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EFFECT OF GUINEA CORN HUSK ASH ON THE MECHANICAL PROPERTIES AND WEAR BEHAVIOUR OF EPOXY MATRIX COMPOSITES

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ABSTRACT

The utilization of polymeric materials for certain engineering applications have been limited due to their mechanical properties observed to be time, rate and temperature dependent. However, with the recent development in technology, there has been a demand for advanced materials of which polymer matrix composites are potential candidates. This has geared up the interest in development of reinforced polymeric materials. Inorganic particulate reinforced polymers has shown significant improvements in mechanical properties but their limitation lies their high cost and

availability. Hence, a need to develop polymer composite using readily available organic particulates. The research work studies the influence of guinea corn husk ash (GCHA) particulate on the mechanical and wear properties of epoxy matrix composites. The GCHA was produced by burning guinea corn husk in an enclosed cylindrical chamber and conditioning it at a temperature of 650 ^{o}C for 3 h in order to reduce its carbonaceous constituents. The conditioned GCHA was sieved to 150 µm passing. The compositional analysis of the sieved GCHA carried out using X-ray fluorescence (XRF) spectrometer, revealed that it is silica dominated with other trace compounds. The epoxy matrix composites were reinforced by incorporating 2, 4, 6, 8, and 10 wt. % of GCHA. After curing, the composites produced were subjected to tensile, flexural, impact and wear tests. There was an appreciable improvements in the mechanical properties of the GCHA reinforced epoxy matrix composites developed while the wear property appears to suffer. However, the study has shown that GCHA is a promising reinforcement for polymeric composites.

Key words: Guinea corn husk ash, organic particulate, epoxy resin, agglomerates and interfacial bonding

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1. INTRODUCTION

Recent advancement in technology has increased the quest for engineering materials with improved mechanical and physical properties [1]. Polymer matrix composites have been reported to possess promising properties such as light weight, ductility, good mechanical properties and ease of processing which are potentials for modern engineering applications [2, 3]. More interesting is that these properties can be tailored towards achieving the desired properties required for such applications. Among the classes of polymeric composites is epoxy. It is a thermosetting polymer with a unique mechanical, chemical and thermal properties. It is often used as impregnating materials, adhesives or matrices for composites [4]. Epoxy-matrix composites possess high adhesion, low weight, good mechanical and tribological properties, adequate chemical and corrosion resistance, low shrinkage on curing (good dimensional stability) and less rigour in processing [1,3-5]. These properties has encouraged the continuous usage and demand of epoxy-based composite materials for structural components, electrical and electronic systems and industrial tooling [2,6]. However, the limitation of epoxy-based matrix composites lies in their average mechanical properties in relation to metals matrix/hybrid composites [4]. In bid to overcome these challenges, fillers are used to reinforce the matrix and it is pertinent to mention that there have been significant improvement [7]. Particulates, fibre and whiskers have been utilized in reinforcing PMCs. The macroscopic behaviour of particulate polymeric composites have been reported to be affected by the size, shape, aspect ratio, particle loading, the distribution of the inclusion in the polymer matrix and the interfacial adhesion between the matrix and the inclusion [8,9]. Previous studies revealed that properties such as stiffness, coefficient of thermal expansion, creep and scratch resistance, wear properties, compressive strength, impact performance and fracture toughness can be improved by the addition of rigid particles [2,9]. Inorganic particulates have been predominantly used for polymeric composite reinforcement. Examples of inorganic particulate fillers that has been investigated are silicon carbide, alumina, silica (SiO_2), glass microspheres, $Mg(OH)_2$ and limestone ($CaCO_3$) particles, carbon black,

graphite, atomize aluminium, titanium carbide, portland cement, potassium titanate and layered silicate [8, 10, 11]. Organic particulates that have been investigated includes rice husk ash, palm kernel shell ash, coconut-shell powder and snail shell [12-14]. GCHA is an agricultural waste which is readily available in the Nigeria. They are either burnt off or disposed after harvesting the desired guinea corn from it. This constitute another source of environmental pollution. Hence, there utilization for reinforcement in composites materials is a welcomed development as this presumed "trash" is being converted to "treasure" in the development of polymeric composites. The GCHA is an organic particulates. Since it is readily available, its utilization as reinforcement in epoxy matrix help to reduce the cost of production while enhancing the overall properties [5]. In this study, the mechanical (tensile, flexural and impact strength) and wear properties of GCHA particulate reinforced epoxy composites were investigated. This is to evaluate the performance of readily available and low cost organic GCHA for the development of epoxy matrix composites.

2. MATERIALS AND METHODS

2.1. Materials

The materials used for the composite production are epoxy resin, amine-based hardener and guinea corn husk ash. Guinea corn husk (for producing the ash) used in the study was obtained from Akure Metropolis, Ondo State, Nigeria. The epoxy resin and the amine-based hardener (SL 1000 grade) was procured from Pascal Scientific and Chemical Ltd., Akure, Nigeria.

2.2. Methods

2.2.1. Production of the GCHA

Inclusions and other unwanted particles present in the guinea corn husk obtained were hand-picked. The sorted guinea corn husk was thoroughly washed, sun dried and then burnt in a cylindrical chamber. The ash obtained was conditioned in a muffle furnace at 650 ^{o}C for 3 h. The conditioned GCHA was sieved to 150 µm passing with the aid of laboratory sieve shaker and was thereafter characterized using X-ray fluorescence spectrometer in order to determine the chemical composition of the GCHA.

2.2.2. Composite Production

The composite was mixed manually and produced using hand lay-up method (open moulding techniques). The production was done at room temperature and the composites produced contained 2, 4, 6, 8, and 10 wt. % fractions of guinea corn husk ash. The epoxy and the amine-based hardener which are the matrix materials were prepared in ratio 2:1 respectively. The GCHA was first added to the epoxy resin and mixed thoroughly before the introduction of hardener. The process was in accordance to [4]. Epoxy sample was produced without the addition of GCHA and was denoted as control. This is to serve as a base for composites performance evaluation. In order to ensure homogeneity, the mixture was stirred before pouring into the pre-coated aluminium moulds. The mould was lubricated with silicone oil to aid easy removal of the composites after curing. The mixture was left for over 2 h at room temperature in order to cure before been stripped off. The cast samples were subjected to test after 14 days. Table 1 shows the formulation table for the production of the GCHA reinforced epoxy matrix composite.

Table 1 Composite Samples Formulation Table

Sample Designation	Weight of Epoxy Resin (g)	Weight of Hardener (g)	Weight of Guinea Corn Husk Ash (g)
Control	300.00	150.00	-
A (2 wt.% of GCHA)	294.00	147.68	9.00
B (4 wt.% of GCHA)	288.00	144.00	18.00
C (6 wt.% of GCHA)	282.00	141.00	27.00
D (8 wt.% of GCHA)	276.00	138.00	36.00
E (10 wt.% of GCHA)	270.00	135.00	45.00

2.2.3. Mechanical Testing

Tensile, flexural and impact testing were used to characterize the mechanical properties of the composites produced. The tensile tests were performed in accordance with [16] standard procedures. Dog-bone shaped samples prepared by hand lay-up technique were used and the tensile test of both the control and GCHA reinforced epoxy composites were carried out using INSTRON 1195 at fixed crosshead speed of 10 mm/min, the flexural strength of the composites were determined by carrying out three-point flexural tests on the control and GCHA reinforced epoxy composites. The flexural tests were performed in accordance with [17] standard using a Testometric universal testing machine at a crosshead speed of 0.3 mm/min. In order to evaluate the impact strength, tests were performed on the notched samples in accordance with [18] standard using Housefield balanced impact testing machine. The notched samples were placed in a cantilever position, with the notched surface directly opposite the swinging pendulum. The pendulum of the testing machine was swung freely through 180^{o} to fracture the samples. In order to obtain a reliable result, the average results of three samples were calculated and presented.

2.2.4. Wear Test

The wear behaviour of the epoxy matrix and GCHA reinforced epoxy matrix composites were performed using Rotopol-V. The samples were weighed before subjecting them to test. The test was carried out at room temperature under dry sliding condition in accordance with. ASTM G195-13a standard as reported by [19]. The taber wear index was evaluated using equation 1

$$\text{Wear Index} = \frac{Initial\ weight - Final\ weight}{time\ of\ cycle}\ x\ 100 \qquad (1)$$

Table 2 Compositional Analysis of GCHA obtained from Akure Metropolis.

Constituents	% Composition
SiO_2	78.998
Al_2O_3	1.345
Fe_2O_3	0.837
CaO	3.338
MgO	3.757
SO_3	0.494
K_2O	7.674
Na_2O	0.249
P_2O_5	2.946
Mn_2O_3	0.081
TiO_2	0.180
SrO	0.020

3. RESULTS AND DISCUSSIONS

3.1. Ultimate Tensile Strength

Figure 1 shows the variation in the ultimate tensile strength of the epoxy matrix (control sample) and the GCHA reinforced epoxy composites. It was observed that there was linear increment in the UTS of the composites from samples A to D and the values of UTS for these composites are higher than that of the control sample. The increase in strength can be attributed to the uniform distribution of hard GCHA in the epoxy matrix which impedes dislocation motion. Also, chain inter diffusion and entanglement between the epoxy and the GCHA particles enhanced the improvement in UTS [20]. The decrease in the UTS value of the composites at 10 wt.% GCHA may be due to the formation of agglomerated particles within the epoxy matrix at this weight fraction which led to interfacial debonding at the particles matrix interface thereby decreasing the strength of the composite [4,20].

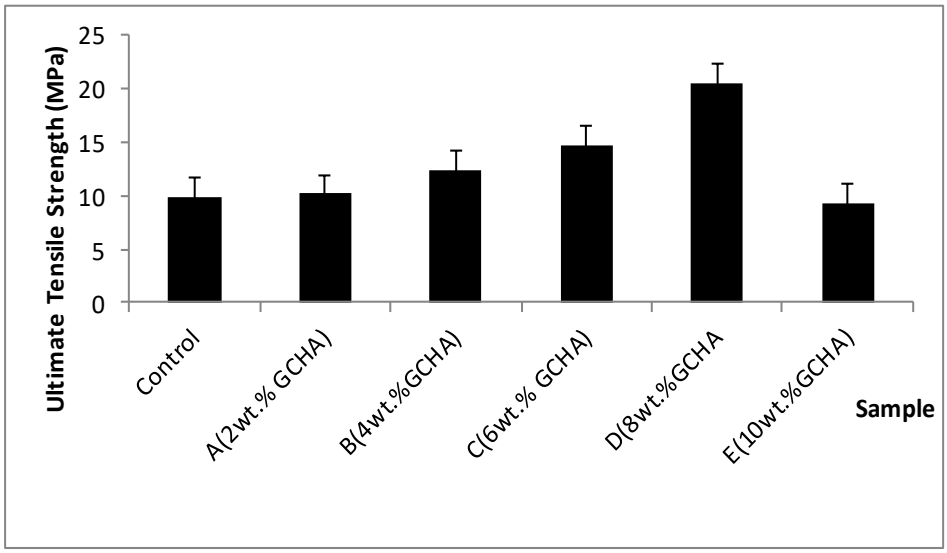

Figure 1 Variations of Ultimate Tensile Strength of Epoxy Matrix and GCHA/Epoxy Composites

3.2. Young's Modulus of Elasticity

Young Modulus is a measure of the stiffness of a material at the elastic region during tensile test. Figure 2 illustrates the Young Modulus of the control sample (epoxy matrix) and GCHA/epoxy composites. The Young Modulus for the control sample was 269.77 MPa. There was a significant improvement in the Young Modulus of the composites produced from samples A to D and the value slightly decreased in sample E. The result shows that the introduction of GCHA increases the young modulus of the epoxy matrix. Sample A with 2 wt.% of GCHA has the highest young modulus (820.004 MPa). The presence of uniformly dispersed hard phase (due to the presence of silica in the GCHA) account for the high stiffness and rigidity of the composites. This concords with Mudradi *et al.* [21] and Fu *et al.* [8]. Also, the small particle size of the GCHA account for the high aspect ratio of the composite thereby increasing the young modulus [8,22]. The decrease in young modulus of sample E (10 wt.% GCHA) can be linked to poor dispersion of the particles in the epoxy matrix. In addition, since GCHA contains high concentration of silica, this lowers the crosslinking density of the composites and this aid the detachment of the epoxy matrix from the hard dispersed GCHA particulate phase during loading [20].

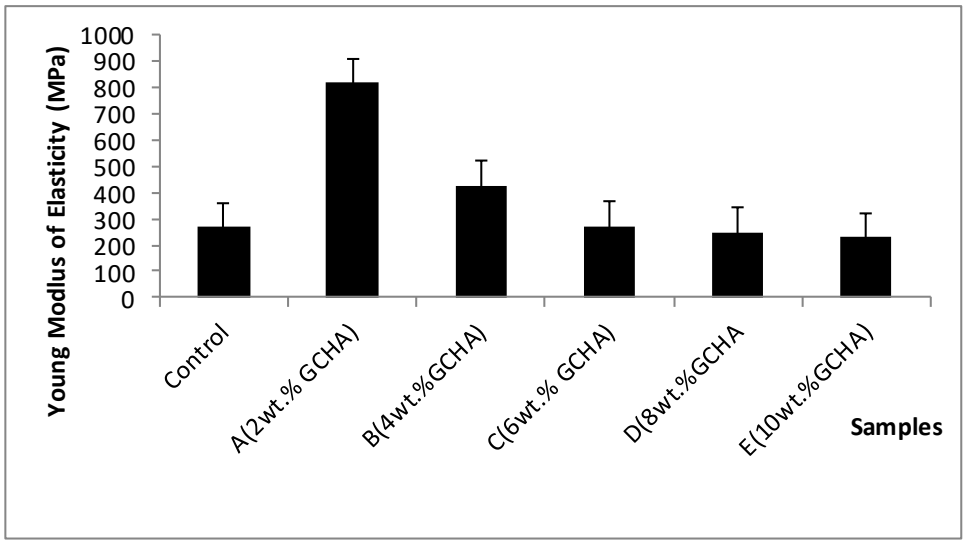

Figure 2.Variation of Young Modulus of Elasticity of Epoxy Matrix and GCHA/Epoxy Composites.

3.3. Flexural Strength

The variation in the average flexural strength of the epoxy matrix and GCHA/epoxy composites is presented in Figure 3. There were appreciable increases in the flexural strength of sample B and C (with 5.1 % and 10.9 % respectively). The increment can be attributed to the homogenous dispersion of the GCHA particles in the epoxy matrix at lower weight fractions (4 and 6 wt.%) which aid the load bearing capacity of the composites [4]. It is pertinent to mention that the improvement in the flexural strength observed contradict the proposition that rigid fillers have a devastating effects on strength as reported by [23]. However, it was observed that increasing the wt.% of GCHA particulates gradually decreases the flexural strength of sample D and E. This has been attributed to increase in viscosity of the resin phase due to higher concentration of GCHA silica in the resin [4].

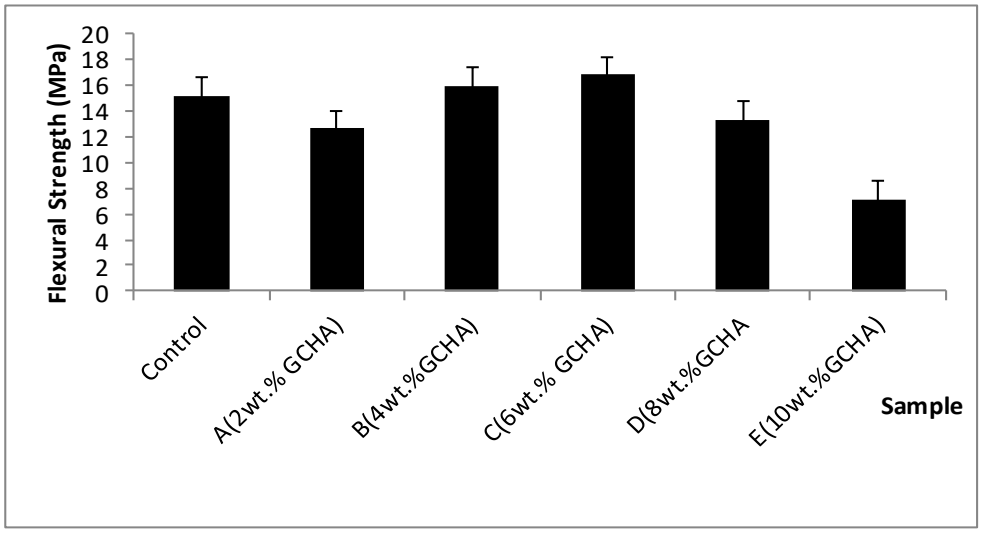

Figure 3. Variation of Flexural Strength of Epoxy Matrix and GCHA/Epoxy Composites

3.4. Flexural Modulus

Figure 4 shows the variation in the flexural modulus of the epoxy matrix and the GCHA/epoxy reinforced composites. It was observed that there was a general and significant improvement in the flexural modulus of the GCHA/epoxy composites over the control sample. Sample C has the highest flexural modulus with a value more than twice of the control sample. The increase in the flexural modulus have been reported to be due to high surface energy possessed by the small sized fillers [20]. The increase in the flexural modulus of the composites specimens agreed with the other result from literature [13]. This shows the propensity of GCHA as a potential reinforcement for polymeric composites.

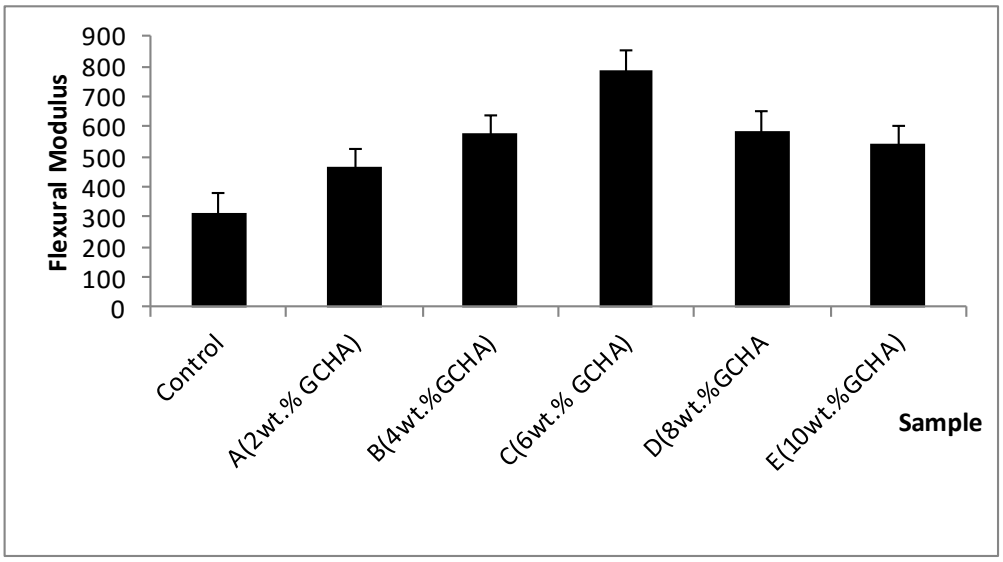

Figure 4. Variation in Flexural Modulus of Epoxy Matrix and the GCHA/Epoxy Composites

3.5. Impact Properties

The variation in the impact strength of the epoxy matrix and GCHA/epoxy composites is presented in Figure 5. The results revealed that all composites have higher impact strength than the control sample

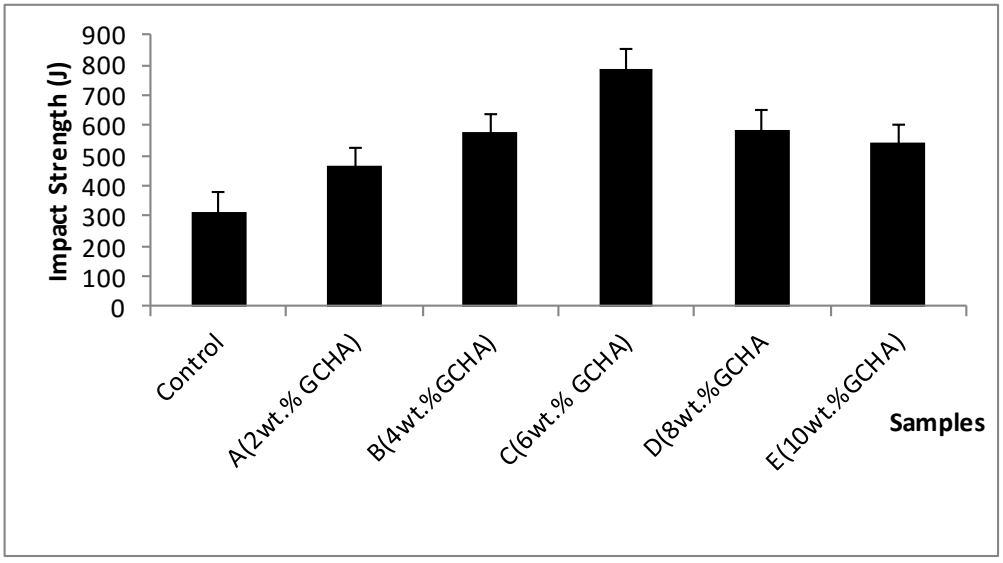

Figure 5.Variation in Impact Strength of Epoxy Matrix and GCHA/Epoxy Composites

Sample C has the highest impact energy which is 149.82 % improvement. It has been reported that the impact strength of filled polymers depends on the degree of interfacial bonding between the polymer matrix and the filler [24]. The presence of fillers helps to pin down/hinder crack propagation which causes a change in the fracture behaviour during impact of the composites [8]. Composites with higher impact energy will decelerate the propagation of cracks [20]. Thus, for the composites produced for the impact test, the increase in the impact energy is due to the presence of good adhesion between the epoxy matrix and the GCHA particulates.

3.6. Wear Properties

The variation in the wear index of the epoxy matrix and GCHA/epoxy composites is illustrated in Figure 6. It was observed that the wear resistances of the GCHA/epoxy composites are generally lower than the control sample. Several factors have been identified to affect the wear behaviour of a composites which includes the nature of the matrix material, the type of reinforcement, surface roughness of the composite, sliding speed and type of friction [3, 25]. The decrease in the GCHA/epoxy composite can be due poor interfacial bonding with the epoxy and the hard particles and agglomeration of the GCHA particulates during production. This causes the easy removal of the GCHA during friction, thereby lowering the composite wear resistance.

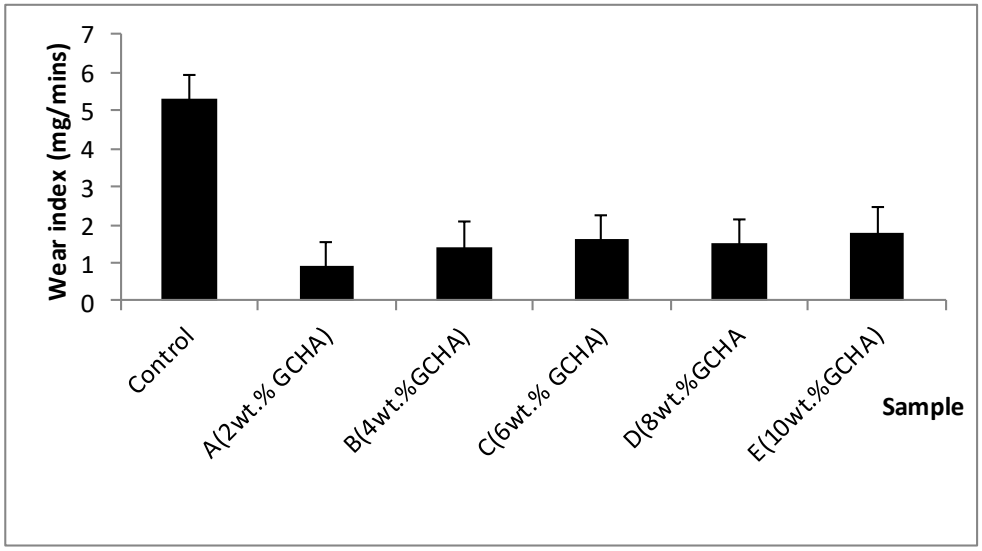

Figure 6. Variation in Wear Resistance of Epoxy Matrix and GCHA/Epoxy Composites

4. CONCLUSIONS

The mechanical properties (tensile, flexural and impact strength) and the wear behaviour of guinea corn husk ash (GCHA) reinforced epoxy matrix composites has been studied. The following conclusion are derived from the investigation:

- There was an appreciable increase in the tensile strength of the composite produced over the control sample. The decrease in the tensile strength of sample E has been attributed to agglomeration of the GCHA particulates in the epoxy matrix.
- The flexural properties of the GCHA/epoxy composites were enhanced significantly.
- There were improvements in the impact strength of the GCHA/epoxy composites.

- The wear properties of the GCHA/epoxy composites suffered depreciation due poor interfacial bonding with the epoxy matrix and the hard particles coupled with the presence of agglomerated particles of GCHA in the epoxy matrix.
- The study has shown that guinea corn husk ash if incorporated at lower weight fractions (2-6 wt.%) can be a potential reinforcement for the development of polymer matrix composites..

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