Evaluation of Mechanical Properties of Rice Straw Fibers Reinforced Epoxy Resin Matrix

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Abstract:
A composite material can be defined as a combination of two or more materials that results in better properties than those of individual components used alone. Properties of rice straw fibers reinforced epoxy composite was investigated with a view of evaluating its mechanical properties by determining its suitability for industrial purposes. Here casting method was used to produce the specimens for evaluation. The materials were milled and sieved into sieve grades of 75, 100 and 150µm at different proportions of rice straw fiber and epoxy. The Brinell hardness, impact, tensile strength and microstructure were then determined. The results obtained showed that specimen composite of 75µm sieve grade gave higher hardness, tensile strength and lower resistance to impact. This was evident in the microstructure which showed a better dispersion of the fiber's particles in the matrix, leading to better bonding as the particle size decreased. The results suggest that specimen formulation below 75µm gave better mechanical properties for industrial applications.

Keywords: *Reinforcement, Rice straw, Microstructures, Evaluation, Tensile*

1. INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. Composite materials are an amalgamation of two or more constituents, one of which is present in the matrix phase, and another one could be in particle or fibre form [1, 2].

Advanced composite materials (ACMs) are characterized with high strength, high stiffness or modulus of elasticity characteristics, compared to other materials. They are termed advanced composite materials in comparison to the composite materials commonly in use such as reinforced concrete, or even concrete it. They exhibit desirable physical and chemical properties that include light weight coupled with high stiffness, and strength along the direction of the reinforcing fibre, dimensional stability, superior tribological properties and corrosion resistance behaviour, flex performance, and relative ease of processing. However, much of the advanced composites manufacture technology is progressively evolving [3, 4].

Fibre-reinforced polymer (FRP), also Fibre-reinforced plastic, is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, or aramid, although other fibres such as paper or wood or asbestos have been sometimes used. The polymer is usually an epoxy, vinyl ester or polyester thermosetting plastic, and phenol formaldehyde resins are still in use. Now a day, the composite engineers are focusing on the development of new stronger, tougher, lightweight structural materials supporting latest technologies and design concepts for the complex shaped structures like aircraft, automotive structures and large wind turbine blade structures. FRPs are commonly used in the aerospace, automotive, marine, and construction industries [5, 6].

Among epoxies, phenolic, polyurethanes and polyimides which are matrix materials commonly used in the development of advanced composite materials, epoxy resins currently dominate. Epoxy resin has been a dominant matrix material used in the development of advanced composite materials because of its following excellent properties: high strength, high adhesion to substrates, high electrical insulation, low toxicity, low shrinkage, low cost and high amenability to various processes and applications. It can be used to temperatures as high as 175°C and are compatible with all common reinforcements. They possess fatigue strength superior to aluminium alloy. However, its widespread use for many applications is limited because of in-

herent brittleness, delamination and low fracture toughness. Epoxy resin normally cures or undergoes a crosslinking reaction on addition of curing agent or hardener to it, leaving no volatiles and by-product. Traditionally epoxy resin belonged to a family of polymeric materials under the aegis of thermoset [6].
Composites can be classified according to fillers/reinforcement. The reinforcement is usually a particulate or filler. Particulate composites have dimensions that are approximately equal in all directions. Particulate composites tend to be much weaker and less stiff than continuous fibre composites, although they are usually much less expensive. A fibre has a length that is much greater than its diameter. The length-to-diameter (l/d) ratio is known as the aspect ratio and can vary greatly. Continuous fibres have long aspect ratios, while discontinuous fibres have short aspect ratios. Continuous-fibre composites normally have a preferred orientation, while discontinuous fibres generally have a random orientation. There are numerous types of fibres available for fabrication of fibre-reinforced composites; those are categorized as natural and synthetic fibres. Synthetic fibre provides more stiffness, while natural fibres are cheap and biodegradable, making them environmentally friendly [6,7].
In this research, rice straw which is a natural fibre will be used as reinforcement in a polymer matrix, in view of determining its mechanical properties and suitability for industry purposes.

2. EXPERIMENTAL PROCEDURE

2.1 Materials

The raw composite materials used in the production of these reinforced polymers are rice straw fiber and resin were sourced from *Ofada*, Obafemi Owode, *Ogun State* and Epoxy Oilserv Ltd, Rumuogba, Port Harcourt; Nigeria respectively. Below is the raw materials pics for the rice straw and epoxy resin in Fig 1.

Rice Straw fiber Epoxy Resin

Fig 1. Shown the raw materials of rice straw fibers and epoxy resin

2.2 Pre-Treatment of Feed Stock Materials

The rice straw fiber of 5kg were sun dried for two weeks and charged into a ball milling machine (Model 87002 Limoges – France, A50 – 43, at 250 rpm) for one week, with 25kg of pebbles to form fine powder. The pulverized samples were sieved into different size particles of 75 µm, 100 µm and 150 µm powder. 100 µm sieve size aperture, using a vibro sieve machine.

2.3 Formulations of the Brake Pads

The sieved size particles were mixed in different proportion with the matrix (epoxy resin) and rice straw as shown in the formulation table 1 below.

Table 1: Formulation of rice straw and epoxy

S/N	EPOXY RESIN	RICE STRAW (75µm, 100µm, 150µm)
1	100	0
2	95	5
3	90	10
4	85	15
5	80	20
6	75	25

2.4 Production of Brake Pad Specimens.

The 15-minute mixture of the above formulation was poured into a mould of different cavities that are suitable for the mechanical test conducted or carried out. Standard methods were applied to determine the hardness, impact and tensile properties of the rice straw epoxy composite for various sieve grades 75 µm, 100 µm and 150 µm. While the microstructure was conducted using a Scanning Electron Microscope: Model EVO-MA10 LAB6 Analytical VP-SEM at 20 KV. Below is the mould of different cavities, pouring process of the produced specimens and produced specimens shown in Fig 2.

(a) (b) (c)

Fig 2. Shown the (a) mould of different cavities, (b) pouring process of the produced specimens and (c) specimens produced

3.0 MATERIALS TESTING

3.1 Determination of the Specimen's Properties

Some properties of the materials mixes (moulded specimens) were tested for proper evaluation of their suitability for the products to be in compliance with National and International procedures and ASTM standards.

3.1.1 Chemical Analysis:

Representative sample of the rice straw fiber was analyzed to determine the chemical compositions using UNICAM 929 London Atomic Absorption Spectrometer for the chemical analysis. The method describes a procedure for extraction of rice straw fiber for further analysis, such as cellulose, lignin, ash and others chemical composition analysis as shown in table1 above [7].

3.1.2 Microstructural

The microstructural analysis of the samples was carried out by grinding the samples using 300, 400 and 600 grit papers respectively. Dry polishing was then carried out on these specimens and the internal structures were viewed under Scanning Electron Microscope (SEM), Model Evo-ma10 LAB6 Analytical VP-SEM at 20kv. Necessary precaution was observed so as to increase surface conductivity [7].

3.1.3 Brinell Hardness

The hardness values were determined using the Briness hardness teste (BS240) using Tensormeter M500 to 25KN, Gunt Hamburt Hardness Tester and WP300) pressing hardness steel ball with diameter D into a test specimen. Based on ASTM specimen, a 10mm diameter steel ball was used and the load applied P was kept stable at 300kg/f. The diameter of the indentation d was measured alone two perpendicular directions for up to 5 seconds. The load was then removed by returning the crack handle to the latched position and the hardness values was read directly from the semi-automatic digital scale using an optical micrometer screw gauge. The mean value was taken and incorporated into equation 1 to obtain the Brinell Hardness Number (BHN) [7]

$$\mathrm{BHN} = 2P \div D(D\sqrt{D^2 - d^2}) \qquad (1)$$

Where P is the load applied, D is the diameter of hardened steel ball into a test specimen and d is the diameter of indentation

3.1.4 Tensile Strength

The tensile strength test value was carried out in the conversion table of Brinell hardness values. The formula is shown in eqn 2 below.

$$HV = 1.854P \div d12 \quad (2)$$

$$Ts\ (Mpa)\ 3.453HB \quad (3)$$

$$Ts\ (Mpa)\ 500HB \quad (4)$$

Where HB is the Brinell hardness value, P is the load applied and d is the diameter of indentation

3.1.5 Impact Strength

Here, a pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen. The test result is typically the average of 5 specimens. ISO impact strength is expressed in kj/m^2 and is calculated by dividing impact energy in j (or ft-ib) by the area under the notch (thickness of the specimen).

4.0 RESULT AND DISCUSSION

4.1 Materials Chemical Composition

The chemical composition of rice straw fibre consist of cellulose 44 - 57 %; Lignin 15 - 19 %; Pentosan; 22 – 23%; Ash 2 – 5% and and Silica 9 – 1%4. The lignin content of the rice straw fibre is lower compare to woods lignin contents [10]. According to an FPL study on rice straw fibre, the lignin content increases whereas the extractive content decreases as a function of growth [10]. The chemical composition of rice straw fibre content is shown in Table 2 and 3 respectively.

Table 2: Chemical composition of rice straw fibre in weight (%)

Sample		Lignin	Pentosan	Ash	Silica
Rice straw fibre	44 – 57	15 – 19	22 – 23	2 – 5	9-14

Table3: Chemical composition of rice straw fibre content in weight (%)

Sample	SiC2	CaO	MgO	Na2O	K2O
Rice straw fibre	74.67	3.01	1.75	0.96	12.32

4.2 Brinell Hardness

The hardness values are presented in Fig 3. It is shown that highest hardness of 995.02 N/mm^2 was obtained for a sieve grade of 75 µm for samples 3 and 6. The higher hardness for 75 µm is due to a reduced particle size. This results in an increase in the surface area, more uniform dispersion of reinforcement particles, leading to an increasing bonding ability of the resin. This is an agreement with results from another research [8].

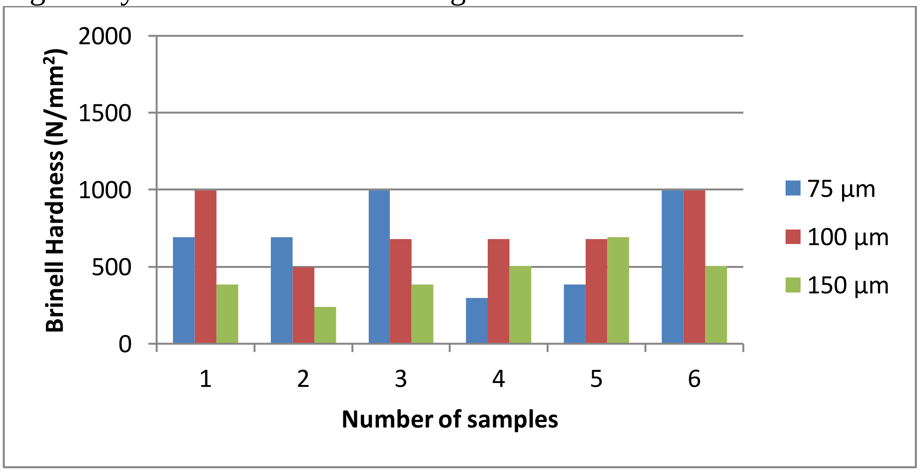

Figure 3: Variation of Brinell hardness with different sieved size particles of samples produced.

4.3 Impact Strength

From **figure 4,** it can be observed that the impact value varies inversely with the hardness. Results obtained show that for high hardness of 995.02 N/mm^2 for samples 3, 6 at 75 µm the impact value is 0 N/mm^2. Samples 4, 5 show the highest impact 75 µm with the lowest strength. This is in agreement with the fact that high hardness reduces the toughness, hence making the material more brittle.

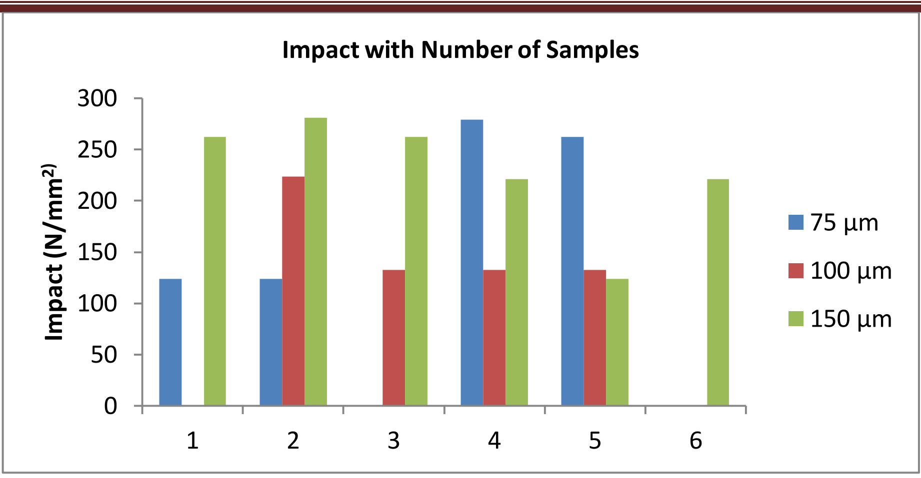

Figure 4: Variation of Impact with different sieved size particles of samples produced.

4.4 Tensile Strength

Tensile strength is commonly an indicator of the ductility of the sample. **Figure 5;** show a direct relationship between the hardness and the tensile strength. For the 75 µm, samples 3, 6 though showing high hardness, yet show the highest elongation. This is due to the anisotropic properties of the composite which depends on certain factors such as the fiber orientation, length, direction, size and concentration [8].

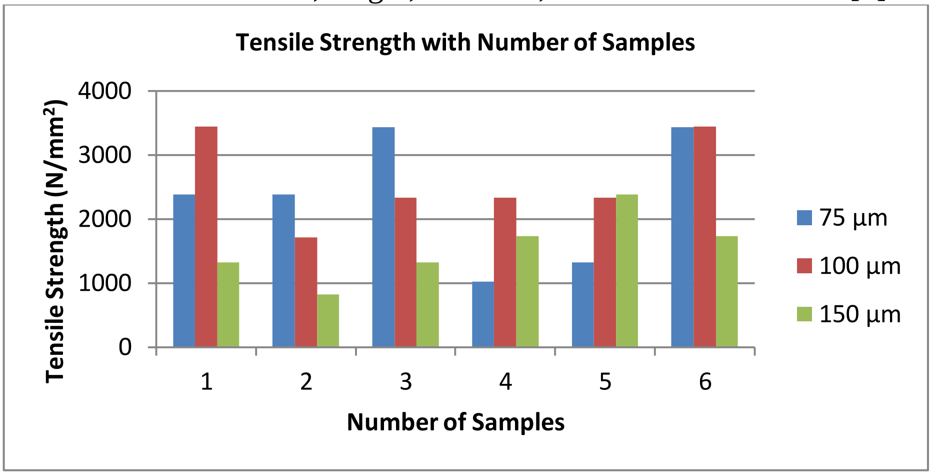

Figure 5: Variation of Brinell hardness with different sieved size particles of samples produced.

4.5 Microstructure

Microstructural studies of the specimens revealed a uniform distribution for the new formulations A, B and C identified to be satisfactory with the commercial one revealed from the experimental analysis. The distribution of particles is influenced by good bolding of the composition materials with micro structural analysis that was carried out on the samples A, B and C along with the control.

However, it is observed from the SEM micrograph of samples A1, A2, A5, B2, B3 and C3 smooth wear tracks and few micro-voids on the surface. While others sized micro voids was due to the improper mixture, increase in size particle and increase of rice straw wt%. Smooth wear track was seen in the sample A1, A2, A5, B2, B3 and C3 constituents were evenly distributed in the matrix **(Fig 6).** Voids absent were as a result of fine particle size.

All the specimens indicated a uniform distribution of the resin with rice straw which resulted to closer inter-packing interface.

Meanwhile, **Fig. 6** shown that rice straw phase is white and the resin phase is dark and also observed that smallest particles size has a good interfacial bonding than the bigger particles size.

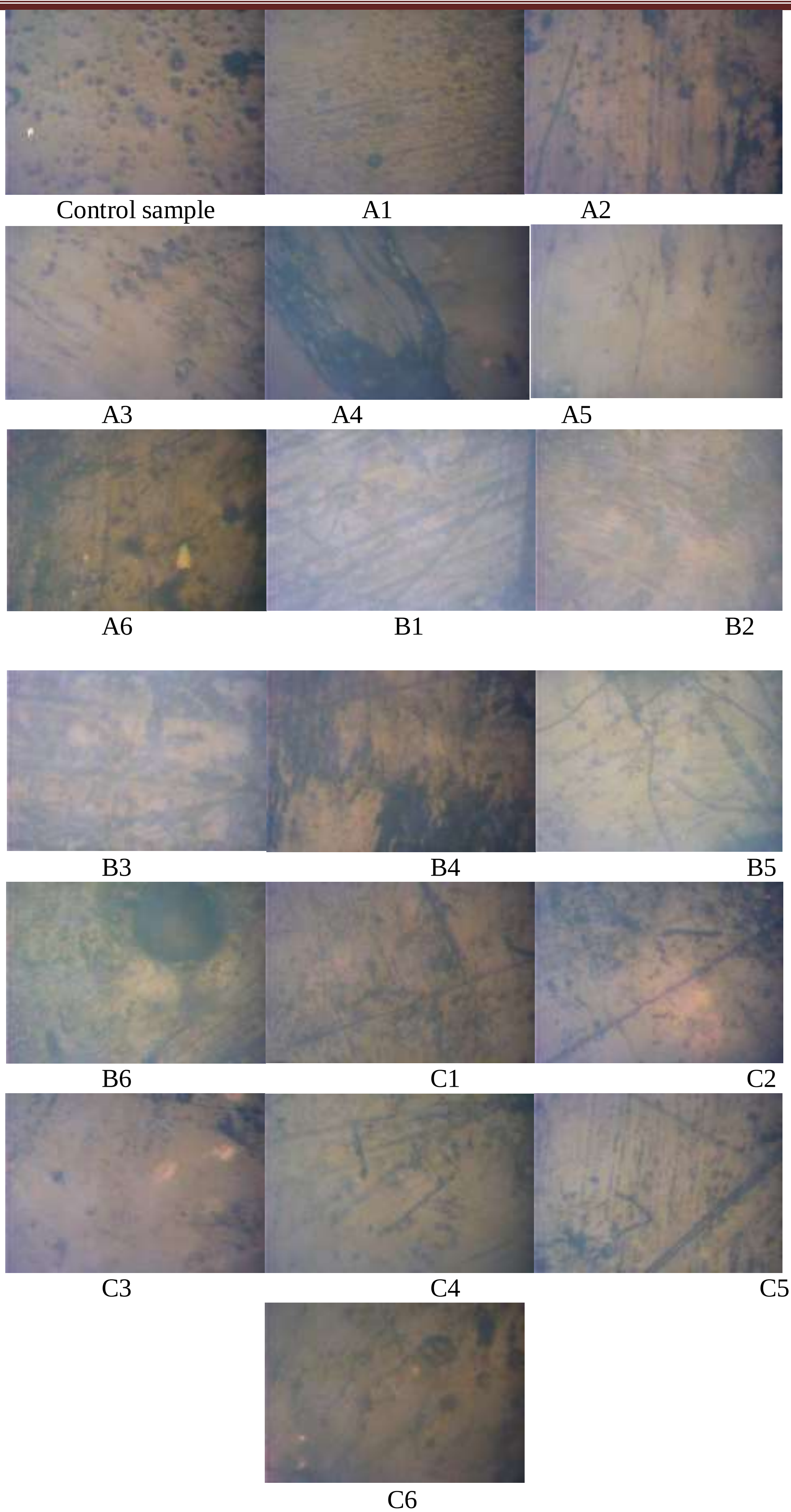

Fig 6. SEM Micrograph of different sieved particles of 75 µm, 100 µm and 150 µm of samples produced at 500X magnification.

Note; Control sample = commercial car bumper, while 75 µm, 100 µm and 150 µm of various constituents are A, B and C respectively.

5. CONCLUSION

The evaluation of the mechanical properties of rice straw fibers reinforced matrix composite was investigated in this present work. Figure 1-3 show the trend of the properties for the formulation and sieve grades. For the 75 µm and 100 µm, sample 6 showed the highest value of the mechanical properties. The 75 µm composite gave the highest hardness and tensile strength, giving the most desirable of properties. This easily corroborates the fact that a reduction in particle size leads to better bonding and improved properties.

6. REFERENCES

i. *Campbell F.C., Structural Composite Materials, ASM International, 2010*

ii. *Dipen K. R, Durgesh D. P, Pradeep L. & Menezes E. L., Review Fiber-Reinforced Polymer Composites: Manufacturing, Properties, and Applications, Polymers 2019, 11, 1667; doi:10.3390/polym11101667, 1-37.*

iii. *Bello S.A., Agunsoye J.O., Hassan S.B., Zebase Kana M.G., Raheem I.A. Epoxy Resin Based Composites, Mechanical and Tribological Properties: A Review, Tribology in Industry Vol. 37, No. 4 (2015) 500-524*

iv. *Dipti K.D., Purna C.M., Saranjit S. & Ratish K.T., Properties of ceramic-reinforced aluminium matrix composites - a review, International Journal of Mechanical and Materials Engineering 2014, 1:12*

v. *Martin Alberto Masuelli, Fiber Reinforced Polymers - The Technology Applied for Concrete Repair, Intech Open Science 2013, http://dx.doi.org/10.5772/54629*

vi. *Jagannatha T. D. and Harish G, Mechanical Properties of Carbon/Glass Fiber Reinforced Epoxy Hybrid Polymer Composites, International Journal Mechanical Engineering & Robotics Research, Vol. 4, No. 2, April 2015, ISSN 2278 – 0149*

vii. *Asotah W., and Abraham A., Development of Asbestos Free Brake Pads Using Corn Husks, Leonardo Electronics Journal of Practices and Technologies, 2017, ISSN 1583-1078*

viii. *Elakhame Z.U., Alhassan O.A., Samuel A.E., Development and production of brake pads from Palm Kernel composites, International Journal of Scientific and Engineering Research, 2014, 5, p. 735 – 44*