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Hybridizing Effect of Palm Frond Fibre on Helmet Shell Cast from Elaeis Guineensis Male Flower Bunch Fibre Reinforced Biocomposite

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Abstract
Biomass fibres obtained from agricultural wastes have found application in the production of structural reinforcement for bio-composites used for manufacturing of engineering components because of their low cost, biodegradable and eco-friendly advantages. Ademoh and Olanipekun (2014) had produced motorcycle safety helmet using a bio-composite reinforced with 20% male flower bunch stalk fibre. In this research, 20% weight of treated hybrid composite from treated oil palm male flower bunch stalk fibre and oil palm frond fibre in the ratio of 3 to 1 respectively were used in reinforcing unsaturated polyester resin to fabricate anti-crash helmet shell using hand lay-up method. The mechanical performance of the helmet shell was determined and the results obtained were compared with past literatures. From the result, hybrid composite of oil palm male flower bunch stalk fibre hybrid and oil palm frond fibre with unsaturated polyester has good mechanical attributes and can replace ABS plastic commonly used in conventional helmet productions. On comparison with immediate preceding work of Ademoh and Olanipekun (2014) the 15% male flower bunch/5% palm frond reinforced bio-composite of this study showed improvement 77.06% on modulus; 68.20% on impact strength and 13.61% on harness and reduction of 21.04% on toughness.
Keywords: palm frond fibre, male flower bunch stalk, fibre, polyester, helmet shell.

1.0 INTRODUCTION
Natural fibres are non-adhesive strands of materials which can be form into structural pattern when mixed with appropriate binder as matrix to form composite. Hybrid composites are systems in which one kind of reinforcing material is incorporated into a mixture of different matrices or blends (Thwe and Liao, 2003). Two or more reinforcing and filling materials are present in a single matrix or both approaches are combined for improved composite properties. Hybrid composites which contain two or more types of fibres in single matrix have been found to be more advantageous as one type of the fibres can complement what is lacking in the other. Hybrid composites fabricated by proper material design help to achieve balance in cost and performance (John and Thomas, 2008). Many studies have tried blending of two fibres for composite reinforcement to achieve the best utilization of the positive attributes of each fibre and to reduce its negative attributes as far as practicable (Abdul Khalil et al., 2009 and Jawaid et al., 2012). However, it has been reported that fibre content, length, orientation, extent of intermingling, fibre/matrix interface and arrangement of fibres in the matrix mainly affect the overall properties of hybridized composites (Munikenche et al., 1999). Hybrid effect is defined as the positive or negative deviation of certain mechanical properties from the rule of mixture behavior (Kickelbick, 2007). The rule of mixture has been defined as composite property as weighted average of the properties of its constituents. For instance if two fibres of different properties like oil palm and jute fibres are incorporated into a polymer, the resulting hybrid composite will most probably exhibit properties which are some sort of an average between those individual fibre components.

Biomass waste generated after crop harvest is usually left to rot or incinerated causing environmental pollution and release of green house gases like CO and CO_2 which cause ozone layer depletion and global warming. Recent advances in technology have led to identification and utilization of some of these biomass wastes most especially in forms of fibres for fiber reinforced polymer (FRP) for bio-composite production for fabrication of engineering components. Biomass fibres have been found to offer similar physical and mechanical properties with synthetic materials used regularly in industries to manufacture engineering products for automobiles, aircrafts, ships, electronics, building and structural applications (Mishra et al., 2010) etc. Biomass materials are very cheap, readily available as they are wastes generated from human agricultural practice and most importantly biodegradable unlike the synthetic counterpart. These give them great potentials for use as compliments or total replacement for synthetic materials in many fields of application. In Nigeria lots of high quality biomass fibre is generated from her agrarian activity especially from oil palm trees that are available at numerous plantations distributed throughout southern parts of the country (Shehu et al, 2014).

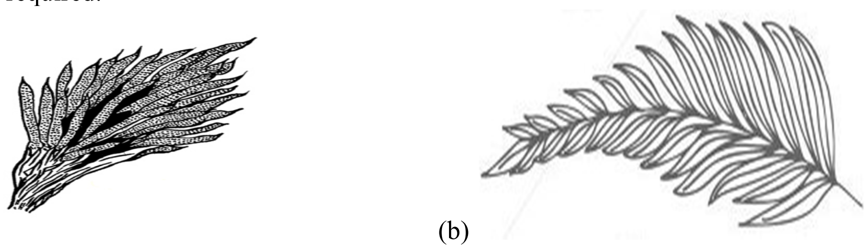
Following a review by the Federal Road Safety Corps (FRSC) of Nigeria that reported a staggering of road accidents especially by commercial motorcycles in 2008 the relevant government authorities introduced and enforced wearing of anti-crash helmets for motorcyclists (Adewale, 2010). This brought sudden rise in demand for crash helmets that are mostly imported into the country as Nigeria lacks industrial ability to locally manufacture them. This opened up a big research challenge to find local raw materials like agro-biomass fibre reinforced composites for production of motorcycle anti-crash helmets. Shuaieb et al. (2002) produced three prototype helmet shells from natural fibres that included coir natural fibre alone; coir hybridized with glass fibre and oil palm with glass fibre using polyester resin as matrix. It was observed that addition of glass woven roven layer to outside surface could give helmet superior impact resistance than coir/glass. Yuhazri and Dan (2007) used coconut fibre reinforcement with resin from thermosetting polymer as matrix to manufacture motorcycle helmet. Mechanical performance measured showed coconut fibre as suitable reinforcement for epoxy resin matrix which may perform better if at least 20% reinforcement fibre was used. Prasannasrinivas and Chandramohan (2012) analysed natural fiber reinforced composite materials for helmet outer shell with CAD model. They found hybrid mix of natural fiber composites to be good replacements for plastic in helmet. Murali et al. (2014) concluded that hybridized composites gave higher impact strength, lower weight and cost than acrylonitrile butadiene styrene (ABS) plastics.

Adewale (2010) produced helmet with 40% hybridized composite of jute, banana, 2.5mm sisal fibres and 60% epoxy binder. Ademoh and Olanipekun (2014) characterized fibres of male flower bunch stalk and frond of oil palm (elaeis guineensis) for polymer reinforcement and concluded that the materials treated with NaOH were suitable for structural strengthening of polymer composites. In a follow up work, Ademoh and Olanipekun (2014) successfully produced prototype helmets from bio-composites reinforced with fibre of oil palm male flower bunch stalk. The physical, mechanical and chemical properties of helmet produced in the work favourably compared with those produced with conventional materials in earlier studies. The aim of this work is to introduce treated oil palm fronds fibre as hybrid mix with male flower bunch stalk fibre reinforced composite for production of helmet shell. The main objectives are to select and intermix fibres of oil palm frond and stalk of male flower bunch as hybrid structural reinforcement materials for polymer composite for production of safety helmets; produce prototype helmets by the hand laying method of casting; analyze the physical and mechanical properties of the helmet composite and compare results with anti-crash helmets produced from other materials. The significance of the work lies in the fact that materials for the production of better quality helmet and related products would be revealed by the success of this work.

2.0 RESEARCH MATERIALS AND METHODS

2.1 Research Materials

Materials and equipment used for the experimental work included distilled water, cobalt naphthanate, unsaturated polyester, calcium carbonate,, oil palm and fronds and male flower bunch obtained from a tree in a Nigerian palm plantation, methyl ethyl ketone peroxide, sulphuric acid, sodium hydroxide solution purchased from an industrial chemical vendor, glucose peroxidase assay kit, dinitrisalicyclic acid autoclave, Instron universal test machine- model 3396, Ceast Resil Impactor machine, helmet mould, Shore D durometer, Micro Vision Industries universal test machine, pipettes, burettes, plastic and stainless steel containers. fibres were produced from male flower bunch stalk and fronds of oil palm (shown in figure 1) beating to looseness to free them into thin strands as fibres. These were washed, dried, classified accordingly and stored appropriately stored for use when required.



(a) (b)

Figure 1:-Sections of interest interest to study; (a) Oil palm male flower bunch (b)Oil palm frond.

2.2 Rsearch Methods

2.2.1 Chemical Treatmentof Fibres:-The dried raw fibres of male flower bunch stalk and oil palm fronds obtained from the production processes explained above were subjected to chemical treatment using sodium hydroxide (NaOH) solution as practiced by Mishra et al. (2008). As observed in past related works this type of chemical treatment causes mercerization process to occur on the raw fibres and lead to reduced hydrophilic characteristic by reducing moisture content and increasing strength of the materials. Mishra et al. (2008) treated sisal-polyester with 5% NaOH at room temperature and reported that the material strength increased by 4% higher than 10%NaOH treated fibre reinforced polyester composites. This method was adopted and used in this study to increase concentrations of cellulose by delignification; clear adjoined impurity, enhance flexural rigidity and stabilize molecular orientation of the fibres (Shehu et al, 2014). NaOH treatment solution was prepared by dissolving appropriately weighed dry NaOH in measured distilled water in a stainless steel container. Treatment process involved soaking of washed and dried fibres of palm fronds and male flower stalk in separate 5%NaOH solutions for 3hours to enable necessary reaction take place. Fibres were then withdrawn, thoroughly washed to remove traces of residual chemicals classified and stored (Shehu et al, 2014).

2.2.2 Chemical analysis of fibre:-Chemical analysis was conducted on standard test specimens to determine cellulose, hemicellulose, lignin and ash content of both treated and untreated fibres in accordance with Ververis et al. (2007) and as adopted by Ademoh and Olanipekun (2014).

2.2.3 Analysis fibres for Mechanical properties:-The Instron universal test machine model 3396 was used to stress and measure the tensile and strain properties of the treated fibres. Five tests were conducted on individual fibre selected carefully from each of the two different sets of oil palm bio-fibres in accordance with the procedures used by Mishra et al. (2008) and Shehu et al. (2014).

2.2.4 Density Test:-Weighed quantity of each of male flower stalk fibre and oil palm frond fibre were recorded as w accordinglt, distilled water was poured into measuring cylinder with its initial volume also recorded as V_1 per fibre sample. Weighed dried fibre was then introduced into the distilled water filled measuring cylinder and final volume recorded as V_2 for oil palm fond fibre and male flower stalk fibre seperately. These steps were repeated for each set of specimens and fibre density was then calculated with the equation stated below as used by Abdul Khalil (2011):

$$\frac{W}{V2-V1}\ x\ 1000 \text{ Kg/cm}^3 \quad \ldots\ldots (1)$$

2.2.5 Hybridized bio-composite formulation:-The classified treated/dried biomass fibres of male flower oil palm bunch and oil palm frond was each weighed and used to formulate the compositional mix of a hybridized bio-composite shown in table 1. Some quantity of the composite was taken and used to cast prototype helmet and some was used to prepare test specimen for property analyses to ascertain the likely practical performance of the material during service

Table 1: Materials and formulation.

S/N	Name of constituent	Structural role of Constituent	Composition (%)
1	Unsaturated polyester	Matrix	70
2	Oil palm male flower bunch stalk fibre	Reinforcement A	15
3	Oil palm frond fibre	Reinforcement B	5
4	Calcium carbonate	Filler	8
5	Cobalt naphthanate	Accelerator	1
6	Methyl ethyl ketone peroxide	Catalyst	1

2.2.6 Casting of Helmet Shell with hybridized bio-composite:-According to Shuaieb et al. (2002) and Yuhazri and Dan (2007) open mould casting of polymer composites using hand lay-up method when compared to other methods of polymer fabrication aids fast product development sequence due to its simplicity at relatively lower cost. As a popularly and common method that was observed to have been used universally to manufacture reinforced polymer composite products it was adopted easily to fabricate the prototype helmet in this work. Moreover it is reported to be more suitable for this type of work that involved casting from exterior to interior surfaces and the low quantity of production units that was needed. In the production process, a pigmented gel coat was first spread on the inside and coat was allowed to cure before fibre reinforcing mat was placed in the mould so as to achieve high quality surface. Catalyzed resin and filler were poured-in and properly brushed on by manual rolling. It helped to remove entrapped air in mix, compacted composite and also; thoroughly wetted the reinforcement with resin. Additional layers of mat or woven roving and resin were made repeatedly until the required thickness of product was achieved. Curing process of the composite was initiated without external heat application by addition of catalyst and accelerator on resin. For helmet casting, treated fibres were first chopped into desired length (5mm-20mm), wetted with resin, laid in mould uniformly and hand brushed continuously to apply it to the fibres. Mould treatment was done with release agent to facilitate removal of product. After 40 minutes of curing, helmet was removed from mould. Desired test specimens were cut out according to standard dimensions and shapes from cast composite and sent for necessary property analyses at laboratories and workshop of Technology Incubation Centre Bauchi, Nigeria. The metal mould, male flower bunch stalk fibre and the oil palm frond fibre that were used in the bio-composite fabrication are as shown in figure 2 below.

(A) (B) (C)

Figure 2: Samples of the fibres as cut to sizes and the casting mould; (A) Helmet open mould (B) stalk of oil palm male flower bunch fibre cut to sizes; (C) oil palm frond fibre cut to sizes.

2.2.7 Mechanical property analyses of the hybridized composite test specimens:-The test schedule used by Akindapo et al. (2014) was adopted for use. Specimen impact test was conducted on the composite according to ASTM D256 standard with Ceast Resil impactor machine. Specimen was dimensioned 85 x 8 x 3 mm as required for the machine. Each specimen was set as vertical cantilever and broken with single swing of hammer. Test speed was set to 3.4 m/s and test done with hammer of 4J. Impact strength (J/m) was computed as the energy absorbed divided by specimen's thickness. In accordance with ASTM (D2240) hardness was tested on specimens using the Shore D durometer; and tensile strength of composite was determined according to ASTM D638 standard with the Micro Vision Industry's universal testing machine. Composite's toughness was evaluated from the stress-extension graph as the area under stress extension curve as practiced by Akindapo et al. (2014).

2.2.8 Water Absorption Test:-Similar procedures used in some past related work on bio-mass fibre reinforced composites (Abdul Khalil, 2011) were used to test for the water absorption rates of the hybridized composite. During the test, initial dry weight (W_d) of composite specimen was measured and recorded. Specimens were then immersed in distilled water at room temperature for 24 hours. Samples were then withfrawn and re-weighed as W_1. The samples were again re-immersed in water for 24 hours and another weight W_1 was re-measured and recorded. This was repeated continuously until the weight became constant. Percentage equilibrum of water absorption was computed with the equation below (ASTM D570) as practised by Abdul Khalil (2011).

Water absorption (%) = $\frac{Wn-Wd}{Wd}$ x 100 ………………………………….……………….(2)

Where: $Wn_{1,2,3\ldots c}$. was the weight of composite samples after immersion; and W_d was the weight of composite samples before immersion.

3.0 RESULT AND DISCUSSION

In table 2 the summarized result of some physical property test is as presented; showing the averaged mass, averaged volume and averaged density of selected representative untreated and treated of male flower bunch stalk and oil palm fronds fibres. Values for treated fibres varied after NaOH treatment.

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

Physical property description	Untreated oil palm frond fibre	Treated oil palm frond fibre	Untreated male flower bunch fibre	Treated male flower bunch fibre
Aver. Weight (g)	0.1375	0.1455	0.1355	0.226
Ave. volume (mm^3)	8.5275	7.045	6.0325	8.06
Averaged Density (X 10^{-3} Kg/cm^3)	1.61	2.065	2.246	2.804

The variation in values was due to high presence of moisture and ash in untreated fibres that reduced by mercerization reaction which made fibres less hydrophilic and have more cellulose concentration. Before chemical treatment 5%NaOH, palm frond fibres had higher averaged weight, volume and density than male flower bunch stalk fibre but after treatment the reverse was the order, showing that raw oil palm fronds had higher ash and moisture contents than raw fibres of male flower bunch stalk. Result in table 3 shows the concentrations of cellulose, hemicelluloses, lignin and ash in fibres.

Table 3:-Chemical analysis of treated and untreated male flower and oil palm frond fibres

S/No	Fibre	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Ash (%)
1	Untreated male flower bunch fibre	62.95	20.28	13.28	2.05
2	Treated male flower bunch fibre	81.24	8.52	7.04	1.29
3	Untreated frond fibre	59.64	17.57	19.05	2.1
4	Treated frond fibre	81.04	5.86	9.85	1.4

The trend was confirmed by the result of chemical analyses for both the treated and untreated fibres of male flower bunch stalk and oil palm fronds for similar reasons as explained above. Figures 3-6 present result of tensile stress/stain tests conducted on one randomly selected representative fibre of each of both untreated and treated male flower bunch stalk and oil palm frond. .

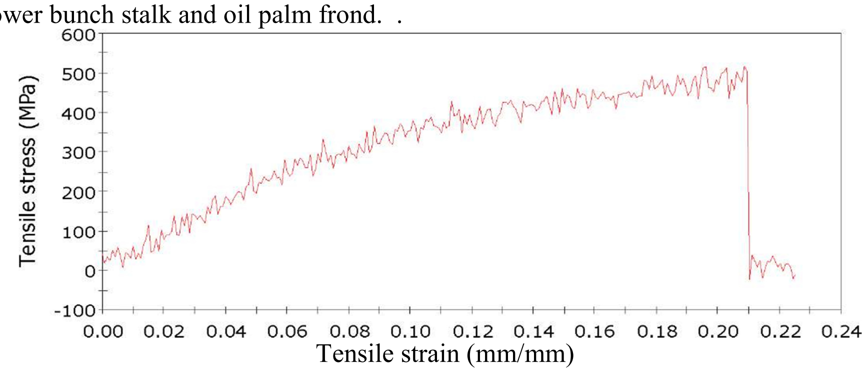


Figure 3: Tensile stress/strain curve of untreated stalk of male flower bunch fibre

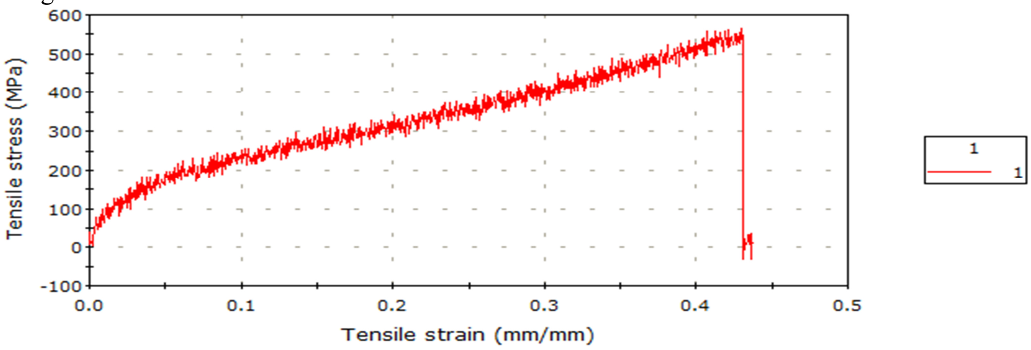


Figure 4: Tensile stress/strain curve of treated stalk of male flower bunch fibre

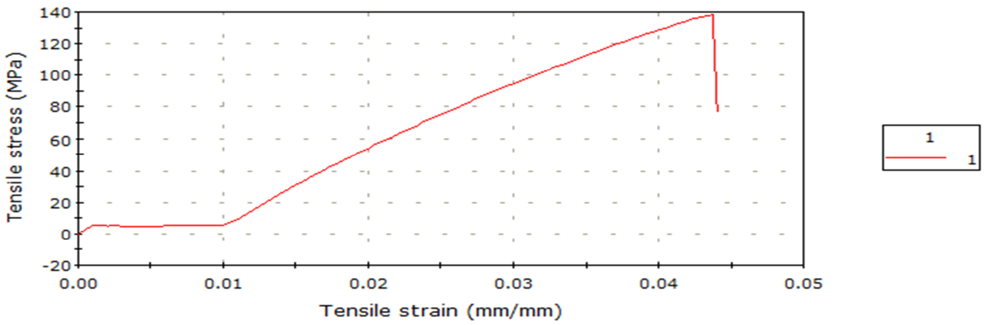


Figure 5: Tensile stress/strain curve of untreated oil palm frond fibre

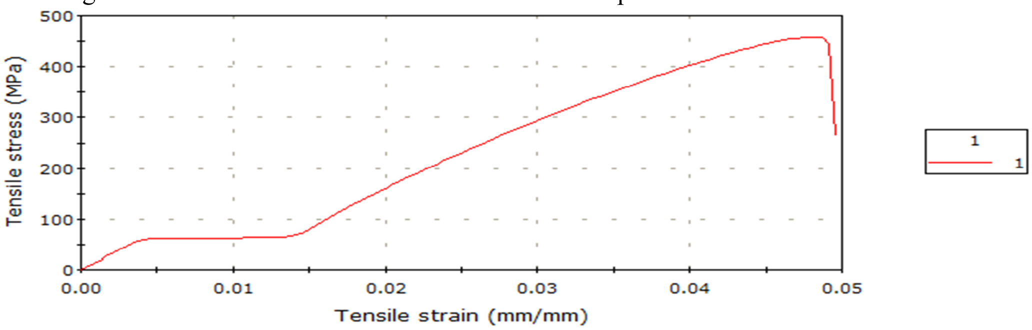


Figure 6: Tensile stress/strain curve of treated oil palm frond fibre

The results in the figures showed that stress/strain plots of male flower bunch stalk are wavy for both the treated and untreated fibres while those for oil palm frond fibres are more of solid curves. This shows the level of variability of properties that is possible with the materials; that male flower bunch stalk fibres are more anisotropic in nature than oil palm frond fibres. In composite formulation, palm frond fibres will offer itself to a more stable lamination in a matrix than the former. Table 4 presents the mechanical property summaries for the fibres tested in figures 3-6.

Table 4: Mechanical properties of fibres tested in figures 3-6

S/No	Fibre Type	Length (mm)	Diameter (mm)	UTS (Mpa)	Modulus (GPa)	Extension (mm/mm)
1	Untreated male flower bunch	100.00	0.275	517.328	2.4632	0.2100
2	Treated male flower bunch	100.00	0.170	563.495	4.0436	0.4375
3	Untreated oil palm frond	100.00	2.220	138.573	3.1674	0.0438
4	Treated oil palm frond	100.00	1.320	458.566	9.3261	0.0492

Result in table 4 showed the extensive beneficial effects that chemical treatment had on mechanical properties of both type of fibres. It showed that untreated fibre with thick diameters of equal lengths had much lower ultimate tensile strength, modulus and extension rate than treated fibres with thinner diameters. This is very vital especially in structural application in polymer reinforcements where low weights with high strengths are preferred in materials. Figure 7 presents the cast helmet shell with its external (A) and internal (B) appearances as shown without dressing and lying of internal foam liner.

(A) External (B) Internal

Figure 7: Internal and external surface of helmet prototypes waiting to be laid on the foam liner.

The external surface of shell appears smooth because of the gel coat that was applied to the mould before casting in composite and setting to impart its thixotropic effect that gave the helmet its hard, smooth and shiny surface which may be coloured for added aesthetics if needed. The internal surface shows roughness of laminating resin and mat which was a thick viscous liquid spread after curing the gel coat, allowed to set and surround fibre strands. A fine grade layer could be achieved if needed by addition of surface tissue to improve the appearance of the rough side (non-mould side) of helmet.

Table 5 presents a summarized result of the mechanical property tests on the hybridized composite, part of which was used to hand cast helmet shell. Properties determined included hardness, modulus, impact strength and toughness; which are the most important characteristics of helmet that certify its suitability (Yuhazri and Dan 2007). For each property 3 independent tests were done and averaged.

Table 5: Mechanical Properties of the Composites.

Test No	Modulus (gPa)	Impact (J/m)	Hardness (No)	Toughness (J)
Test 1	6.337	43.33	63	1.78
Test 2	6.06	41.67	82	3.23
Test 3	5.869	38.33	97	2.67
Average	6.089	41.11	80.66	2.59

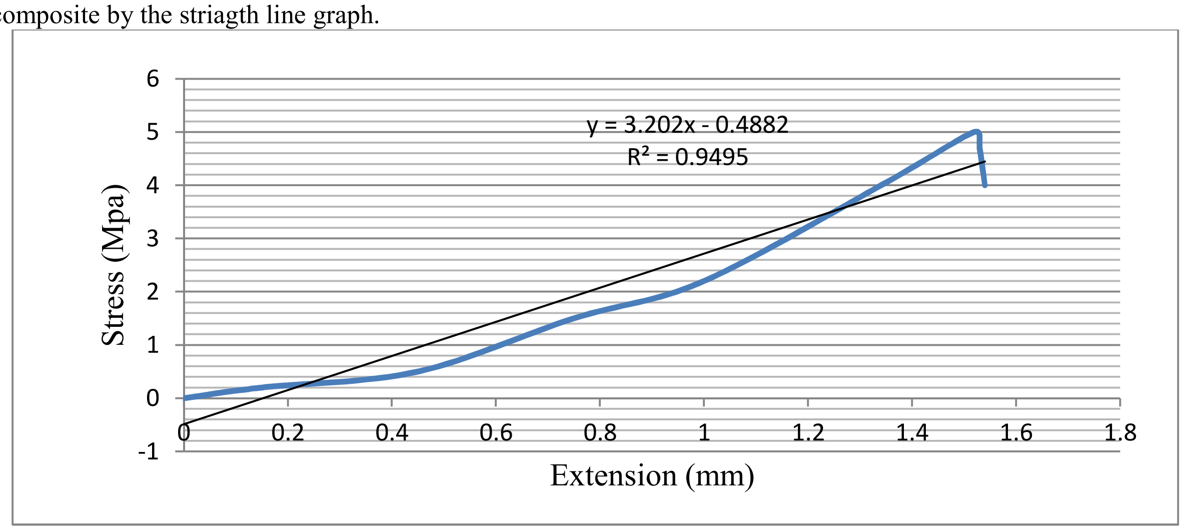
In table 5, averaged impact, hardness, toughness and modulus were 41.11J/m, 80.66, 2.59J and 6.089 gPa respectively. These are quite satisfactory as compared with past related works in table 6 that also incorporate immediate past work of Ademoh and Olanipekun (2014) that this one is to compliment.

Table 6: Comparison of the result obtained with those of past related works.

Samples	Modulus	Impact Strength (J/m)	Hardness (No)	Toughness (J)	Weight (g)	Thickness (mm)
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	-	-	252	-
Murali et al, 2014; ABS Plastic	-	50	-	-	370	-
Ademoh and Olanipekun (2014):20% oil palm male flower bunch stalk fibre composite helmet shell	3.439 gPa	24.44	71.00	3.28	950	4.8
15% hybridized male flower bunch stalk fibre with 5% oil palm frond fibre.	6.089 gPa	41.11	80.66	2.59	650	4.5

In table 6 by impact strength of the hybrid fibre reinforced composite developed in this work was closer to that of ABS plastic and hybrid reinforced composite developed by Murali B. et al (2014). By comparing the result with that obtained by Yuhazri and Dan (2007) who produced helmet shell with 10% coir fibre and 90% epoxy resin, helmet shell produced in this work with hybridized palm fibre reinforced composite gave higher hardness, modulus and impact strength. On comparison with immediate preceding work of Ademoh and Olanipekun (2014) the 15% male flower bunch/5% palm frond reinforced bio-composite of this study showed improvement 77.06% on modulus; 68.20% on impact strength and 13.61% on harness but a reduction of 21.04% on toughness. This is reasonable especially as it is the only work in the table that obtained values for impact strength of the composite. In the table, the average thickness and weight of the helmet were 4.5mm and 660g respectively. The 70% matrix binder used raised weight of helmet produced as compared with that produced by Murali et al (2014) with 40% hybrid of jute/banana/sisal fibres and 60% epoxy binder and helmet by Murali et al (2014) made with ABS plastic which weighed 252g and 370g respectively; though their average thicknesses were unknown for close comparison as weight depends on thickness of composite.

The result of the three representative specimens prepared from helmet hybridized oil palm fibre reinforced composite are presented in figures 8, 9 and 10. Each figure incorporated the tensile stress and modulus computed against extension. Tensile stress plots are represented by curved graphs and modulus of composite by the striagth line graph.



Figue 8:- Tensile strength versus extension curve of hybridized composite (test 1).

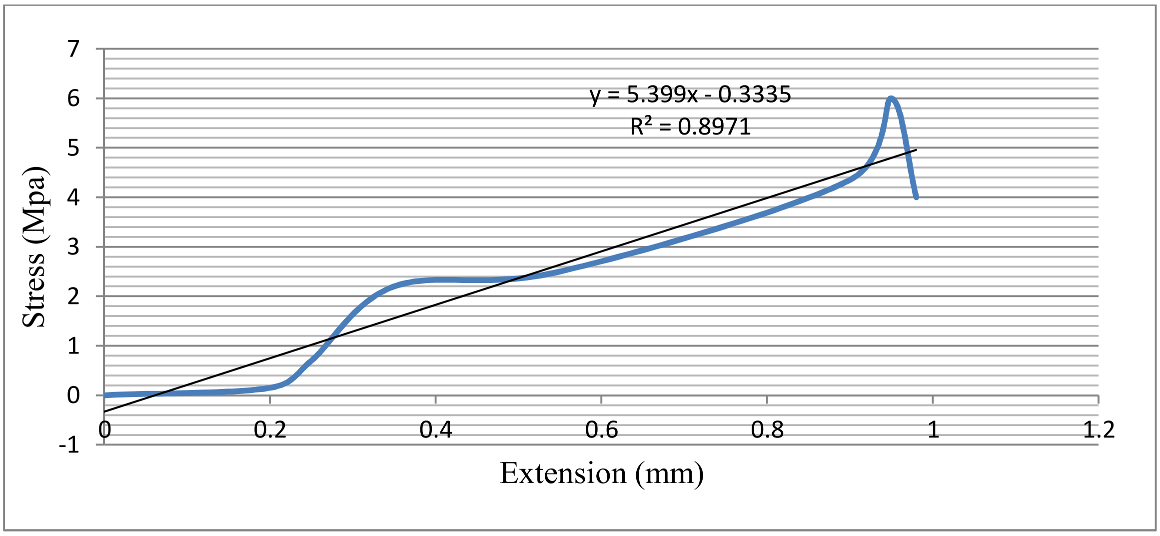


Fig 9: Tensile Stress versus extension curve of hybridized composite (test 2).

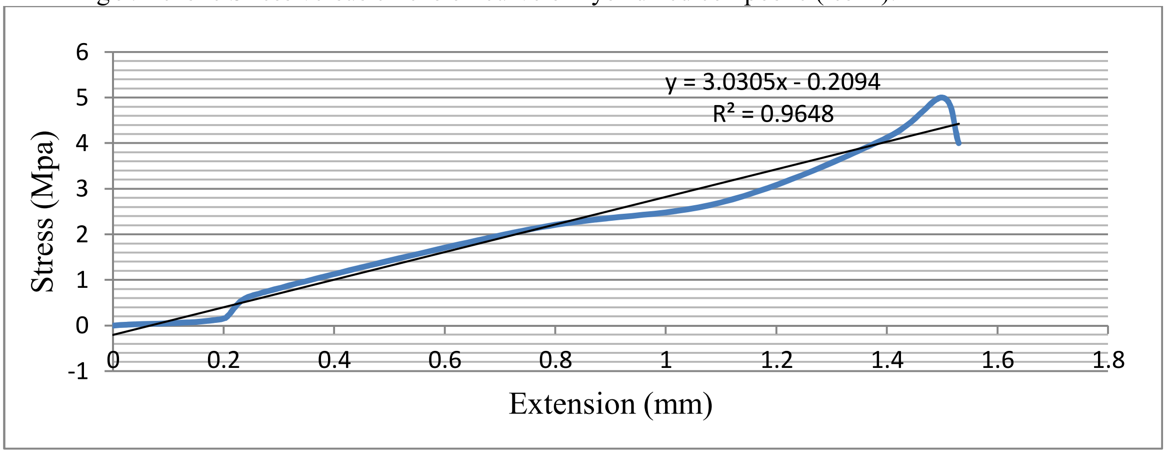


Figure 10:-Tensile stress versus extension curve of hybridized composite (test 3).

Tensile stress increased irregularly with increased extension of composite up to the ultimate strength of about 5mPa and then dropped down very sharply at an extension of about 1.6mm. The modulus of the composite increased linearly with increased extension in agreement with past related work with biomass fibre reinforced composites (Akindapo et al., 2014). The plot in figures 9 and 10 followed a similar trend of irregular increase of tensile strength up an ultimate value of 6mPa and 5mPa and then suddenly dropped at extensions of about 0.95mmand 1.5mm respectively. The extent of stain energy absorbable before failure of composite was shown by extension before the sudden drop of the stess. The usual anisotropic nature retained by bio products was responsible for the slight differences in stress and corresponding strainobserved across the three test results.In table 7 are results of water absorption tests on hybridized oil palm fibre reinforced composite..

Table 7: Water absorption test result

Description	Days of immersion in water				
	Dry weight (g)	Day 1	Day 2	Day 3	Day 4
Weight (g)	6.998 (4.015)*	7.478 (4.346)*	7.527 (4.385)*	7.529 (4.386)*	7.529 (4.386)*
As percentage (%)	-	6.859 (8.244)*	0.655 (0.890)*	0.026 (0.023)*	0.000 (0.000)*

All values not enclosed in brackets are results obtained in this work while those enclosed in brackets and marked with astericks ()* are values of immediate preceing work of Ademoh and Olanipekun (2014). Just like work of Ademoh and Olanipekun (2014), table 7 shows that rate of water absorption decreased after every 24 hours until at the period when no more water was absorbed by specimens as shown by the constant weight of composite in days 3 and 4 when water absorption rate became 0%. On comparison the two works it is observed that the dry weight of composite developed in this work is 6.998g while that of preceding work composite was 4.015 (a difference of 2.983). The daily water absorption rate of the hybridized composite of this work was also higher than that of the immediate past work (by about 20.19%) of Ademoh and Olanipekun (2014) because of the boundary interfaces between laminates of two different fibre types that trapped and retained some intermediate moisture.

4.0 CONCLUSION

The fabricated helmet shell from hybrid of oil palm male flower bunch stalk fibre and oil palm frond fibre shows a good attribute for helmet shell production and have the potential of replacing Acrylonitrile butadiene styrene (ABS) plastic which is commonly used in the production of helmet, however further research is hereby suggested with the fibres arranged in a weave or mesh pattern, more percentage weight of fibres with the length range of 20mm – 50mm is also suggested and the ratio of reinforcement 2 (oil palm frond fibre) can be increased in further research.

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