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Evaluation of Mechanical Properties of Coconut Shell Fibres as Reinforcement Material in Epoxy Matrix

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***Abstract*— The morphology and mechanical properties of coconut shell reinforced with epoxy resin composite have been evaluated to establish the possibility of using it as a new material for engineering applications. Coconut shell reinforced composite was prepared by compacting epoxy resin matrix with 10% - 30% volume fraction coconut shell fibres and the effect of the fibres on the mechanical properties of the composite produced was investigated. The result shows that the hardness and tensile strength of the composite increase with increase in coconut shell fibre content while impact energy of the composite decreases with increase in the fibre content. Initially, the toughness was observed to increase as the ratios of fibre/epoxy and amine/epoxy increase but later dropped due to the presence of coconut shell powders which precipitate out of the solution and produce a weak composite. The prepared composite has an average hardness number of 54.51 DHN. The average impact strength is 60Joules/mm^2. Scanning Electron Microscopy (SEM) of the composites indicates good interfacial interaction between the coconut shell fibre and the epoxy resin matrix.**

Keywords*— *Composite, coconut fibres, tensile strength, toughness, impact strength.

I. INTRODUCTION

In recent years, the continuous and increasing demand for environmentally friendly materials such as bio-composites from plant-derived fibres and from recycled fibre based products has been on the increase due to their potential characteristics [1]. Natural fibres like flax, jute, hemp, banana and sisal are emerging as realistic alternatives to glass fibres in various industrial sectors owing to their low cost, low specific weight which result in higher specific strength and stiffness, non-abrasiveness, availability, biodegradability and problem-free disposal. Moreover, bio-composites are also claimed to offer environmental advantages such as reduced dependence on non-renewable energy, lower pollutant emissions, lower greenhouse gas emissions, and enhanced energy recovery[1]. In particular, the use of recycled lignocellulosic fibres such as waste paper, waste wood and agricultural residues in the development of composite materials, is attaining increased importance both in scientific and the industrial world where The relation between stress and percentage of filler for tensile and flexural tests were found to be linear with correlation factors of 0.9929 and 0.9973 respectively.

they offer a valid answer to maintaining a sustainable development of economical and ecological attractiveness, especially due to the enormous quantity of such agricultural waste which are generated daily [2].

Coconut shell is an important filler for the development of new composites as a result of its inherent properties such as high strength and high modulus [3]. Coconut shell fibres are wastes from agricultural products, often being used as a fertilizer to other plantations, or at worst is being thrown away by the agricultural industry. They are available in large quantities in the southern part of Nigeria.

The need to start reinforcing resins arises due to high needs for the exhibition of mechanical characteristic of composite materials [4]. A number of components in particular, military ware, structural materials, interior of aircrafts, automotive components previously made with glass fibres composite are now being manufactured using environmental friendly composites [5], waste coconut shell fibre is not left out due to its thermal properties, low density, flexibility, low cost, lightweight and apparently its environmentally superior alternatives to glass fibres in composite.

Apart from the inherent mechanical properties, the use of such agricultural wastes in engineering materials would obviously save our environment from untidiness. In addition, waste is being converted to wealth for our dear nation.

The tensile and flexural properties of composites made from coconut shell filler particles and epoxy resin have been studied by S.M. Sapuan et al [6]. They performed several Characterization studies on composites prepared from coconut shell filler particles at three different filler contents 5%, 10%, and 15%. Their Experimental results showed that tensile and flexural properties of the composites increased with the increase in the filler particle content. The composite materials demonstrate somewhat linear behaviour and sharp fracture for tensile and slight non-linear behaviour and sharp fracture for flexural testing.

Sapuan S, et al [7] in their work, evaluated the Mechanical properties of coconut shell powder reinforced polyester composites to assess the possibility of using it as a new material in engineering applications. They prepared Coconut shell filled composites from polyester polymer matrix containing up to 15 % weight of coconut shell powder (CSP) as fillers. The effects of coconut shell powder content and coir fiber on the mechanical properties of the composites were investigated. It was revealed that the value of tensile modulus and tensile strength values increases with the increase of in fiber length, while the impact strength slightly decreased, compared with pure polyester resin. This work has shown that coconut shell powder and coir fiber can be used to improve properties of polyester polymer composites.

Mansur and Aziz [8] studied bamboo-mesh reinforced cement composites and found that the reinforcing material could enhance the ductility and toughness of the cement matrix, and increase significantly its tensile, flexural, and impact strengths. On the other hand, jute fabric-reinforced polyester composites were tested for the evaluation of mechanical properties and compared with wood composites, the result showed that the jute fiber composite has better strengths than wood composites.

An attempt is made in this work to use the agro-based coconut shell fibres as reinforcement in epoxy matrix. In the current study, coconut shell fibres and epoxy (bisphenol-a-co-epichlorohydrine) were used to fabricate the composites with the aim of exploring the potential of coconut fibres as reinforcement for epoxy matrix composites.

II. PROPERTIES ENHANCEMENT OF CELLULOSE FIBERS-POLYMER COMPOSITES

Mechanical behaviour of short fibre composites are heavily influenced by such factors as fibre dispersion, fibre-matrix adhesion, fibre aspect ratio, fibre orientation and fibre volume fraction.

A. Fibre dispersion

The primary requirement for obtaining a satisfactory performance from short-fiber composites including cellulose-based composites is good fiber dispersion in the polymer matrix. Good dispersion implies that the fibers are separated from each other (i.e. there are no clumps and agglomerates), and each fiber is surrounded by the matrix. Insufficient fiber dispersion, on the other hand, results in an inhomogeneous mixture of resin-rich areas and fiber-rich areas. This is undesirable because the resin-rich areas are weak and the fiber-rich areas (i.e., clumps) are susceptible to microcracking. Micro cracks contribute to inferior mechanical properties of composites. It is therefore important to ensure homogeneous fiber dispersion in order to achieve maximum strength and performance of the composite materials. If fibers are too short, the stress transfer area will be too small for the fibers to offer effective reinforcement. Among them are fiber surface modification, use of dispersing agents such as stearic acid, and fiber pre-treatments such as acetylation. Fiber dispersion can also be improved with increased shear force and mixing time.

B. Fiber-matrix adhesion

Fiber to matrix adhesion plays a very important role in the reinforcement of composites with short fibers. During loading, loads are not applied directly to the fibers but to the matrix. To have composites with excellent mechanical properties (Ultimate strength with adequate toughness), the load must be transferred effectively from the matrix to the fibers. This requires good interaction as well as adhesion between the fibers and the matrix, i.e. strong and efficient fiber-matrix interface. This can be controlled by either surface treatment applied to the fiber or by the use of additives such as coupling agents.

C. Fiber aspect ratio

Fiber aspect ratio is the length to diameter ratio of a fiber, is a critical parameter in a composite. An expression relating critical fiber aspect ratio (lc/d) to interfacial shear stress (τy) has been proposed on the basis of shear-lag analysis.

$$l_{c/d} = \sigma_{fu} / 2\tau_y \quad \text{.........2.1}$$

Where:
l_c= critical fiber length (mm)
d = diameter of fiber (mm)
σ_{fu} = fiber ultimate strength in tension (N/mm^2)
τ_y = interfacial shear stress (N/mm^2)
When $l_{c/d}$ becomes short (low) as τy, interfacial shear stress (transfer) becomes efficient (high). Interfacial shear stress, which influences fiber aspect ratio, can be varied by modifying the fiber-matrix interface by using chemicals such as coating agents.

For maximum reinforcement, the fiber aspect ratio of any composite system should be above its critical value. This will ensure maximum stress transfer to the fibers before the composite fails. If the fiber aspect ratio is lower than its critical value, insufficient stress will be transferred and reinforcement by the fibers will be inefficient, i.e., the fibers are not loaded to their maximum stress value. By contrast, if the fiber aspect ratio is too high, the fibers may get entangled during mixing causing problems with fiber dispersion.

D. Fiber orientation

Fiber orientation is another important parameter that influences the mechanical behaviour of short-fiber composites. This is because the fibers in such composites are rarely oriented in a single direction, which is necessary for the fibers to offer maximum reinforcement effects. As a result, the degree of reinforcement in a short-fiber composite is found to be strongly dependent on the orientation of each individual fiber with respect to the loading axis. Changes in fiber orientation take place continuously and progressively during the processing of short-fiber composites. The changes are related in a complex way to the geometrical properties of the fibers, the viscoelastic properties of the matrix, and the change in shape of the material which is produced by the processing operation. In these operations, the polymer melt will undergo either elongational or extensional flow and shear flow.

E. Fibre volume fraction

The properties of short-fiber composites are also crucially determined by fiber concentration. Variation of composite properties, particularly tensile strength, with fiber content can be predicted by using several models such as the 'Rule of Mixtures', which involves extrapolation of matrix and fiber strength to fiber volume fractions. At low fiber volume fraction, a drastic decrease in tensile strength is usually observed. This has been explained with dilution of the matrix and introduction of flaws at the fiber ends where high stress concentrations occur, causing the bond between fiber and matrix to break. At high fiber volume fraction, the matrix is sufficiently restrained and the stress is more evenly distributed.

III. MATERIALS, EQUIPMENT AND EXPERIMENTAL PROCEDURE

A. Materials

The major materials used in this experimental work are listed below:

- i. Epoxy resin (Bisphenol-A-Co-Epichlorohydrine)
- ii. Acetone
- iii. Tetraethylenepentamine.
- iv. Coconut shell fibres.
- v. Granulated coconut shell powder.

- Epoxy Resin (Bisphenol-A-Co-Epichlorohydrine)

Epoxy resin (ER) is one of the most important classes of thermosetting polymers which are widely used as matrices for fiber-reinforced composite materials and as structural adhesives. They are amorphous, highly cross linked polymers and this structure results in these materials possessing various desirable properties such as high tensile strength and modulus, uncomplicated processing, good thermal and chemical resistance, and dimensional stability.

- Curing Agent

Tetraethylenepentamine has been used as curing agent along side with the matrix material.

- Coconut shell fibres

Coconut fibres are extracted from the outer shell of a coconut. Coconut shell fibres were used as reinforcing material for investigation in this work.

B. Equipment

The major equipment used for the study are as follows:

i. Vacuum electrical oven (0-300^{0}C)
ii. Hydraulic press with heating and cooling plates (craver)
iii. Hounsfield Tensometer
iv. Durometer Hardness Testing Machine
v. Impact tester

C. Experimental Procedure

- Preparation of specimens

The fabrication of the various composite materials was carried out through the hand lay-up technique. Short coconut fibres of length 100mm were reinforced with Epoxy resin (Bisphenol-A-Co-epichlorohydrine) as the matrix material. (15-35ml) of the Epoxy and (20ml) of acetone were mixed with (0-1ml) of amine (tetraethylenepentamine). The cast composites were pre-cured by drying it in open air for 24 hours. It was thereafter placed inside a vacuum oven for 2 hours at 60°C- 80°C for curing. Then this cast was post-cured using a hydraulic press at a pressure of 10 bar at 110°c for 10 mins. Based on this procedure, a total number of 20 samples were produced by varying the volumes of Bisphenol-A-Co-epichlorohydrine and Amine reacted with the prepared coconut fibres.

D. Mechanical Tests

The mechanical properties of the various samples prepared were determined by tensile, impact and hardness tests.

- Tensile test

The tensile test was carried out in accordance with the international standard ASTM D636-08 standard test method for tensile properties of plastic materials. The test samples from various composites under study were cut into rectangular shapes with an average dimension of 10x50mm. The thickness varies slightly ranging from 2.0-6.6mm. The samples were mounted on Hounsfield Tensiometer with a maximum capacity of 20KN. The various samples were loaded to fracture. After fracture, the elongation and tensile strength were recorded.
Experimental set up and loading arrangement for the specimens for tensile test.

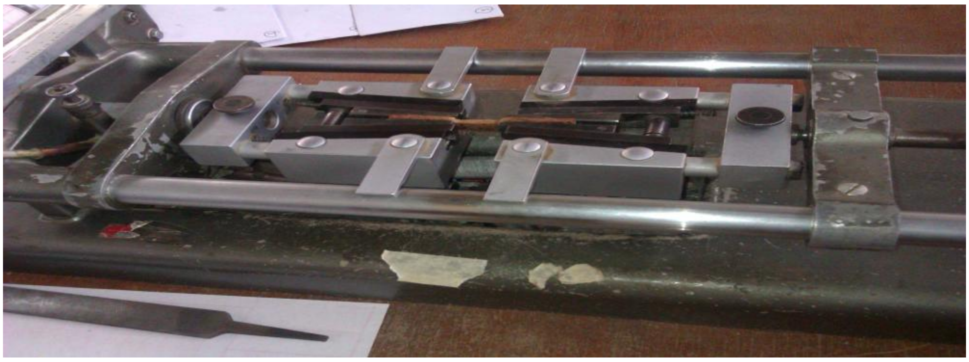

Plate 1. Tensile test experiment using tensometer equipment

- Hardness test

The test was carried out in line with international standard test of measurement ASTM D785 for the determination of the hardness numbers. Test specimens were cut from each of the samples being investigated. The specimens were grounded to provide a smooth flat surface prior to testing. The prepared specimen was secured on the Durometer-type D machine platform while the 1.5mm indenter with a load of 50kg was applied gradually onto the specimen for duration of 10 seconds. The load was then removed and the indented diameter read from the screen. The obtained diameter was loaded into the measuring system of the tester so as to display the hardness number on the screen. Three readings were taken from which the average value was obtained for each sample.

- Impact test

Three layers of identically prepared samples were placed together in its wet condition to form a single layer of higher thickness. The layers were allowed to go through the same process of post curing. The standard specimens of 10x10x50mm were prepared from the three layers of each of the fibres chosen for the final work. Impact test using charpy impact tester (Denison Charpy Impact Tester) with maximum capacity of 100 joules and a striking velocity of 5.24m/sec were carried out on all the specimens.

IV. RESULTS AND DISCUSSIONS

The results of various characterization tests are reported here. This includes evaluation of tensile strength, impact strength and micro-hardness. The interpretation of the results and the comparison among various composite samples are also presented.

A. Results

- Result of tensile properties of polymer matrix composites

The results obtained for tensile strength and toughness are presented in figures 1-14.

- Results of hardness test

Table 1 below indicates the various results for Durometer Hardness test.

Table 1: Result of hardness test

Sample No	Fibre weight (g)	Epoxy weight (g)	Amine (ml)	Coconut powder weight (g)	Fibre/ Epoxy Ratio	Amine/ Epoxy Ratio	Hardness value (DHN) 1st Test	2nd Test	3rd Test	Average Value
1	5.764	20	O.75	0.0	0.29	0.3750	49	55	61	55.00
2	5.020	20	1.00	0.0	0.25	0.0500	40	43	42	41.67
3	5.000	20	1.25	0.0	0.25	0.0625	63	54	56	57.67
4	5.023	20	1.50	0.0	0.25	0.0500	55	64	64	61.00
5	4.033	15	1.00	0.0	0.20	0.0500	57	54	59	56.67
6	3.938	25	1.00	0.0	0.16	0.0400	57	50	57	54.67
7	4.781	20	1.00	0.0	0.21	0.0400	58	55	55	56.00
8	5.309	20	0.10	0.0	0.17	0.0050	58	52	54	54.67
9	5.195	25	1.00	3.0	0.19	0.0333	47	43	41	43.67
10	5.633	30	1.00	4.0	0.18	0.0286	49	44	46	46.33
11	3.906	20	0.50	1.0	0.20	0.0250	45	52	48	48.33
12	3.902	20	0.75	2.0	0.20	0.0375	84	50	78	70.67
13	3.857	20	1.00	3.0	0.19	0.0500	60	62	65	62.33
								Total Average		54.51

- Results for impact strength

Table 2 below shows the impact strength of the coconut shell fibre composites.

Table 2: Result of impact strength

Sample No	Test 1 (Joules/mm^2)	Test 2 (Joules/ mm^2)	Test 3 (Joules/ mm^2)	Average Value (Joules/ mm^2)
1	60.00	61.00	62.00	61.00
2	58.00	60.00	61.00	59.67
3	57.00	62.00	58.00	59.00
4	59.00	60.00	59.00	59.33
5	61.00	62.00	60.00	61.00
			Total Average force absorbed	60.00

B. Discussion of Results

- Tensile strength

The coconut shell fibres have significant effect on the tensile strength of the composites. Figures 1-7 show the effect of fibre/epoxy ratio and amine/epoxy ratio on the tensile strength of the composites.

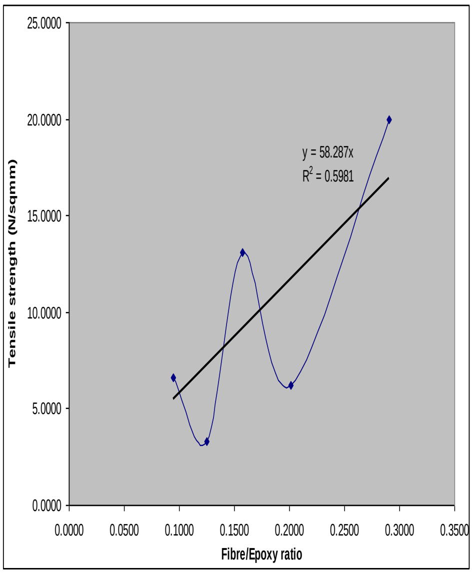

Fig 1: Variation of tensile strength with respect to fiber/epoxy ratio for sample A

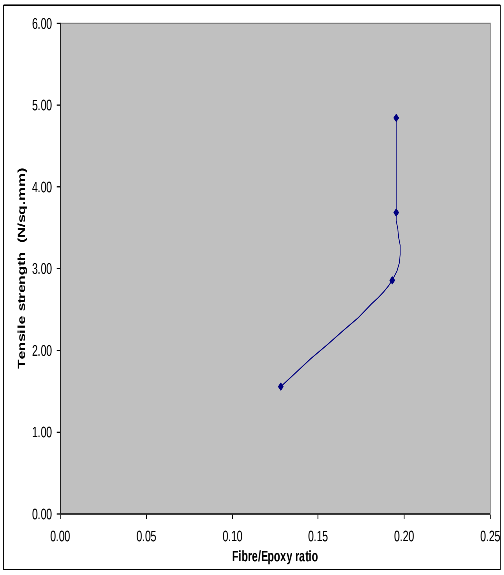

Fig 3: Variation of tensile strength with respect to fibre/epoxy ratio for sample C

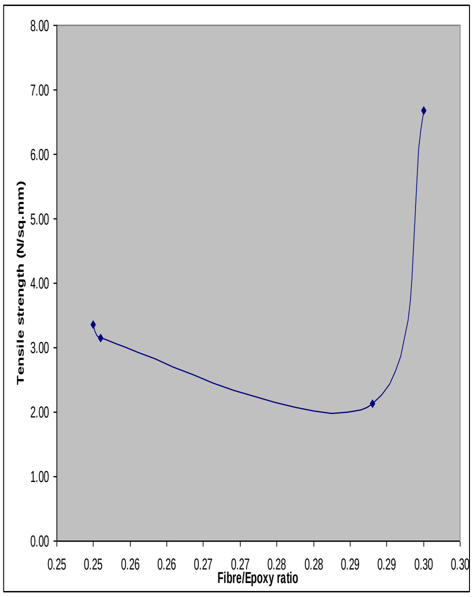

Fig: 2: Variation of tensile strength with respect to fibre/epoxy ratio for sample B

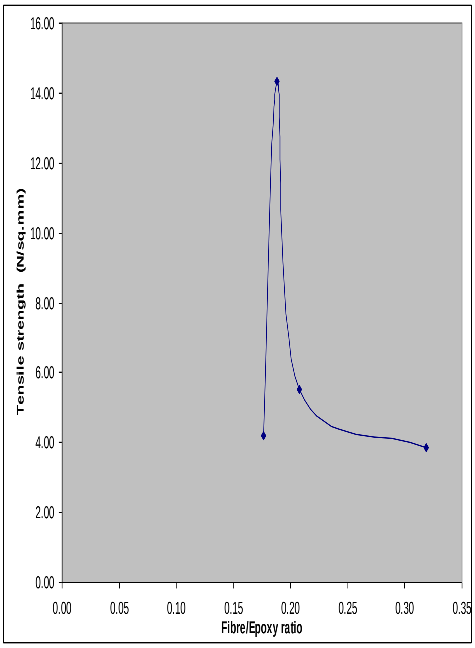

Fig 4: Variation of tensile strength with respect to fibre/epoxy ratio for sample D

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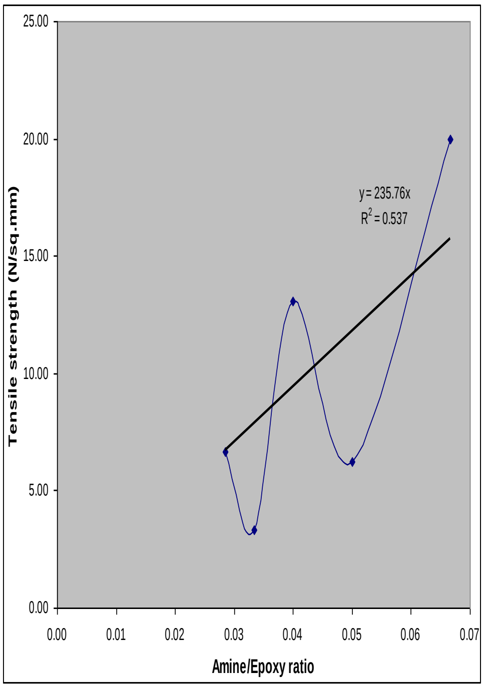

Fig 5: Variation of tensile strength with respect to amine/epoxy ratio for sample A

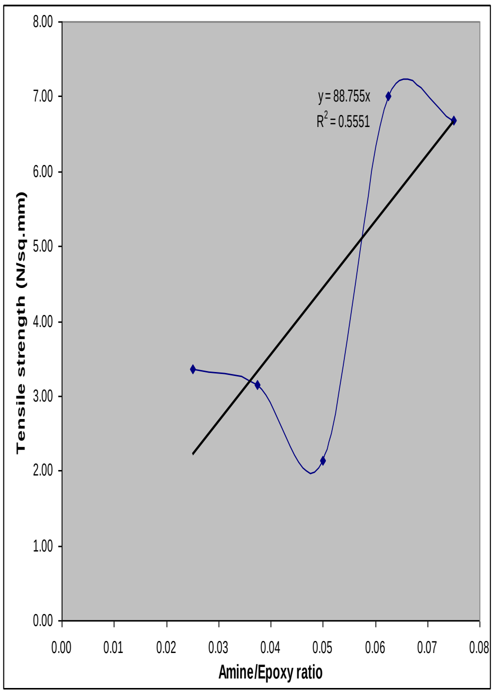

Fig 6: Variation of tensile strength with respect to amine/epoxy ratio for sample B

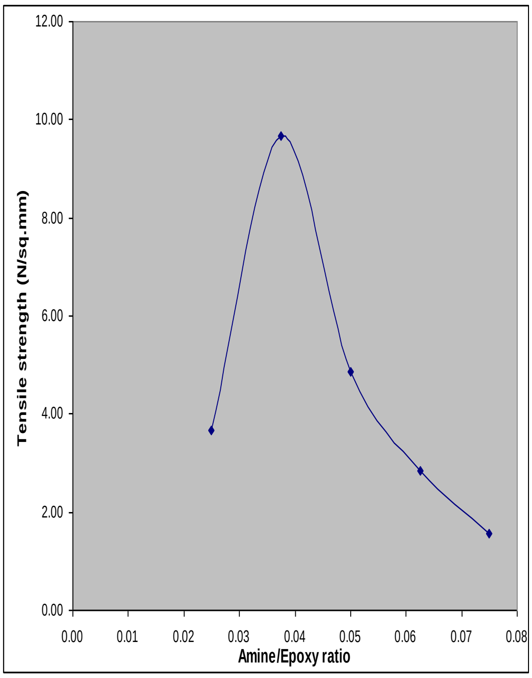

Fig 7: Variation of tensile strength with respect to amine/epoxy ratio for sample C

In figures 1-4, the tensile strength increased with increase in fibre/epoxy ratio up to an optimal ratio of 0.2. this is due to the fact that polymer strength increases with molecular weight of fibres. When coconut granulated powder were added to aid the strength, a reduction was observed when more than 2g of powder was added. This is as a result of the coconut powder absorbing the epoxy resin which subsequently reduced the adhesion bond between the fibres and the matrix. Initially, it formed dislocation points which impedes the flow and resulted in increase in tensile strength (fig3 and fig4).

The relationship between tensile strength and amine/epoxy ratio (figures 5-7) was observed to be similar to that of tensile strength against fibre/epoxy ratio. That is, the tensile strength increased as the amine/epoxy ratio increased. The presence of amine assists in increasing the bond between the fibre and the epoxy up to an optimal ratio of 0.035 when coconut powders were added. Beyond this optimal ratio, the strength reduces due to the presence of unreactive amine in the system.

- Toughness

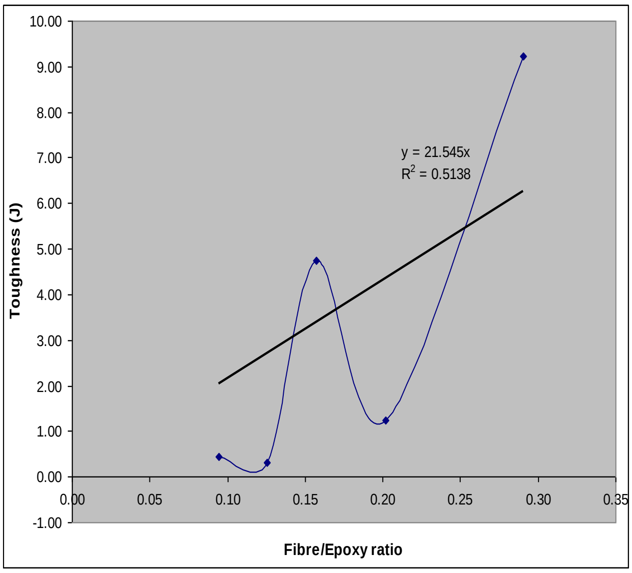

Fig 8: Variation of toughness with respect to fibre/epoxy ratio for sample A

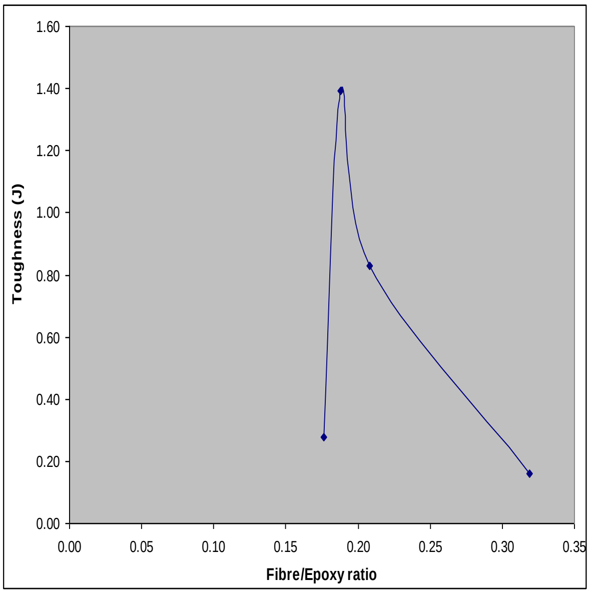

Fig 10: Variation of toughness with respect to fibre/epoxy ratio for sample D

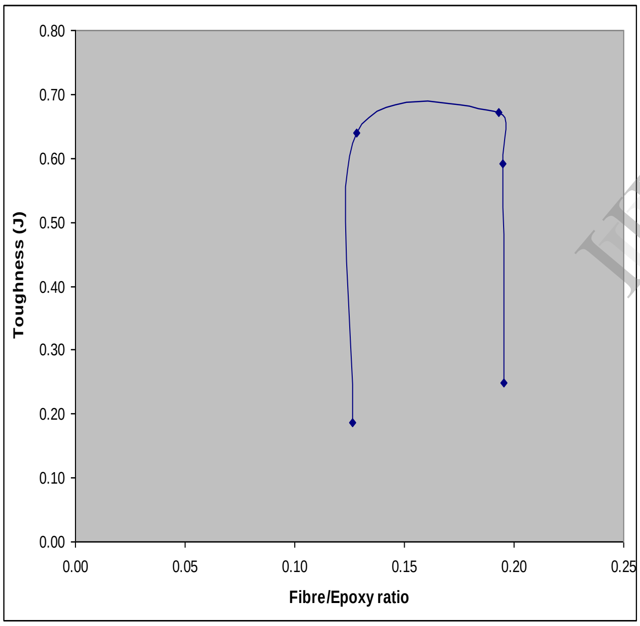

Fig 9: Variation of toughness with respect to fibre/epoxy ratio for sample C

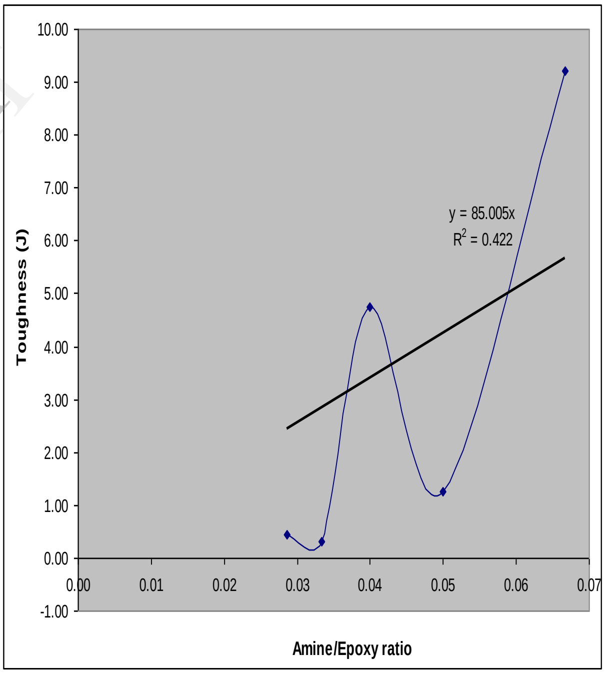

Fig 11: Variation of toughness with respect to amine/epoxy ratio for sample A

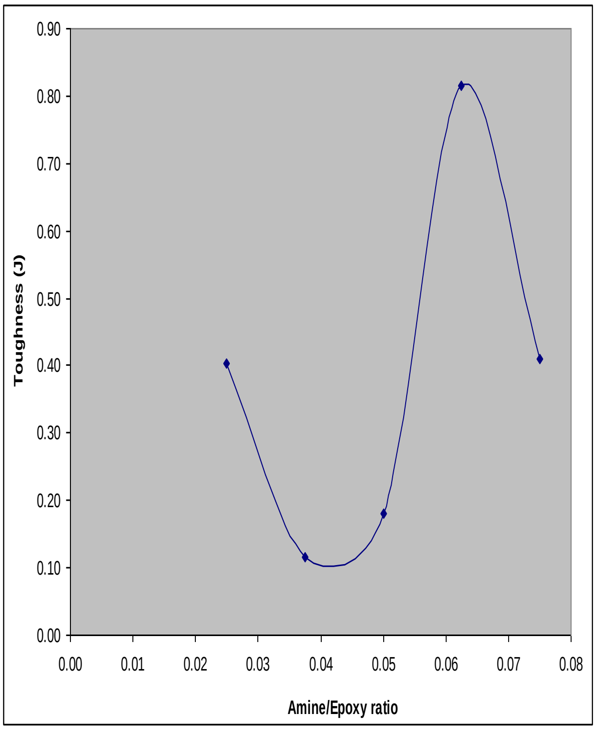

Fig 12: Variation of toughness with respect to amine/epoxy rat for sample B

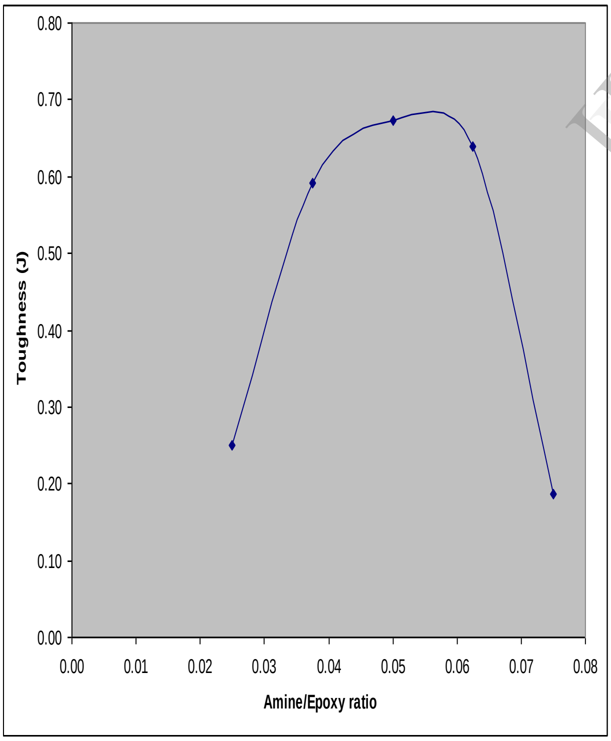

Fig 13: Variation of toughness with respect to amine/epoxy ratio for sample C

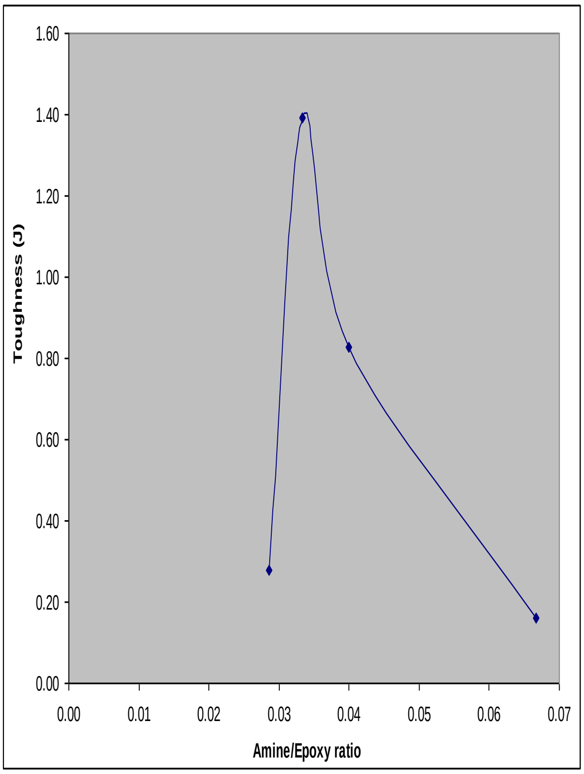

Fig 14: Variation of toughness with respect to amine/epoxy ratio for sample D

In fig 8-14, the results revealed that toughness initially increased as the ratio of fibre/epoxy and amine/epoxy increased up to optimal ratios of 0.2 and 0.04 respectively. After the optimal ratios, the toughness properties progressively decreased. This is due to the precipitation effect of the coconut shell powder used. The powder material absorbed the resin which resulted in a decrease in the energy value.

- Hardness

The measured hardness values of all the composite samples are presented in Table 1. The result revealed that the average Durometer Hardness Number (DBN) is 54.51. Increase in fibre/epoxy and amine/epoxy ratios results in increase in hardness number. However, when coconut powders were injected into the matrix, the hardness value reduced as a result of the powder absorbing the epoxy which resulted in weak bonding.

Figure 15-17 shows the effect of fibre/epoxy ratio and amine/epoxy ratio on the hardness of the composites.

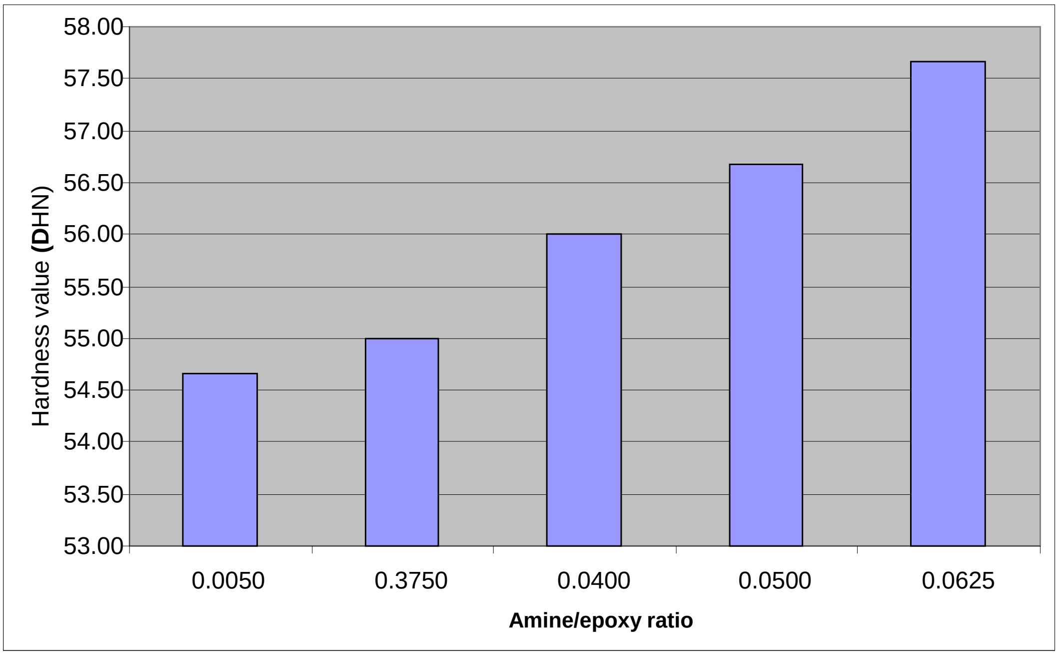

Fig 15: Effect of amine/epoxy ratio without the coconut shell powder on hardness of the composites

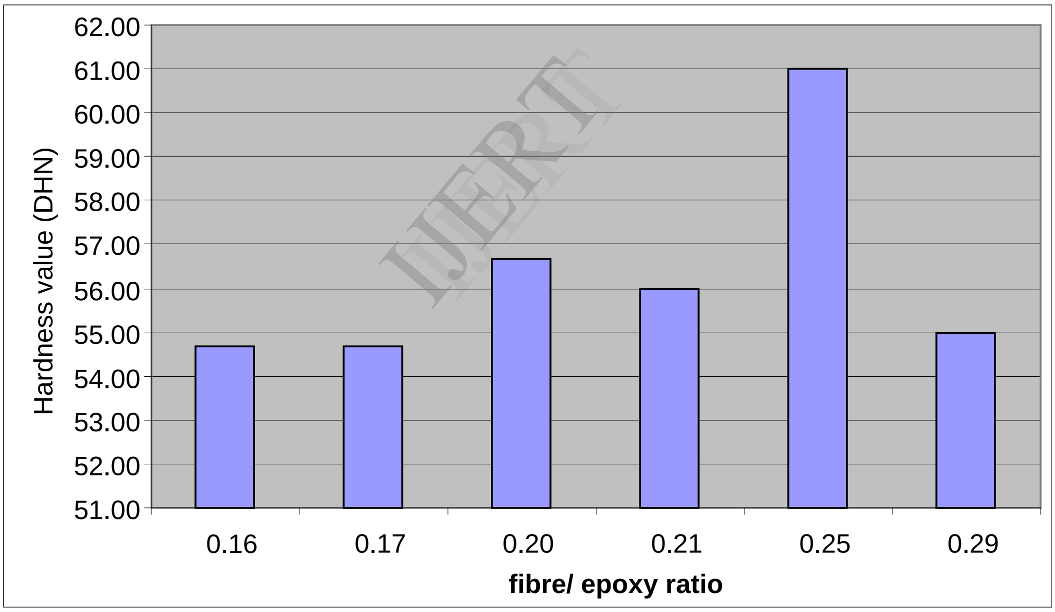

Fig 16: Effect of fibre/epoxy ratio without the coconut shell powder on the hardness of the composites

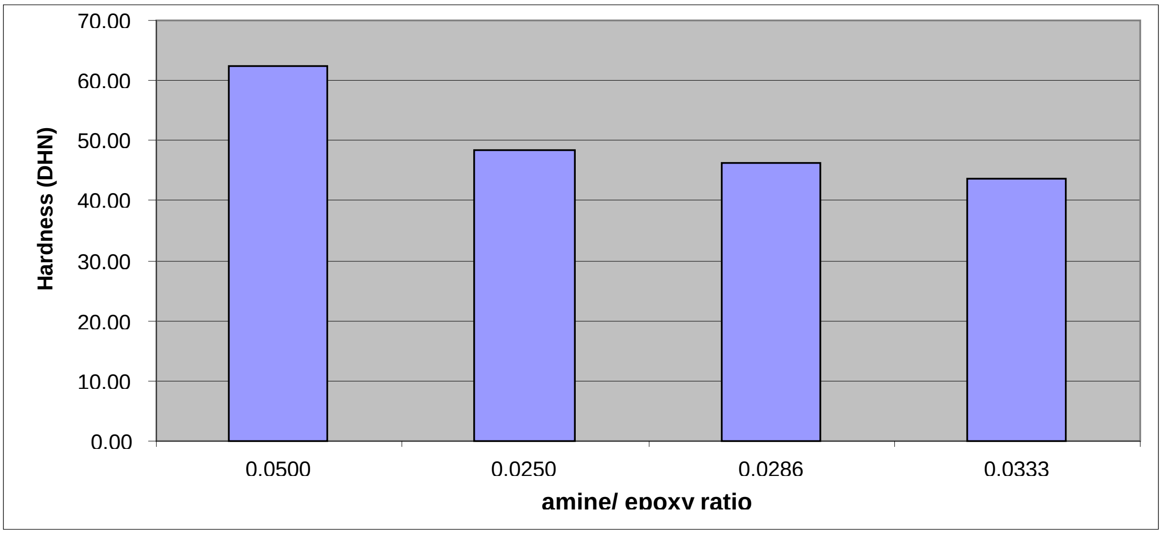

Fig 17: Effect of amine/epoxy ratio with coconut shell powder on the hardness of the composites

- Impact strength

The average impact strength of the coconut shell fibre composites obtained in table 2 is 60.0 Joules/mm^2.

- Microstructural analysis

Plates 2 and 3 show the microstructures of the coconut shell fibre composite. The micrographs showed a good bond between the coconut shell fibre and the matrix. There was no sign of segregation of the phases. However, plate 4 and 5 revealed the effect of injecting coconut shell powder into the matrix which results in inhomogeneity of phases. The powder absorbs the resin and produces weak bond between the fibre phase and the matrix.


Plate 2: Scanning electron micrographs showing a good bond between the coconut shell fibre and the matrix

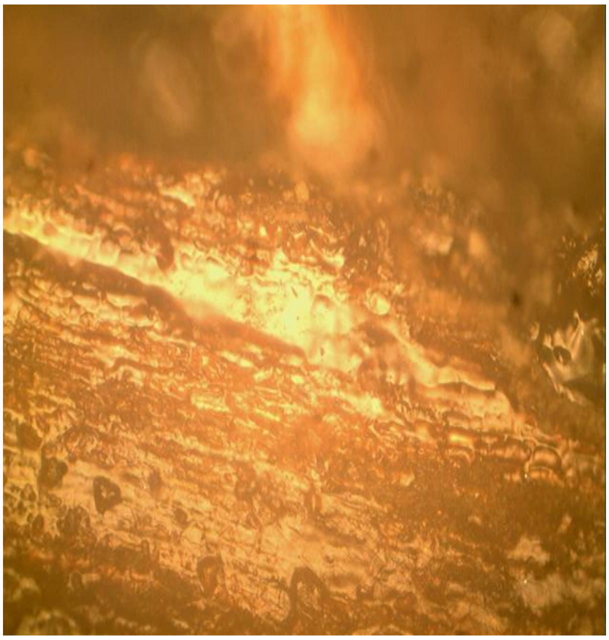
Plate 3: Scanning electron micrographs showing no sign of segregation

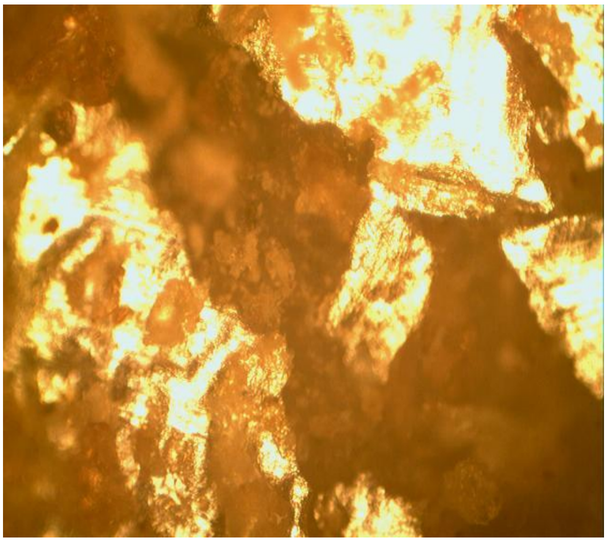

Plate 4: Scanning electron micrographs showing a weak bond between the coconut shell fibre and the matrix due to the addition of coconut shell powder

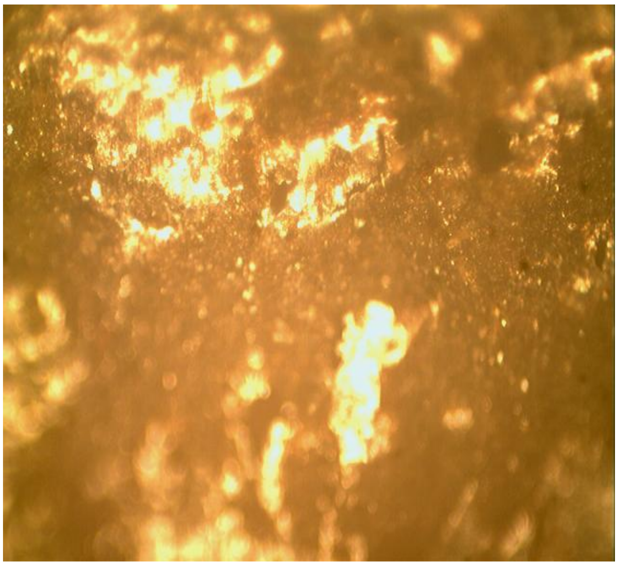

Plate 5: Scanning electron micrographs showing the weak bond after injecting coconut shell powder into the matrix

V. Conclusion and Recommendations

A. *Conclusion*

From the results of the investigations and discussion, the following conclusions are draw:

i. Tensile strength of the composite material increase with increase in fibre/epoxy ratio.
ii. As the percentage of the coconut shell powder increase, there was a corresponding decrease in tensile strength.
iii. There is an increase in hardness number as the ratio of fibre/epoxy and amine/epoxy increases.
iv. Coconut shell fibres improve the hardness properties of the epoxy resin matrix composite.
v. This work has revealed that coconut fibre is suitable as a reinforcement material for polymer matrix composites.
vi. The work has shown the possible area of application which could be for the production of military helmet.
vii. The use of coconut fibres in polymer matrix composites would definitely save the environment and also convert waste to wealth.

B. *Recommendation*

i. Further research should be centered on the use of other agricultural waste such as maize stem fibres or banana stem fibres for the production of polymer matrix composites.
ii. Ballistic tests should be carried out on the samples to evaluate its resistance towards impacts.

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iii. The Department of Polymer Technology, Chemical and Leather Research, Zaria.

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