Specimens before Tensile Test

Specimen Identification	Width (mm)	Thickness (mm)	Cross sectional Area (mm^2)	Gauge Length (mm)
A	18.7	9.1	170.17	295
B	16.6	8.8	146.08	295
C	17.8	8.7	154.85	295
D	17.2	9.2	158.24	295

Table 6: Result of Specimen (A) Tensile Strength Test

LOAD (kN)	Extension (mm)	Stress Load/Area (MPa)	Strain Extension/Gauge Length
4.1	2.400	23.51	0.099
6.5	4.100	44.49	0.092
8.7	6.500	56.18	0.12
11.0	7.900	69.51	0.11

Specimen (A) failed at a maximum load of 11 KN.

Table 7: Result of Specimen (B) Tensile Strength Test

Load (kN)	Extension (mm)	Stress Load/Area (MPa)	Strain Extension/gauge Length
4.1	2.44	24.09	0.1
6.6	4.60	45.18	0.10
8.9	7.50	57.47	0.13
12.1	8.60	76.47	0.11

Specimen (B) failed at a maximum load of 12.1 KN

Table 8: Result of Specimen (C) Tensile Strength Test

Load (kN)	Extension (mm)	Stress Load/Area (MPa)	Strain Extension/Gauge Length
4.1	2.80	24.09	0.12
6.50	4.20	44.49	0.09
8.7	6.80	56.18	0.12
10.5	8.40	66.35	0.13
13.2	9.00	83.42	0.11

Specimen C failed at a maximum load of 13.2 (kN)

Table 9: Result of Average Tensile Strength Test

Load (kN)	Extension (mm)	Stress Load/Area (MPa)	Strain Extension/gauge Length
4.1	2.55	23.76	0.1
6.6	4.30	45.18	0.10
8.9	6.93	56.61	0.13
12.1	8.30	76.47	0.11

The ultimate tensile strength occurs at maximum average load of 12.1 (kN)

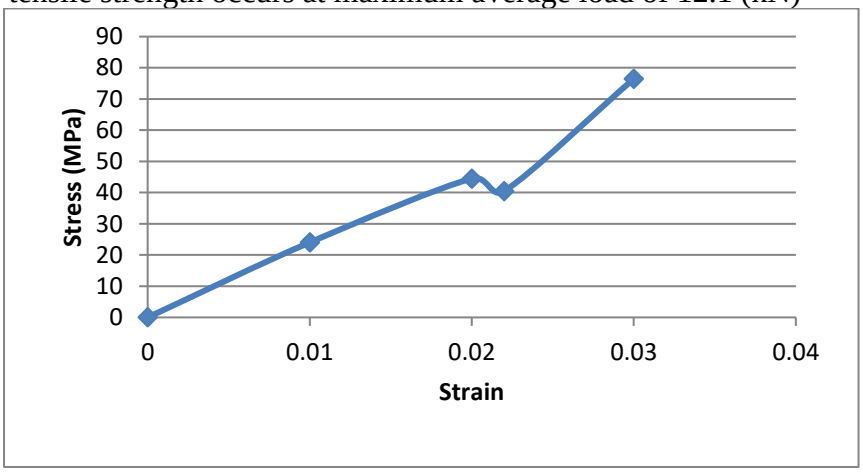

Figure 4: *Tensile Strength graph of composite bumper*

Determination of Compressive Strength

The test was carried out to ascertain the force the bumper can withstand on compression load. The test was carried out using G. Cusson tensile and compressive testing machine with a capacity of 100 kN. Four specimens of dimension 8mm x 18mm 250mm as per ASTM D3410 were used and subjected to compressive load; the change in length of each specimen was measured using digital vernier calliper at an interval of 0.7 kN load. The result obtained for each sample is shown in Table 10, 11, 12 and 13.

Table 10: Result of Sample (A) Compressive Strength.

Load P (kN)	Original length (mm)	Final length (mm)	Change in length $\|\partial L\|$ (mm)	Original cross-sectional area(A) (mm^2)	Stress (P/A) (MPa)	Strain $\|\partial L\|/L$
0.00	19.00	19.00	0.00	361	0.00	0.00
0.80	19.00	18.70	0.30	361	2.22	0.016
1.6	19.00	18.60	0.40	361	4.43	0.021
2.40	19.00	18.30	0.70	361	6.65	0.037
2.50	19.00	18.20	0.80	361	6.93	0.042

Table 11: Result of Sample (B) Compressive Strength

Load L (kN)	Original length (mm)	Final Length (mm)	Change In length $\|\partial L\|$ (mm)	Original cross-sectional Area (mm^2)	Stress (L/A) (MPa)	Strain $\|\partial L\|/L$
0	19.00	19.00	0.00	361	0.00	0.00
0.8	19.00	18.75	0.25	361	2.22	0.013
1.6	19.00	18.70	0.30	361	4.43	0.016
2.4	19.00	18.40	0.60	361	6.65	0.032
2.8	19.00	18.30	0.70	361	7.76	0.037

Table 12: Result of Sample (C) Compressive Strength Test

Load L (KN)	Original length(mm)	Final length (mm)	Change in length $\|\partial L\|$ (mm)	Original. cross sectional Aarea (mm^2)	Stress (L/A) (MPa)	Strain $\|\partial L\|/L$
0	19.0	19.00	0.00	361	0.00	0
0.7	19.00	18.75	0.25	361	1.94	0.013
1.4	19.00	18.65	0.35	361	3.88	0.018
2.1	19.00	18.60	0.40	361	5.82	0.021
2.2	19.00	18.50	0.50	361	6.10	0.026

Table 13: Computations of Average Compressive Stress and Strain

Average load (KN)	Original length(L) (mm)	Final length (mm)	Average change in length|∂L| (mm)	Original Cross sectional area (mm^2)	Average Stress (MPa) Load/area	Average strain |∂L|/L
0	19.00	19.00	0.00	361.	0.00	0.00
0.80	19.00	18.73	0.27	361	2.22	0.0142
1.50	19.00	18.65	0.35	361	4.16	0.0184
2.30	19.00	18.43	0.57	361	6.37	0.030
2.50	19.00	18.35	0.65	361	6.92	0.0342

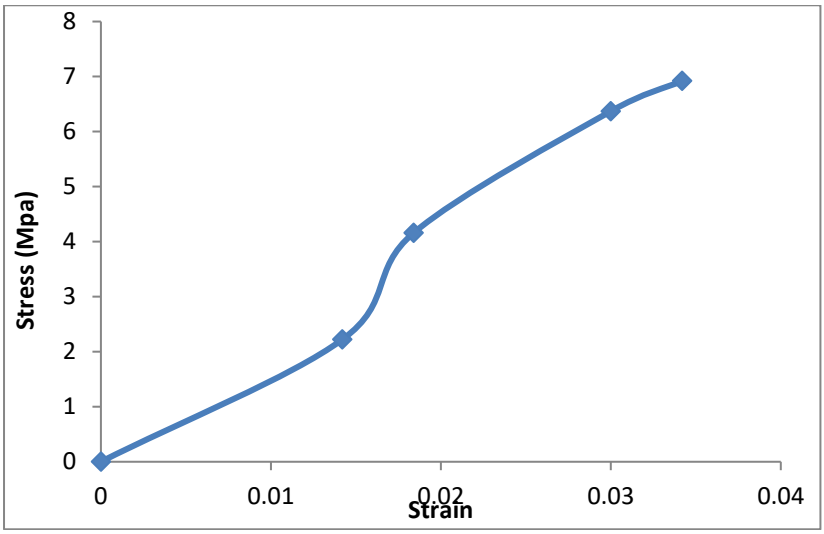

Figure 5: *Compressive strength graph of composite bumper*

Flexural test of composite bumper.

Flexural test was carried out on the bumper specimen to determine the flexibility of the bumper by a 4-point flexural test machine. (Tinius Olsen H10K.L (Bi-axial). The maximum span of the machine is 500mm. per ASTM D790 standard. The test was carried out at a normal temperature with a cross head ram speed of 2mm/min. Four specimens of different length of sisal- composite bumper were used. The specimens were placed at 2- point lower support and the ram attached to two points pressed the specimen to bend until it fails at maximum load. The maximum flexural stress can be calculated at each point load using the equation 1.0 and the average result recorded in table 14.

$\sigma_f = \frac{FL}{wd^2}$ ..... 3.

F = Force applied by the machine

L = Length of the specimen

w = the width specimen

d = the depth of the specimen.

Table 1.0 shows the flexural strength of the composite bumper specimens at four different points and its average strength at various lengths. The graph shown in figure 6 indicated the material failed at a maximum strength of 73.67 MPa.

Table 14: Flexural test results

Specimen	Load (KN)	Length of span (mm)	Area of specimen (wb^2) mm^2	Flexural strength (MPa)
A				
B	1.21	450	6272	86.81
C	1.22		"	
D	1.19	400	"	77.81
Average	1.33 1.24		"	
		350	6272 73.67	66.41
		300		
		375		63.62

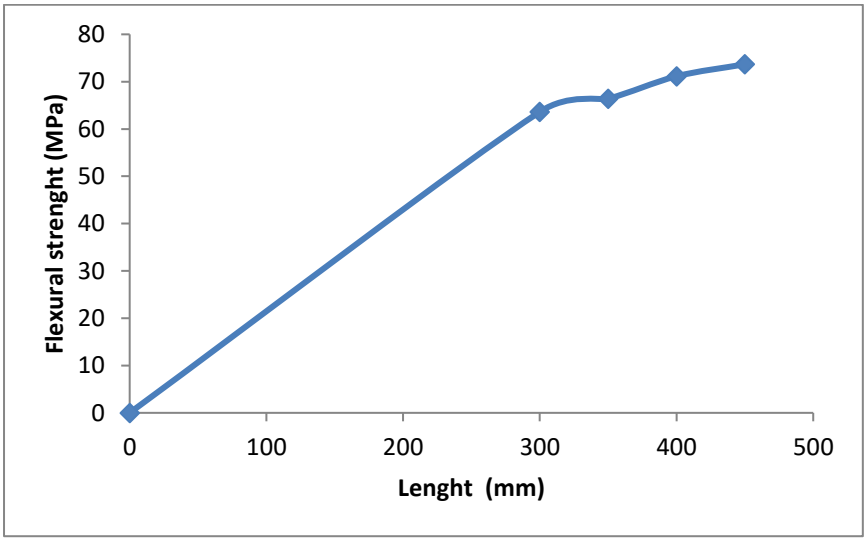

Figure 6: *Flexural strength graph* of composite bumper

Determination of Density of a Composite bumper

Water absorption behavior of sisal reinforced polymer composite was investigated by using electronic digital scale (Mettler AE 200) as per ASTM D570 standard. In determining the density of the bumper, three pieces of sizes (10×10) mm^2 was cut from the specimen and weighed on an electronic digital scale. The same piece was dropped into a volume measuring cylinder containing water at an initial volume V_1. After the piece has been submerged completely in water, it displaced the water and the volume of water rose to final V_2. According to Archimedes principle the volume of water displaced is equal to the volume of the piece (sample) submerged in water. The percentage water absorption was calculated by using the given equation.

Water absorption= $\frac{W2-W1dy}{W2} \times 100$ 4

Where w_1= weight before soaking into water (g)
w_2 = weight of soaked substance (g)
The readings obtained were recorded in Table 12.

Table 15: Result of Density Test

Sample identification	Mass of Sample (g)	Initial Volume of water (ml)	Final Volume of water (ml)	Displaced volume of water (ml)
A	20.04	150	167.31	17.32
B	20.56	150	167.74	17.75
C	20.23	150	167.56	17.58
Average	20.277	---	---	17.55

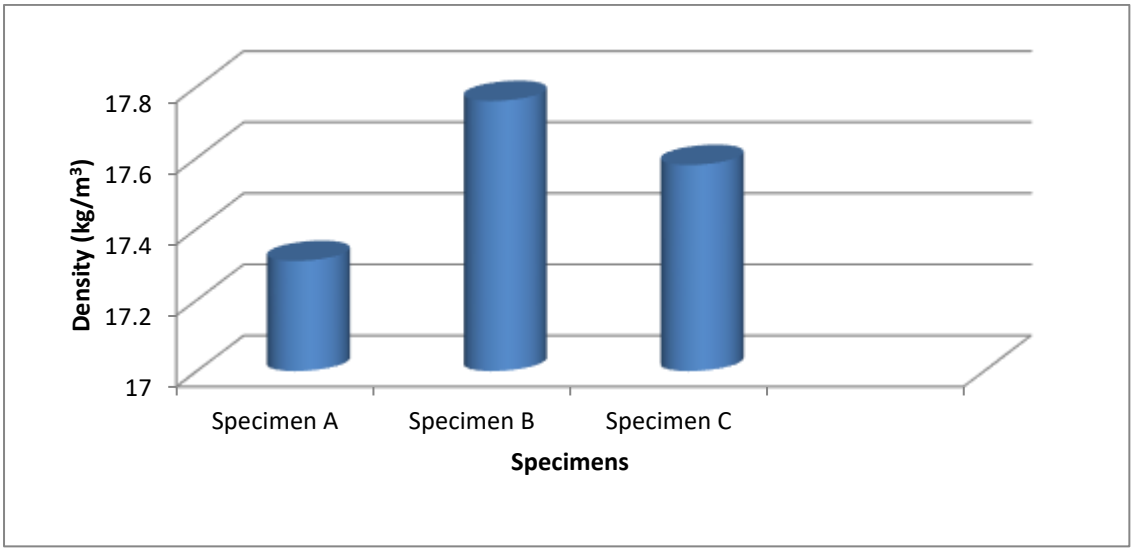

Figure 7: *Density chart of composite bumper specimens.*

Table 16: Computation of Density

	Initial data	Computation	Result
Average density of composite	Average mass of composite (M_{avc}) = 20.277g Average volume of composite V_{avc} = 17.5ml	Density = $\frac{Mave}{Vave}$ $=\frac{20.277}{17.500}\times 1000$	1192.76kg/m^3

Determination of Void Content

The void content is the pocket of air entrapped in the bumper during production this may significantly affect some of its mechanical properties. Higher void contents usually mean lower fatigue resistance, greater susceptibility to water penetration and un even distribution of strength properties. Table 2 showed the computed value of void content.

Computation of Void Content

Data: ρ_e= 1236.kg/m^3

ρ_t= 1236.37kg/m^3

Void content = $\frac{\rho_t-\rho_c}{\rho_t}$ x100

= 0.03%

Determination of Water Absorption

Water absorption behavior of sisal reinforced polymer composite was investigated as per ASTM D570 standard. In determining the density of the bumper, a piece of specimen of size (10×10) mm^2 was cut from the cast bumper. It was dried in an oven set at a temperature of 80^{0}C for 3hrs. The sample was removed, cooled to room temperature and weighted on a digital scale. The result of the sample was recorded. The sample was then immersed in clean water for 12hrs at 30^{0}C as per ASTM D570 standard. Afterward the specimen was removed and cleaned with rag. The weight of the specimens was then recorded as given in the table 15. The percentage water absorption was calculated by using the given equation. Water absorption= w_2-w_1 X 100 5

Where w_1= weight before soaking into water (g)

w_2 = weight of soaked substance (g)

Table 17: Result of Water Absorption Test

Sample	Dry weight (W1) in grams	Weight (W2) after soaked in water in grams for 12hrs
A	24.2373	24.2464
B	23.9725	24.1006
C	23.0360	23.0103
Average	23.7486	23.7858

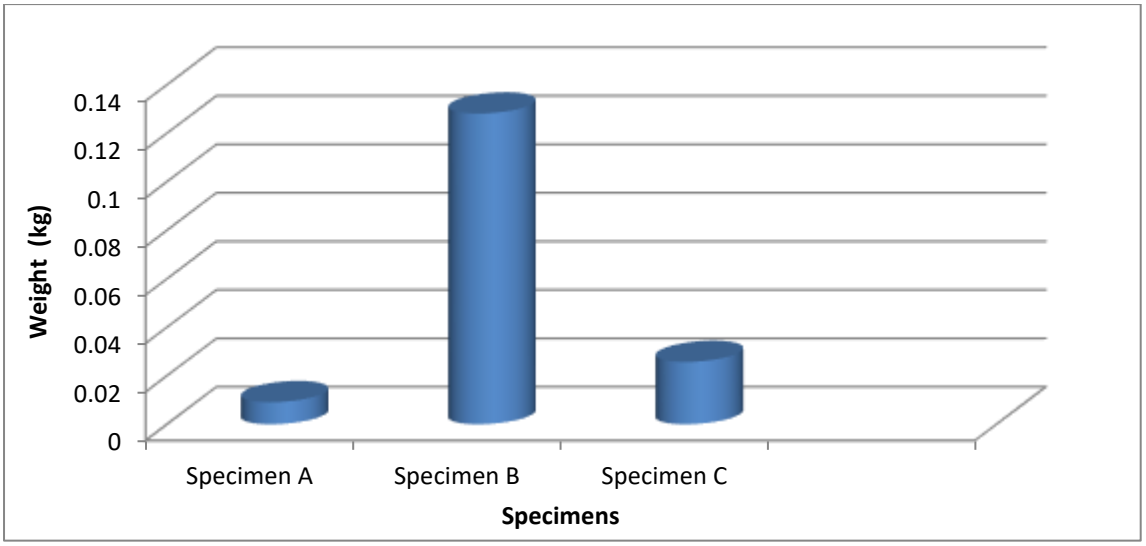

Figure 8: *Water absorption of bumper specimen*

Computation of Water Absorption

Data. W_{1Ave} = 27.7489g

W_{2Ave} = 23.7855g

Water absorption = $\frac{W_{2ave}-W_{1ave}}{W_{1ave}}$ X100

= 0.2

Determination of Moisture Content

The test was carried out to determine the amount of moisture in the composite bumper.

To determine the moisture content, an empty crucible was weighed and the weight recorded as W_1. The scale was zero and the weight of each sample in the crucible was taken and recorded as W_2. The sample in the crucible was taken to oven to dry at a temperature of 120^0C for 3hrs. After drying, it was removed from the oven and taken to desiccators which has desiccates to dehydrate and cooled the sample. After cooling, the crucible and sample were weighed and recorded as W_3 and the same was done for each sample and the records are showed in Table 7. This is based on ASTM D5229.

Table 18: Result of Moisture Test

Sample	W_1 (grams)	W_2 (grams)	W_3 (grams)
A	47.3926	20.1816	67.3366
B	47.1300	23.4313	70.3263
C	47.4212	21.5231	68.7443
Average	47.3146	21.7120	68.8024

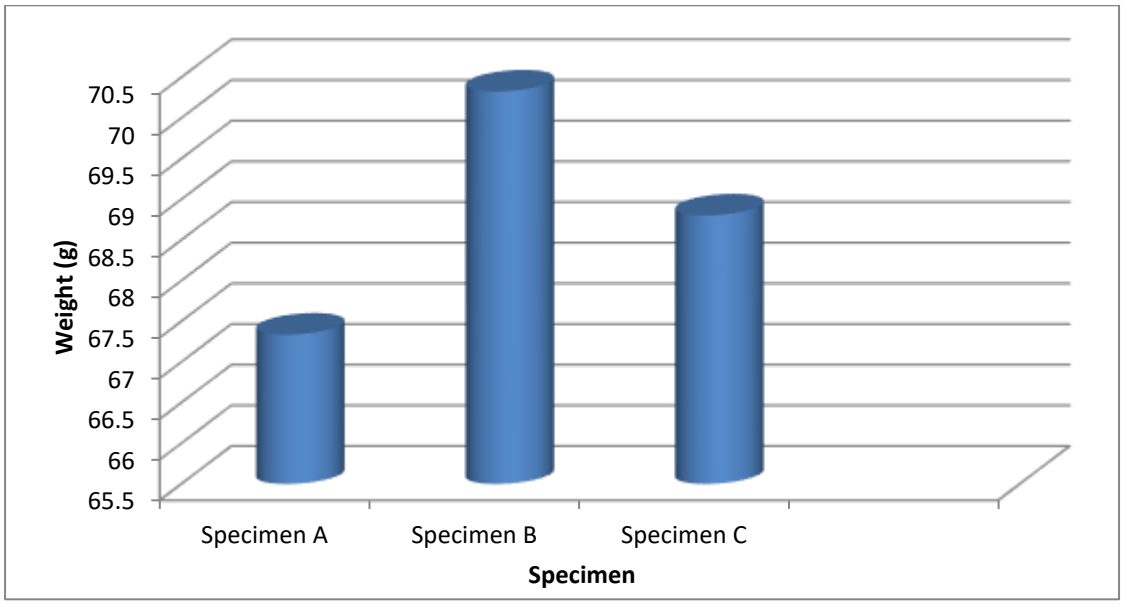

Figure 9: *Moisture content of bumper specimens.*

Table 19: Computation of Moisture Content

	Initial data	Computation	Result
Moisture content (M_c)	W_{1Ave} = 21.7120 W_{2AVe} = 47.3146 W_{3Ave} = 68.8691	$M_c = \frac{W_{1Ave}+W_{2Ave}-W_{3Ave}}{W_{1Ave}}$ X 100 $\frac{21.7120+47.3146-68.8691}{21.7120} \times 100$	1.00%

Impact Energy of Bumper

Table 4 showed the impact energy absorbed per unit area by the bumper and was found to be 32.215kJ/m^2 at an impact velocity of 3.32m/s (11.27km/hr). The result was also interpreted in a graph figure 3 for behavior of internal stresses the specimen undergoes. This result obtained is higher than the recommended value of 25.04kJ/m^2 at a speed of 8km/hr. It can be inferred that the bumper will withstand the impact by the vehicle at 8kh/hr without damage as stated by National Highway traffic Safety Administration (NHTSA) and Federal Motor Vehicle Safety Standard No 215 1972 0f US.

Tensile Strength of the Bumper

The tensile strength of the composite bumper was tested at four different points. The ultimate tensile strength of each specimen computed and the maximum average value of 76.47 MPa was obtained as given in table 9. The interpretation of graph in figure 4 shows that the bumper specimen was elastic up to the limit of proportionality of 44.49MPa before yielding. Much interest is not laid in the behavior of the material shown in the graph. The major purpose of the test is to determine the ultimate tensile stress at which the composite bumper will fail. This means that if the bumper is subjected to a tensile stress beyond 76.47MPa, it will fail.

Compressive Strength of the Bumper

The compressive strength of the bumper was computed at three different points. The average value in table 13 was 6.37 MPa, taken as the ultimate compressive strength at critical condition. This means that if the composite is stressed beyond this value it will fail. The failure of the composite was characterized by brittle fracture as indicated on Stress -strain graph figure 5.

Flexural Strength of bumper

The flexural strength test was carried out on the sisal reinforced composite bumper at different points and lengths of span. The result computed given in table 14 indicated that the bumper can withstand maximum stress up to 73.67 MPa before failure. That shows that with increase in size of the specimen the flexibility increases hence the flexural strength which is applicable to the composite bumper.

Density of Bumper

The average density of the sisal-reinforced epoxy composite bumper in table 15 was found to be 1192.76kg/m^3 which were less than the theoretical density of 1236kg/m^3. The experimental density is less than the theoretical density of the fabricated composite bumper because of void content. The void content affects the strength of the composite bumper; therefore, roller brush is suggested to be used in applying the resin to reduce the void content in subsequent production.

Void Content of composite Bumper

The percentage void content in the sisal-reinforced polyester composite bumper was calculated and found to be 0.03%. The value shows that it is less than the recommended value of 1% (little J.E., 2012) for good bonded composite. Therefore, the void content is negligible and the composite bumper is within the standard quality.

Water Absorption of Bumper

The percentage of water absorbed by the composite bumper was found to be 0.2% when it was soaked in water for 12hrs as showed in table 17. This means that if the bumper is exposed to continuous rain for 12hrs, its weight will increase by 0.5%. Interestingly, when the bumper was exposed to sun at an average temperature of 30^0C for 4hrs the absorbed moisture was

dried off. This shows that the bumper will not retain water for long period when exposed to excessive moisture or water

Moisture Content of the Bumper

In table 28, the moisture content of the composite was found to be 1.0%. This result showed that 1.0% of the weight of the bumper is moisture, it was noticed that when the composite was oven dried at a temperature of 80^0C for 3hrs the moisture was completely lost. Therefore, there is need to oven-dried the bumper after production to reduce the moisture content of the composite bumper.

Production Cost of the Composite bumper

Table 20 below summarizes the cost of production of a single automobile sisal-reinforced composite bumper.

Table 20: Summary of Production Cost

Material	Cost per unit (N)	Quantity (kg)	Cost (N)
Epoxy-resin	2000	3	6,000.00
Sisal fibre	300	0.3	900.00
Catalyst	700	0.2	1,400.00
Calcium carbonate	300	2.0	600.00
Pigment	600	0.02	600.00
Painting	-	-	3,500.00
Labour	-	-	3,000.00
Miscellaneous	-	-	1,500.00
Total	**-**	**-**	**17,500.00**

From the above table, the total cost of production of the Toyota corolla starlet bumper was N17, 500.00. The plastic bumper which was used as pattern for the production was purchased at the cost of N24,000.00, when these costs are compared, a saving of N6500.00 was achieved, hence for mass production more income can be generated from composite bumper.

Comparative analysis of the bumpers.

Table 21 illustrates the Comparative results between the existing steel- chrome plated bumper, thermoplastic bumper and sisal fibre-polyester composite car bumper.

Table 21: Comparison between steel, thermoplastic and composite car bumpers.

S/No.	Description of parameter	Steel bumper	Synthetic bumper	Composite bumper
1	Effective length	975mm	975mm	975mm
2	Total length (L)	2055mm	2055mm	2055mm
3	Thickness	2mm	4mm	3mm
4	Effective breath	78mm	78mm	78mm
5	Total breath	172mm	172mm	172mm
6	Weight	5.16kg	4.6kg	3.6kg
7	Tensile strength	460MPa	46MPa	68.9MPa
8	Density	7800kg/m^3	1,230kg/m^3	1330kg/m^3
9	Modulus of elasticity (E)	4.5 GPa	4.2GPa	3.5GPa
10	Poisson ratio	0.3	0.3	0.27
11	Cost (N)	32,000	28,000	17,500

Source. (Prabhakaran, 2012) *Properties and cost of steel and thermoplastic bumpers*

From table 21, the steel and thermoplastic car bumpers were selected for comparison with the sisal fibre composite car bumper. The steel and plastic bumpers commonly found on cars are taken into consideration for the comparative analysis. The sizes and dimensions of the bumpers were the same. In the comparison, the properties of the three bumpers vary when compared to each other. Charpy impact test was conducted on the sisal fibre composite bumper to determine its properties for the comparative analysis with the other two bumpers. Result showed that the sisal composite bumper can absorb a maximum energy of 32.215kJ/mm^2 when compared with steel bumper of the same size. The composite bumper is N14, 500 less in cost when compared to the steel bumper and a weight reduction of 1.56kg is achieved. Steel bumper has the highest tensile strength of 450 MPa, while sisal composite and thermoplastic bumpers have the tensile strength of 73.67MPa and 46 MPa respectively. The density of steel is 7800kg/m^3 (Kumar, 2010), whereas for sisal the density was computed to be 1192.76kg/m^3. The impact strength of the sisal fibre composite bumper is more than that of the steel bumper by 3.89J/m^2. Steel bumper despite having the highest tensile strength when compared to sisal fibre composite bumper has the major disadvantage due to heavy weight which can cause excessive fuel consumption and poor engine efficiency of the car. The plastic bumper on the other hand is less resistance to fire and high temperature which can result to its easy deformation of the shape and contour when compared to the steel and composite bumpers. From the Comparative analysis, it shows that sisal fibre will be a better material for the production of a car bumper than steel and plastic for better performance and economy in automotive industries.

Comparison in terms of cost.

The chart in figure 10 shows that steel bumper has the highest cost of N32,000 which is more than the costs of plastic and composite bumpers at N17,500 and N28,000 respectively. When compared, the sisal reinforced composite bumper costs less than the two bumpers.

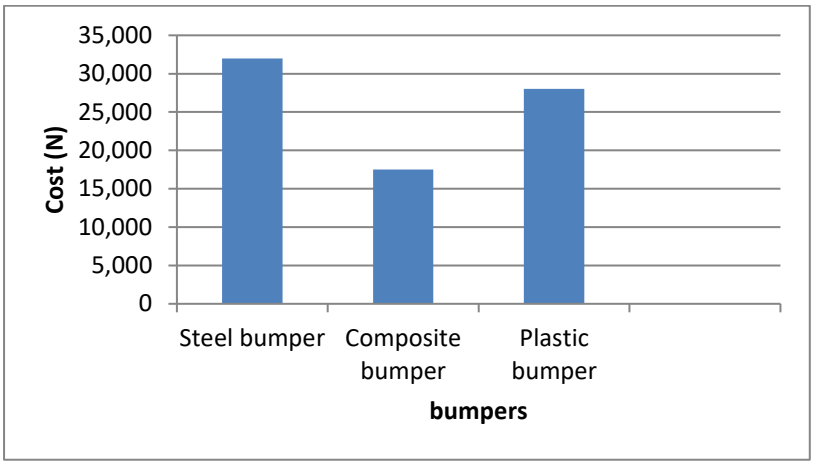

Figure10: *Comparison cost of bumpers.*

Comparison in terms of weight.

From the chart shown in figure 11, the weight of the steel bumper is 5.16kg. While the weight of thermoplastic and composite bumpers is 4.2kg and 3.6kg respectively. Therefore, the steel bumper has the highest weight compared to plastic and composite bumpers.

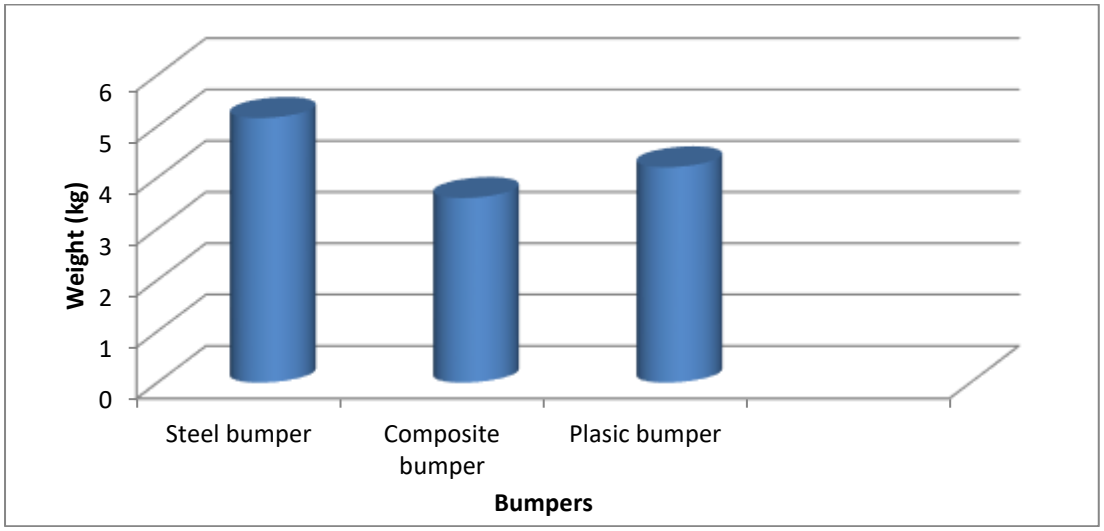

Figure 11: *Weight comparison of bumpers.*

Comparison in terms of tensile strength of bumpers

From the chart shown in figure 12, steel bumper has the highest tensile strength of 450MPa. It is higher than the composite and plastic bumpers having 46 MPa, and 76.47 MPa respectively. But the major disadvantage of steel bumper is the heavy weight which can affect the overall engine efficiency of the car.

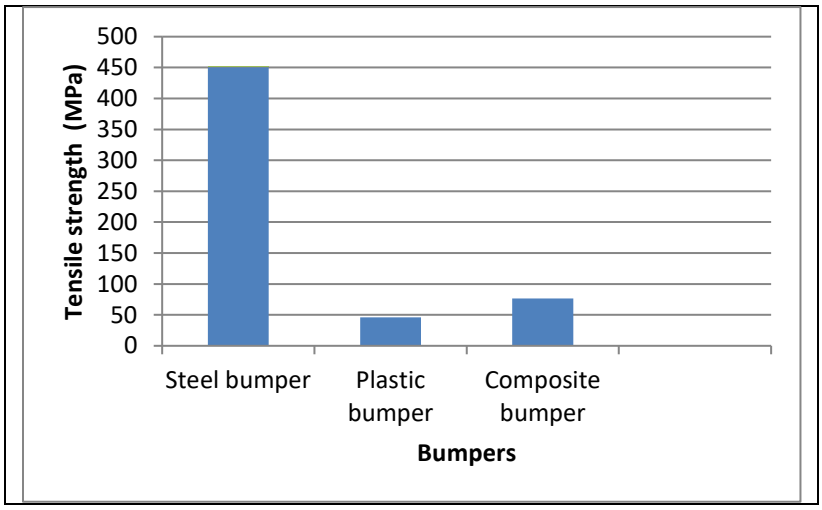

Figure 12. *Tensile Strength Comparison of bumpers*

Weight Saving

After producing the composite bumper, it was weighed on a digital scale, the weight was found to be 3.6kg and the weight of the steel bumper was found to be 5.16kg. This means that a weight saving of 1.5kg was achieved. This weight difference can influence the reduction of fuel consumption and increase the efficiency of the car. These factors justify the objective of the research.

CONCLUSION

The aim of this research was achieved by Toyota corolla car bumper was produced from sisal-reinforced polyester composite by hand lay-up technique. The following conclusions were drawn from the research work.

The processing of sisal fibre used as raw material for the production of composite bumper was obtained in significant quantity.

A bumper mould used for the fabrication of the composite car bumper was successfully fabricated from E-glass fibre and polyester resin- matrix.

A high strength, less weight composite car bumper was successfully produced using the processed sisal fibre as reinforcement and polyester resin as a matrix.

From the analysis the results obtained are; tensile strength, 76.47MPa; Impact strength 32.215kJ/m^2 at an impact velocity of 3.32 m/s; Compression strength; 6.92MPa; and Flexural strength; 63.66MPa. All the results meet the standard requirement of the bumper as per Federal motor vehicle safety standard (FMVSS) No.215, 1971 at 8km/hr.

From the cost analysis, 45.3% cost was saved from sisal composite bumper when compared to the existing bumpers. Hence, the use of sisal fibre for production of composite bumper is economical when compared to steel and plastic bumpers available in the market.

Recommendations

It is recommended that:

- ✓ Sisal fibre should be processed and knitted into mat form for uniform stress distribution during bumper fabrication.
- ✓ The cultivation of sisal fibre plantation should be encouraged in Nigeria so that commercial quantity of the fibre could be obtained to develop the indigenous automobile industries
- ✓ The research is recommended for further improvement and large-scale production
- ✓ Sisal fibre processing factory should be established in Nigeria for easy processing of fibres for export and economy growth of the nation.

Contribution to knowledge

It has been established that sisal fibre can conveniently be used as a material for composite car bumper. More knowledge was also acquired on how to formulate a polyester and fibre to fabricate a solid composite car bumper which can perform better than other materials. The research has also shown that the sisal plants which has been under-utilized in Nigeria can be converted into useful product thereby creating job opportunities for the teeming population of the country to generate wealth and promote economy.

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