American Journal of Materials Engineering and Technology, 2015, Vol. 3, No. 2, 27-34
Available online at http://pubs.sciepub.com/materials/3/2/2

DOI:10.12691/materials-3-2-2

Production of Motorcycle Anti-crash Helmet Shell from Composite Reinforced with Male Flower Bunch Stalk Fibre of Elaeis Guineensis

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Received February 10, 2015; Revised March 09, 2015; Accepted May 06, 2015

Abstract The use of natural fibres in polymer reinforcement has gained serious attention due the fact that they are biodegradable and possess qualities similar to synthetic fibres. Chemical treatments have been successfully used to improve the qualities and performance of natural fibres. This has made natural fibre reinforced polymer gain wide applications in the production of structural componentd. In this work anti-crash helmet was fabricated using the male flower bunch stalk fibre of elaeis guineensis treated with 5% concentrated sodium hydroxide (NaOH) and unsaturated polyester as binder. Hand lay-up method of casting composites was used for helmet fabrication process. Standard test samples were fabricated using same formulation and analysed for water absorption, physical and mechanical properties that included tensile strength, hardness, impact strength and modulus. The mechanical performance of treated reinforcement fibres and composite were determined and the results obtained were compared with past literature. The result showed that chemical treatment greatly improved the mechanical properties, hydrophobic and chemical stabilities of the natural fibres and made them more suitable for the application. Composites reinforced with 20% male flower bunch stalk fibre of oil palm (elaeis guineensis) gave the optimum performance in terms of tested properties of helmet. The composite formulation was also observed to have high potentials for production of related engineering components like car bumper, dash board, military and industrial safety helmets.

Keywords: *oil palm, male flower bunch fibre, polyester, helmet, sodium hydroxide*

Cite This Article: Nuhu A. Ademoh, and Olasoji C. Olanipekun, "Production of Motorcycle Anti-crash Helmet Shell from Composite Reinforced with Male Flower Bunch Stalk Fibre of Elaeis Guineensis." *American Journal of Materials Engineering and Technology*, vol. 3, no. 2 (2015): 27-34. doi: 10.12691/materials-3-2-2.

1. Introduction

A rider is highly prone to life threatening accidents and injuries due to the two legged and high speed nature of motor cycles. Helmets are protective head gears worn by motorcycle riders for protection against injury in case of accident. They act as face shields, provide ventilation and ear protection. Its main components are the shell and inner foam liner. The shell is usually hard and helps resist objects from penetrating during impact thereby preventing direct injury on skull. The foam liner help absorb most of the impact energy. Most helmets are made from resins or plastics reinforced with fibers like aramid. Helmets protect user head by absorbing mechanical energy and protect against penetration. The structure and protective capacity are altered in high-energy impact. Beside energy-absorption capacity, their volume and weight are critical issues that must be considered so as not to increase injury risk and discomfort user's head and neck as observed by neurosurgeons that developed anatomical helmets adapted to the inner head structure (Prasannasrinivas and Chandramohan, 2012). Generally, modern helmets are made from acrylonitrile butadine styrens (ABS) plastics reinforced with glass or carbon fibres, fabric and foam interiors for comfort. Its inner foam is soft, thick and conventionally made of expanded polystyrene foam (EPS) designed to cushion/crush on impact. The outer shell is thin, hard and conventionally made of plastic or fibres like polycarbonate, fibre glass or Kevlar that crush on impact for protection and comfort.

In Nigeria the use of motorcycle as means of commercial transportation became a common feature mid 1990s to compliment taxis that could no longer cope with passenger population explosion and expansion of human settlements in remote areas taxis cannot access. Unfortunately, most operators of commercial motorcycles are unemployed youths who were never trained for the job. This resulted to accidents that have killed or maimed riders and passengers, as motorcyclists are at high risk in traffic crashes. In 2008, Federal Road Safety Corps (FRSC) of Nigeria reported a staggering surge in number of road accidents, a significant percentage of which was traced to commercial motorcycles. This made the authorities to enforce a regulation of wearing of anti-crash helmets as an intervention as anti-crash helmets were reported to reduce risk of brain injury by 85%, head injury by 69%, death by 42% and cervical spine injury drastically (Adewale, 2010). This brought sudden rise in demands for crash helmets mainly imported as Nigeria lacked technological ability for its local manufacture.

As part effort for local helmet production, Shuaieb et al. (2002) made three prototype helmet shells from natural fibres that included coir fibre, coir hybridized with glass fibre and oil palm with glass fibre using polyester resin matrix. They observed that glass woven layer added on the outside surface gave helmet superior impact resistance than coir/glass. Yuhazri and Dan (2007) used coconut fibre reinforcement and thermosetting polymer resin matrix to make motor cycle helmet. Its mechanical evaluation showed that 20% coconut fibre was a suitable reinforcement for epoxy resin matrix. Prasannasrinivas and Chandramohan (2012) studied natural fiber reinforced composite for helmet outer shell with CAD model for impact analysis and showed that a hybrid of natural fiber composites are better replacements for plastic in helmet. Murali et al. (2014) showed that hybridized composite gave better impact strength, lower weight and cost than acrylonitrile butadiene styrene (ABS) plastic. Adewale (2010) produced helmets of acceptable properties with 40% hybridized composite of jute, banana, 2.5mm sisal fibres and 60% epoxy binder. Based on the emergent needs for safety helmets occasioned by Nigerian Government regulations and past related works on indigenous production of the gadget from locally sourced materials, this study is aimed at developing composite materials reinforced with biomass fibres from stalk of male flower bunch of oil palm (elaeis guineensis) for the hard outer shell of motorcycle anti-crash helmets. The main objectives include production of raw fibres of stalk of male flower bunch of oil palm, chemical treatment of fibres for improved chemical property, physical and mechanical strengths, formulation of composite reinforced with treated fibres, production of sample motorcycle crash helmet and characterization of helmet composites. The significance of the research when completed is that it would promote indigenous technology, reduce importation of helmets and cause saving on foreign exchange; create employment opportunities for youths; reduce incineration of agro-wastes that release green house gases that deplete ozone layer.

2. Experimental Materials and Procedures

2.1. Experimental Materials

The research materials and facilities consisted of unsaturated polyester, calcium carbonate, distilled water, cobalt naphthanate, oil palm male flower bunch, methyl ethyl ketone peroxide, sulphuric acid, sodium hydroxide solution (purchased in Bauchi), glucose peroxidase assay kit, dinitrisalicyclic acid (DNS) autoclave, Instron universal test machine (model 3396), Ceast Resil Impactor machine, helmet mould, Shore D durometer, Micro Vision Industries universal machine, plastic/stainless steel container. Fibre was obtained from stalk of male flower bunch of selected trees of oil palm plantation in Offa, Kwara State of Nigeria. A sample of the male flower bunch is as shown in Figure 1 below.

Figure 1. Oil palm male flower bunch

2.2. Experimental Procedures

2.2.1. Fibre Treatment

The raw fibres were subjected to chemical treatment in sodium hydroxide (NaOH) solution to improve its properties as done by Mishra et al. (2008) who treated sisal-polyester with NaOH at room temperature and reported 4%tensile strength increase. Also 5% NaOH treated fibre reinforced polyester composite was reported to improve tensile strength more than 10% NaOH treated composite. Because of high concentration of cellulose induced by chemical treatment, there was delignification that enhanced flexural rigidity and stabilized the molecular orientation (Shehu et al, 2014). During treatment, washed and dried fibre was soaked in 5%NaOH solution for 3hours. The NaOH solution was prepared by dissolving weighed NaOH in measured distilled water accordingly. Thereafter fibre was removed and rewashed until all slipperiness was lost and then re-dried to reduce its hydrophilic state. The reaction of fibre–cell and NaOH occurred as shown by Shehu et al (2014):

$$\text{Fibre} - \text{cell} - \text{OH} + \text{NaOH} = \text{Fibre cell} - \text{O} - \text{Na}^{+} + \text{H} \quad (2.1)$$

2.2.2. Mechanical Testing of Fibres

The tensile and strain properties of treated fibres were determined using the Instron universal testing machine. Tests were done on five standard specimens of treated fibres adopting procedures used by Mishra et al. (2008) and Shehu et al. (2014).

2.2.3. Density Test

Some quantity of the dried treated samples were weighed and recorded as w, distilled water was poured into measuring cylinder with initial volume recorded as $V_{1.}$ Weighed dried fibre was put into measuring cylinder with distilled water and final volume recorded as V_2. This was repeated for specimens and density was calculated with the formula (Abdul Khalil, 2011):

$$\frac{W}{V2 - V1} \times 1000 \; Kg / cm^3 \quad (1)$$

2.2.4. Bio-composite Formulation

The treated and dried biomass fibre of stalk of male flower oil palm bunch was weighed in accordance with the compositional mix presented in Table 1 and used to prepare the composite. The formulation in Table 1 was used to produce sample anti crash helmets for motorcycle riders. The role of each constituent in composite is as defined in Table 1. Test specimens were taken for analyses to determine the characteristics and physical performance of composite.

Table 1. Constituent materials and formulation for the bio-composite

S/N	Role of Constituent	Name of constituent	Composition (%)
1	Matrix	Unsaturated polyester	70
2	Reinforcement	Oil palm male flower bunch stalk fibre	20
3	Filler	Calcium carbonate	8
4	Accelerator	Cobalt naphthanate	1
5	Catalyst	Methyl ethyl ketone peroxide	1

2.2.5. Composite Production and Casting of Helmet Shell

An open mould casting using hand lay-up method was used to fabricate helmet shell. The process as compared with other methods aids fast product development sequence due to simplicity of fabrication at lower cost. Products of reinforced polymer composites using this universal method are fabricated from exterior to interior as required for low quantity helmets (Shuaieb et al., 2002; Yuhazri and Dan, 2007). A pigmented gel coat was spread inside of mould for fine surface finish and allowed to cure before fibre reinforcing mat was placed in the mould. Catalyzed resin and filler was poured, properly brushed on and manual rolling was used to remove entrapped air, compact composite and thoroughly wet reinforcement with resin.

Additional layers of mat or woven roving and resin were made repeatedly until required thickness was achieved. Curing of composites was initiated by addition of the catalyst and accelerator on the resin without external heating. For helmet casting, treated fibre were first chopped into desired length of 5-20mm. Mould treatment was done with a release agent to facilitate easy removal of products. Treated chopped fibre was wet with resin, laid in mould uniformly and hand brush used to apply resin on fibre. After curing mix for 40 minutes, the helmet was removed from mould. Required test specimens were cut out from cast composites for property tests. The composite helmet and specimen were produced in a collection of workshops at Technology Incubation Centre (TIC) Bauchi, Nigeria. Figure 2 presents some major processes used in the composite helmet production. Test specimens were made directly from helmet mix and shaped according to the required test standards.

Figure 2. Helmet production processes (A) Helmet open mould; (B) Treated chopped fibre; (C) Internal surface of helmet pattern; (D) External surface of helmet pattern

2.2.6. Mechanical Testing of Composite Specimens

Impact tests were conducted on the composite samples according to ASTM D256 standard using Ceast Resil impactor machine. Sample was cut to a dimension of 85 x 8 x 3 mm as required bymachine specification. Each sample was set as a vertical cantilever and broken with a single swing of the hammer. Speed was set to 3.4 m/s and test was done with a hammer of 4J. The impact strength (J/m) was calculated by dividing energy absorbed (J) with thickness of specimen (m). Hardness test was carried out on specimens according to ASTM (D2240) using the Shore D durometer. Tensile test of composite samples was done according to ASTM D638 standard using the universal testing machine by Micro Vision Industries. The toughness of composite samples was deduced from the stress-extension curve, which represented the area under stress extension curve as practiced by Akindapo et al. (2014).

2.2.7. Water Absorption Test

Initial dry weight (Wd) of composite specimen was determined and recorded. After immersion in distilled water at room temperature for 24 hours weight (W_1) of the composite after was recorded. Another weigth (W_1) was recorded again after another 24 hours. This continued repeatedly until a constant weight (W_1) was obtained. The percentage equilibrum of water absorption was calculated using this equation in accordance with ASTM D570 (Abdul Khalil, 2011).

$$\text{Water absorption } (\%) = \frac{W_n - W_d}{W_d} \times 100 \tag{2}$$

Where: $Wn_{1,2,3}$.. is weight of sample after immersion and W_d is weight of sample before immersion.

3. Result and Discussion

Table 2 presents the physical properties of untreated and treated fibres of male flower bunch stalk. It showed weight, volume and density of 3 sampled of untreated and treated fibres. The table showed that untreated fibres' weigth, volume and density varied through the tests because of the hydrphilic and anisotropic natures of the untreated materials. However after 5%NaOH treatment, values became constant over the three tests as material became more chemically and physically stable.

Table 2. Summarized result of physical property tests of sampled fibres

Physical property description	Untreated male flower bunch stalk fibre			Treated male flower bunch stalk fibre		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
W (g)	0.136	0.135	0.137	0.226	0.226	0.226
V_1 (mm^3)	6.00	5.90	6.10	8.00	8.00	8.00
V_2 (mm^3)	6.03	5.93	6.13	8.12	8.12	8.12
Density (X 10^{-3}Kg/cm^3)	4.53	4.50	4.57	1.88	1.88	1.88
Average Density (X-10^{-3}Kg/cm^3)	4.53			1.88		

The NaOH treatment as illustrated in the equation removed moisture content from the fibers thereby increasing its strength; enhanced flexural rigidity of fibers; cleared all impurities adjoining fiber and stabilized molecular orientation. It is an alkaline treatment referred to as mercerization of natural fibres. It caused surface modification to make fibre wettable to matrix for polymer production. According to Reza et al., (2013), the treatment removed lignin, hemicellulose, wax, and oil covering fibre surface. NaOH mercerization lead to fibrillation that caused break down of composite fibre bundle into smaller fibres, reduced fibre diameter, increased aspect ratio and caused development of rough surface topography that gave better fibre/matrix interface adhesion that resulted to inproved mechanical properties. The alkali sensitive hydroxyl (OH) groups present in raw fibre molecules broke down, reacted with water and moved out of fibre structure. The remaining reactive molecules formed fibre cell–O–Na group between cellulose molecular chains. Due to this, hydrophilic hydroxyl groups were reduced making fibres hydrophobic. It also eliminated certain portion of hemicelluloses, lignin, pectin, wax and oil covering materials. Thus, fibre surface became more homogeneous due to elimination of microvoids. Stress transfer capacity between alternate cells improved and increased effective fibre surface area for good adhesion with matrix. It decreased hydrophilic nature of fibre by raising its cellulose content and stabilized the material. This accounted for constancy of values of the samples. Figure 3-Figure 7 present results of tensile stress/stain tests conducted on 5 randomly selected representative treated fibres. Table 3-Table 7 present a summary of the length, ultimate tensile strength, modulus, extension and diameter of corresponding fibres as derived during the stress/strain tests.

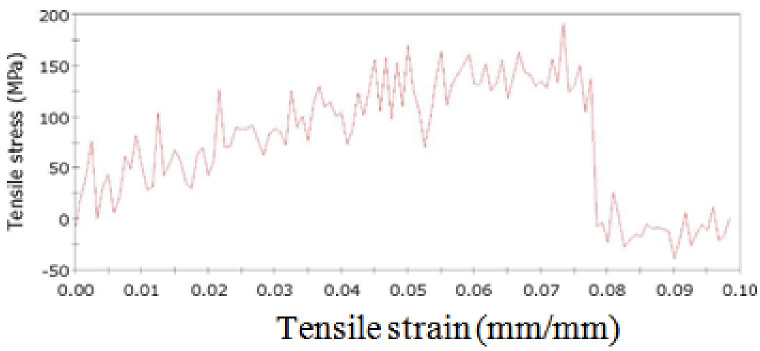

Figure 3. Tensile stress /strain curve of treated stalk of oil palm male flower bunch fibre (test 1)

Table 3. Fibre dimension and property summary of fibre tested in Figure 3

Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus GPa)	Extension (mm/mm)
100.00	0.035	158.49600	2.16762	0.07312

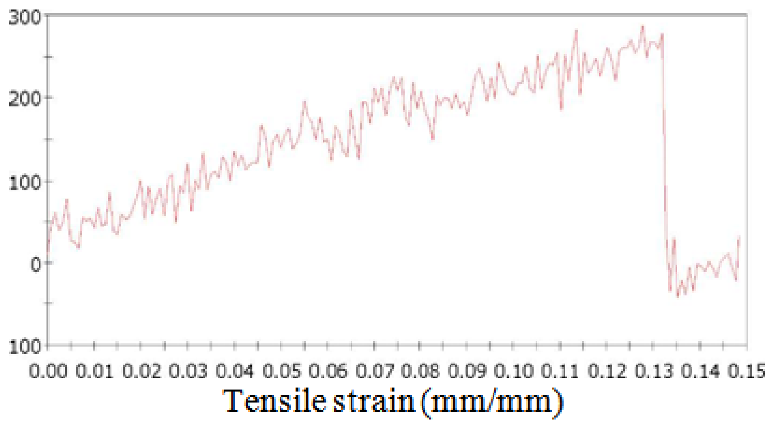

Figure 4. Tensile stress /strain curve of treated stalk of oil palm male flower bunch fibre (test 2)

Table 4. Fibre dimension and property summary of fibre tested in Figure 4

Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus (GPa)	Extension (mm/mm)
100.00	0.095	290.00000	2.26333	0.12813

In Figure 3 tensile strength rose with increasing strain from zero strain up to 0.73mm/mm where tensile strength reached its optimum value of 158.496mPa after which it dropped sharply. The corresponding Table 3 shows the length (100.00mm) and diameter (0.035mm) of the tested sample. The ultimate tensile strength of another sample fibre of length (100mm) and diameter (0.95mm) tested as shown in Figure 4 and Table 4 is 290mPa at a strain of 0.12813mm/mm. Comparatively, the results in Table 3 and Table 4 shows that ultimate strenght and modulus of fibres of same length increased with increasing diameter due to increased cellulose content. Generally FTIR, FESEM, XRD and, TGA/DSC analyses on natural fibres and composite polymers reinforced with them always yield results that directly give reliable information about mechanical and salient physical properties and vice versa (Kumar et al. 2012). Based on this as equipment for FTIR, FESEM, XRD and TGA/DSC tests were either faulty or unavailable around venue of this research experimental works the study was designed around results obtainable from readily available and functional equipment.

Figure 5, Figure 6 and Figure 7 with related Table 5, Table 6 and Table 7 show test result of fibres each of 100mm length and diameters; 0.120mm, 0.145mm and 0.170mm respectively. Fibres of same length but with increasing diameter were carefully selected to reveal property changes with varied sectional thicknesses.

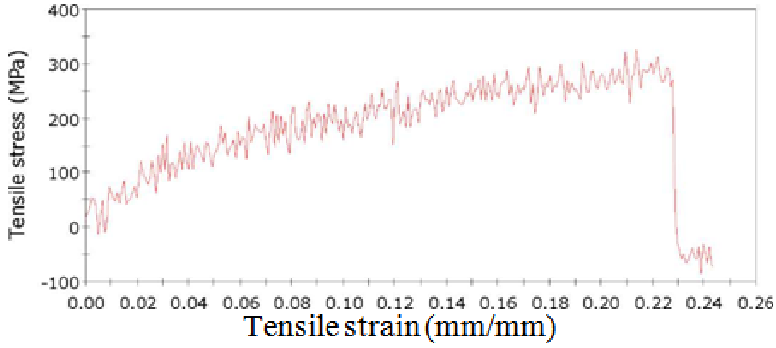

Figure 5. Tensile stress /strain curve of treated stalk of oil palm male flower bunch fibre (test 3)

Table 5. Fibre dimension and property summary of fibre tested in Figure 5

Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus (GPa)	Extension (mm/mm)
100.00	0.120	320.37600	1.51756	0.21111

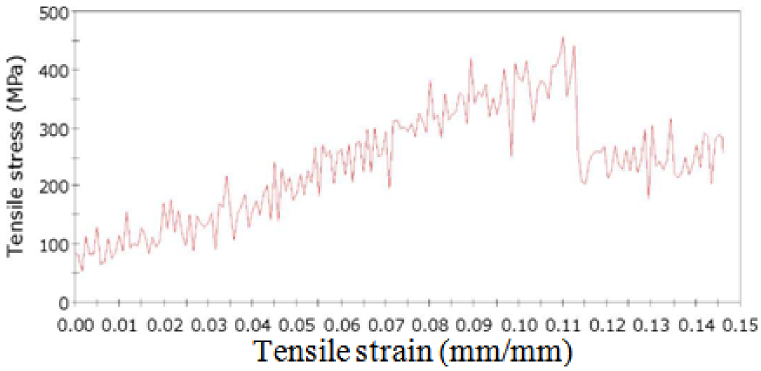

Figure 6. Tensile stress / strain curve of treated stalk of oil palm male flower bunch fibre (test 4)

Table 6. Fibre dimension and property summary of fibre tested in Figure 6

Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus (GPa)	Extension (mm/mm)
100.00	0.145	450.05700	4.04364	0.11130

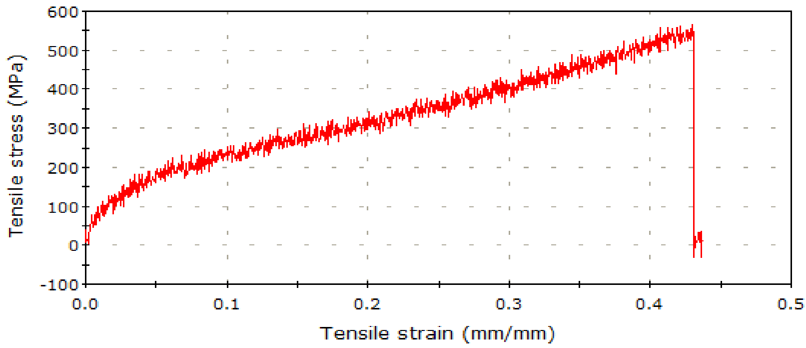

Figure 7. Tensile stress /strain curve of treated stalk of oil palm male flower bunch fibre (test 5)

Table 7. Fibre dimension and property summary of fibre tested in Figure 7

Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus (GPa)	Extension (mm/mm)
100.00	0.170	563.49500	4.04360	0.43748

The grphical plot for each of the five tested fibres was not a single solid continuous curve but of wavy patterns because of the anisotropic nature of this tupe of biomass fibre that causes the material to display highly iiregular property values at different points. This is also why treatments are highly essential to be done on biomass fibres to reduce this defficiency and stabilize the material for easier predictivity for service applications. The graphs showed that range of scatter of the plots reduced and tended towards near solid curves with increased fibre thickness. These result followed similar trends discussed above, that mechanical and physical properties increased with increased fibre diameter. Thus, diameter more critically affect fibre properties than length. Fibres with higher thickness must be preferred to those with smaller diameters to achieve better reinforcement and stronger composites. This agreed with of past related works on agro- fibres (Mishra et al., 2008 and Shehu et al., 2014). Figur 8 presents true photographs of the internal and external surfaces of the cast prototype helmets as directly produced from the fabrication moulds. Items (a) and (b) in the figure are the external and undressed internal surfaces awiting foam liber respectively.

Figure 8. Photographs of cast helmets waiting to be laid with foam liner; (J) External surface of the cast helmet; (K) Internal surface of the cast helmet before and after cleaning off excess materials

The external surface of shell appears smooth because of a gel coat applied to mould before casting in composite and setting. The coat imparted it with thixotropic effect that gave helmet the hard, smooth and shiny surface which may be coloured for added aesthetic. The internal surface showed roughness of laminating resin and mat which was a thick viscous liquid spread after curing the gel coat, allowed to set and surround fibre strand. A fine grade layer was achieved by addition of surface tissue to improve the appearance of the rough side (non-mould side) of helmet. The average thickness of the helmet was measured to be about 4.8mm and the weight was about 950g. The heavy weight was due to high percentage content of matrix binder constituent which was heavier than reinforcement fibres. In the work of Murali et al (2014) which used 40% hybrid (jute, banana sisal fibres) with 60% epoxy matrix binder, helmet produced weighed about 252g; though the average thickness was not available. Also the thickness of helmet produced by Murali et al (2014) with ABS plastic wasn't available but it weighed 370g. Comparatively, helmet weigth will relate directly with thickness based on amount of binder/matrix used in formula. The result of three representative specimens prepared from helmet composite are presented in Figure 9, Figure 10 and Figure 11. Each figure incorporated tensile stress and modulus value computed against extension. Tensile stress against extension result is represented by the curved graph. The straight line graph represents the modulus of the fabricated composite helmet outer shell.

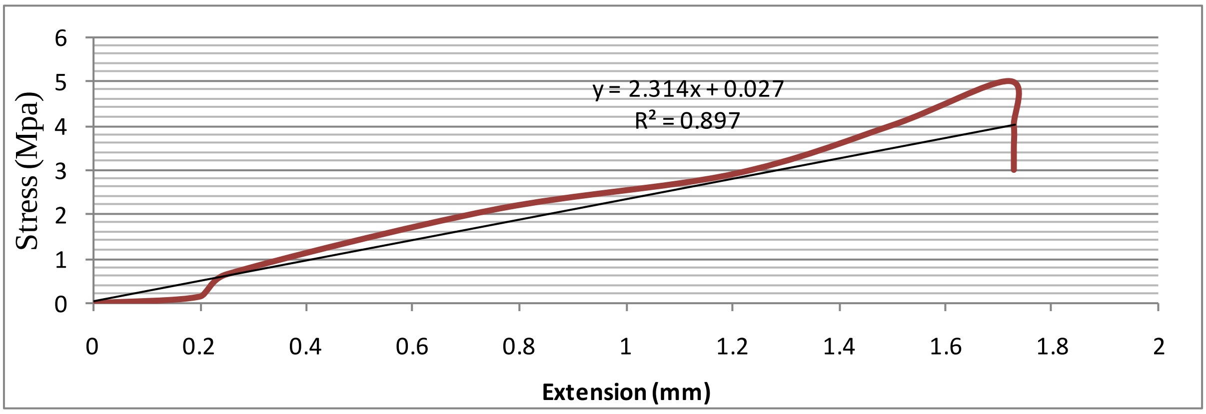

Figure 9. Stress (mPa) against extension (mm) curve of helmet composite (test 1)

In Figure 9, tensile stress increased irregularly with increased extension of the composite up to an ultimate value of 5mPa at an extension of 1.8mm. The modulus increased linearly with increased extension as reported in a previous work with agro-fibre reinforced composites (Akindapo et al., 2014). In Figure 10 and Figure 11, tensile stress and modulus plotted against extension followed a similar increase with increased extension. Here result followed near similar trend except the irregularity patterns of tests 2 and 3 that sightly differ from that of test 1 between extentions of 0.5-1.2mm and 0.8-1.2mm respectively. This was due to retained anisotropy of agro-fibre used for reinforcement.

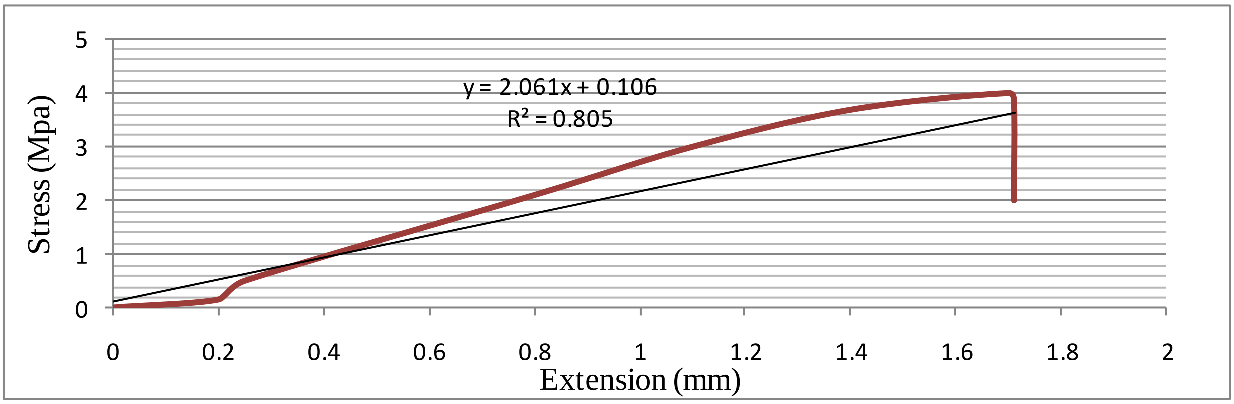

Figure 10. Stress (mPa) against extension (mm) curve of helmet composite (test 2)

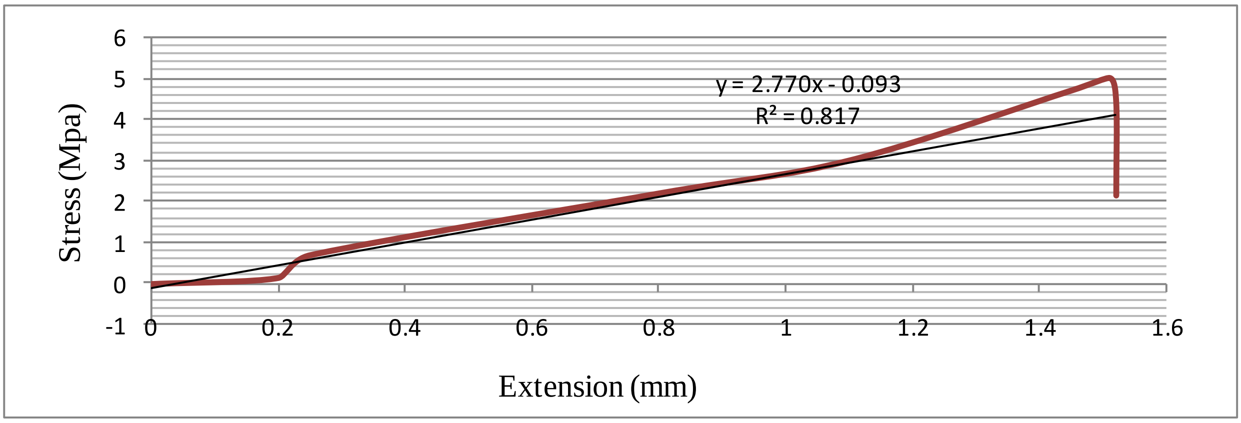

Figure 11. Stress (mPa) against extension (mm) curve of helmet composite (test 3)

The result of each of three specimen tests for other mechanical properties for the hardness, impact and toughness of bio-mass reinforced composite helmet are presented in Table 8.

Table 8. Mechanical properties of the helmet composite.

Test	Modulus (Gpa)	Impact (J/m)	Hardness (No)	Toughness (J)
Test 1	3.676	26.33	79	3.19
Test 2	3.164	22.33	74	3.06
Test 3	3.478	24.00	60	3.59
Average	3.439	24.22	71	3.28

Though there are fluctuations in test result due to anisotropy of bio-mass reinforcement fibres, values obtained are generally acceptable when compared with previous work (Mishra et al., 2008 and Shehu et al., 2014). Summaries of works of Yuhazri and Dan (2007) and Murali et al. (2014) that used both bio-mass and plastic to produce safety helmets are extracted into Table 9 for direct comparison with this work. The temperature at which composite was poured during casting which is a vital factor on mechanical properties were unavailable for precise comparison with the reviewed works. Generally, when compared with related works on composites reinforced with natural fibres (Kumar et al., 2012; Reza et al., 2013), result of composite helmet analysis of this work show satisfactory performance.

Table 9. Comparison of the result obtained with those of past lieteratures.

Samples	Modulus	Impact Strength (J/m)	Hardness (No)	Toughness (J)
Yuhazri and Dan (2007);10% coir with 90% epoxy resin	8.773 mPa	9.95 J/mm^2	80.45	-
Murali et al (2014): 40% hybrid (jute, banana sisal fibres) with 60% epoxy	-	53.06	-	-
Murali et al (2014): ABS Plastic	-	50	-	-
20% oil palm male flower bunch stalk fibre composite helmet shell	3.439 gPa	24.44	71.00	3.28

In Table 9, impact strength of the 20% oil palm male flower bunch composite was less than half of that obtained of ABS plastic with hybrid composite by Murali B. et al. (2014). Also in comparison with result of helmet produced with 10% coir and 90% epoxy (Yuhazri and Dan, 2007), composite helmet shell with 20% oil palm male flower bunch fibre of this work gave hardness closer to; but a modulus much higher than that of Yuhazri and Dan (2007).

The water absorption test result is as presented in Table 10. Weight of specimens after 24hourly immersion in water for a period of four days was determined and used to compute water absorption rates in percentages.

Table 10. Water absorption test result

Description	Days of immersion in water				
	Dry weight (g)	Day 1	Day 2	Day 3	Day 4
Weight (g)	4.015	4.346	4.385	4.386	4.386
As percentage (%)	-	8.244	0.890	0.023	0.000

The result in Table 10 showed that water absorption rate decreased after every 24 hours up to a point when no more water could be absorbed by composite shown by constant weight (with 0% weight change) of samples in days 3 and 4. Water absorption rate is very critical to biomass fibre reinforced composites to ensure that the high hydrophilic property of natural fibres are not substantially retained in composite to avoid time related degradation of products as a result of continuous water absorption from atmospheric vapour.

4. Conclusion

The properties of helmet shell fabricated from the stalk fibre of oil palm male flower bunch showed it had good prospects for helmet shell production. Helmet shell produced in this work with 20% oil palm male flower bunch fibre reinforced composite had hardness close to; but modulus much higher than those with other natural fibre reinforced composite polymers. The chemical/physical stabilities of the composite helmet were satisfactory as compared with those of past related works reviewed. Based on these observations, appropriately treated fibres of male flower bunch stalk could be used as composite reinforcements for manufacture of industrial safety helmets. By extension of the study in a modified future work, the fibres can be used to reinforce military anti-projectile helmets and many related applications like automobile bumpers, dashboards and other engineering components that require high impact resistance. Non-chemical, more environmentally friendly bio-degenerable matrix like gum Arabic can be experimented using treated male flower bunch stalk fibre for reinforcement.

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