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EFFECT OF PARTICULATE OF MILD STEEL AND ALUMINIUM DROSS ON THE PHYSICAL AND MECHANICAL PROPERTIES OF EPOXY RESIN MATRIX COMPOSITES

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ABSTRACT

Particles reinforced polymer matrix composites were developed by mould casting method. 5 – 25 weight percent of particulate of mild steel and aluminium dross, which are metal waste were applied as reinforcement for the production of epoxy resin matrix composites. The unreinforced epoxy resin and composite specimens were subjected to microstructural, water absorption, tensile, Young's modulus, impact, and hardness tests. The results showed that the hybrid specimen demonstrated the lowest water absorption of 0.01 %, highest tensile strength, elastic modulus, and impact energy of 81.05 MPa, 600 MPa and 17.24 J respectively at 15 wt. % filler content. The results indicated that the hybrid polymer matrix composite has potential for applications where low strength is required.

1. INTRODUCTION

Polymers are giant organic chain-like molecules having molecular weights with each molecule having repeating units known as monomers, which are joined together by covalent bonds [1]. The three major groups of polymers are thermoplastics, thermosets, and elastomers. Epoxy resin, polyester resin, phenolic resin, and vinyl ester are thermosets while thermoplastics are polyethylene, polyvinylchloride, polypropylene, polystyrene, nylon, polyetheretherketone, polyetherimide, and polyphenylene sulphide [2]. Rubbers are examples of elastomers.

Epoxy resin exhibits some desirable attributes such as appreciable strength, good adhesion ability, high electrical insulation, reduced toxicity and shrinkage, very economical and amenable to many processes and uses [3]. Epoxy resin can be used in areas where the temperature is up to 175 0C and it has a good compatibility with common fillers/reinforcements. Despite the desirable attributes of epoxy resin, it is not extensively used because of its brittleness, delamination and reduced fracture toughness [3]. These are the general disadvantages of polymers and efforts have been made to solve these problems with the introduction and application of polymer matrix composites. Composites produced using polymers as matrix are polymer matrix composites. In polymer matrix composites, the filler is dispersed in the polymer [2]. Polymer matrix composites are developed using polymer matrices, which can be reinforced by filler. Polymers transfer load to the filler, which improves the characteristics of composites. The type of materials used also determines the characteristics of composites. Thus, proper selection of filler, matrix, and method of production are vital factors in developing composites. Generally, there are various methods of producing polymeric composites such as solution casting; melt compounding, in-situ polymerisation, etc. Solution casting involves dissolving the polymer in a solvent and uniform dispersion of the filler in the mixture [4].

Particles are blended with polymers to produce polymer matrix composites because they are economical and easy to mould. Hence, many studies have been carried out using particulate to reinforce epoxy resin with improved physical and mechanical properties. Aluminium-epoxy composites demonstrated increased density and elastic modulus as aluminium particles content increased [5, 6]. Mechanical characteristics of epoxy resin reinforced with silica (quartz) and alumina particulate were investigated. The composites demonstrated enhanced elastic modulus, fracture toughness, compressive strength and hardness [7]. The influence of coconut shell-ash on the mechanical characteristics of epoxy composites was also studied.

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The composites demonstrated increased tensile strength, elastic modulus, and hardness as coconut shell-ash content increased [8]. In addition, the influence of goat bone particles on mechanical characteristics of epoxy composites was studied. The results revealed that the composites demonstrated increased tensile strength, flexural strength and hardness as goat bone particles increased [9]. The need to continuously improve the characteristics of polymers via particulate reinforcement to develop polymer matrix composites with enhanced functional characteristics cannot be overemphasized. Hence, this study is aimed at developing mono reinforced and hybrid polymer matrix composites using epoxy resin and particulate of mild steel and aluminium dross.

2. METHODS

2.1. Preparation of Materials

Epoxy resin and hardener were obtained from a registered vendor in Lagos. The weight ratio of the epoxy resin to hardener was 2:1. Mild steel chips obtained from the Engineering workshop of the University of Lagos were ground and sieved to the desired particles size using British standardised sieves (BSS). As-received aluminium dross was also ground and sieved. Figure 1 shows the materials used and their chemical composition is presented in Tables 1 and 2.

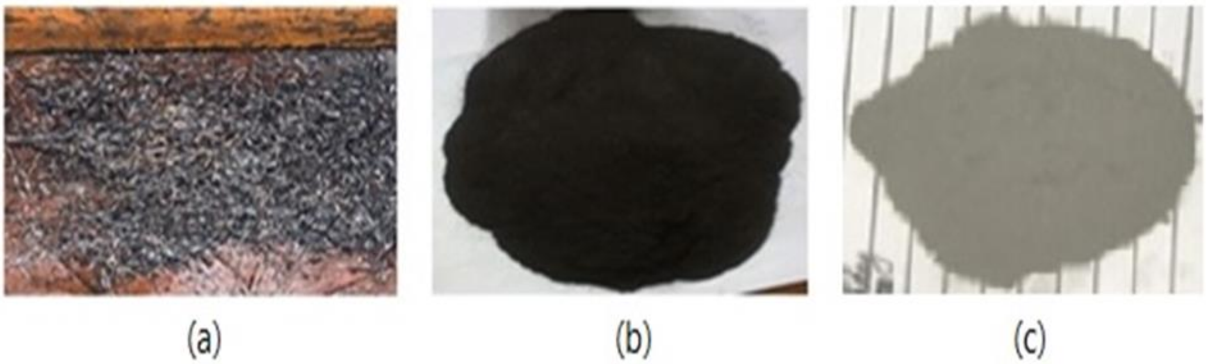


Fig. 1. (a) Mild steel chips (c) 100-μm mild steel particles (d) 100-μm aluminium dross particles

Table 1 a. Composition of mild steel chips

Element	Fe	Mn	C	Ni	Si	Cr	S	P	Cu	Mo
Wt. %	98.836	0.616	0.226	0.104	0.102	0.04	0.024	0.021	0.015	0.004

Table 1b. Composition of mild steel chips continued

Element	Pb	Zn	Vn
Wt. %	0.003	0.002	0.002

Table 2. Composition of aluminium dross

Element	Al_2O_3	Al	SiO_2	CaO	Na_2O	MgO	Fe_2O_3	SO_3	K_2O
Wt. %	63.85	28.76	7.14	0.08	0.06	0.04	0.03	0.03	0.01

2.2. Production of the Composites

Appropriate amount of epoxy resin and hardener were poured into a beaker using a mixing ratio of 2:1 (epoxy: hardener). Varied quantities (5 – 25 wt. %) of mild steel particulate were separately added to the polymer and stirred. Thereafter, the mixture was fed into the wooden mould lined with paper tape. After 24 hrs, the casts were removed from the mould and taken as 1st batch as illustrated in Table 3. Aluminium reinforced epoxy composites were produced using the same procedure and were taken as 2nd batch. The hybrid specimens containing equal amount of mild steel and aluminium dross particulate were produced and taken as the 3rd batch. Mixture of epoxy resin and hardener specimens (control) without filler were taken as the 4th batch.

Table 3. Materials formulation

Matrix (wt. %)	Reinforcement (wt. %)			
Epoxy Resin	**MSP**	**ADP**	**Hybrid (MSP + ADP)**	**Total (wt. %)**
			1st Batch	
95	5	-	-	100
90	10	-	-	100
85	15	-	-	100
80	20	-	-	100
75	25	-	-	100
			2nd Batch	
95	-	5	-	100
90	-	10	-	100
85	-	15	-	100
80	-	20	-	100
75	-	25	-	100
			3rd Batch	
95	-	-	2.5 MSP + 2.5 ADP	100
90	-	-	5 MSP + 5 ADP	100
85	-	-	7.5 MSP + 7.5 ADP	100
80	-	-	10 MSP + 10 ADP	100
75	-	-	12.5 MSP + 12.5 ADP	100
			4th Batch	
100	-	-	-	100

MSP = Mild Steel Particulate
ADP = Aluminium Dross Particulate

3. EXPERIMENTAL

3.1. Characterisation of the Composites

A scanning electron microscope was used to examine the microstructure of the specimens. Water absorption (WA) of the specimens was determined by recording their weights (W1) in air. They were dipped in water for 144 hrs and their weight (W2) was recorded at an interval of 24 hrs. Eq. (1) [10] was used to calculate WA.

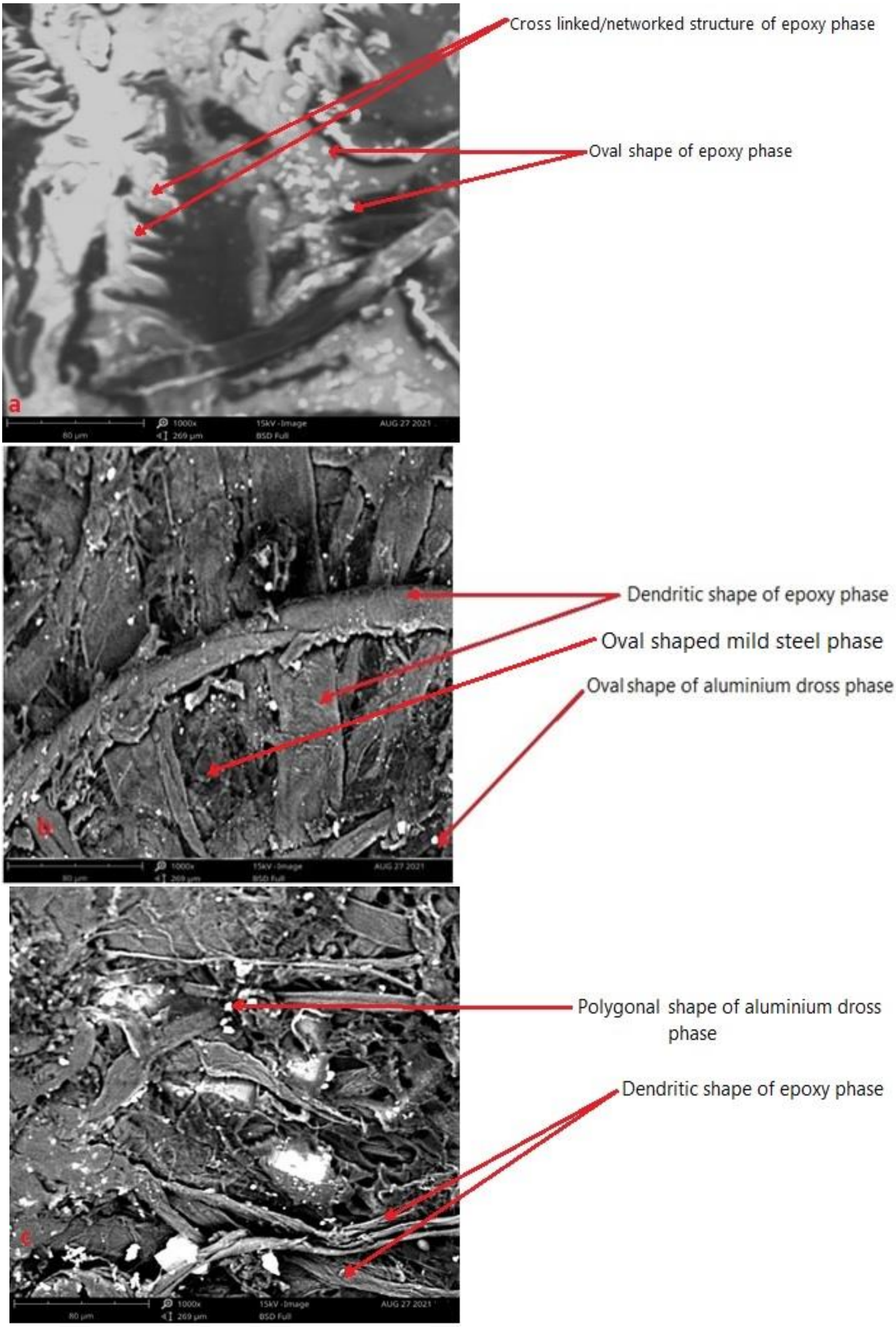
$$W_A(\%) = \frac{W_2 - W_1}{W_1} \text{ x } 100 \quad (1)$$

Tensile test was done according to ASTM standard D3039. Elastic modulus test was carried out according to ASTM standard D638. The hardness test was done using a Brinell hardness tester according to ASTM standard D2240. Impact energy test was also carried out with an Izod impact-testing machine according to ASTM standard D256.

4. RESULTS AND DISCUSSION

4.1. Microstructure

The specimens show some degrees of cross-linking in their microstructure because of the presence of thermosetting polymer (epoxy) as illustrated in Fig. 2(a – d). Cross-linking or network of polymer molecules makes polymers to become chemically set and strong in the solid state [11]. Fig. 2 also shows that the phases in the microstructure differ in morphology with some having dendritic, oval and polygonal shapes. The micrographs also reveal inhomogeneity in the microstructure of the reinforced specimens. The mild steel and aluminium dross phases are represented by the gray and white coloured phases in the microstructure of the specimens.



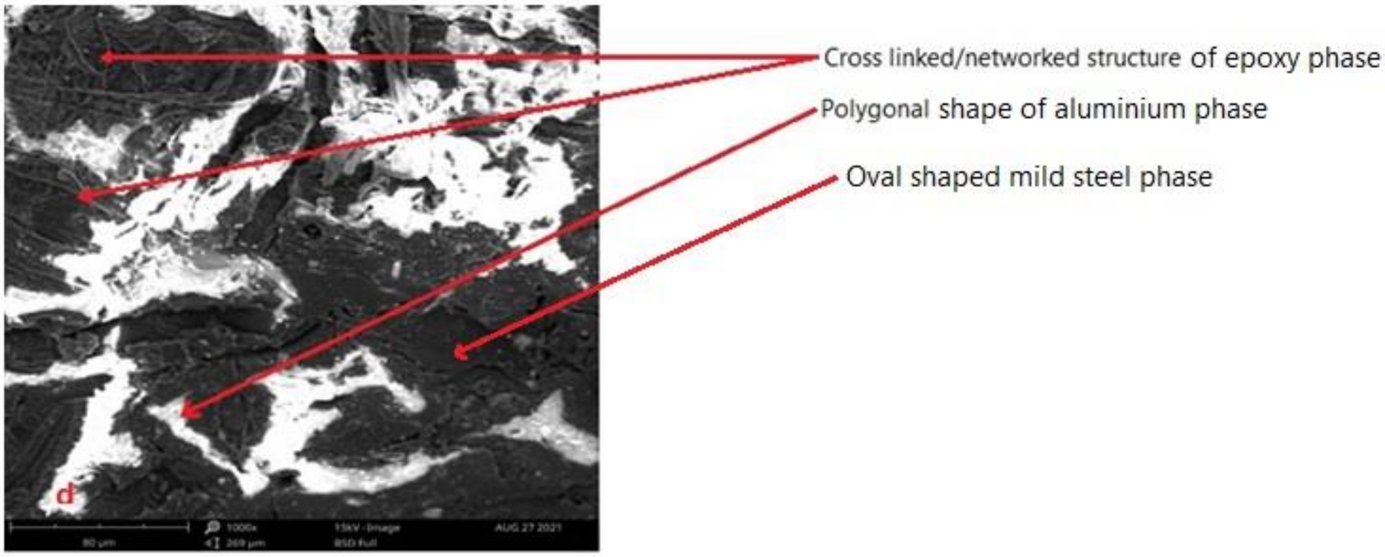


Fig. 2. Microstructure of the specimens (a) Epoxy resin and hardener (b) 5 wt. % hybrid polymer matrix composite (c) 10 wt. % hybrid polymer matrix composite (d) 15 wt. % hybrid polymer matrix composite

4.2. Water Absorption

The water absorbed by the specimens increased from 24 hrs to 72 hours as illustrated in Fig. 3 indicating that there were pores in their microstructure. However, water absorbed was constant from 72 to 144 hours indicating saturation. The diffusion of water into the microstructure of the specimens can cause changes in the structure and increase flexibility and break up, which could have an adverse effect on the mechanical characteristics [12]. This leads to an increase in the space of the polymer molecules, which can reduce their bonds and will cause a reduction in resistance to applied stress [10]. The water could have an adverse effect on the characteristics of polymers [10, 13]. The hybrid composite specimen exhibited the lowest water absorption of 0.011 %, which is because of the strong bond between the hybrid reinforcing particles and epoxy resin.

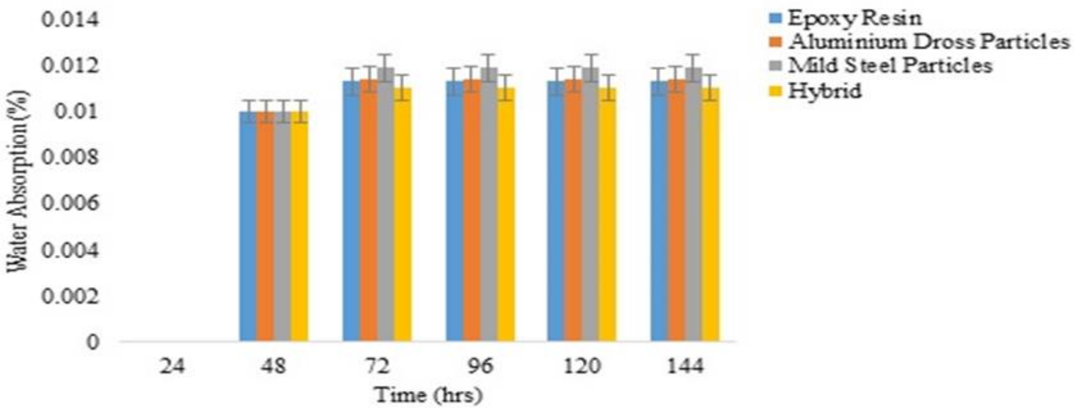


Fig. 3. Water absorption against the specimens' immersion time

4.3. Tensile Strength

The mechanical properties of polymer matrix composites depend on some factors such as stress-strain behaviour of filler (particulate) and matrix phases, concentration, orientation and distribution of filler. The stress-strain curves of the specimens are illustrated in Fig. 4. Generally, all the composites exhibited greater tensile strength than epoxy resin. The epoxy resin exhibited tensile strength of 50.01 MPa while the hybrid composite specimen reinforced at 15 wt. % demonstrated the highest tensile strength of 81.05 MPa. There is a gradual increase in tensile strength of the specimens as reinforcement increased to 15 wt. % as illustrated in Fig. 5. The increase in tensile strength could be because of the reduced or no porosity and strong bond between the hybrid reinforcing particles and epoxy resin. This agrees which agrees with the report by [14]. The decrease in the tensile strength beyond 15 wt. % reinforcement may be due to reduction in space between the particles, which enhanced stress raiser/riser that interrupted the distribution of stress in the composite. This agrees with the report by [15].

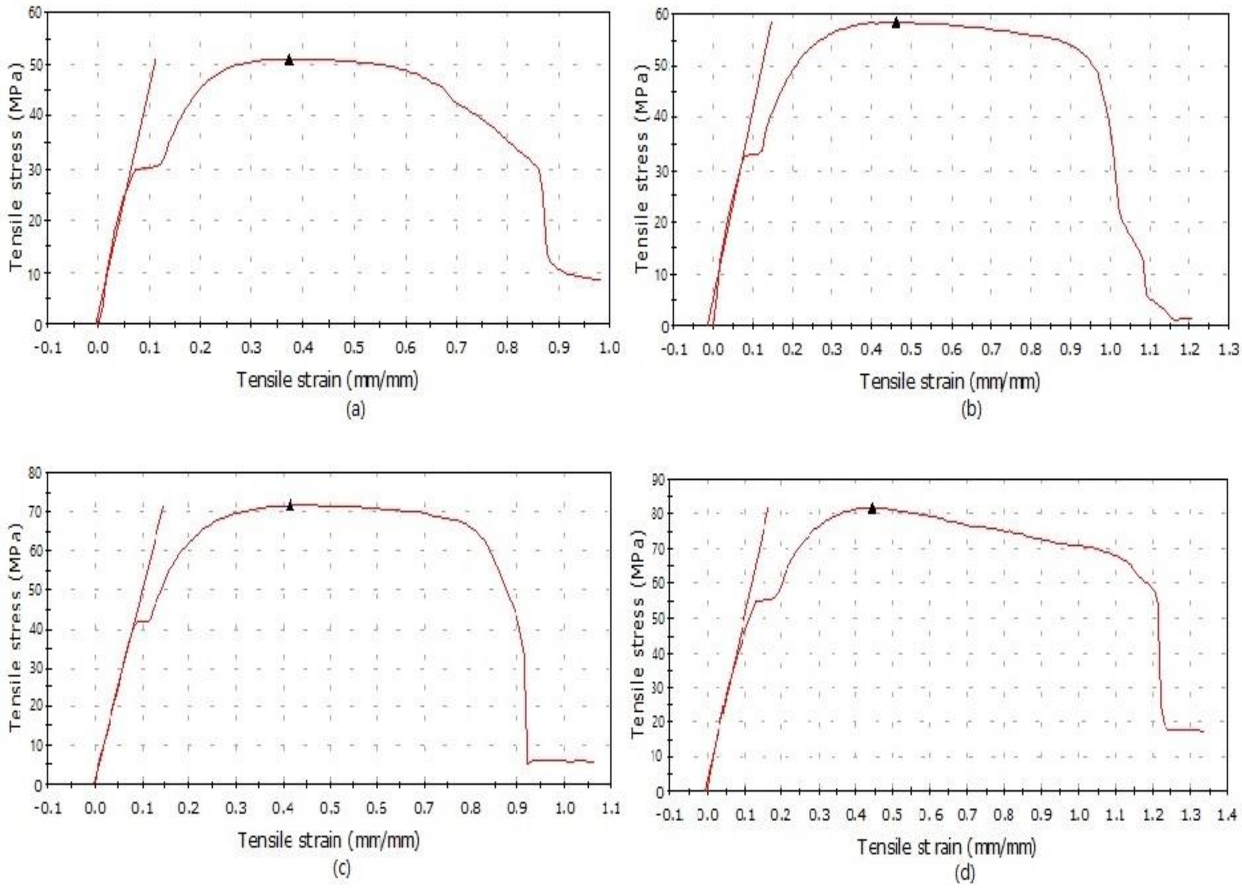


Fig. 4. The stress-strain curves (a) epoxy resin (b) 15 wt. % aluminium dross reinforced specimen (c) 15 wt. % mild steel iron reinforced specimen (d) hybrid specimen

4.4. Elastic Modulus

The elastic modulus is elongation of a material under stress when deformation is elastic. It gives an indication of the stiffness of the material. The composites demonstrated a gradual increase in elastic modulus as reinforcement increased up to 15 wt. % as illustrated in Fig. 6. Generally, the elastic modulus of the specimens is higher than their tensile strength values as illustrated in Fig. 5. The epoxy resin exhibited elastic modulus of 200 MPa but the hybrid composite demonstrated the highest elastic modulus of 600 MPa at 15 wt. % filler content. The strong bond of the specimens reduced elongation when the specimens were under stress (elastic deformation). Hence, the values of the modulus of elasticity are higher than the ultimate tensile strength. The strong bond between the particulate and epoxy resin was responsible for the increase in elastic modulus. Above 15 wt. % reinforcement, there was a decrease in the modulus of elasticity of the specimens. This could be because of the equality of the strain energy stored in epoxy resin with the bond of particulate with epoxy resin during stress. This caused the particles-epoxy resin interface to debond thereby decreasing the elastic modulus, which agrees with the earlier report by [16].

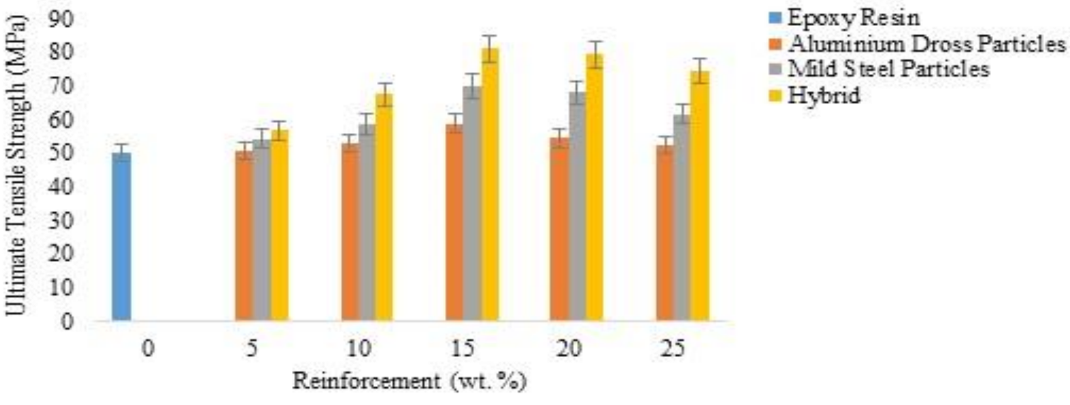


Fig. 5. Specimens' ultimate tensile strength against reinforcement

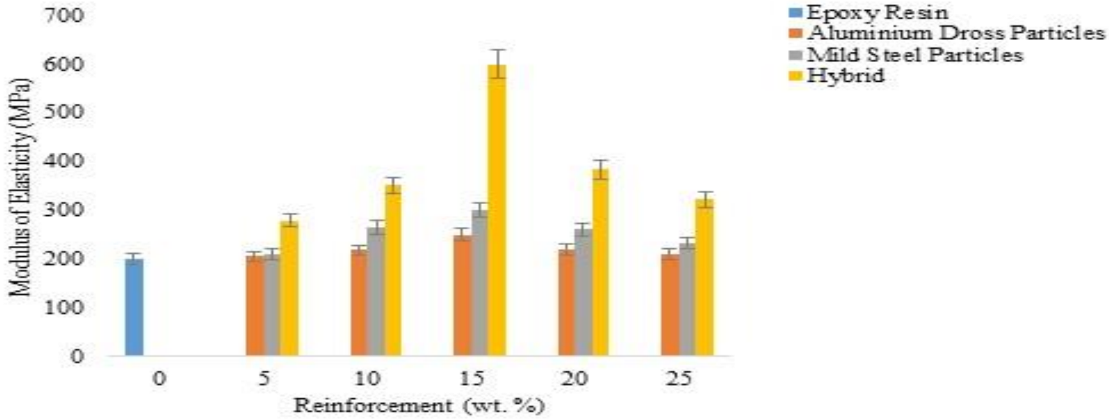


Fig. 6. Specimens' modulus of elasticity against reinforcement

4.5. Impact Energy

The energy absorbed during fracture of a material is its impact energy. This gives an indication of the toughness of the material. Generally, polymers do not exhibit high impact energy. As illustrated in Fig. 7, the composite specimens exhibited gradual increase in impact energy as reinforcement increased up to 15 wt. %. The unreinforced epoxy resin exhibited impact energy of 7 J while the hybrid composite specimen reinforced at 15 wt. % exhibited the highest impact energy of 17.24 J, which is 146.3 % greater than that of the neat epoxy resin. The ductile nature of the filler (mild steel and aluminium particulate) phase enhanced the impact energy of the composites, which agrees with the report by [17]. The strong bond between the reinforcing particles and epoxy resin reduced elongation or elastic deformation thereby improving the impact energy of the composites. The bond also restrained crack growth and dislocation in the composites.

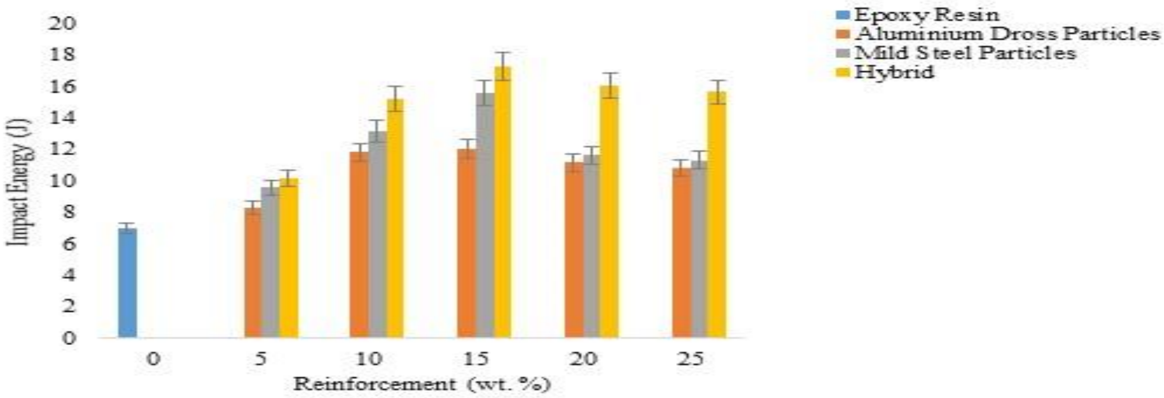


Fig. 7. Impact energy against specimens' reinforcement

4.6. Hardness

The epoxy resin exhibited hardness value of 56.4 BHN as illustrated in Fig. 8. When compared with epoxy resin, the composites demonstrated a gradual decrease in hardness, which indicates that epoxy is harder. The decrease in hardness is because of the increased content of the ductile reinforcing particles, which agrees with the report by [17].

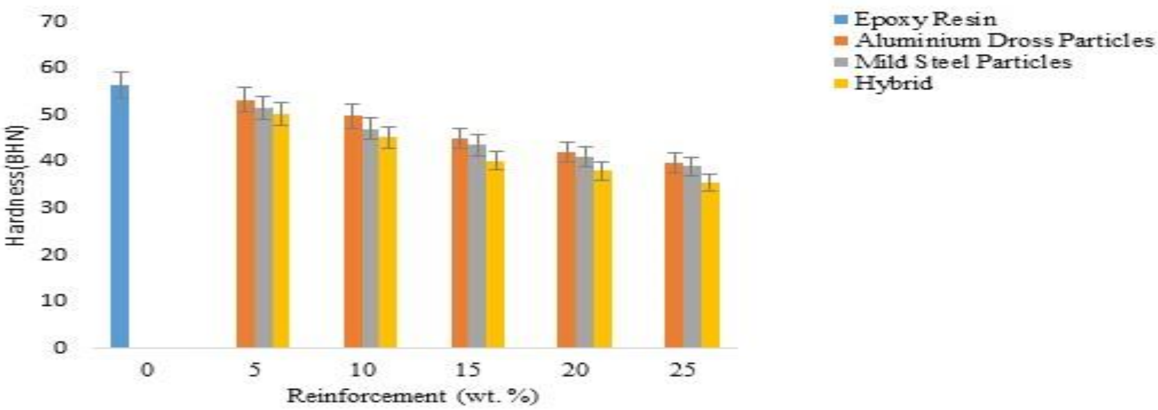


Fig. 8. Hardness against specimens' reinforcement

5. CONCLUSION

Mono reinforced and hybrid-polymer matrix composites were developed and characterised employing particulate of mild steel and aluminium dross, and epoxy resin as input materials. The hybrid composite demonstrated the lowest water absorption of 0.01 % after 144 hours. It also demonstrated the greatest tensile strength, elastic modulus, and impact energy of 81.05 MPa, 600 MPa and 17.24 J respectively at 15 wt. % filler content. The strong bond between filler and epoxy resin contributed to the reduction of water absorption and improved the tensile strength, elastic modulus, and impact energy. The reduction in hardness is because of increased content of ductile reinforcing particles. The results indicated that the hybrid polymer matrix composite has potential for applications where low strength is required.

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