Iranian Journal of Materials Science & Engineering Vol. 13, Number 1, March 2016

CHARACTERIZATION OF SHORT E-GLASS FIBER REINFORCED GRAPHITE AND BRONZE FILLED EPOXY MATRIX COMPOSITES

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Received: July 2015 **Accepted: January 2016**

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Abstract: *The mechanical characterization of short E- glass fiber reinforced, graphite and sintered bronze filled epoxy composite was carried out in this study. The aim of the present study was to develop tribological engineering material. In this study the flexural strength, theoretical and experimental density, Hardness and Impact strength of composites was investigated experimentally. The results showed that the increased percentage of graphite (10 to 15%Vol) and E-glass fiber (10 to 15%Vol) enhanced flexural strength (149 MPa) of the composite and the maximum flexural modulus (13.3 GPa and 13.1 GPa) was obtained for composite C2 and C5 respectively. Maximum hardness (84 on L scale) and impact energy (90 Joule) was obtained for the composite C6 with increased percentage of glass fiber and graphite filler. The metallurgical electron microscopic images were discussed to interpret the effect of graphite and sintered bronze on mechanical characterization of composite.*

Keywords: *Tribological material, Flexural strength, Density, Metallurgical electron microscope (MEM).*

1. INTRODUCTION

Polymer composites are made by physically combining two or more existing materials to give a multiphase material system. The desired tailored properties can be achieved by selecting appropriate combination of materials without change in its identity. Fiber reinforced polymer filled with particulate filler can be a viable alternative for tribological applications [1]. The system of matrix material may be thermosetting or thermoplastic polymer and the filler material or reinforcement may be ceramics, metal, carbon particulates or fibers. The most used reinforcing fiber for polymer is glass fiber. Glass fiber has very high strength and stiffness. The main function of reinforcing the polymer with fiber is to enhance the mechanical properties of polymers. The polymer composite exhibits combined properties, possessed by filler and reinforcement. Epoxy resins exhibit good adhesion with reinforcements, low shrinkage and low volatility. Because of their high strength to weight ratio, they are extensively used for a wide variety of structural applications as in aerospace, automotive and chemical industry. Moreover, addition of particulates or fibers in the epoxy resin improves its mechanical and thermal properties significantly [2]. Engineers designing tribo-components need to take care of working life span, wear and also enhance performance under critical conditions of loads, speeds, temperatures. The development of polymer composite for tribological application is area of interest of many researchers. Still higher strength tribo polymeric materials are required.

There is extensive study of mechanical properties of polymer composites reinforced with both natural and inorganic fibers. It was observed that size and volume fraction of filler and fiber play important role in improving strength and stiffness [3]. Because of the increasing industrial applications, epoxy composites filled with solid lubricant have been extensively studied. Many researchers found variation in properties of epoxy composites filled with solid lubricants viz. graphite, MoS_2, and PTFE. A comparative study of PTFE, graphite, MoS_2, and SnS_2 on sliding wear of epoxy matrix composite was reported by Jacobs et al. [4]. They observed that specific wear rate was reduced only for PTFE. Zhang et al. [5] observed improved tribological performance of 5–25wt% of PTFE and 5–30wt% of graphite at room temperature. Pettarin et al. [6] studied the effect of MoS_2 on the tribological behavior of polyethylene and fond that addition of 10 wt% of

[DOI: 10.22068/ijmse.13.1.28]

MoS_2 increased the wear resistance under both sliding and abrasive wear conditions. Many researchers [7–9] have proposed that solid lubricant alone will not improve the tribo-performance of neat polymer but fiber reinforcement will have major effect on the performance of composites. Suresha et al. [7] reported improved tribological properties of glass-epoxy composites filled with graphite. Kishore et al. [1] compared performance of two different levels 2.5 and 4.5 wt% of graphite in glass-epoxy composites. For higher graphite 4.5wt% they found a lower coefficient of friction and lesser wear for any combination of load and velocity. Zhang et al. [8] found that reduction in friction coefficient was possible by addition of more than 5wt% MoS_2, and decrease in wear rate was observed by addition of more than 10wt% MoS_2.

Bijwe and Indumathi [9] have reported on influence of fibers and solid lubricants on low oscillating wear of polyetherimide composites. 10% inclusion of GF inclusion showed highest wear resistance. Suresha et al. [10] also reported effect of fillers on friction and slide wear in glass-epoxy composite. The study revealed that with increase in sliding velocity, coefficient of friction and wear rate increases. Thomas et al. [11] reported effect of particle addition and fibrous reinforcement on epoxy-matrix composites for sliding conditions. The study revealed that the COF of EP/PTFE was approximately 30% lower than EP. Singhal and Chawla [12] reported that addition of 2 wt% of glass fiber reported increased compressive strength (104.7 N/mm^2) and impact strength (4.2 J). Joshi et al. [13] reported 4 fold increase in Vickers hardness and 8 fold decrease in moisture absorption rate for 32 vol% glass fiber composite. Varga et al. [14] modified the fiber surface and his study revealed that the tensile and flexural properties of glass woven fabric reinforced composites could be improved by 18.0% and 40.1% compared with untreated glass fiber containing polyester composite with same reinforcement. Satheesh et al. [15] reported mechanical properties of fly ash impregnated glass fiber reinforced polymer composite. The study revealed that 70 wt% of resin and 30 wt% of fiber showed a superior strength in tensile, compressive, flexural, hardness and impact properties. Sayer [16] reported elastic properties and buckling load evaluation of ceramic particle filled glass epoxy composites. The result indicated that the load carrying capacity of composites was significantly influenced by particle weight fractions, different particle sizes and different ceramic fillers. The addition of 10 wt% boron carbide particle to composite showed 42% increased critical buckling load value of composite. Raju et al. [17] investigated mechanical and tribological behaviour of particulate filled glass fabric reinforced epoxy composites. The results showed that 10 wt% addition of Al_2O_3 gave highest hardness value (72) and highest tensile strength of 352 MPa for 7.5 wt%. Guo et al. [18] reported the tribological and mechanical properties of epoxy with hybrid filling. The results showed that small amount of oil loaded microcapsules, grafted nano SiO_2 and short carbon fibers into epoxy lead to improved tribological and mechanical properties.

2. MATERIALS AND EXPERIMENTAL DETAILS

2. 1. Materials

Commercially available epoxy resin CY230 was used as matrix and chopped E-glass fiber was used as reinforcement. The fillers, graphite and sintered bronze (85/15) were also obtained from local vendor in Maharashtra, India. The curing agent selected was HY951. The particle size of graphite and sintered bronze fillers specified by manufacturer is 20 and 47 microns respectively and the length of chopped glass fiber is 6 mm. The densities of the materials provided by manufacturer are listed in Table 1. The elemental content in terms of volume percentage of glass fiber, graphite and sintered bronze in epoxy matrix with its designation is shown in Table 2. The volume percentage of glass fiber was kept constant (10 vol% and 15 vol%) for two different composition and the fillers, graphite and sintered bronze were varied between 5 vol% to 20 vol%.

[DOI: 10.22068/ijmse.13.1.28]

Table 1. Density of materials used in the composite.

Material	Size in micro-meter	Density (g/cm^3)
Epoxy resin	-----	1.1383
E-Glass fiber	14	2.62
Graphite	20	2.15
Sintered Bronze	47	5.3

2. 2. Fabrication of Composites

In this study, glass fiber reinforced, graphite and sintered bronze filled epoxy matrix composite specimens were manufactured using moulding box of size 200 x 300 x 3 mm by Hand Layup Technique. The moulding box surfaces were coated with wax polish, which acted as releasing agent for easy removal of the composite plate. Epoxy resin was heated at 1000 ˚C to remove moisture content and allowed to cool at room temperature. Glass fiber was then added to epoxy and mixed thoroughly. Graphite and sintered bronze powders were sonicated in sonicator and this mixture was slowly added in the epoxy glass fiber solution. At the end hardener HY951 was added in the proportion 10:90. This mixture of composite was stirred for about 30 minutes. The homogeneous mixture was powered in to the mould and the pressure was applied by mechanical clamping designed for composite preparation. For curing the composite, the following procedures were followed: 1hr at 1100˚C with mould under clamp pressure, 24 hr at room temperature and post curing :30 minutes at 1600˚C followed by 12 hr curing at room temperature. The same cycles were followed for all samples (C1 to C6).

Table 2. Details of the Composite Composition

<table>
<tr><th rowspan="2">S. no</th><th rowspan="2">Composite</th><th rowspan="2">Designation</th><th colspan="4">Composition (vol %)</th></tr>
<tr><th>Resin</th><th>E-Glass Fiber</th><th>Graphite</th><th>Bronze</th></tr>
<tr><td>1</td><td>C1</td><td>GF10/G10/B20</td><td rowspan="3">60</td><td rowspan="3">10</td><td>10</td><td>20</td></tr>
<tr><td>2</td><td>C2</td><td>GF10/G15/B15</td><td>15</td><td>15</td></tr>
<tr><td>3</td><td>C3</td><td>GF10/G20/B10</td><td>20</td><td>10</td></tr>
<tr><td>4</td><td>C4</td><td>GF15/G5/B15</td><td rowspan="3">65</td><td rowspan="3">15</td><td>5</td><td>15</td></tr>
<tr><td>5</td><td>C5</td><td>GF15/G10/B10</td><td>10</td><td>10</td></tr>
<tr><td>6</td><td>C6</td><td>GF15/G15/B5</td><td>15</td><td>5</td></tr>
</table>

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2. 3. Mechanical Tests

Three point bending tests were carried out on rectangular specimen using ASTM D 790 standard at a crosshead speed of 1.5mm/min, test specimens fabricated are shown in Fig. 1. All the specimens were flat and rectangular in cross section having thickness of 3mm. Hardness, Impact strength and density were experimentally calculated as per ASTM: D 785, ASTM: D 256 and ASTM: D 792 standards respectively. All the tests were carried out for five specimens and average results obtained were taken for each sample (C1-C6).

3. RESULTS AND DISCUSSION

3. 1. Flexural Properties

The flexural properties of the glass fiber reinforced, graphite and bronze particulate filled epoxy composites were tested and the results were plotted as shown in Fig. 3. From the Fig. 2 (a) it can be observed that the flexural strength of samples C1 to C3 goes on increasing and for C4 to C6 it goes on declining. For 10 vol% of glass fiber samples C1 to C3 the flexural strength increased with increase in graphite filler from 10 vol% to 20 vol%. On the other hand flexural strength declined for 15 vol% glass fiber C4 to C6 with increase in graphite filler form 5 vol% to 15 vol%. This is attributed to increase in volume percentage of graphite fillers. It can be noted from table1, that the volume percentage of bronze in samples was not much varying. Hence volume percentage of graphite and glass fiber was responsible for obtaining flexural strength of epoxy composites. Glass fiber reinforcement and graphite filler improved ability of material to resist bending of the composites.

Flexural modulus of samples C1 to C6 is shown in Fig. 3 (b). It is clear that the flexural strength is equally influenced by graphite and bronze filler along with glass fiber reinforcement. It is maximum (13.3 GPa) for 10 vol% of glass fiber with 15 vol% of graphite and bronze (C2) and (13.1 GPa) for 15 vol% of glass fiber with 10 vol% of graphite and bronze filler (C5). It indicate that equal volume percentage of graphite and bronze play important role in improving flexural strength, it might be because the sound and homogeneous samples.

3. 2. Measured and Theoretical Density

Fig. 3 shows theoretical and measured density of the glass fiber reinforced, graphite and bronze filled epoxy composites. The measured density of the prepared sample was (2.017 g/cc), found little bit lesser than theoretical density (2.078 g/cc). The measured densities for 15 vol% glass fibers and 5-15 vol% of graphite and 15-5 vol% pf bronze filled composite were close to theoretical density. On the other hand, for the composite with 20 vol% of glass fiber, volume fraction of voids found was 4.33%. This was attributed to

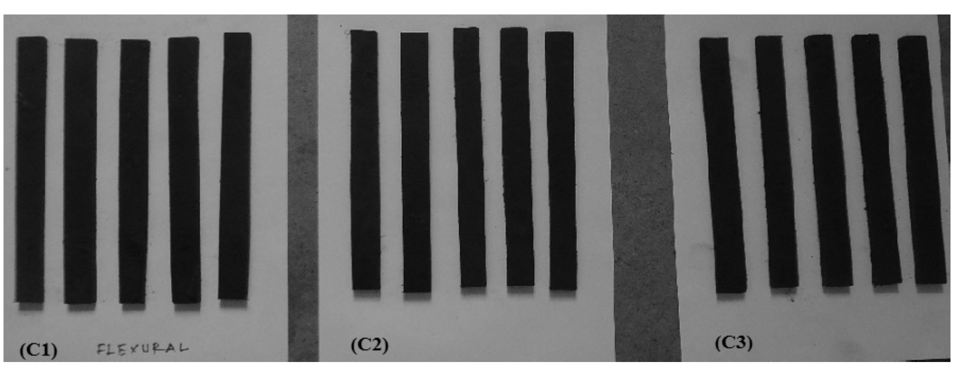

Fig. 1. Flexural test specimens: Five replicates of each samples (shown only of C1 to C3)

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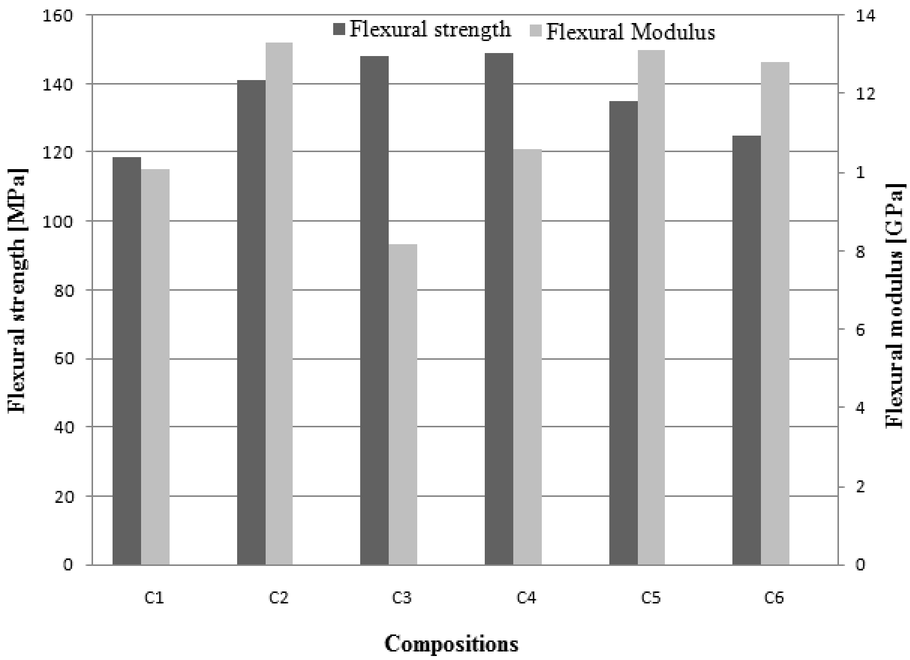

Fig. 2. Flexural property of glass fiber reinforced solid lubricant filled composites with different ratios (a) flexural strength (b) flexural modulus.

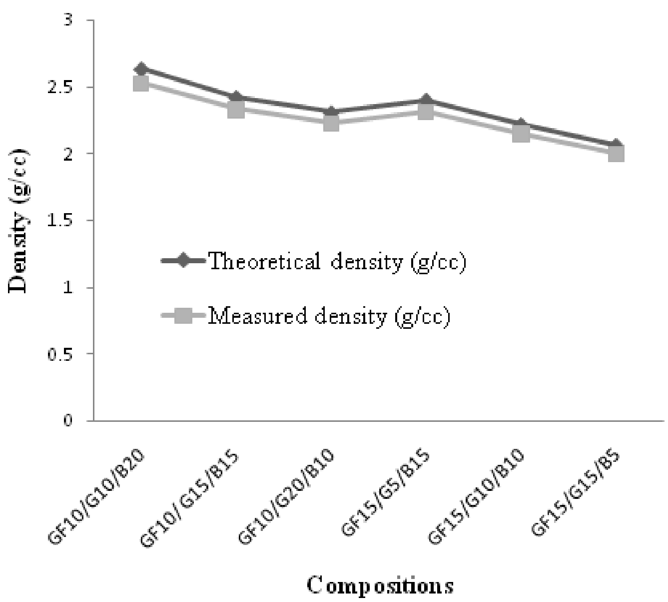

Figure 3

Fig. 3. Measured and theoretical densities of glass fiber reinforced solid lubricant filled composites with different ratios.

clustering of glass fibers and non wetted surface of glass fibers at these clusters. Clustering of glass fiber occurs due to high loading.

Fig. 4(a-b) shows metallurgical electron microscopic images of glass fiber reinforced and graphite, bronze filled epoxy composite. Fig. 4(a)

[DOI: 10.22068/ijmse.13.1.28]

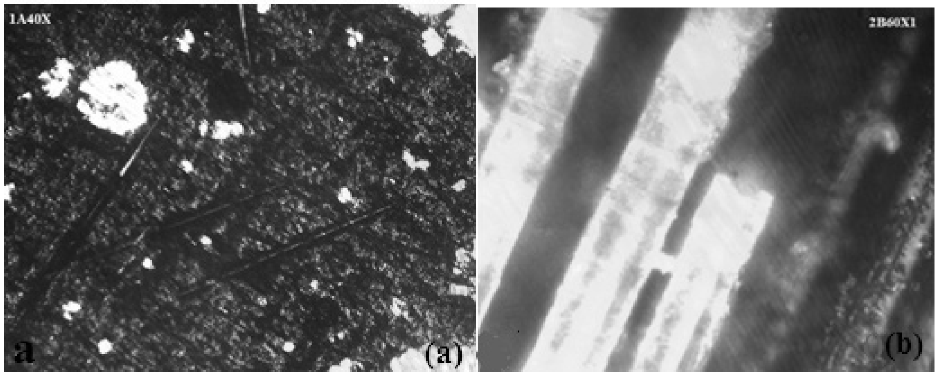

Fig. 4. Metallurgical electron microscopic images of glass fiber reinforced and solid lubricant filled epoxy composite (a) C1 at 400x (b) C5 at 600x

shows randomly distributed glass fibers filled with graphite and bronze particulates in the epoxy matrix composite. Fig. 4(b) indicates clustering of glass fibers with 15 vol% of glass fiber at magnification 600X. This indicated the influence of the percentage of glass fiber and graphite on density. It can be seen that the graphite and bronze particles were sticking on glass fiber surface so wetting of glass fiber with epoxy resin was not proper. This may be the reason of density difference.

3. 3. Rockwell Hardness

The hardness of glass fiber reinforced graphite and bronze particulate filled epoxy composite increased with increase of graphite filler loading C1-C6. The Rockwell hardness tester (Meta test instruments Pvt., Ltd.) was used to measure the hardness of composites. The average results obtained for five different locations were taken for each sample and shown in Fig. 5. Increase in volume percentage of glass fiber and graphite filler greatly increased the hardness of composites C1-C6, which can be attributed to uniform dispersion of glass finer and bronze filler. The higher hardness is exhibited by the 15 vol% glass fiber, 15 vol% graphite and 5 vol% bronze filled sample (C6) compared to other composites. The hardness of 15 vol% glass fiber and 15 vol% graphite, 5 vol% bronze composite is 84, which is highest among all the composites tested. During the Rockwell hardness testing of composites the action of force is compressive. The matrix phase, glass fiber and particulate filler phase will be under compression touching each other and offer resistance. Hence the interface can transfer load more effectively although the interfacial bond may be poor. This results in improvement in hardness of glass fiber, graphite and bronze filled epoxy composites. The increased hardness value indicates that wear resistance and resistance against abrasion or scratching of glass fiber reinforced solid lubricant filled epoxy composite is enhanced [20].

3. 4. Izod Impact Test

Impact resistance is the property by virtue of which a material resists breaking under a shock loading or it may the ability of a material to resist fracture under stress applied at high speed. Impact behaviour is one of the important characteristics of the polymeric materials [21]. The Izod Impact testing AIT-300EN (Fasne test equipments Pvt., Ltd.) was used to measure the impact strength of composites. The average results obtained for five specimens were taken for each sample and shown in Fig. 5. The impact value of 15 vol% glass fiber with 5 vol% of graphite and 15 vol% of bronze shows better ability of the composite material to absorb energy during plastic deformation. It also represents the high toughness strength of the composite.

[DOI: 10.22068/ijmse.13.1.28]

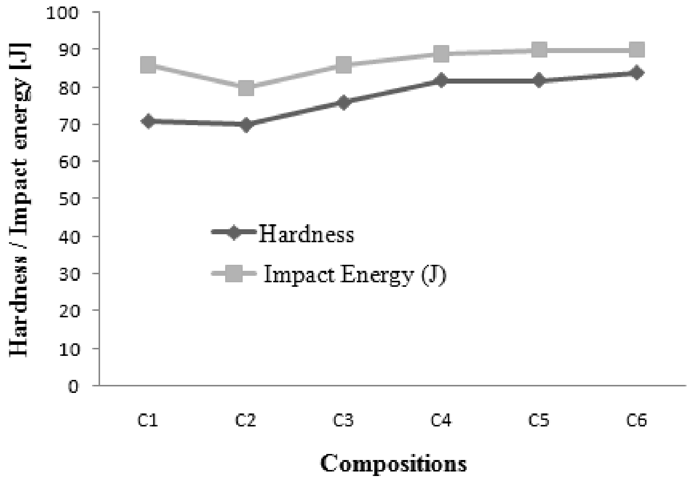

Fig. 5. Rockwell hardness and Izod Impact energy of glass fiber reinforced and solid lubricant filled epoxy composites C1 to C6.

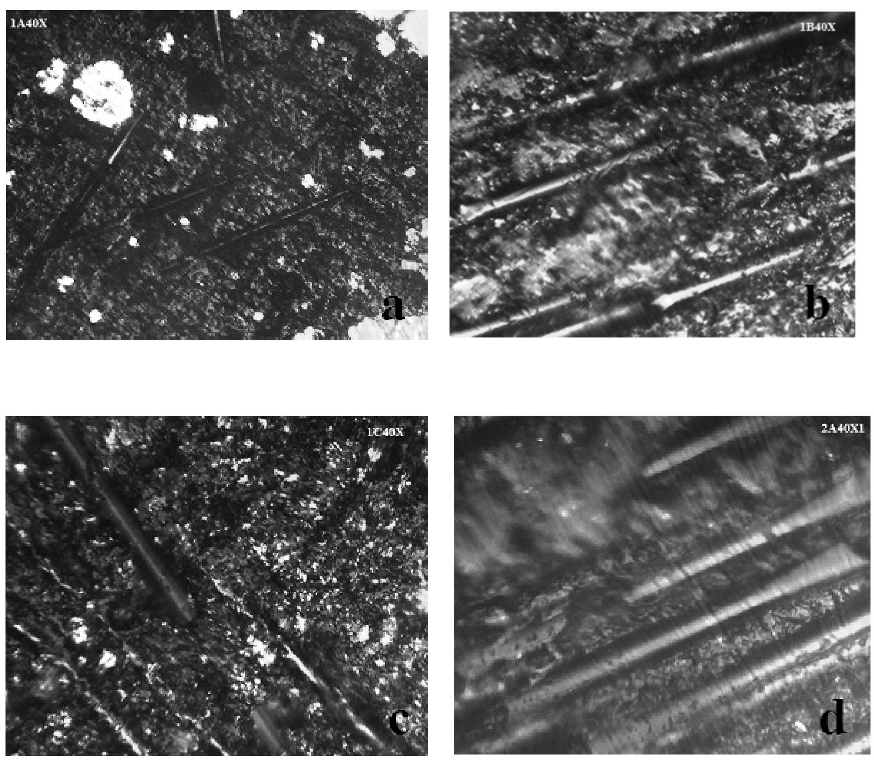

Fig. 6. Metallurgical Microscopic images showing reinforcement and filler distributions: Reinforcement content in (a, b, c) : 10 vol% and (d, e, f): 15 vol% of fixed glass fiber reinforcement.

3. 5. Metallurgical Microscopic Study

The metallurgical electron micrograph analysis was carried to study dispersion of graphite and bronze fillers and orientation of glass fiber reinforcement. The specimens were prepared using different emery papers having grades 400 to 1200 before micrographs were taken on metallurgical electron microscope. In this analysis it was found that graphite and bronze particles were uniformly distributed and glass fibers were randomly distributed as shown

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in Fig. 6(a-f). The experimentally obtained mechanical properties discussed in section 3 are very much in line with these micrographs.

4. CONCLUSION

Glass fiber reinforced graphite and sintered bronze filled polymer composites have been developed and are characterized. Most of the studies were focused on tribological characterization with little attention towards mechanical characterization. In our work, the focus is on characterization of mechanical properties as well along with tribological characterization. Two different fillers (graphite and bronze) with varying volume percentage have been used to study their effect in glass fiber reinforced epoxy resin. Remarkable difference was observed in each mechanical property of glass fiber reinforced; graphite and bronze filled and epoxy composites. The increasing and or decreasing volume percentage of graphite and bronze filler have shown positive effect on one or the other mechanical property. As per the experimental results of flexural, density, hardness and impact tests the glass fiber, graphite and bronze have an effect on fiber-filler-matrix interaction in the composites. The improved interaction can be seen from the electron micrographs. Hence the electron micrographs are evident for the results obtained from mechanical tests.

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[DOI: 10.22068/ijmse.13.1.28]