DEVELOPMENT OF A MILITARY HELMET USING COCONUT FIBER REINFORCED POLYMER MATRIX COMPOSITE

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ABSTRACT

Coconut fiber reinforced polymer composite was used to investigate its suitability for the production of a military helmet. The coconut fiber, otherwise known as the coir fiber was used as the reinforcement while epoxy resin (*bisphenol-A-diglycol*) served as the matrix. Seven specimens were produced having 20%, 40%, 50%, 60%, 70%, 80% and 85% coir fiber content in the composite and their mechanical properties (tensile strength, impact strength, flexural strength and hardness strength) were evaluated. Specimen helmets were formed from blanks that were produced by simple hand lay-up technique adopting the formulation that offered the most acceptable combination of mechanical properties. Specimen E, having a fiber content of 70% in 28% resin offered remarkable combination of properties: impact strength of 8.733J/mm², hardness strength of 30.03HRF, tensile strength of 13.81N/mm² and a flexural strength of 31.88N/mm². Since impact test result is the most critical test in this research, and specimen E offered the highest, it was adopted for the production of the sample military helmets in this work. The impact strength showed by specimen E (70% coir fiber in 28% resin), which was 8.733J/mm² clearly implies that the composite material can be used for the production of military protective helmets. Therefore, coir fiber can be used comfortably as reinforcement in polymer matrix composite for the production of Military helmet.

Keywords: Military helmet, Protective helmet, Coconut fiber, Coir fiber, Polymer matrix composite, Fiber reinforments, Epoxy resin.

INTRODUCTION

Composites can be defined as 'compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated in the mix as to take advantage only of their attributes and not of their shortcomings' in order to obtain improved materials [1].

Coir fiber is thick and coarse, it is obtained from the husk of the fruit of the coconut palm tree (*cocos nucifera*), which is grown extensively in the south eastern part of Nigeria and considerably in the Northern part of Nigeria. The coconut fiber is used in making a wide variety of floor furnishing materials, for example ropes, mats, mattresses, brushes, sacks, rugs etc. However, production of these traditional coconut products is only a small percentage of total production of the coconut husk. Hence, research and development work to find new markets for the value added products containing coconut fiber [2].

In the last three decades, composite materials, plastics and ceramics have been the dominant emerging materials. The amount (volume) and number of applications of composite materials have grown steadily, penetrating and conquering new markets persistently. Composite materials have today constituted a significant proportion of engineering materials in the markets ranging from everyday products to sophisticated niche applications. Although composite materials have shown their worth as weight-saving materials, the lingering issue now is to make them cost effective. The quest for producing composites that are friendly, economical, have resulted in several innovative manufacturing methods that are presently in practice today in the composite industry [3]. It is clear, especially for composites, that the improvement in manufacturing technology alone is not enough to overcome the cost hurdle. It is therefore important to have integrated effort in design, process, tooling, quality assurance, and manufacturing and even programmed management for composites to become competitive with metals [4].

For certain applications, the use of composite rather than metals has in fact resulted in saving both cost and weight. Furthermore, 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. Composites are now being extensively used for rehabilitation and strengthening of pre-existing structures that have to be retrofitted to make them seismic resistant, or to repair damage caused by seismic activity. Unlike conventional materials (e.g. 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. Composite properties (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(run length), complexity of product shape, possible savings in assembly costs and on the experience and skills of the designer in tapping the optimum potential of composites[5].

Technology nowadays requires materials with sophisticated mix of properties that are not satisfied by conventional metal alloys. They are put into extensive engineering applications in many different fields such as oil and gas, food processing industries, aerospace etc. Apart from their superior corrosion resistance, composite materials show good resistance to temperature and wear, especially in industrial settings [6]. As replacement for conventional synthetic fibers like aramid and glass fibers, natural fibers are increasingly used for reinforcement in polymer due to their low density, good thermal insulation and mechanical properties, reduced tool wear, unlimited availability, low price and minimal problem of disposal [7].

LITERATURE REVIEW

Jayabal et al [8] researched on the development of woven coconut (coir) fiber-reinforced polyester composites. The mechanical properties of woven coir-polyester composites were evaluated as per ASTM standards and the machinability behavior was studied by conducting drilling tests. The woven coir-polyester composites exhibited the average values of tensile, flexural and impact strength of 19.9 MPa, 31.3 MPa and 49.9 kJ/m^2 respectively. The effect of NaOH treatment on the improvement of mechanical properties of woven coir-polyester composites were studied also. The 40% increase of tensile strength, 42% increase of flexural strength and 20% increase of impact strength were achieved by treated woven coir fiber-reinforced polyester composites. The regression models for predicting thrust force, torque and tool wear in drilling of woven coir-polyester composites were developed and the effect of drilling parameters were analyzed.

Wang and Hang[9], worked on the characteristics of coir fiber. Length of the fibers was in the range of 8 and 337mm. The fiber amount with length range of 15-145mm was 81.95% of all measured fibers. Weight of fibers with length range of 35-225mm accounted for 88.34% of all measurement. The average fineness of the coir fibers was 27.94 tex. Longer fibers usually had higher diameters. Composite boards were fabricated by using a heat press machine with the coir fiber as the reinforcement and the rubber as matrix. Tensile strength of the composites was investigated.

Anyakora A[10] studied the correlation between fiber treatment and ash content on the tensile behavior of coir reinforced polyester composite. He made composite panels by hand lay-up technique from untreated and saline-treated coir reinforced with polyester matrix. The processing parameters included surface treatment and manipulation of fiber content and the evaluation of ash content in relation to the tensile strength properties. The results obtained indicated that fiber content and surface treatment can lead to improved tensile strength and modulus of rigidity of coir composite panels. The Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) analysis showed the presence of higher ash content, which is indicative of positive effect of improved tensile strength of the treated coir reinforced polyester composite panels. Chiefly noted is the higher percentage calcium in the untreated coir which tends to neutralize toxic effects of acid on fiber.

MATERIALS AND METHODS

Materials

The raw materials used in this work are: Coconut fiber, epoxy resin (*bisphenol-A-diglycol*) and hardener (*tetra ethylenepentamine*). The coir -fibers were obtained from fruited coconut palm plants, which were felled and dried. The coconut plants are available in large proportion in the Southern part of Kaduna State. Coconut plantations can be found in that region around Kagoma district of Jema'a local government, Kagoro district of Kaura local government, Gwantu area of Sanga Local Government etc. The coconut husk containing the fibers and the pith (the mass holding the fibers firmly) were dried in open air and consequently beaten mechanically thereby separating the brown fibers from the pith. The fibers were then segregated into different lengths as were obtained.

The matrix materials namely epoxy LY556 resin (*bisphenol-A-diglycol ether*) and curing agent (tetraethylenepentamine) were obtained commercially from Zayo-Sigma Chemicals Limited, Jos, Plateau State, Nigeria. The epoxy LY556 resin has a specified modulus of 3.42GPa and a density of 1100kg/m^3.

EQUIPMENT

The equipment used in this study are: Charpy Impact Testing Machine (Model 6703; 25 Joules), Rockwell hardness Testing Machine (F-scale Model DFH-100), Monsarto Tensometer (Serial number 9875, 20KN) and H ounsfield Universal Testing Machine, (100KN).

EXPERIMENTAL PROCEDURE

Specimen formulation and blanks fabrication were performed at the Centre for Technology Incubation, Federal Ministry of Science and Technology, Bauchi, Nigeria. The composition of the composite specimen is as shown in the figure below:

Figure 3.1: Formulation of specimen composites

SPECIMEN NOMENCLATURE (COIR FIBER) (%)	EPOXY RESIN (%)	HARDENER (%)
A – 20%	78%	2%
B – 40%	58%	2%
C – 50%	48%	2%
D – 60%	38%	2%
E – 70%	28%	2%
F - 80%	18%	2%
G - 85%	13%	2%

Seven pieces of a two part mould facility (made of mild steel flat 4mm thick) of dimensions 100mm * 100mm with active surfaces grounded, prescribed cavity of 10mm was made and adopted in the production of test specimen plates. The fibers (in their specified proportions) were mixed manually to disperse the fibers in the matrix (also in its specified proportions). The specimens were mixed in the ratio of coir fiber percentage to matrix material percentage ranging from 20% to 85% by total weight of the specimen. The cast for each composite was cured under a load of 50kg for 24 hours before they were removed from the mould. Then the casts were post cured in the air for another 24 hours after removal from the mould after which the specimens were due for the mechanical tests. Utmost care was ensured to maintain uniformity and homogeneity of the composites.

The composite formulation with optimum characteristics was then be selected for the fabrication of a sample Military helmet where the same mixing procedure was followed with the cast in a mould made for the specimen helmet. The specimens for laboratory tests were prepared according to the formulation presented in figure 3.1 above.

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RESULTS AND DISCUSSION

Results

Impact test result

SPECIMEN	IMPACT ENERGY (J)	AVERAGE IMPACT ENERGY (J)	IMPACT STRENGTH (J/mm^2)
A1	190	190.00	1.900
A2	190		
A3	190		
B1	310	316.67	3.167
B2	320		
B3	320		
C1	505	505.00	5.050
C2	505		
C3	505		
D1	710	710.00	7.100
D2	710		
D3	710		
E1	870	873.33	8.733
E2	870		
E3	880		
F1	649	633.00	6.330
F2	630		
F3	630		
G1	290	276.00	2.760
G2	283		
G3	255		

Rockwell hardness test result

SPECIMEN	HARDNESS (HRF)	AVERAGE HARDNESS (HRF)
A1	25.20	25.01
A2	25.00	
A3	25.20	

B1	26.60	
B2	26.68	26.23
B3	26.20	
C1	27.30	
C2	27.30	27.23
C3	27.10	
D1	28.40	
D2	28.90	28.70
D3	28.80	
E1	30.10	
E2	29.79	30.03
E3	30.20	
F1	15.34	
F2	14.59	15.31
F3	16.01	
G1	14.78	
G2	13.67	14.49
G3	15.01	

Tensile test result

SPECIMEN	GAUGE LENGTH (mm)	WIDTH (mm)	THICKNESS (mm)	AREA (mm^2)	BREAKING LOAD (N)	AVERAGE TENSILE STRENGTH (N/mm^2)
A1	35	9	6	54	599	11.28
A2	35	9	6	54	620	
A3	35	10	5	50	394	
B1	35	10	2.5	25	222	12.05
B2	35	10	3	30	318	
B3	35	8	2.5	20	241	
C1	35	10.5	4	42	590	16.60
C2	35	9	3.5	31.5	670	
C3	35	9	4	36	420	
D1	35	8	4	32	600	14.50
D2	35	8	4	32	350	
D3	35	7	4	28	400	
E1	35	7	4.5	31.5	600	13.81
E2	35	8	4.5	36	550	
E3	35	10	4	50	590	
F1	35	8	5	29	590	12.9
F2	35	8	3.5	45	650	
F3	35	7	5	50	600	
G1	35	8	5	32	600	9.23
G2	35	10	4	43	550	
G3	35	9	6	45	450	

Flexural test result

SPECIMEN	WIDTH mm	SPAN LENGTH mm	THICKNESS mm	LOAD N	DEFLECTION mm	FLEXURAL STRENGTH N/mm^2	AVEREAGE FLEXURAL STRENGTH N/mm^2
A1	50	100	4	60	2.001	11.25	16.88
A2	50	100	4	90	1.742	16.88	
A3	50	100	4	120	1.452	22.5	
B1	50	100	4	110	2.637	20.63	23.10
B2	50	100	4	130	2.112	24.30	
B3	50	100	4	130	2.001	24.38	
C1	50	100	4	160	2.119	30.00	26.87
C2	50	100	4	140	2.537	26.25	
C3	50	100	4	130	1.784	24.38	
D1	50	100	4	140	1.889	24.76	25.33
D2	50	100	4	110	2.504	24.45	
D3	50	100	4	160	1.770	26.78	
E1	50	100	4	180	1.831	33.75	31.88
E2	50	100	4	160	1.721	30.00	
E3	50	100	4	170	1.991	31.88	
F1	50	100	4	150	1.889	22.77	24.02
F2	50	100	4	120	2.124	24.56	
F3	50	100	4	150	1.770	24.75	
G1	50	100	4	100	2.637	20.63	23.10
G2	50	100	4	120	2.112	25.38	
G3	50	100	4	140	2.001	23.30	

Fabricated helmets

DISCUSSION OF RESULTS

Impact Strength: Impact test, which is the most important test in this research, shows a considerable improvement in the Impact strength of the specimen as the fiber content increases. Specimen A which has 20% of the fiber in 78% of the resin showed the least impact strength as expected. This is because the matrix material, the coir fiber, which is expected to form the base for the strength of the composite was overpowered by the resin. Effectively, the strength of the resin is the result on this specimen. However, a steady increase in the impact strength was observed as the fibre content increased upto 8.733J/mm^2 for specimen E having 70% of fibre in 28% of the resin. Specimen E had enough coir fibre bonded by the resin available to give a composite with such a quality property.

Hardness Strength: Since hardness is the material property that shows its ability to resist penetration, the results above have further illustrated a steady growth in Hardness as the fibre content increases. Yet again, specimen E, with fibre content of 70% in 28% resin has showed the highest Hardness of all with 30.03HRF. This is due to the fact that the matrix material increased proportionately to bond with the resin. However, a drop in hardness was noticed when the matrix material became too much that the resin available was not enough to bond them thereby resulting in a loose composite with low hardness.

Tensile Strength: From the tensile test result obtained, the tensile strength increased steadily as the fiber content increased from 20% to 50%. Specimen C, which has the highest tensile strength of 16.60N/mm^2 has 50% fiber and 48% resin composition. This may be attributed to the near perfect bonding between the fiber and the resin. However, as the fiber content increased from 50% upwards, a considerable drop in the tensile strength was observed owing to the fact that bonding was not perfect due to insufficient resin.

Flexural Strength: Flexural test is basically a bending and deflection test, it is interesting to note that the flexural strength, which is the ability to resist bending or deflection increases steadily with increasing fiber content.

Measurement of physical properties of helmet produced vs standard helmets

The Military helmet produced was measured using digital scales and vernier calipers and the following physical properties were obtained:
1. Weight: 3.15kg
2. Avearge thickness: 5mm
3. Colour: Gray
These properties can therefore be compared with standard physical properties of existing helmets, as measured, and presented in the table below:

Physical properties of selected helmets

S/N	TYPE	WEIGHT	THICKNESS	COLOUR
1	Chinese	3.56 Kg	3mm	Silver
2	British	3.25 kg	2mm	Silver
3	US Ballistic	2.12 kg	10mm	Dark blue

Source: Academy Laboratory, NDA Kaduna

Comparison of the results obtained for some mechanical properties with those of past literatures

SAMPLE	IMPACT STRENGTH	HARDNESS (No)
Yuhazri and Dan(2007); 10% coir with 90% epoxy resin	9.95J/mm^2	80.45
Murali et al (2014); 40% hybrid(Jute, banana sisal fibres) in 60% epoxy	53.06J/m	-
20% oil palm male flower bunch stalk fiber composite helmet shell[11]	24.44J/m	-
Stephen Natsa (2015) 70% coir with 28% epoxy	8.733J/mm^2	30.03HRF

CONCLUSION AND RECOMMENDATIONS
Conclusion

This research aimed at producing a military helmet using coconut fiber reinforced polymer composite matrix. This aim has been successfully achieved. Different specimens were produced with different formulation of fiber in epoxy resin.

The physical properties of the helmet were measured and compared with selected helmets. It is interesting to note that the helmet is lighter than both the Chinese and the British helmets. It is only heavier than the US Ballistic helmet. The mechanical properties of the helmet samples produced were evaluated and favourable results were obtained. The Impact test, which is the most critical test in this research, showed a steady improvement in the Impact strength as the fibre content increased to specimen E (8.733N/mm^2). Thereafter, a considerable drop in the Impact strength was noticed from specimen F and a further drop in specimen G. Specimen E, having a fibre content of 70% in 28% epoxy resin therefore became the formulation with the best combination of properties and was adopted for the casting of the Military helmet.

Generally, the research showed that increase in coir fiber content, until after 70% coir fiber, improves the mechanical properties of the specimen, except for Tensile strength, where the highest value obtained was at a near 50-50 mix, thereafter the tensile strength decreased with increasing coir fiber content.

RECOMMENDATION

1. This research work can further be extended to study other aspects of this composite like effect of fiber length, fiber orientation, loading patterns, fiber treatment on the mechanical properties etc.
2. The composite is also recommended for ballistic test to ascertain its level of military application.

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