

Production of A Safety Helmet Using Palm Kernel Fiber And Shell Particulates

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Abstract: Palm Kernel Fiber (PKF) with Palm Kernel Shell (PKS) particulates as filler were used as reinforcement in polymer matrix composite to investigate their suitability for the production of a safety helmet. The Palm Kernel Fiber (PKF) was initially used as the reinforcement while epoxy resin (Bisphenol-A-glycidyl) served as the matrix. Six specimen were produced having 2.5%, 5%, 7.5%, 10%, 12.5% and 15% PKF content in the composite and their mechanical properties (Tensile strength, Impact strength, Flexural strength and Hardness strength) were evaluated. The specimen having the optimum desirable mechanical properties was adopted for hybridization with the PKS as filler. Specimen D (10% PKF) with the highest impact strength of 6.62 J/mm², hardness of 6.9 HRF, tensile strength of 26.75 N/mm² and flexural strength of 31.02 N/mm² was selected and reproduced with PKS particulates as filler. The PKF and PKS were mixed in the ratio of 1% PKS - 9% PKF, 2% PKS - 8% PKF, 3% PKS - 7% PKF, 4% PKS - 6% PKF, 5% PKS - 5% PKF and 6% PKS - 4% PKF. All the mechanical tests (Impact, hardness, tensile and flexural strength) evaluated for the hybrid samples. Specimen D₆ (6% PKF - 4% PKS) offered the most acceptable combination of mechanical properties; impact strength of 7.27 J/mm², hardness of 6.7 HRF, tensile strength of 21.55 N/mm² and flexural strength of 34.61 N/mm². Since impact is the most critical property in this research, and specimen D₆ offered the highest, it was adopted for the production of the sample safety helmet.

Keywords: Composites, Hardness, Hybridiation, Impact, Tensile.

I. Introduction

The merits of composite materials over conventional materials stem largely from their higher specific strength, stiffness and fatigue characteristics, which enables structural design to be more versatile. By definition, composite materials consist of two or more constituents with physically separable phases [Mueller, 2003]. However, only when the composite phase materials have notably different physical properties it is recognized as being a composite material. Composites are materials that comprise a strong load carrying material, referred to as reinforcement imbedded in a weaker material known as matrix. Reinforcement provides strength and rigidity helping to support structural load while the matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. The reinforcement may be platelets, particles or fibres and are usually added to improve mechanical properties, such as stiffness, strength and toughness of the matrix material [Lihort, 2000]. In various applications, the use of composite rather than metals has in fact resulted in saving both cost and weight. Also, the need of composite for lighter construction materials and more seismic resistant structures has placed high emphasis on the use of new and advanced materials that not only decreases dead weight but also absorbs the shock and vibration through tailored microstructures. Unlike conventional materials like steel, structural requirements can be incorporated into the properties of the composite material to be designed. The design of a structural component using composites involves both material and structural design. Properties such as stiffness, thermal expansion, etc., can be varied continuously over a wide range of values under the control of the designer. Careful selection of reinforcement type enables finished product characteristics to be directed to satisfy almost any specific engineering requirement. While the use of composite will be a clear choice in many instances, material selection in others will depend on factors such as working lifetime requirements, number of items to be produced, complexity of product shape, possible savings in assembly costs and on the experience of the designer in tapping the optimum potential of composites [Oskman, 2003].

In recent years, many studies have been dedicated to utilize lignocellulosic fillers such as coconut shell, wood, pineapple leaf, palm kernel shell, etc. as fillers in order to replace synthetic fillers through utilization of natural fillers or reinforcement in thermoplastic and thermoset polymer composites in an attempt to minimize the cost, increase productivity and enhance mechanical properties of product [Salmah et al, 2013]. Lignocellulosic materials as reinforcing fillers in plastics, in place of the previously used inorganic substances and synthetic fibres, offer a major benefit in terms of environmental protection [Yang et al, 2004]. The benefits offered by lignocellulosic materials over synthetic fibres like aramid, carbon or glass fibre are low densities, non-abrasive, non-toxic, high filling levels possible resulting in high stiffness and specific properties,

biodegradable, low cost, good thermal and acoustic properties, good calorific value and enhanced energy recovery [Raju et al, 2012]. More importantly, lignocellulosic-based fillers are derived from renewable resources [Salmah et al, 2003]. Extensive studies on the preparation and properties of thermosetting and thermoplastic composites filled with jute [Rans et al, 1999], sisal [Joseph et al, 2002 and John et al, 2008], coconut shell [Blendzki et al 2010)], coir [Salmah et al, 2003], bagasse [Yang et al, 2004], Rice-husks [Yang et al, 2004] have been investigated. The use of biomaterials in general and agro-waste in particular is a subject of great interest nowadays not only from the technological and scientific points of view but also socially and economically in terms of employment, cost and environmental issues.

Nigeria is endowed with a lot of mineral and agro-based resources including palm oil from palm kernels that could be used in the development of environmental-friendly composite materials such as Eco-pad used in modern vehicle braking systems. Food Agriculture Organization (FAO) data showed that Nigeria is the third-largest producer of palm oil with more than 2.5 million hectares under cultivation as at 2011[Rout, 2001]. Palm oil production generates large amounts of process residues such as fibres, shell and empty fruit bunches. A large fraction of the fibre and much of the shell are used as fuel to generate process steam and electricity in the palm processing mill itself. However, much is wasted by pile burning in the open air with attendant air pollution, dumped in areas adjacent to the mill, or utilized as manure in the palm oil plantation [<http://www.sciencedirect.com>]. Palm kernel shell (PKS) is the hard endocarp of palm kernel fruit that surrounds the palm seed. It is obtained as crushed pieces after threshing or crushing to remove the seed which is used in the production of palm kernel oil [Saini, 2010]. Furthermore, they are waste materials that are normally stockpiled in open fields thereby subjecting them to varying climatic conditions [Dagwa, 2012]. The shells are flaky and of irregular shape that depend on the breaking pattern of the nut. The shell is made up of 33% charcoal, 45% pyroigneous liquor and 21% combustible gas [Rout, 2001]. Oil palm fibres have been extensively studied for the production of various composites, such as thermoplastic composites, particleboard, medium density fireboard polymer impregnated oil palm trunk and other thermoset composites [Olutoge, 2010]. Some of the areas where palm kernel shell are used or are being considered for use include: automobile disk brake pad, carbon activation for water purification, concrete ingredient in building industry, fuel for heat generation, thermal insulation [Rout, 2001]. As society begins to recognize the importance of utilizing renewable bio products that are beneficial to the environment, focus is beginning to return to agricultural materials [Alengaram, 2008]. Agricultural wastes are recently researched into in great extent to reduce the problem of waste disposal, produce much cheaper materials, increase the use of waste materials and make use of a more available material with little or no processing and low production cost.

Palm kernel fibre and palm kernel shell are some of the most important natural reinforcements produced in Nigeria. They are therefore being investigated with the hope of using them for the production of safety helmets.

Helmets are not only used by the military but have also been widespread use in more peaceful areas like building, cycling, horse riding, etc.

II. Review of Existing Literatures

Naveen and Dharma, in 2013 studied the development and characterization of a new set of natural fibre-based polyester composites consisting of coir as reinforcement and epoxy resin as the matrix. Coir composites were developed and their mechanical properties were evaluated, at five different volume fractions. The experimental results show tensile, static and dynamic properties of the composite are greatly influenced by increasing the percentage of reinforcement and indicate that coir can be used as potential reinforcing material for many structural and non-structural applications [Naveen, 2013].

Natsa and Akindapo in 2015 produced military helmet using coconut fibre reinforced polymer matrix. Seven specimen were produced from 20%, 40%, 50%, 60%, 70%, 80% and 85% coir fibre content in the composite and their mechanical properties were evaluated. Specimen helmets were formed from blanks that were produced by the simple hand lay-up technique, adopting the formulation with the most acceptable combination of mechanical properties. Specimen E with a fibre content of 70% in 28% resin, 2% hardener, offered a remarkable combination of properties; impact strength of 8.733J/mm², hardness strength of 30.63HRF, tensile strength of 13.81N/mm² and a flexural strength of 31.88N/mm². The impact strength remarkably increased as the fibre content increased [Natsa, 2015].

Shehu et al, investigated the effect of particle size on the properties of polyester/palm kernel shell (PKS) particulate composites. The palm kernel shell particles were varied thus; 0, 10, 20, 30 and 40wt% at three different particle sizes; 75µm, 150µm and 300µm. Cobalt accelerator and Methyl-ethyl Ketone catalyst was used for initiating polymerization reaction. The effect of palm kernel shell particles and particle size on mechanical and physical properties of polyester was studied. The results showed a better interaction of polyester and palm kernel shell particles at 300µm sieve size with density, water absorption, ultimate tensile strength and impact

energy increasing upon increase in percentage of palm kernel shell particles with only hardness decreasing upon increase in percent palm kernel shell [Shehu, 2014].

Agunsoye et al investigated the effects of palm kernel shell on the microstructure and mechanical properties of recycled low density polyethylene and palm kernel shell particulate composites. The composites were produced by compounding and compressive moulding technique by varying the Palm kernel shell particle from 5 - 251% volume with particles size of 150, 300 and 400 μ m. The micro-structure and the mechanical properties of the composites were investigated. The hardness of the composite increased with increase in palm kernel shell content and the tensile strength of the composite increased to optimum of 5% volume. Scanning electron microscopy (SEM) of the composites surfaces indicated fairly interfacial interaction between the palm kernel shell particles and the Recycled Low Density Polyethylene matrix. The composites produced with 150 μ m particle size had the best properties of the entire grade. Hence, the grade can be used for interior applications such as car seat, dash board, and car interior for decorative purposes or other interior parts of automobile where high strength is not considered a critical requirement [Agunsoye, 2012].

Dagwa et al in 2012, carried out a research on the characterization of palm kernel shell powder for use in polymer matrix composites. This work was aimed at characterizing the powdered palm kernel shell for use in composite materials formulation. Properties such as powder porosity, hydration capacity, moisture absorption, particle size distribution, bulk density, tapped density, powder flow, pH of powder dispersion as well as differential scanning calorimetry thermal (DSC), X-ray diffraction (X-RD) and scanning electron microscopy (SEM) were evaluated. The following results were obtained; pH was found to be 4 ± 0.0 , average true density, powder porosity and hydration capacity were; 1.58 ± 0.07 g/cm³, $6.76 \pm 0.42\%$, and $150.08 \pm 76.91\%$, respectively. The average values of the moisture content and moisture absorption were; $11.16 \pm 0.16\%$ and $2 \pm 0.54\%$, respectively. The average angle of repose for the palm kernel shell (PKS) was found to be 34.09 ± 4.770 . The scanning electron microscopy showed that PKS powder had spherical shape. Based on EDX analysis PKS has a high carbon content of about 63 wt %. The XRD pattern for the PKS powder showed that the PKS powder was more of amorphous material with small amount of micro crystalline materials [Dagwa, 2012].

III. Materials, Equipment And Methods

3.1 Materials

The following materials were used for the research work:

- Palm kernel shell particulates.
- Palm kernel fibres.
- Epoxy resin.
- Hardener (tetra ethylene pentamine).
- Acetic acid.
- Sodium hydroxide.
- Hemihydrated calcium sulphate (plaster of Paris).
- Aluminium foil.

3.2 Equipment

The following equipment were employed for the project:

- Charpy Impact Testing Machine (Cat Nr. 412, Capacity- 15J and 25J).
- Rockwell Hardness Testing Machine (Indentec, Model: 8187.5 LKV (B)).
- Tensometer (Monsato Limited, Model: A260-2).
- Universal Materials Testing Machine (100 KN Capacity-Cat. Nr. 261).

The Department of Mechanical Engineering, Ahmadu Bello University was used as research centre for this work.

3.3 Specimen Processing and Formulation

The palm kernel fibres were treated in sodium hydroxide solution (NaOH) for 90 minutes at a liquor ratio of 1:15, after which they were rinsed with acetic acid. The palm kernel shell particles in powdered form were treated with sodium hydroxide for 15 minutes at a liquor ratio of 1:10 and then rinsed with acetic acid.

Glass moulds of dimension (200*120*6) mm lined with aluminium foil were designed and used in casting the samples. The fibres in their specified proportions were mixed manually to disperse the fibres in the matrix. The specimen were mixed in the ratio of fibre percentage ranging from 2.5% to 15% by total weight of the specimen. The cast for each composite was cured for 24 hours before they were removed from the mould and post cured in air for another 24 hours, after which they were taken for mechanical tests.

The optimum value obtained from the mechanical tests was utilized for the production and cast with varying percentages of palm kernel shell particles as filler. The samples were then taken for mechanical tests to

observe the effects of the PKS particles as filler. The composite formulation with optimum characteristics was then selected for the fabrication of the helmet.

The specimen for the laboratory tests were prepared according to the formulation presented in table 1 below. Six loading levels of palm kernel fibre content having 2.5, 5, 7.5, 10, 12.5 and 15% based on weight composition of composite material were formed by simple hand lay-up technique as shown in table 1 below:

Table 1: Formulation of PKF composites

Specimen - PKF (%)	Epoxy Resin (%)	Hardener (%)
A – 2.5	65	32.5
B – 5	63.3	31.7
C – 7.5	61.7	30.8
D – 10	60	30
E – 12.5	58.3	29.2
F – 15	56.7	28.3

The optimum characteristics of the PKF composites were found to be 10% PKF – 90% (Epoxy and hardener). Various formulations were then cast using the PKS as filler in the ratios shown in table 2 below:

Table 2: Formulation of PKF and PKS composites

Specimen	PKF (%)	PKS (%)	Epoxy (%)	Hardener (%)
A	9	1	60	30
B	8	2	60	30
C	7	3	60	30
D	6	4	60	30
E	5	5	60	30
F	4	6	60	30

3.4 Experimentation

The following mechanical tests were conducted:

- Tensile test: The test was performed in accordance with ASTM D638-03 standard method of testing plastics.
- Hardness test: The hardness test was carried out in accordance with ASTM D785=08 s ISO 2039 standard.
- Impact test: The Charpy impact test was carried out in accordance with ASTM D256 - 05, ISO 179 standard method of testing hardness properties.
- Flexural test: The flexural tests also referred to as bending tests were performed using the three-point bending method in accordance with ASTM D790-03 standard.

3.5 Choice of Mould

The choice of mould used in this research work was influenced by a number of factors, most important; good surface finish and cost. The hemihydrated calcium sulphate (plaster of Paris) mould was therefore selected for this work as it gives a good surface finish and also affordable. This work has shown that the plaster of Paris (POP) mould is about 350% lower in cost compared to fabricated metal moulds. To prevent a secondary reaction between the POP mould surface and the resin used, the mould was lined with aluminium foil.

3.6 Helmet Fabrication

The blanks used in this research were fabricated by hand lay-up technique which is the simplest method of composite processing. The helmet mould was made from hemihydrated calcium sulfate (POP), lined with aluminium foil. A release gel was sprayed in the mould to avoid sticking of the polymer to the surface. Reinforcement in the form of chopped strands was placed at the surface. The resin, having been mixed in suitable proportion with the tetraethylene pentamine was poured onto the surface of the PKF with the PKS used as filler in the specified proportion. The resin was uniformly spread with the help of a brush. Subsequent reinforcements were added until the required thickness was obtained and then a roller was moved over the composite with mild pressure to remove any air trapped as well as distribute the resin uniformly. The composite was cured in open air for about 48 hours. Thereafter, the helmet was removed from the mould and trimmed at the edges to give the final shape.

IV. Results, Analysis And Discussion

4.1 Impact Test Result of PKF Composite

The result obtained for the impact strength of Palm Kernel Fibre is indicated in Table 3 below:

Table 3: Result of Impact Strength for Palm Kernel Fibre Composite

Specimen	Width (mm)	Thickness (mm)	Area (mm ²)	Impact Energy (J)	Average Impact Energy (J)	Impact Strength (J/mm ²)
A1	13	6	78	200	283.33	3.63
A2	13	6	78	350		
A3	13	6	78	300		
B1	13	6	78	300	333.33	4.27
B2	13	6	78	350		
B3	13	6	78	350		
C1	13	6	78	450	416.67	5.34
C2	13	6	78	400		
C3	13	6	78	400		
D1	13	6	78	450	516.67	6.62
D2	13	6	78	550		
D3	13	6	78	550		
E1	13	6	78	350	400.00	5.13
E2	13	6	78	300		
E3	13	6	78	550		
F1	13	6	78	400	283.33	3.63
F2	13	6	78	200		
F3	13	6	78	250		

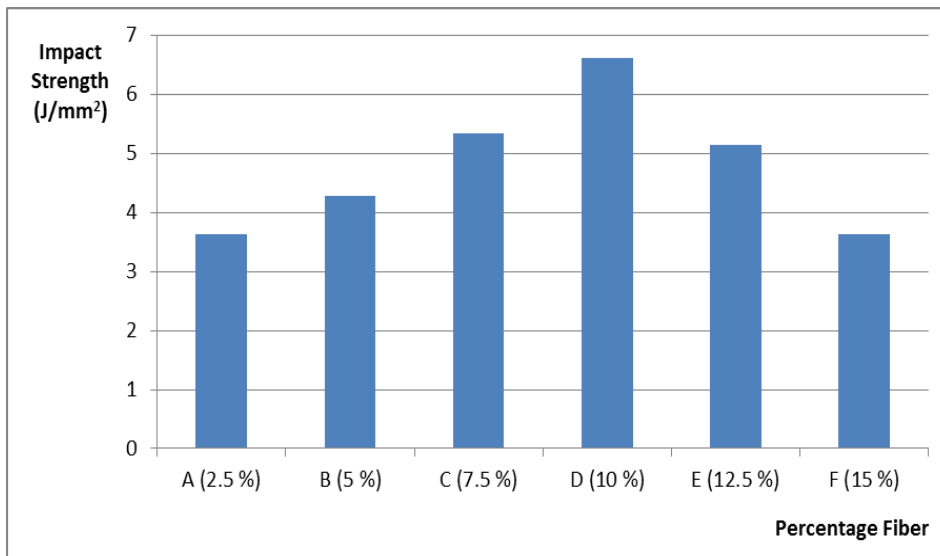


Figure 1: Impact Test Chart of PKF

The impact test as far as this research is concerned, is the most important test. There is a considerable improvement in the impact strength of the specimen as the fibre content increases. Specimen A which has 2.5% fibre in the composite showed the least impact strength as expected. This is so because the fibre which is supposed to act as reinforcement or the base of strength in the composite was overpowered by the resin. However, a steady increase in the impact strength was observed to a maximum value of 6.62 J/mm² for specimen D having 10% fibre in the composite. Specimen D had the best bond of fibre and matrix which gave the composite the best impact strength. Beyond specimen D, the impact strength is observed to decrease with further increase in fibre content. This is due to the fact that the resin could not properly bind the fibre, hence, resulting in a reduction of impact strength.

4.2 Rockwell Hardness Test Result

The result of the hardness property is indicated in Table 4 below:

Table 4: Rockwell Hardness property of PKF Composite

Specimen	Hardness (HRF)	Average Hardness (HRF)
A1	8.4	8.1
A2	7.8	
A3	8.2	
B1	7.5	

B2	7.5	7.6
B3	7.8	
C1	6.9	6.5
C2	6.4	
C3	6.2	
D1	7.4	6.9
D2	6.9	
D3	6.4	
E1	7.9	7.0
E2	6.8	
E3	6.4	
F1	6.4	6.9
F2	7.4	
F3	6.9	

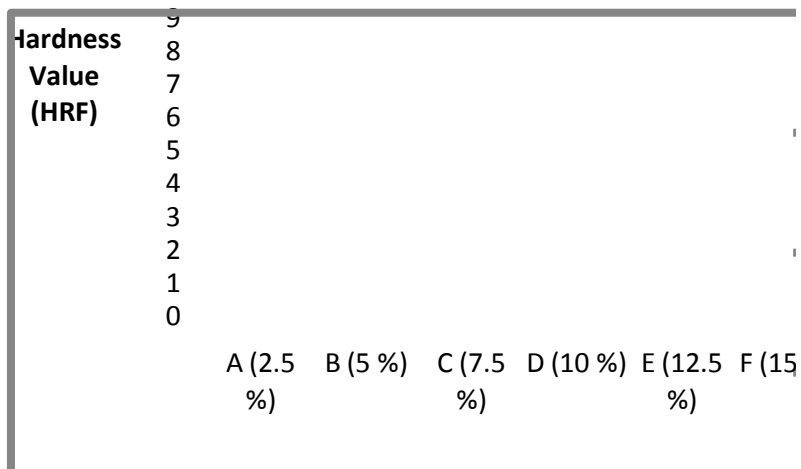


Figure 2: Rockwell Hardness Chart

The result above shows specimen A with the highest hardness, which supports the relationship between impact strength and the hardness of a material. Specimen C had the lowest value of Rockwell hardness with 7.5% fibre content. The values obtained from the experimental work are in the same range with an average value of 7.2 HRF.

4.3 Tensile Test Result

The result obtained during the laboratory test on the tensile test experiment is indicated in Table 5 below:

Table 5: Tensile test result of PKF Composite

Specimen	Gauge length (mm)	Width (mm)	Thickness (mm)	Area (mm ²)	Average Area (mm ²)	Breaking Load (N)	Average Breaking Load (N)	Average Tensile Strength (N/mm ²)
A1	40	9.9	4.2	41.58	42.38	1025.0	879.17	20.68
A2	40	9.7	4.8	46.56		950.0		
A3	40	10.0	3.9	39.00		662.5		
B1	40	10.0	4.1	41.00	40.46	570.0	727.50	17.98
B2	40	10.0	4.1	41.00		912.5		
B3	40	10.1	3.9	39.39		700.0		
C1	40	9.9	5.4	53.46	53.82	720.0	840.00	15.52
C2	40	10.0	5.7	57.00		1075.0		
C3	40	10.0	5.1	51.00		725.0		
D1	40	10.0	5.5	55.00	55.13	1500.0	1466.67	26.75
D2	40	9.9	6.0	59.40		1400.0		
D3	40	10.0	5.1	51.00		1500.0		
E1	40	9.5	5.7	54.15	57.14	1150.0	1029.17	18.23
E2	40	9.7	5.8	56.26		1212.5		
E3	40	10.0	6.1	61.00		725.0		
F1	40	9.8	7.2	70.56	61.69	812.5	758.33	12.32
F2	40	9.8	6.1	59.78		837.5		
F3	40	9.9	5.7	54.72		625.0		

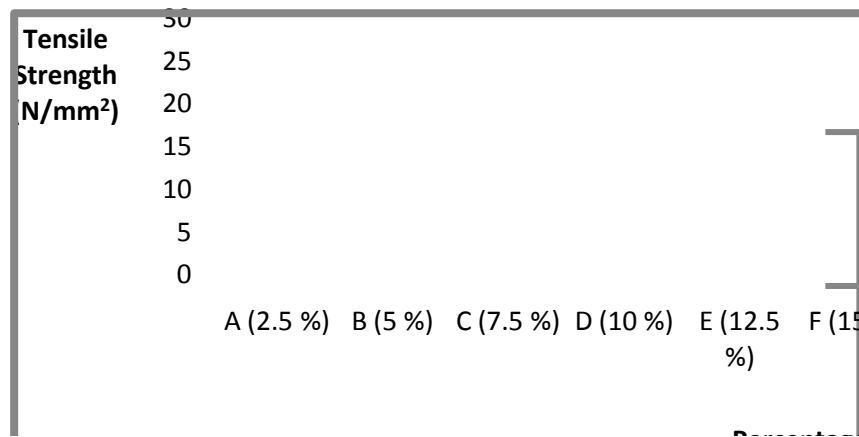


Figure 3: Tensile Test Chart

The result obtained shows that specimen D having 10% fibre content has the highest tensile strength. This may be attributed to the near perfect bonding of fibre and matrix in the composite. It is observed that beyond 10% fibre content, the tensile strength declines, which may be due to the increased fibre content with limited resin to properly bond them together.

4.4 Flexural Test Result

Table 6 shows the result obtained from the flexural test experiment performed on Palm kernel fibre composite.

Table 6: Result of flexural test conducted on PKF Composite

Specimen	Width (mm)	Thickness (mm)	Length (mm)	Load (N)	Deflection (mm)	Flexural Strength (N/mm ²)	Average Flexural Strength (mm ²)
A1	33.0	4.7	70	110	3.59	15.84	18.10
A2	30.4	4.5	70	130	1.91	22.17	
A3	30.8	4.8	70	110	1.82	16.28	
B1	31.1	4.2	70	160	3.69	30.62	22.37
B2	31.0	5.0	70	130	2.90	17.61	
B3	30.2	4.5	70	110	3.52	18.89	
C1	32.3	6.1	70	260	1.91	22.71	25.25
C2	31.7	5.9	70	300	2.91	28.55	
C3	31.2	5.5	70	220	1.95	24.48	
D1	30.3	6.6	70	400	1.94	31.82	31.02
D2	30.1	6.4	70	400	1.95	34.07	
D3	32.6	6.8	70	390	1.93	27.17	
E1	31.2	5.9	70	380	1.91	29.36	29.55
E2	31.9	6.0	70	400	1.96	36.57	
E3	31.0	6.1	70	310	2.95	22.71	
F1	30.6	6.7	70	300	1.96	22.93	27.34
F2	31.3	6.0	70	350	2.82	32.62	
F3	31.0	6.4	70	320	1.92	26.46	

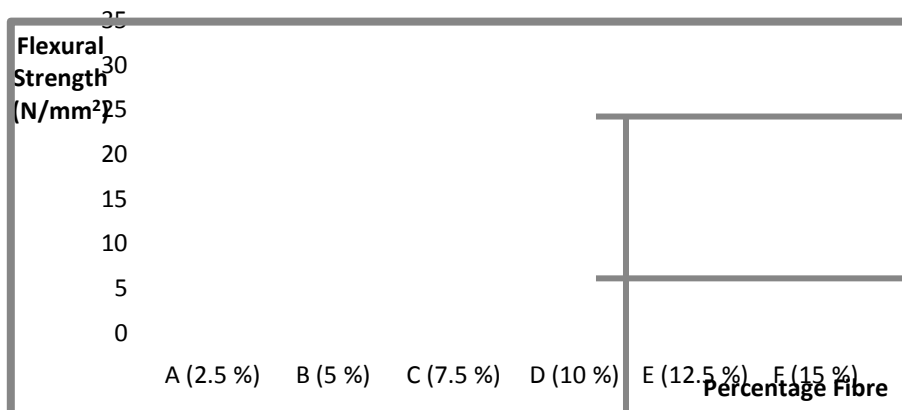


Figure 4: Flexural Test Chart

The flexural strength, also known as the modulus of rupture, bend strength, or fracture strength, is defined as a material’s ability to resist deformation under load. The results obtained showed a steady increase in the flexural strength up to 31.02 N/mm² for Specimen D having 10% fibre content. The near perfect bonding between the matrix and the reinforcement gives the composite a suitable property. A gradual decline in flexural strength is observed as the fibre content increases beyond 10%. This is being attributed to insufficient resin to properly bind the fibre.

4.5: Impact Test Result of PKF and PKS

The impact test experiment was carried out on the sandwiched palm kernel fibers and shell particulate which acted as filler. The results obtained are shown in table 7 below:

Table 7: Result of Impact test on hybrid PKF and PKS

Specimen	Width (mm)	Thickness (mm)	Area (mm ²)	Impact Energy (J)	Average Impact Energy (J)	Average Impact Strength (J/mm ²)
D _{9A}	13	6	78	350	383.33	4.92
D _{9B}	13	6	78	500		
D _{9C}	13	6	78	300		
D _{8A}	13	6	78	370	406.67	5.21
D _{8B}	13	6	78	450		
D _{8C}	13	6	78	400		
D _{7A}	13	6	78	450	473.33	6.07
D _{7B}	13	6	78	500		
D _{7C}	13	6	78	470		
D _{6A}	13	6	78	500	566.67	7.27
D _{6B}	13	6	78	650		
D _{6C}	13	6	78	550		
D _{5A}	13	6	78	600	483.33	6.20
D _{5B}	13	6	78	450		
D _{5C}	13	6	78	400		
D _{4A}	13	6	78	400	466.67	5.98
D _{4B}	13	6	78	600		
D _{4C}	13	6	78	400		

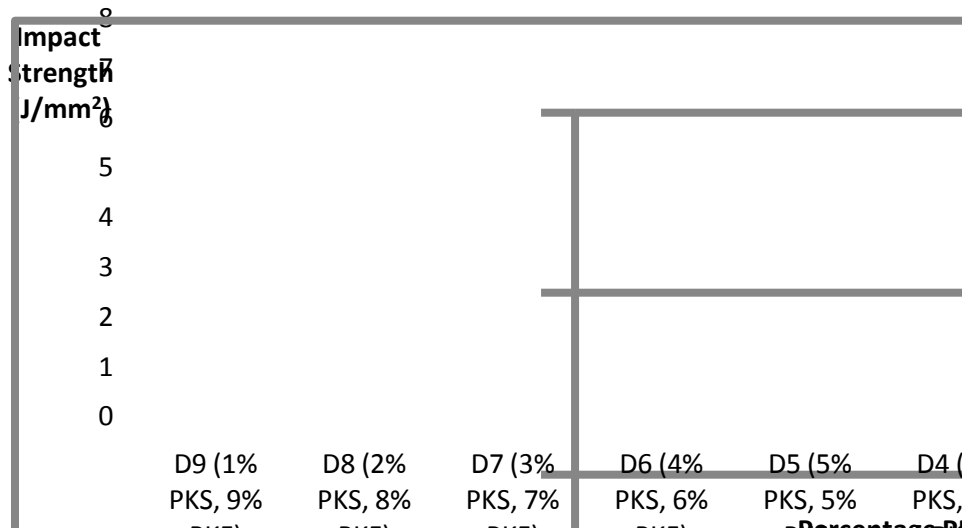


Figure 5: Impact Test Chart of PKF and PKS

The optimum mechanical properties were obtained in specimen D, after which various composition of PKS were varied with the PKF, where the PKS acted as filler. From the impact test conducted, there was a remarkable improvement in the impact strength, with the highest strength obtained in specimen D₆ (4% PKS, 6% PKF). It is also observed that as the PKS content increases, the impact strength increases up to specimen D, and a steady decline occurs beyond this point. The drop in strength is being attributed to the material becoming more brittle with the increase in PKS particles.

4.6 Rockwell Hardness Test Result

The Rockwell hardness test results for the hybrid palm kernel fiber and shell particulates are shown in table 8 below:

Table 8: Rockwell hardness test result for PKF and PKS Composite

Specimen	Hardness (HRF)	Average Hardness (HRF)
D _{9A}	6.3	7.8
D _{9B}	9.3	
D _{9C}	7.9	
D _{8A}	6.2	7.5
D _{8B}	7.4	
D _{8C}	8.9	
D _{7A}	8.4	7.5
D _{7B}	6.4	
D _{7C}	7.9	
D _{6A}	7.5	6.7
D _{6B}	5.4	
D _{6C}	7.4	
D _{5A}	7.6	6.7
D _{5B}	6.4	
D _{5C}	6.3	
D _{4A}	6.1	6.1
D _{4B}	6.1	
D _{4C}	6.1	

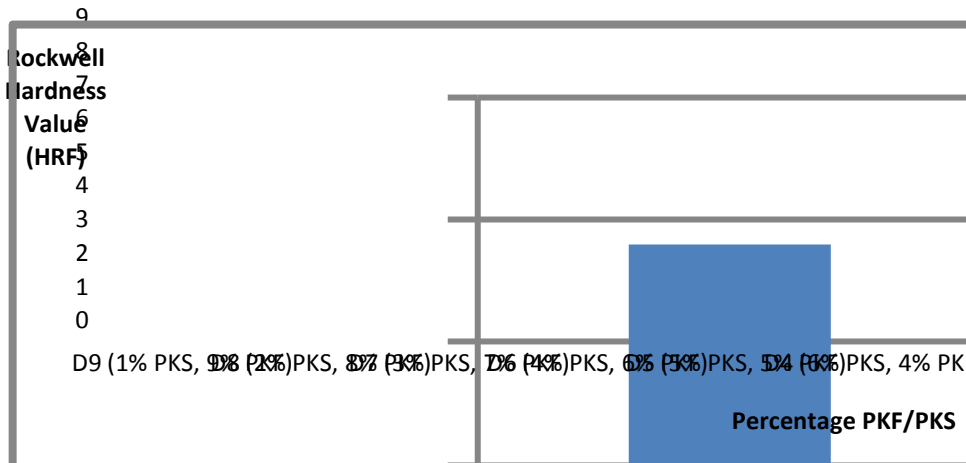


Figure 6: Rockwell Hardness Chart of PKF and PKS

From the result obtained above, specimen A (1% PKS, 9% PKF) has the highest hardness. This hardness is seen to decrease with the increase in PKS and decrease in PKF. The high hardness in specimen A might be attributed to the better bonding between the fibre and matrix with the PKS particles acting as filler in the right proportion. As the particles increased, the resin became more insufficient to adequately bond the fibre and particulates, resulting in a loose composite structure with reduced hardness. The particulate absorbed a large percentage of the workable resin thereby resulting in weak bonding.

4.7 Tensile Strength Test Result for PKF and PKS composite

The tensile test result for the hybrid palm kernel fiber and shell particulates is shown in table 9 below:

Table 9: Tensile Test Result for PKF and PKS Composite

Specimen	Gauge Length (mm)	Width (mm)	Thickness (mm)	Area (mm ²)	Average Area (mm ²)	Breaking Load (N)	Average Breaking Load (N)	Average Tensile Strength (N/mm ²)
D _{9A}	40	10.0	5.9	59.0		637.5		

D _{9B}	40	11.1	5.5	61.1	60.5	1662.5	1233.33	20.39
D _{9C}	40	10.4	5.9	61.4		1400		
D _{8A}	40	9.5	6.1	58.0		650		
D _{8B}	40	10.0	4.9	49.0	56.73	700	800	14.10
D _{8C}	40	10.2	6.2	63.2		1050		
D _{7A}	40	11.1	6.4	71.04		1750		
D _{7B}	40	11.1	6.1	67.7	68.15	1312.5	1475	21.64
D _{7C}	40	10.6	6.2	65.7		1362.5		
D _{6A}	40	10.1	6.0	60.6		1037.5		
D _{6B}	40	9.9	6.2	61.4	59.75	1300	1287.5	21.55
D _{6C}	40	10.6	5.4	57.24		1525		
D _{5A}	40	9.9	6.4	63.4		1500		
D _{5B}	40	10.0	6.2	62.0	58.47	1500	1350	23.09
D _{5C}	40	10.0	5.0	50.0		1050		
D _{4A}	40	9.2	5.7	52.4		1362.5		
D _{4B}	40	8.8	4.8	42.24	53.33	712.5	1291.67	24.22
D _{4C}	40	9.9	6.6	65.34		1800		

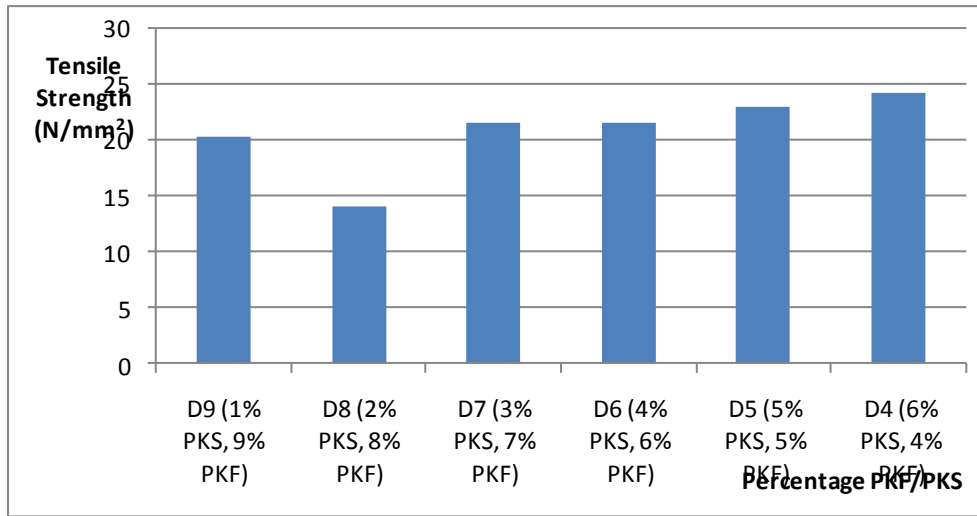


Figure 7: Tensile Test Chart of PKF and PKS

The tensile test results show specimen F (6% PKS, 4% PKF) to have the highest tensile strength of 24.22 N/mm². The addition of PKS as filler did not improve the tensile strength of the original specimen D (10% PKF) that had a tensile strength of 26.75 N/mm². This general drop in tensile strength might be attributed to the fact that the material became less ductile and more brittle.

4.8: Flexural Test Result

The Flexural strength test result for the palm kernel fiber and shell particulate is shown in table 10 below:

Table 10: Flexural strength test result for PKF and PKS Composite

Specimen	Width (mm)	Thickness (mm)	Length (mm)	Load (N)	Deflection (mm)	Flexural Strength (N/mm ²)	Average Flexural Strength (N/mm ²)
D _{9A}	31.0	6.1	70	340	2.46	30.95	31.73
D _{9B}	30.2	6.1	70	330	2.73	30.84	
D _{9C}	29.8	5.9	70	330	2.23	33.40	
D _{8A}	31.2	6.2	70	240	1.91	21.01	24.13
D _{8B}	28.7	6.4	70	240	1.91	21.44	
D _{8C}	30.2	6.0	70	310	2.90	29.94	
D _{7A}	29.4	6.4	70	200	1.85	17.44	21.83
D _{7B}	30.4	6.3	70	240	1.93	20.89	
D _{7C}	30.0	5.9	70	270	3.07	27.15	
D _{6A}	30.3	6.2	70	390	1.94	35.16	34.61
D _{6B}	30.0	6.0	70	380	1.93	36.94	
D _{6C}	29.9	6.4	70	370	2.39	31.72	
D _{5A}	30.4	6.3	70	340	3.09	29.59	30.14
D _{5B}	30.2	6.2	70	300	1.93	27.13	
D _{5C}	30.7	5.7	70	320	3.51	33.69	

D _{4A}	30.1	6.1	70	290	1.91	27.19	25.53
D _{4B}	30.8	6.2	70	240	1.84	21.29	
D _{4C}	30.1	6.4	70	330	2.9	28.11	

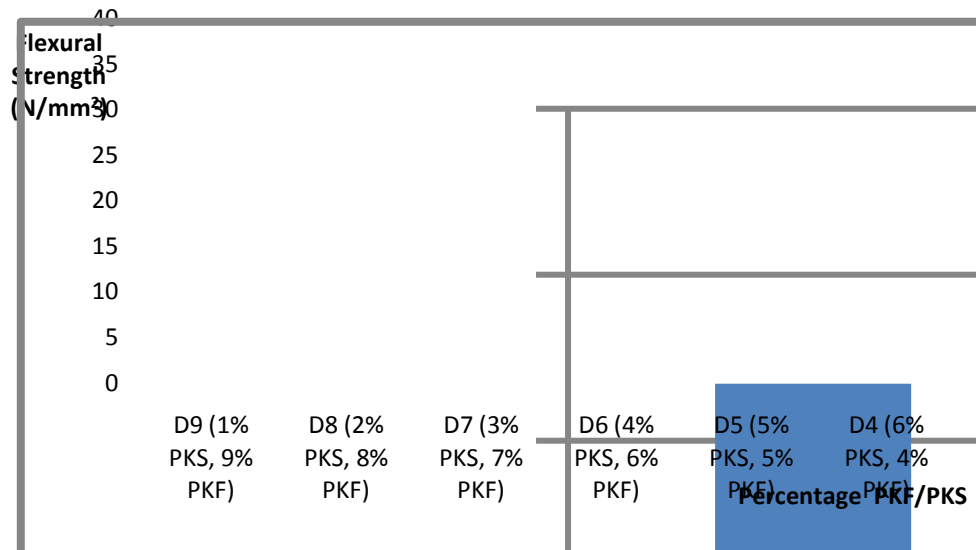


Figure 8: Flexural Test Chart

From the result obtained above, specimen D (4% PKS, 6% PKF) has the highest flexural strength (34.61 N/mm²), which is also an improvement on the first specimen D (10% PKF) that had a flexural strength of 31.02 N/mm². This could also be attributable to the near perfect bonding between the fibre, particulate and resin, giving the composite a better fracture strength.

4.9 Measurement of Physical Properties of Helmet Produced against Standard Helmets

The physical properties of the safety helmet such as weight, thickness and colour were evaluated and compared with standard physical properties of existing helmets. The result is presented in the table below:

Table 11: Physical Properties of Selected Helmets

S/No	Type	Weight (Kg)	Thickness (Mm)	Colour
1	Chinese	3.56	3	Silver
2	British	3.25	2	Silver
3	Us Ballistic	2.12	10	Dark Blue
4	Stephen Natsa Et Al (2015)	3.15	5	Gray
5	Safety Helmet Produced From Pkf/Pks Composite (2016)	0.99	2	Brown

V. Conclusion And Recommendations

5.1 Conclusion

This work resulted in the successful production of a safety helmet using palm kernel fibers and palm kernel shell particulates as filler in a polymer matrix composite by employing simple hand lay-up technique. The following conclusions can be drawn from the research work:

- i. Specimen D having a fiber content of 10% gave the best mechanical properties. This composition was then varied with different proportions of palm kernel shell particulates (1, 2, 3, 4, 5 and 6%) acting as filler.
- ii. The addition of palm kernel shell particulates improved the impact strength of the specimen with optimum mechanical properties from 6.62J/mm² to 7.27J/mm², with the best composition obtained at 4% PKS particulates and 6% Palm kernel fiber content.
- iii. There was a slight decline in the hardness and tensile strength with the addition of PKS particles from 6.9 HRF to 6.7 HRF for the hardness and 26.75 N/mm² to 21.55 N/mm² for the tensile strength.
- iv. Flexural strength was observed to have increased with the addition of PKS particles as filler, from 31.02 N/mm² to 34.61 N/mm². Since the aim of the research was to produce a safety helmet, the most important parameter used in the adoption of the composition was the impact strength.
- v. The helmet was then cast using the formulation obtained from specimen D (4% PKS, 6% PKF).

5.2 Recommendations

New areas of research have been identified during this period. These include:

- i.** The investigation of the performance of other low cost resin system like thermoplastics and biodegradable matrices such as starch and cellulose acetate reinforced with PKF and PKS particles as filler.
- ii.** The density and moisture absorption behaviour of the composites could be further investigated to determine the extent of water intake, as this will help to find wider areas of applications.
- iii.** Other types of surface modifications should be explored apart from alkali treatment for comparison purposes and to know their effects on the composite mechanical properties.
- iv.** A study on the effect of the fibre length and particle sizes of the PKF and PKS respectively on the mechanical properties of the composite material could also be carried out to optimize the entire process.

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