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RESEARCH PAPER

PHYSICO-MECHANICAL PROPERTIES OF POLYMER MATRIX COMPOSITE MATERIAL REINFORCED WITH CARBONIZED CASSAVA BACK PEEL AND IRON FILLINGS

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ABSTRACT

The use of natural particles as reinforcement in polymers has become a subject of research in recent years due to their eco-friendly nature. This study aims to explore the use of cassava back peel, as a reinforcement material in epoxy resin-based composite. Composite plates were prepared for the casting of the epoxy resin reinforced with carbonized cassava back peel (CCBP) and iron fillings (IF) composite samples using a hand lay-up technique. The percentage compositions by weight of the CCBP varied between 0% and 10 %, while that of IF was kept constant (5%). The physical and mechanical behaviours of cassava back peel-reinforced epoxy polymer composites were studied using ASTM standards. The density of the epoxy resin was improved by adding IF and CCBP. The maximum density obtained was 1270 kg/cm3 for 5%CCBP epoxy composite. The percentage of water absorption was also improved by the addition of the filler materials with 5%IF10CCBP epoxy hybrid composite recording 30% water absorption. Conversely, the ultimate tensile strength (UTS) and breaking strength (BS) varied with the addition of the filler materials. 5%CCBP epoxy composite recorded 41.26 MPa for both UTS and BS. Meanwhile, percentage elongation decreased with the addition of the fillers showing that the composites became less ductile. The hardness Brinnel number of epoxy was improved with the addition of fillers. The fabricated composites are suitable for applications where impact energy and hardness are crucial and high strength and ductility are not required such as automobile dashboards.

Keywords: automobile dashboards; carbonization; polymer composites; iron-fillings; hybrid polymer composites; hand lay-up technique

INTRODUCTION

Engineering components and equipment design usually involve the critical task of selecting appropriate materials that will meet service conditions in different areas of application. This led to the development of composite materials, which can combine properties of more than one class of materials since they are developed from materials with inherent different properties [1–3]. This is achieved by the cohesion of the materials made by physically combining two or more compatible materials, different in characteristics, composition, and sometimes in form. The importance of composite materials in engineering regarding polymer composites has led to increased studies in this area [4–8]. Composite materials have dominated many industries ranging from aerospace, transport, sporting, construction, automotive, information, and technology to household products and optical devices, because of their unique combined properties. They consist of high-strength particles (natural and synthetic) such as glass, aramid, carbon, plant, and animal biomass in low-strength polymeric matrices Garkheil and Pejis [9].

Polymer matrix composites are filled or reinforced with fibre or particulate reinforcement [7,10]. Although, fiber-reinforced composites have been prominently utilized in polymer composite production; however, particulate-reinforced composite has gained continual interest owing to their ease of production [8,11]. Particulate reinforced composite is the major focus of this study because of its eco-friendliness, low cost, renewability, lightweight, and lower energy consumption during production [12].

The addition of filler materials (particles) to matrix materials helps in their property's improvement, cost reduction, and processing characteristics modification. Particulate compositions are generally derived from filler/solid addition synthesized from powders. The two main classifications of fillers are organic and inorganic. In polymeric matrix composites, the utilization of organic filler has gained more attention because of their biodegradability, recyclability, renewability, and non-abrasiveness [8].

Several agro-wastes such as rice husk, animal bones, wood, oil palm, bagasse, cassava waste, and so on, have been considered as natural fillers and there has been a significant increase in the properties of the polymeric matrix. Aside from polymer matrix, natural fillers have been utilized in metal matrix composites with improved physical and mechanical properties of the composite

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produced [13] and in biomass energy generation [14–17]. Natural fibres contain some properties or compounds that help to improve the overall properties of the composite. For instance, the carbonized cassava cortex used as filler in polymer matrix composites in the study of Omah et al. [8] improved the reported mechanical properties. A hybrid reinforcement of glass fibres and micronized rubber powder fillers were used to reinforce an epoxy matrix. The additions of both reinforcements improved the mechanical properties of the epoxy matrix, especially at E-glass of 40% and 10% of the micronized rubber powder filler. The mechanical properties of natural fillers are good enough to compete with those obtained from glass fillers [18] concerning specific strength and modulus. The introduction of new natural fillers for the production of lightweight and economical polymeric matrices for mechanical applications is achievable through various studies [19–21].

Although, natural filler utilization is the major focus of this study; however, the combination of this agro-waste filler with industrial waste filler could be considered a novel hybrid filler in epoxy-based composites. The natural filler used in this study is cassava back peel, an agro-waste from cassava, which is used in biomass energy generation. Cassava is an annual crop widely grown in Nigeria as a rich supply of carbohydrates but the back peel is often discarded. Although the back peel with some small amounts of the edible cassava is often used as animal feed due to its abundance, the larger percentage of the back peels were often left to rotten away. Therefore, healthy disposal of its inedible back peel has remained a critical challenge. This waste poses a big challenge in the effort of achieving a clean and safe environment, mostly by harboring harmful insects like mosquitoes, sun flies, and horrible odors. Hence, these peels require carbonization before utilization because a good interfacial bonding may be hindered between the matrix and filler. However, the use of carbonized cassava-back-peel with iron filling as reinforcement in a polymer matrix has been relatively unexplored in the literature. Therefore, this study is aimed at exploring the possibility and effect of synthesizing epoxy-based composites with cassava back peels and iron filings. The physical and mechanical properties of the synthesized composites were determined, while the microstructures were also investigated.

MATERIAL AND METHODS

Materials

The materials used in this research were epoxy resin, cassava-back peel, and iron fillings. The equipment used in this research work were a muffle furnace, sieve, digital weighing balance, rod stirrers, hand gloves, universal testing machine, Izod impact machine, and Hunsfield Tensometer.

Preparation of Epoxy Resin

The type of epoxy resin used in the present investigation is Araldite LY-556, which chemically belongs to the epoxide family. The hardener used was NNO-bis (2 aminoethylethane- 1, 2-diamin). The fabrication of the composite slab was carried out by conventional hand layup technique. The ratio of the epoxy to hardener used in this study was two to one (2:1).

Preparation of cassava-back-peel

The fresh cassava back peel was gathered from a local cassava-processing mill in Ganmo, Ilorin, Nigeria. This was then sorted out to remove the peel from the remains of the edible part (**Fig. 1(a)**) as well as the impurities and dirt, and later sun dry for 24 h. It was later subjected to heating in an open environment under a controlled temperature of 130°C to remove fumes before being taken to a muffle furnace. Here, the carbonized sample (**Fig. 1(b)**) was obtained at a temperature range of 400°C. It was then crushed and sieved using a 150 µm mesh size.

Fig. 1 Cassava-Back-Peel (a) Before Carbonization (b) After Carbonization

Carbonization

The dried peels were crushed into powder form and the weight was recorded. The weighted samples were poured into a clean and pre-heated crucible. The sample was then placed in the muffle furnace. The furnace temperature was increased at a rate of 10°C/min from room temperature up to 400°C for carbonization. The content was then removed from the muffle furnace and cooled in the open air for one hour. The powdery form of the cassava back peel was obtained by crushing and pounding using a laboratory mortar and pestle. It was then sieved using a 150 µm mesh size.

Iron fillings preparation

Iron fillings were gathered from the Mechanical Engineering Central Workshop of a renowned university in Nigeria. It was then sieved using a 200 µm mesh size to have a uniform particle size. **Fig. 2** shows samples of iron fillings before sieving.

Fig. 2 Iron fillings (a) As gathered (b) After sieving

Compounding

This is when all materials were measured as specified for each composition and then compounded together to form the composite. The hand lay-up technique was used in the formulation of this composite material [22]. It was mixed in percentage by weight. The percentage composition by weight of the epoxy and the carbonized cassava-back-peel were varied while that of iron fillings was kept constant at 5 wt.% as shown in Table 1. After the production of the samples, the samples were sun-dried for 7 days before carrying out further tests on them.

Table 1. Percentage composition by weight of the composite constituents

Sample	CCBP (% wt)	IF (% wt)	Epoxy (% wt)
A	0	0	100
B	5	0	95
C	0	5	95
D	5	5	90
E	10	5	85

CCBP – Carbonised cassava back peel; IF – Iron fillings

Physico-mechanical properties of the composite samples

Physical properties

(a) Water absorption test:
The composite samples were prepared with a dimension of 25×25×5 mm. The dried specimens were weighed (W_a) using a laboratory weighing balance and the weight was recorded accordingly. The material was then immersed in water at room temperature for 24 h. Samples were removed, dried with a lint-free cloth, weighed (W_b), and recorded also. Percentage water absorption (PWA) or percentage water gain (PWA) was calculated using Equation (1) [23,24].

$$\mathrm{PWA} = \frac{W_b - W_a}{W_a} \times 100\% \tag{1.}$$

(b) Density
A clean sample was weighed accurately in the air using a laboratory balance. Each sample was then suspended in water. The weight of the sample when suspended in water was determined and the volume of the sample was determined by the displacement method (Archimedean principle). Then, the density of the polymer matrix composite was calculated using Equation (2) [25]

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \tag{2.}$$

Mechanical Properties

(a) Tensile test
Tensile tests were carried out using an Instron Universal testing machine. The ASTM standard test method for tensile properties of polymer composites with the designation D3039-76 was used (ASTM, 2000) after which the tensile strength was calculated using Equation (3) [26]

$$\sigma = \frac{\text{Maximum load (P)}}{\text{Initial cross-sectional area (A)}}\ (\mathrm{N/m^2}) \tag{3.}$$

The extent to which the material elongates is determined by measuring the greatest separation between the gauge marks just before rupture, and it is often expressed as percentage elongation. Thus, Equation (4) was used to calculate the percentage elongation.

$$\%\varepsilon = \frac{\text{Guage length after rupture}}{\text{Initial guage length}} \times 100 \tag{4.}$$

(b) Brinell Hardness Test
The samples of cassava-back-peel reinforced polymer matrix were subjected to hardness tests using Hounsfield Monsanto Tensometer type 'W' with serial number 10055. The carbonized cassava-back-peel and iron fillings reinforced composites were prepared for hardness in conformance with ASTM E10 standards. The Brinell hardness value was calculated for the composites using Equation (5) [27].

$$\mathrm{HBR} = \frac{F}{\left(\frac{\pi D}{2}\right)\left[D - \left(D^2 - d^2\right)^{\frac{1}{2}}\right]} \tag{5.}$$

Where F is the applied force (N/m2), D is the diameter of the indenter (mm) and d is the diameter of indentation (mm).

(c) Impact Test
Impact resistance is the ability of a material to resist breaking under a shock loading or the ability to resist the fracture under stress applied at high speed. The Izod impact machine was used to perform the impact tests on CCBP reinforced with epoxy composite specimens as per ASTM-D256-90 standard [28].

(d) Microscopic Analysis
The morphological characterization of the composite surface was observed in an accuscope microscope of Serial no 0524011, Princeton, USA. The samples were mounted on an accuscope metallographic microscope and were examined using a magnification of X400. Attached to the microscope was an ocular camera and a computer system through which the micrographs were viewed and captured.

RESULT AND DISCUSSION

Physical properties

(a) Density of the composites
The densities for different compositions are presented in **Fig. 3**. It reveals that the density range of 986 to 1270 Kg/cm3 was obtained. The density of epoxy is 1,010 kg/cm^3, while those of epoxy-5 wt% IF, and epoxy- 5 wt% CCBP composites are 1,113 kg/cm^3 and 1,270 kg/cm^3 respectively. Meanwhile, the density of the hybrid composite (epoxy- 5 wt% IF – 5 wt% CCBP) is 986 kg/cm^3, further increase in the percentage of CCBP in the hybrid also increased the density of the hybrid to 1,128 kg/cm^3. The results show that both IF and CCBP individually increase the density of epoxy resin [29], but the addition of CCBP increases the density of epoxy resin more than the addition of IF. Combining both reinforcements at the same proportion caused a significant reduction in the density. This may be due to a mismatch of the IF and CCBP particles in the epoxy resin matrix resulting from the differences in the particle sizes and weight of IF and CCBP. However, the density of the hybrid composite was further increased by increasing the volume of CCBP in the hybrid.

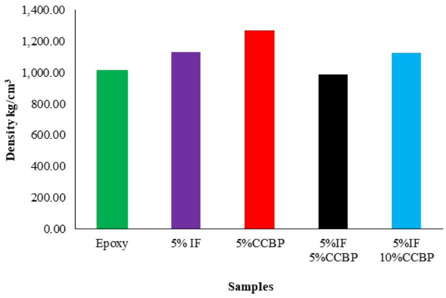


Fig. 3 Densities of the composite materials

(b) Water Absorption
Fig. 4 shows the percentage of water uptake for the composites. The water absorption of the polymer composites ranged from 8.7% in the pure epoxy resin to 32% in the 5%IF10CCBP epoxy composite. The water absorption for the 5%IF epoxy composite was 21% which is higher than that of the 5%CCBP epoxy composite (19%). Meanwhile, the hybrid composite 5%IF5%CCBP epoxy and 5%IF10%CCBP epoxy composites recorded water absorption of 23% and 32% respectively. The increase in the water absorption of the hybrid composites is mainly due to the effect of iron fillings in the mixture. The water absorption values of all the samples are consistent with the findings of Bahrami et al. [30]. The increase in water absorption of the mono- and hybrid-composites can be attributed to the presence of voids due to poor adhesion between the epoxy resin matrix and filler material [31].

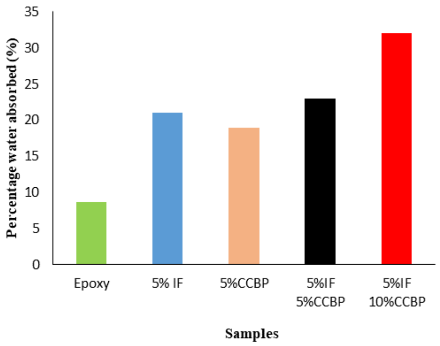


Fig. 4 Percentage Water Absorbed for the Composite Material

Mechanical tests

Tensile test

The ultimate tensile strength (UTS) of the composites varied between 54.5 MPa in the pure epoxy resin and 38.48 MPa in the 5%IF10%CCBP epoxy hybrid composite as shown in **Fig. 5**. It is observed that the addition of filler materials led to decrease in the UTS of epoxy resin. The 5%CCBP (41.26 MPa) led to a greater reduction in the UTS than 5%IF (53.47 MPa). The 5%IF5%CCBP epoxy hybrid composite produced a UTS of 43.03 MPa while further addition of CCBP as shown in the 5%IF10%CCBP epoxy hybrid composite recorded a UTS of 38.48 MPa. This shows that the addition of carbonized cassava back peel to epoxy resin reduces the ultimate tensile strength. The decrease in tensile strength may be due to the scanty dispersion of iron fillings and the carbonized cassava back peel particles in the composite matrix, which lead to the increases in the micro-spaces between the filler and the matrix, and as a result, weakens the filler-matrix interfacial adhesion. The findings of this study contradict those of Balaji et al. [32] who observed that the addition of banana fiber filler increased the tensile strength of epoxy resin. However, Han et al. [33] discovered that the addition of boron nitride (a major compound present in cassava) as a filler in epoxy composites reduces tensile strength. Furthermore, the addition of CCBP as filler to epoxy resin brought the tensile strength within the range of 20 – 40 MPa which is the required limit for polymer composite for automotive parts application [30].

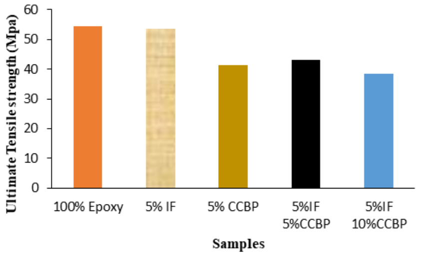


Fig. 5 Ultimate Tensile Strength (U.T.S) for the Composite Materials

Breaking Strength

Fig. 6 shows the breaking strength of the composites which is a measure of the tensile strength at break. The breaking strength of pure epoxy resin is 43.87 MPa, while those of 5%IF and 5%CCBP epoxy composites are 53.47 MPa and 41.26 MPa respectively. Similarly, the breaking strength of the hybrid composites; 5%IF5%CCBP and 5%IF10%CCBP epoxy composites are 43.03 MPa and 38.48 MPa respectively. The result shows that the use of CCBP as a filler material reduces the breaking strength of epoxy resin. However, the addition of 5% iron fillings and 5% carbonized cassava back peel as filler materials in a hybrid composite arrangement is sufficient to produce similar breaking strength as the original epoxy resin. The increase in the breaking strength in the 5%IF epoxy composite is due to the impact of the iron fillings. The reduction in the breaking strength with an increase in CCBP addition is similar to the findings of Han et al. [33] who studied the mechanical behaviour of graphene nanoplatelet/epoxy and boron nitride composites. The similarity of these two studies, as regards the mechanical properties, can be attributed to the presence of similar elements in the fillers used. Boron nitride contains nitrogen and graphene contains carbon. These two elements are well represented in cassava back peel [34].

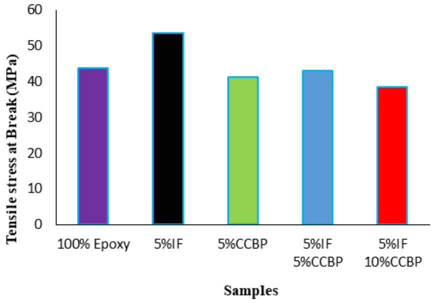


Fig. 6 Breaking Strength (B.S) chart for the composite material

Percentage Elongation

Fig. 7 shows the variations in percentage elongation for the composite. The percentage elongation decreased from 5.2% in the pure epoxy sample to 1.99% in the 5%IF5%CCBP epoxy hybrid composite sample. Reinforcing epoxy resin with 5%IF reduced the elongation to 3.73% while 5%CCBP produced an elongation of 2.63%. Meanwhile, the elongations of the 5%IF5%CCBP and 5%IF10%CCBP are 1.99% and 2.10% respectively.

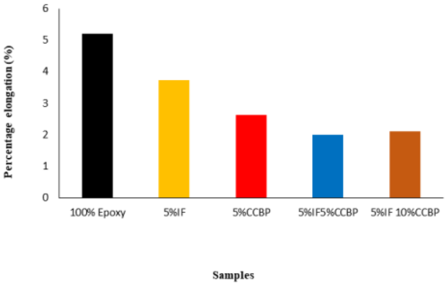


Fig. 7 Percentage elongation (PE) for the composite material

In general, the addition of iron filling and carbonized cassava backpeel fillers reduced the percentage elongation of epoxy resin. The percentage elongation of a material is a measure of the ductility of the material. Ductility has a directly proportional relationship with percentage elongation, which implies that materials with high percentage elongation are more ductile. The reduction in elongation could be attributed to the presence of hard and brittle phases in the composite matrix. The reduction of the ductility of the epoxy resin by the addition of iron fillings and/or carbonized cassava back peelings is desirable in certain applications such as the fabrication of automobile bumpers where moderate ductility is desired. The use of highly ductile materials such as mild steel for automobile bumper application produces excessive deformation during crashes [35].

The Young's Modulus

Fig. 8 shows that Young's modulus of the composite increases from 1710.8 MPa to 3005.9 MPa for 100 % Epoxy and 5%IF5%CCBP respectively, but then dropped to 2570.7 MPa on further introduction of reinforcement to 10% wt. of CCBP in the hybrid composite. Young Modulus is another material property that measures ductility. Materials with lower moduli are said to be more ductile [36]. The results further confirm that the pure epoxy resin sample is more ductile than both the single and hybrid composites. However, the results show that the composites are within the limit of Young modulus (1000 – 2500 MPa) for polymer composite used for automobile applications except the 5%IF5%CCBP epoxy hybrid composite [37].

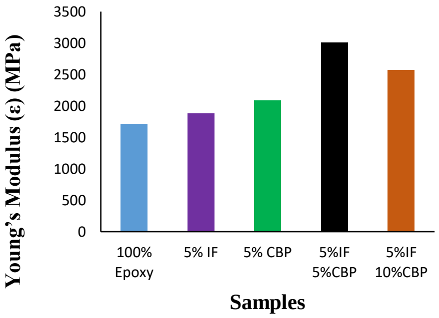


Fig. 8 Young's Modulus (ε) for the Composite Materials

Hardness Test

The result for the hardness test was presented in **Fig. 9** The hardness number increased from 52.2 HBr (100% epoxy) to 100 HBr (5%IF10%CCBP), respectively. This was up to a 47.8 % increment. The higher values are due to the CCBP addition reaction, which dominates the cross-linking process leading to the formation of a stronger material, which exhibits better hardness.

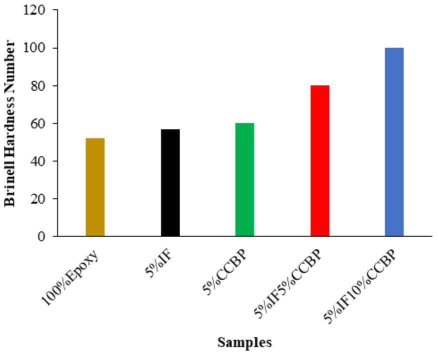


Fig. 9 Hardness Number (H.N) for the composite materials

Generally, particles that increase the moduli of composites increase the hardness of the composite. This is because hardness is a function of the relative particle volume and modulus. Hardness is a required property in polymers used for automotive applications [38]. It is a measure of a material's resistance to scratches.

Impact Test

The results obtained from the impact tests for the carbonized cassava-back-peel (CCBP) and Iron fillings (IF) epoxy composites are shown in **Fig. 10**. It is observed that the highest impact energy of 6.74 J was recorded by the 100% Epoxy sample. As 5% iron filling reinforcement was introduced, the impact energy dropped to 6.21 J, while the addition of 5% CCBP produced an impact energy of 5.94 J. The combined effect of the addition of iron fillings and carbonized cassava back peel led to a further reduction in the impact energy to 4.75 J, and 4.21 J in the 5%IF55CCBP and 5%IF10%CCBP epoxy hybrid composites. It can be observed that an increase in the volume of CCBP led to a decrease in the impact energy. However, the results are still within the range of similar composites obtained in other studies [13,39,40].

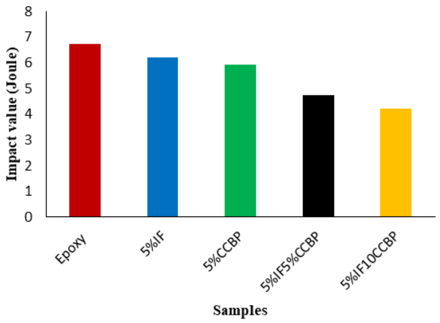
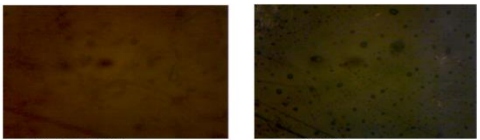


Fig. 10 Impact strength

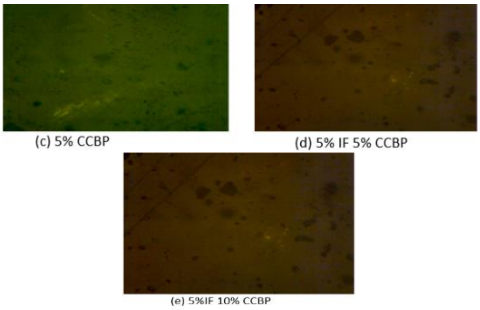
Microstructural analysis

The images of composites containing different percentage weights of CCBP and IF, with epoxy resin, were shown in **Fig. 11.** From Fig. 11(b) - (e), it is possible to verify that the presence of CCBP increased the sizes of the voids and turned the surface more non-homogeneous confirming its effect on promoting adhesion in the interfacial region. Fig. 11 (b) shows the presence of 5 % IF. It was evident that the IF was sparsely distributed in the composite material thereby reducing the intermolecular force by creating voids between them. Fig. 11 (c) shows the presence of 5 % CCBP; there were little or no voids because of the particle sizes. Fig. 11 (d) shows that the CCBP tends to neutralize the effects of the IF due to its particle size; thereby, increasing the intermolecular force between the molecules. Fig. 11(e) further shows that the CCBP neutralizes the effect of the IF completely. The observed morphology confirms the explanations for the higher degree of water absorption and the higher density determined in composites containing a higher percentage of CCBP by the pictorial view of the void created in between the particles.



(a) Pure Epoxy

(b) 5% IF



(c) 5% CCBP (d) 5% IF 5% CCBP

(e) 5%IF 10% CCBP

Fig. 11 Micrograph of the Composite Materials

CONCLUSIONS

The use of agro-wastes as filler materials in polymer matrix composites has gained wide application. The experimental results of this study showed that cassava back peel particles (CCBP) and Iron filings can be used as reinforcing fillers in fabricating polymer composites by suitably bonding with epoxy resin. With increasing cassava-back-peel particles and constant iron-filling reinforcement, the tensile strength and impact strength decrease gradually and it is found that a 5% weight fraction of cassava-back-peel reinforcement gives better strength than others. The ductility of the composite materials was reduced with an increase in the percentage composition of CCBP. The Young modulus also decreased when the filler loading was increased. The morphology of the samples showed that particle breakages were the predominant failure mode which confirms the higher degree of water absorption and higher density determined in composites containing a higher percentage of CCBP.

Hence, based on the availability, low cost, moderate ductility, and good strength of cassava back peel particle composites investigated in the present research work, the composite could be considered a promising material for the fabrication of lightweight materials used in automobile bodies such as bumper and fender, side mirror case, and dashboard. The study also showed the possibility of reinforcing epoxy resin with iron fillings filler to improve the mechanical properties.

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