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Development and Characterization of E-Glass Particulate Reinforced Epoxy Composite for Automobile Application

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ABSTRACT

The structure and mechanical properties of epoxy composites reinforced with E-glass particles have been evaluated to assess the possibility of using the composite as a new material for car bumper fabrication. Epoxy resin of the type LY556 reinforced with 5 – 25% of E-glass particles added at 5% intervals was investigated. The fabrication of E-glass particle reinforced epoxy composite was successful and a prototype car bumper was made. The newly developed E-Glass particles/epoxy composites were characterized for their mechanical and structural properties using Thermo-Gravimetric Analysis (TGA), Differential Scanning Calorimetry (DSC), Scanning Electron Microscopy (SEM), X-Ray Diffraction Analysis (XRD), Tensile, Flexural, and Impact tests. The results showed that 20 wt. % glass particle addition gave the ultimate mechanical properties with tensile and flexural strengths of 154.5 and 181.55 MPa respectively. SEM morphology had also shown good adhesion between fibers and polymer matrix up to 20 wt. % glass particle addition with minimal segregation of reinforcement glass particles. Thermal stability of the composite was not impaired going by a stable degradation temperature (Td) after E-glass particles addition. A prototype bumper was fabricated from epoxy-15 wt% E glass particle composite possessing peak impact energy.

1 Introduction

Since many modern technologies require materials with combinations of properties that cannot be met by conventional metal alloys, ceramics and polymeric materials, there has been an increasing demand for improvised materials including composites. Unlike alloys in which phases are formed by reactions or phase transformations; composites are tailored for various properties by choosing their components, proportions, distribution, morphologies, degrees of crystallinity, their crystallographic textures, as well as the structure and composition of the interface between components. The uniqueness of composites is that the engineering properties which are required in the end product can be achieved by a careful selection of the matrix and the reinforcing phases [1].

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Within the family of composites, polymer matrix composites are a major category with a wide range of applications. There are many types of polymeric materials. Among them, thermosetting epoxy resin systems are the most widely used and they are known to produce a strong network structure characterized by heavily cross-linked monomers. They also have many unique properties including the fact that their elastic limits correspond to their rupture limit, meaning that they do not yield easily. To mitigate the limitations of thermosetting polymers such as epoxy resin that develop brittle structure due to excessive cross-linking reaction or curing, researchers continue to investigate the use of reinforcers, fillers and other additives to enhance their applications in different sectors [2-6].

The reinforcing phases in polymer composites, are often harder, stronger, and stiffer than the matrix. They thus provide strength and stiffness. However, according to Campbell (2010), the practical limit of continuous fiber reinforcement that can be added to form a composite is within 70%. This is because at higher percentages, there is too little matrix to effectively support the reinforcement. Compared to continuous fiber composites, particulate composites are weaker and less stiff. However, ease of even dispersion of particulate fillers within the matrix results in isotropic composite and eliminate directional properties common with fibre reinforced counterparts. Also, their strengths can however approach those of continuous-fiber composites if good adhesion between particulate reinforcement and the matrix is achieved [1, 7]. In particulate composite systems, strength and toughness are strongly affected by three major factors including particle size, particle-matrix adhesion and particle loading. A good composite design with careful selection of particle size and particle loading level always give ideal composite with fortified particle-matrix adhesion [1, 7]. Fu *et al.* [8] investigated three factors on composites' stiffness, strength and toughness for a range of particulate composites. In that study, it was also reported that the strength of the composite produced depends on effective stress transfer between filler and matrix, while toughness or brittleness is controlled by adhesion. It was further established that composites' stiffness depends significantly on particle loading and not particle-matrix adhesion since the fillers have much larger modulus than the matrix. According to the same study however, there is a critical particle size, usually in nanoscale, below which the composite stiffness is greatly enhanced due to the significant effect of the particle size [8].

Manjunatha *et al.* [9] studied the effect of particles size and volume fraction on mechanical properties of coconut shell particle reinforced epoxy composites. The study established that the mechanical properties of the developed composites were substantially affected by both the size as well as the content of filler particles. Impact and even tensile and flexural properties were however found to decrease with the increase in the filler particle size and filler volume fraction beyond a limit. The composite with 40% filler volume fraction and 0.25 mm particle size exhibited highest tensile stress of 32.84 MPa, flexural strength of 52 MPa, and impact strength of 65 kJ/m². In all cases, the coconut shell particle filled epoxy composites generally indicated hardness values higher than that of neat epoxy. The highest value being at 0.25 mm filler particle size and at 40 % filler volume fraction.

Bello *et al.* [3] developed epoxy/aluminium composite and optimized its tensile properties using regression models. Result of their study established epoxy/10% aluminium particulate nanocomposite a candidate material for automobile bumper application [3].

In this present research, development of epoxy/E-glass particulate composite for automobile bumper application is a focus. Many studies on polymeric composites have been established in literature. However, composite development approach from epoxy and recycled glass for bumper application is not common in the literature.

2 Materials and Methods

Mixture of room temperature curing epoxy resin (LY556) belonging to the diglycidyl ether of bisphenol A (DGEBA) and amino based hardener (HY951) in a ratio 3:1 was used as the matrix while 150 μ m glass particles were used as reinforcement. The epoxy resin and hardener were mixed manually using a glass rod for 3 minutes after which the mixture was poured into a wooded mould whose cavities are replica of standard samples for analysis. The mixture was left in the mould until cross linking reaction completed after which the samples were removed from the mould. The produced samples in this step represent epoxy without addition of reinforcement. After this step, 5 wt% of the glass particles was added to epoxy/hardener mixture and stirred manually until homogeneous mixture was achieved after which the mixture was poured into the wooden mould. The epoxy/5wt% E-glass composite (GA) samples were removed from the mould curing at room temperature. The process was repeated with an increment in glass particles additions up to 25wt% addition at 5wt% interval. A designed formulation guiding the development of epoxy-E glass composite is shown in Table 1. Structural properties of the developed epoxy polymer and those of epoxy-E glass composites were evaluated using X-ray diffraction,

Thermogravimetry and scanning electron microscopic techniques. Also, their mechanical properties were also examined using ASTM D638 for tensile, ASTM D-790 for flexural and ASTM Standard E 602-91 for impact energy tests with slight modifications. Tensile and flexural tests were carried out at Engineering Materials Development Institute (EMDI) Akure, Ondo State, Nigeria. A bumper prototype was designed using dimensions taken from an original bumper sourced from the Ladipo Auto Spare Parts market in Lagos, scaling down a ratio of 1:3. SolidWorks software was used for the design. Two-dimensional mould parts models were presented in Fig. 1 while Fig. 2 displays the 3-dimensional mould fabricated for epoxy-E glass production. In each of the mechanical tests, three (3) different samples were analysed at each formulation and the result obtained were averaged to ensure accuracy and reliability of the results. Flexural strength, deformation and modulus were estimated using formulas in Equations 1, 2 and 3, respectively. F is the applied load; L is the span length (60 mm), b is the thickness of the sample (10 mm) and w is the width (6 mm). E is the flexural modulus as used in the equations and the samples were loaded centrally using three-point method in line with [10].

$$\sigma_{flex} = \frac{3FL}{2bw^2} \quad (1)$$

$$\varepsilon_{flex} = \frac{\text{Flexual extension } (l_1 - l_0)}{\text{Original span length } (l_0)} \quad (2)$$

$$E_{flex} = \frac{\sigma_{flex}}{\varepsilon_{flex}} \quad (3)$$

Table 1-Identification Codes for the Developed Composite Mixtures

Identification	Volume of E-glass Particles	Volume of Epoxy
ample GA	0%	100%
Sample GB	5%	95%
Sample GC	10%	90%
Sample GD	15%	85%
Sample GE	20%	80%
Sample GF	25%	75%

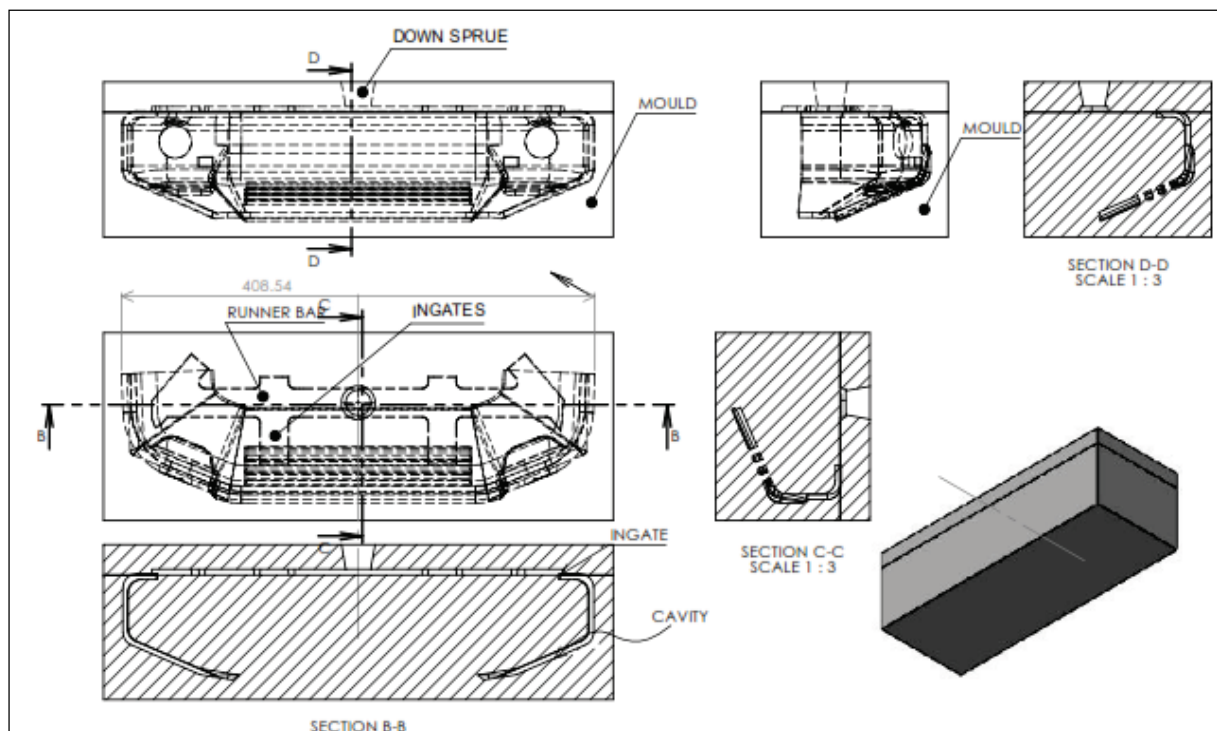


Fig. 1- 2-Dimensional models showing parts of bumper prototype mould



Fig. 2 - Picture of Actual Car Bumper Mould

3 Results and Discussion

3.1 X-Ray Diffractometric Properties of E-glass Reinforced Composite

The XRD pattern of the unreinforced epoxy polymer is shown in Figure 3. Mixture of broad and sharp peaks as shown in Figure 3 suggests that the epoxy is polymer is semi-crystalline in nature. The observed phases on the sharp peaks are simple organic compound that might be produced during curing of the epoxy resin by the hardener in addition to the complex amorphous indicated by the unresolved broad peak. Semi-crystalline structure of epoxy polymer reduces dielectric properties of the polymer and enhances magnetic shield/electric discharge properties which are expected of any candidate materials for exterior automobile applications such as car bumper which is one of the targeted application for the developed epoxy E-glass composites. Addition of glass particles modified structure of the epoxy matrix as revealed in Figures 4-5 which appear different from Figure 3. Although Figures 3-5 show appearances of broad and sharp peaks, orientation of the structures are different from one another due to different compounds or phases matched with the peaks. As earlier disclosed in this write-up, phases in Figure 3 are all simple organic compound. Those in Figures 4-5 contain both inorganic refractory silica (SiO_2) and organic compounds more complex than the organic compounds in Figure 3. Since properties of a material is a function of its properties [11], epoxy polymer and its epoxy-E glass composites are likely to behave differently when loaded mechanically under the same conditions. Similar explanation is found in [2, 3].

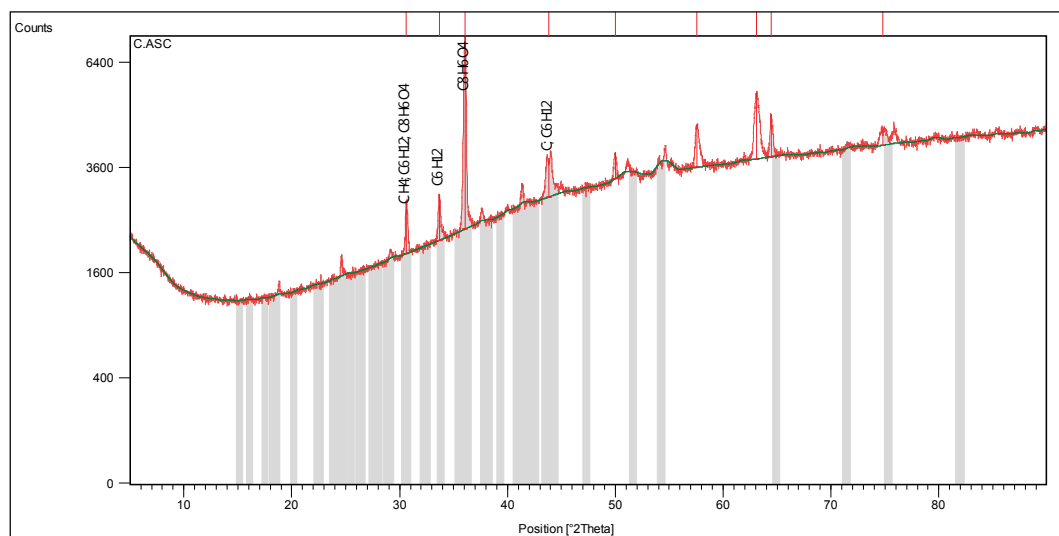


Fig. 3 XRD pattern for Neat Epoxy

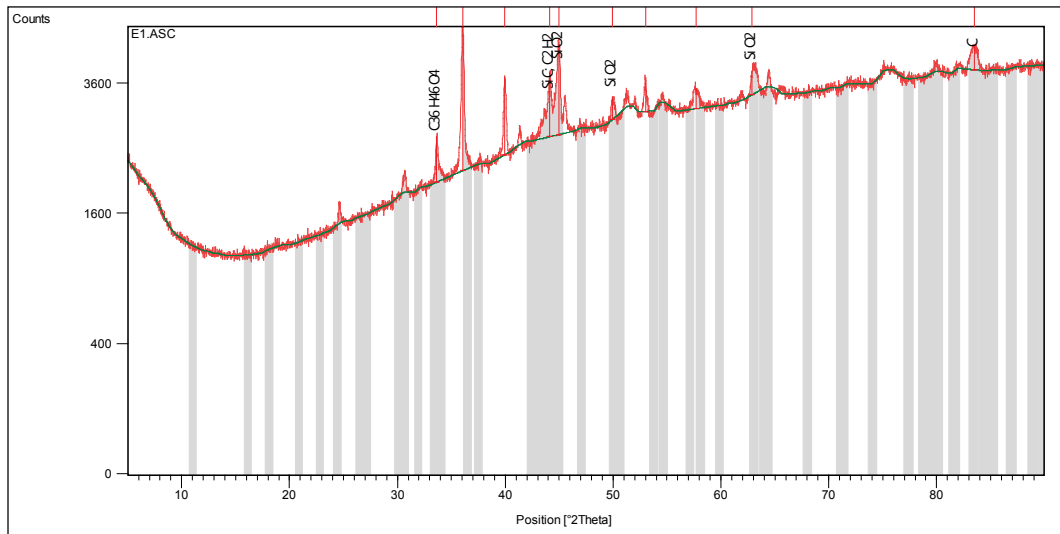


Fig. 4 XRD pattern for 5 wt. % Glass Particle /Epoxy Composite Sample

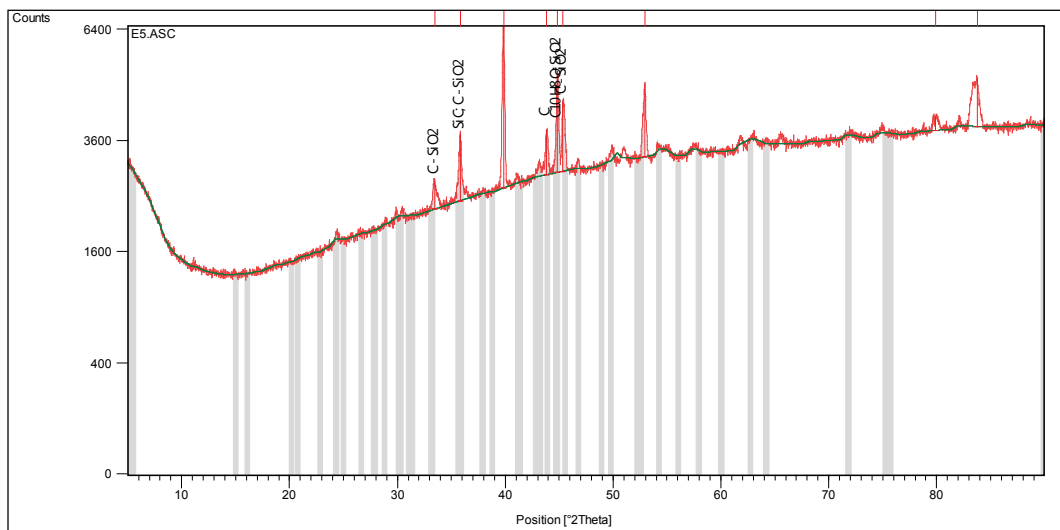


Fig. 5 XRD pattern for 25 wt. % Glass Particle /Epoxy Composite Sample

3.2 Mechanical Properties of E-glass Reinforced Composite

Tensile properties of the epoxy/E-glass composites are shown in Figures 6-7. Both Figures 6-7 indicate increases in tensile strength from 10wt% of glass particles up to 20 wt% addition. Degradation in tensile strength and modulus above 20wt% may be linked with inability of the matrix to bind the particles together. Formulation in Table 1 reveals a decrease in the wt% of the epoxy matrix with an increase in the proportion filler/reinforcement added to the matrix, implying a reduction in the bonding efficiency of the matrix. Since tensile tests involving pulling of the composites, weak bonded particles are likely to break off easily from the matrix and causes in reduction in the resistance offered by the composites to the externally applied load or stress. The composite GB is expected to have greater tensile strength and modulus following increasing trend up to 20wt% additions of glass particles. Its smaller tensile strength and modulus may not be linked to poor interfacial adhesion because of its higher proportion of epoxy to bind smaller fraction of glass particles together when its proportion of epoxy and glass particle is compared with each of those of other epoxy-E glass composites. Presence of defect or flaw within GB may be responsible for its lower tensile strength and modulus. Similar proposition is found in [12-15]. Moreover, observation in Figures 8-9 presenting flexural strength and modulus of epoxy-E glass composites is like those of tensile strength and modulus in Figures 6-7. It can be inferred that glass particle reinforced epoxy composites exhibited single linear inelastic deformation until failure with plastic deformation. The addition of glass particles to the epoxy polymer matrix however resulted in increases in tensile strength, tensile modulus and flexural strength of the composite.

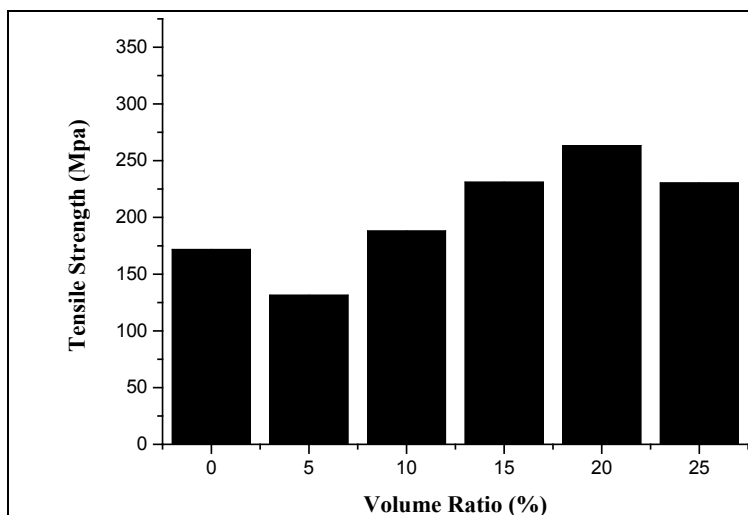


Fig. 6- Effect of Volume Ratio of Glass Particle Reinforced Epoxy Composite on Tensile Strength at Break

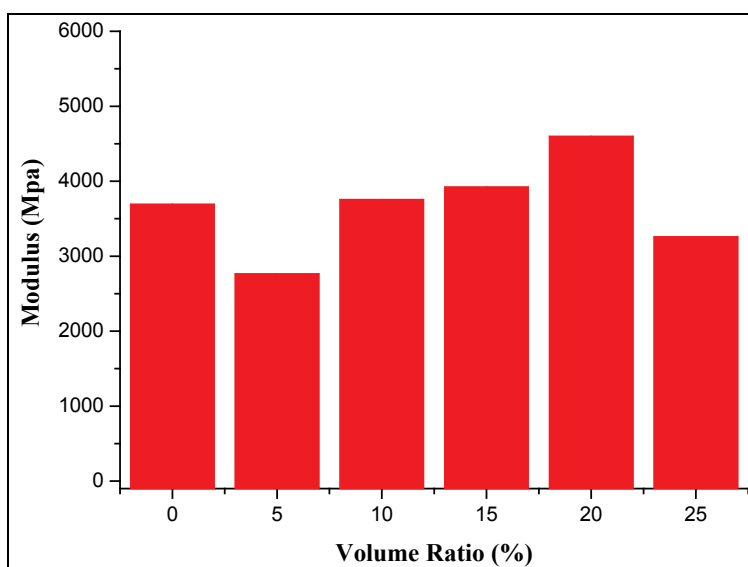


Fig. 7- Effect of Volume Ratio of Glass Particle Reinforced Epoxy Composite on Tensile Modulus

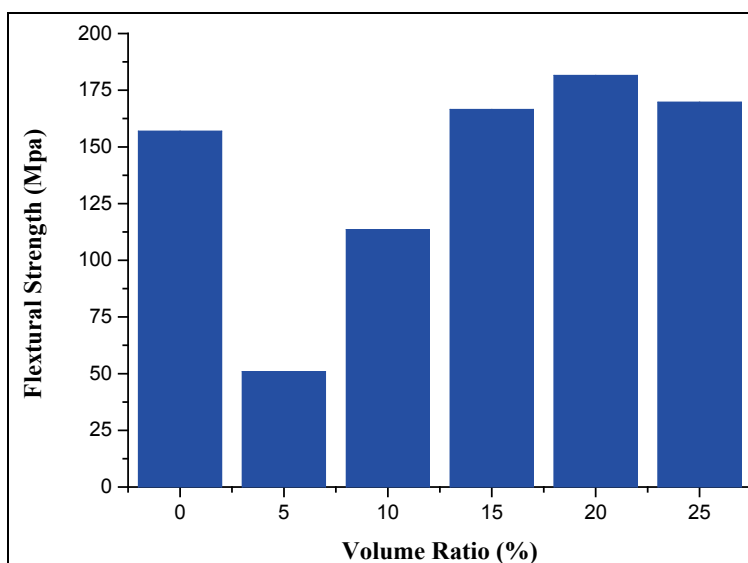


Fig. 8- Flexural Strength of Glass Particle Reinforced Epoxy Composite on Flexural Modulus

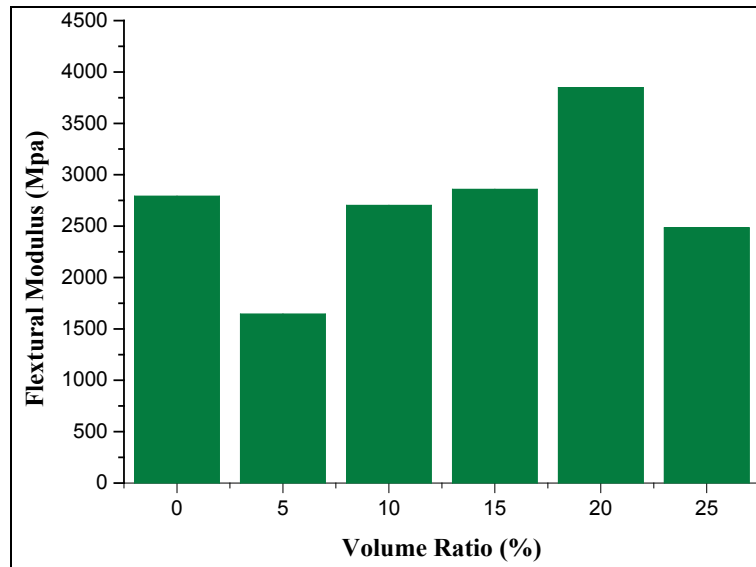


Fig. 9 Effect of Volume Ratio of Glass Particle Reinforced Epoxy

This is because both polymer and glass particles are hydrophobic and compactable [3]. This steady increase of strength of the reinforced composite was made possible due to the absence of defects, such as voids, and weak interface bonding between matrix and reinforcement resulting in delayed shear yielding of the composites [16]. Also, decreases in both tensile and flexural strengths observed at 25% volume ratio were attributed to the segregation of the excess volume of particles added to the epoxy which acted as stress raiser as there was reduced adhesion resulting in inefficient stress transfer. Similarly, an increase in the glass particle content also increased the micro-spaces between the glass and the matrix, which weakened the matrix-reinforcer interfacial adhesion. Figure 10 showed that impact energy continuously reduced with increasing volume fraction of glass particles but overall, minimal reduction in impact energy occurred at 15 wt% addition of glass particles. Impact resistance has been reported to depend on energy dissipation mechanisms in which the interface properties and the complex stress concentration of the type and size of particles and geometry of the fibers play an important role on the control of the composite fracture [17].

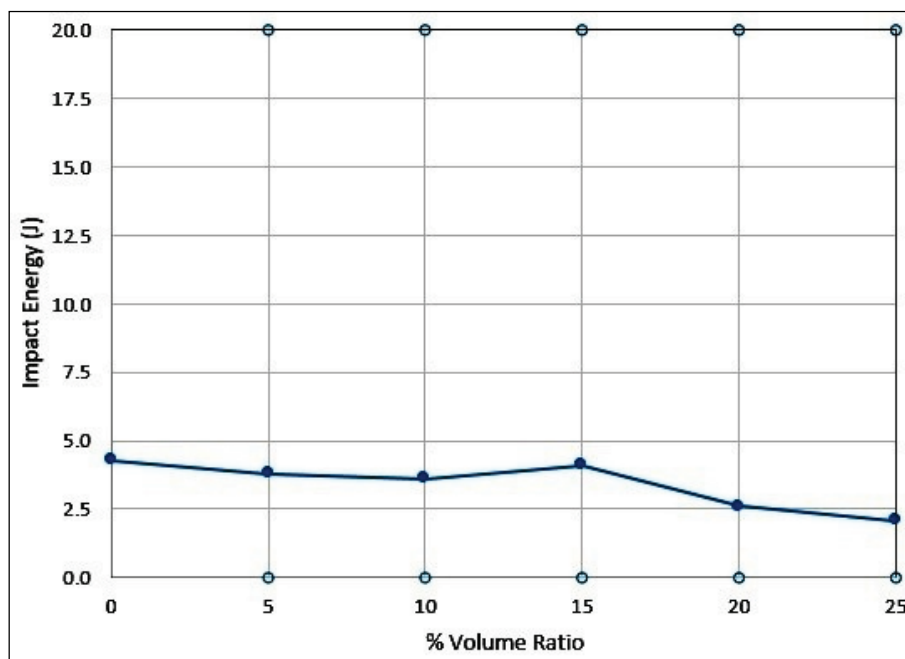


Fig. 10- Effect of Volume Ratio of Glass Particle on Impact Energy

3.3 Thermal Stability Properties of Epoxy-E Glass Composite

Thermographs of neat epoxy composite and reinforced epoxy composite are shown in Figures 11-13. Improved thermal stability of composite was achieved by the addition of reinforcements as exhibited by slower degradation in the first two stages of the 3-stage degradation process.

Analysis of the results however indicated only slight differences between the evolution profiles of the thermal degradation TGA of all samples. In the neat epoxy polymer as shown in Figure 11, the first decomposition stage occurred at 100 – 335°C with an accompanying 17 % weight loss. The second decomposition stage was then observed at 335 – 405°C with 65% weight loss observed. The third decomposition stage was observed at 405 – 500°C, where only 5% weight loss took place in the material. The neat epoxy polymer showed low residue due to the absence of char.

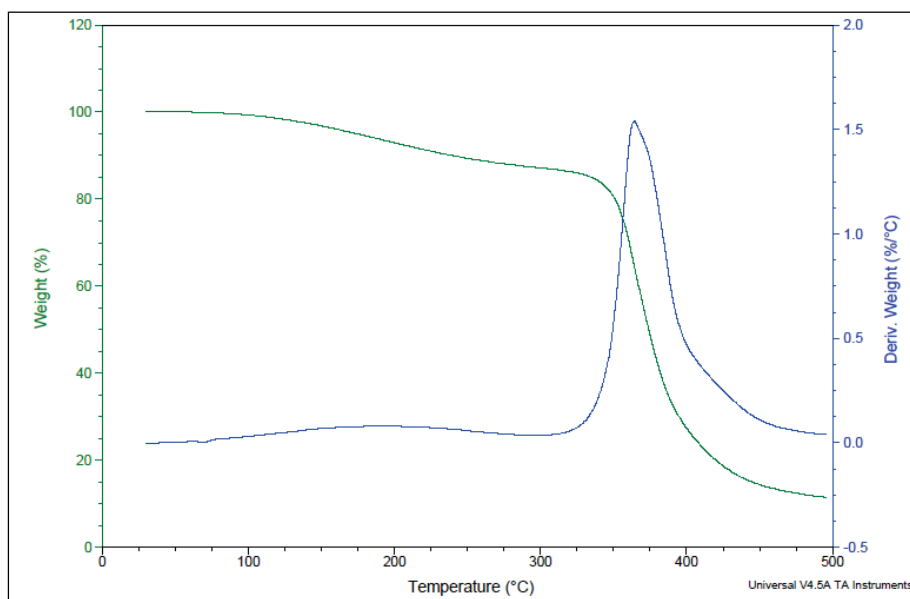


Fig. 11 Thermograph of control epoxy sample

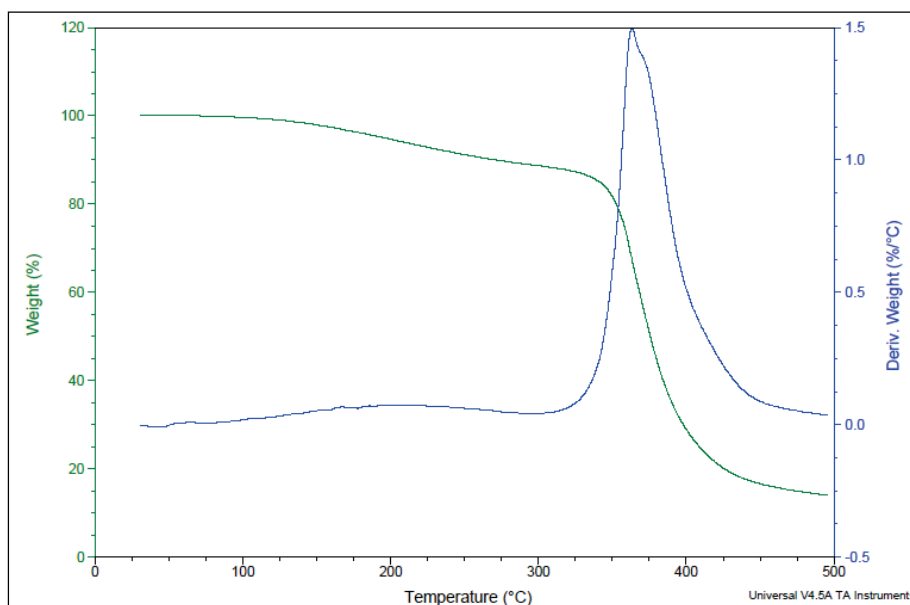


Fig. 12 Thermograph of 5 wt. % Glass Particle /Epoxy Composite Sample

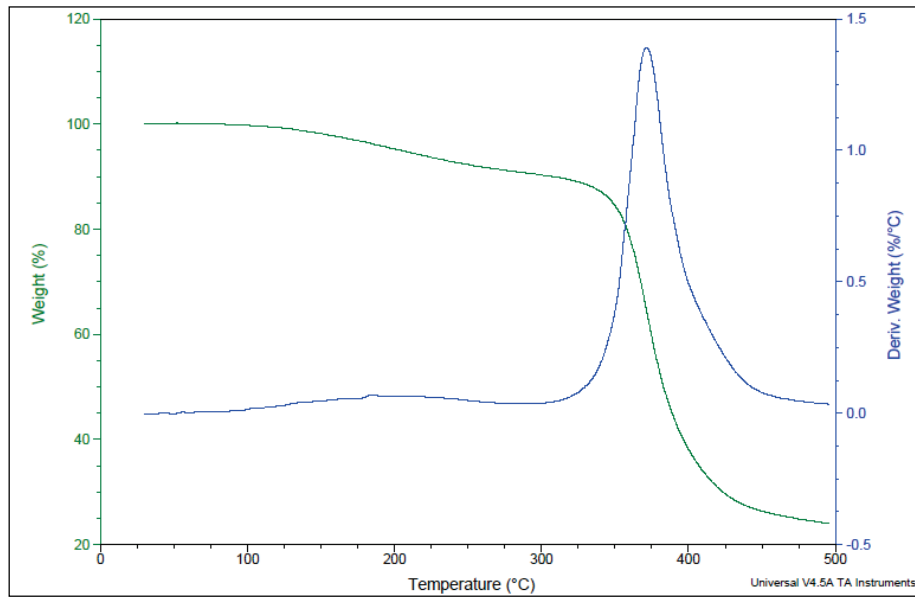


Fig. 13 Thermograph of 25 wt. % Glass Particle/Epoxy Composite Sample

Figures 12-13 show the TGA of GB and GE, respectively. The first decomposition stage was observed at 100 – 335°C and it shows about 20 wt% loss, which was higher than that of pristine epoxy polymer. The second decomposition stage was observed at 335 – 405°C. At this temperature range, 55% weight loss was observed. The third decomposition stage was observed at 405 – 500°C and 20% loss was observed with the composite. The glass particle reinforced composite showed better residue than neat epoxy, thus the inclusion of the reinforcing fibers improved the thermal stabilities of the composites. Covalent bonds can be assumed to have been formed in the composite systems but dispersion of the glass fiber particles in the epoxy matrix is also an important factor contributing to the enhanced thermal stability [18].

3.4 Fracture Properties of Epoxy-E Glass Composite

Figure 14-16 presents micrographs of the fractured surface of neat epoxy polymer and glass particle reinforced composites, respectively. There are two elongated strand-like structures having different networks of crack propagation in Figure 14.

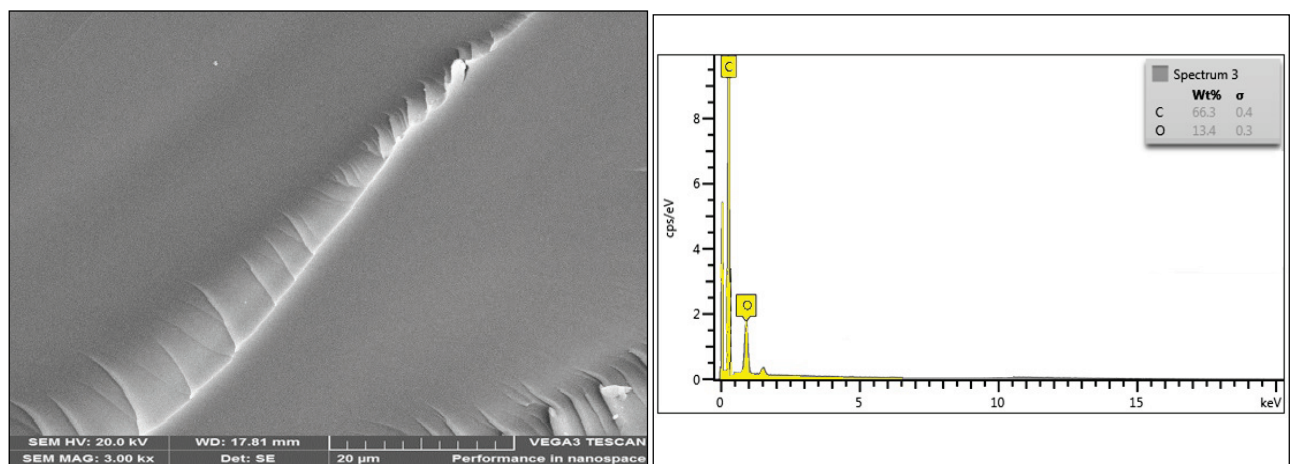


Fig. 14 SEM/EDX of Fractured Surface of Neat Epoxy

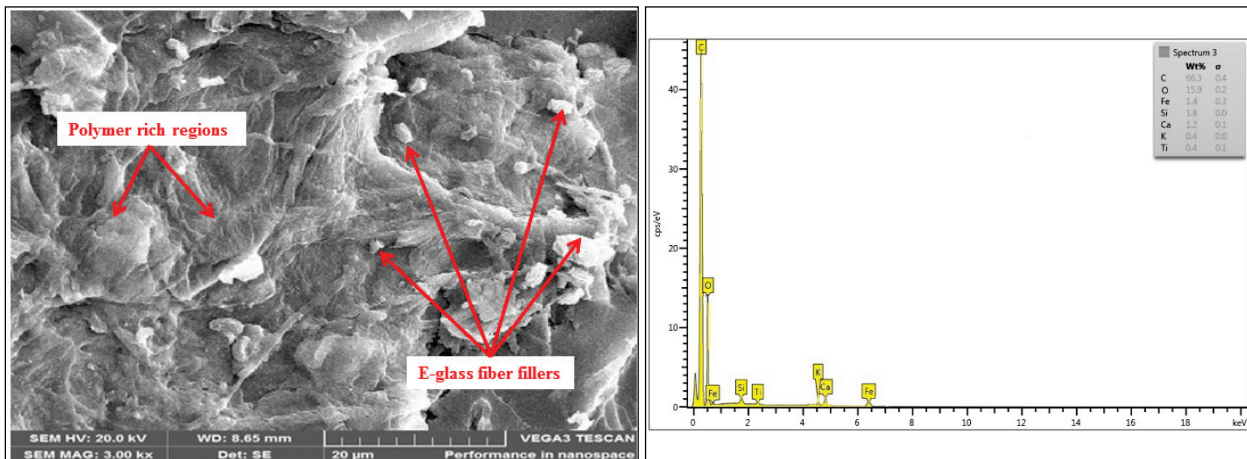


Fig. 15- SEM/EDX of Fractured Surface of 5 wt% Glass Particle

Propagation of cracks leading to failures through crack deflection mechanism is evident from Figure 14. Presence of carbon and oxygen as expected from epoxy polymer agrees with XRD peak phases in Figure 3. The composite containing 5wt% glass dispersed particles showed good adhesion between the polymer matrix and reinforcement as shown in Figure 15. A good adhesion observation also in Figure 16 is compatible with an increase in mechanical properties obtained for the composites up to 20wt% addition. Presence of dispersed particles even remained unbonded from the matrix after the composite pull-out during the tensile tests played stiffening roles in enhancing resistance to cracks propagation. Those particles acted as barriers to crack movement, leading to crack meandering in a zig zag manner during their propagation as it is evident from Figure 16. Formation of zig zag crack propagation network can be explained by firm crack blockages by glass particle causing numerous adjacent crack deflections. Furthermore, energy dispersive X-ray spectrograph in Figure 16 shows the chemical composition of epoxy-E glass composites.

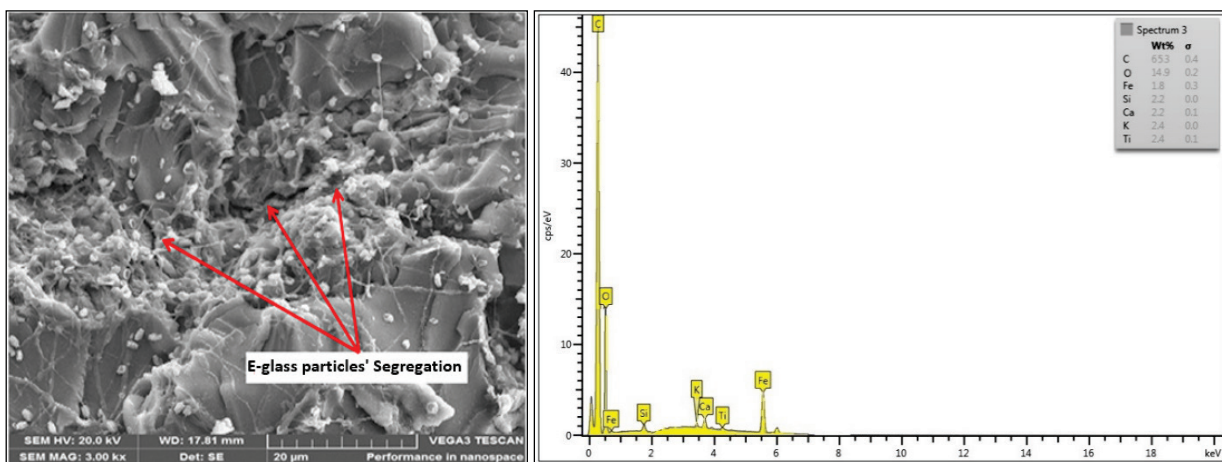


Fig. 16- SEM/EDX of Fractured Surface of 25 wt% Glass Particle Reinforced Epoxy Composite

3.5 Epoxy-E Glass Bumper Prototype

Among basic functional properties of automobile bumper: impact energy; tensile and flexural properties, impact energy value is the most paramount because of the functional requirement of energy absorption of the automobile bumper [3, 19-21]. On this note, epoxy-15%-E glass composite having peak impact energy is selected as a possible candidate for automobile bumper application. The experimental investigation leading to this concept was translated into bumper prototyping as described under the Material and Method Section of this article. The developed epoxy-15wt% E Glass composite is presented in Figure 17.



Fig. 17: Fabricated Epoxy-E Glass composite bumper prototype

4 Conclusions

This study revealed production of polymeric composite from pristine epoxy and glass particles synthesised from discarded florescent tube. Results obtained from structural and mechanical investigation carried out on the developed composite revealed a peak impact energy of 4.35 J at 15wt% of glass particle addition to epoxy matrix. A similar improvement was obtained in respect of tensile and flexural strength. An increase in the thermal stability due to glass particles addition to the epoxy was also observed. Degradation in mechanical properties was noticed at 25wt% of glass particle addition and attributed to saturation of the matrix with excess glass particles.

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