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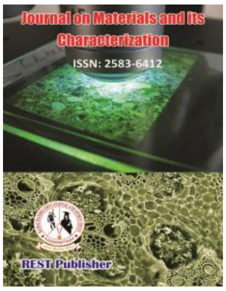

Prediction of Mechanical Properties of Short Glass Fiber Reinforced Epoxy Composites

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Abstract: *This study focuses on mechanical characterization of fiber reinforced polymer matrix (PMC) composite filled with particulate fillers to develop tribological material to sustain contact stress. The tensile strength and modulus of short glass fiber reinforced epoxy composite was investigated experimentally and also predicted using Rule of Hybrid Mixture (RoHM). The tensile tests were carried out as per the ASTM D-3039 standards. The results show the enhanced tensile strength and modulus of the composite for increased volume percentage of bronze filler from 10 vol% to 20 vol % and short glass fiber from 10 vol% to 15 vol %. Density of the composite was evaluated experimentally and predicted using RoHM. The electron microscopic images were discussed to interpret the effect of fillers on tensile strength of composite.*

Keywords: *Polymer composite, RoHM, Elastic Modulus, Tensile strength, Theoretical density.*

1. INTRODUCTION

In polymer composite the system of matrix material may be thermosetting or thermoplastic polymer and the filler material or reinforcement may be ceramics, metal and fibers. The most used reinforcing fiber for polymer is glass fiber [1]. The function of reinforcement is to enhance the mechanical properties of polymers. Epoxy matrix exhibits good adhesion with reinforcements and low shrinkage. Polymer composites are extensively used for aerospace and automotive structures because of their high strength to weight ratio [2]. The development of polymer composite to reduce friction and its effect is the area of interest of many researchers. The focus is to achieve polymeric Tribo materials with higher strength which will resists the contact stresses developed at the time of rolling or sliding.

Mechanical properties of polymeric composites reinforced with natural and inorganic fibers were extensively studied. It was observed that the size and volume fraction of filler and fiber play important role in improving strength and stiffness [3]. Many researchers have found variation in properties of epoxy composites filled with solid lubricants viz. Graphite, MoS_2, and polytetrafluoroethylene (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. Many researchers have proposed that solid lubricant alone will not improve the tribo-performance of neat polymer but fiber reinforcement will have a major effect on the performance of composites. Suresha et al [6] reported improved tribological properties of glass-epoxy composites filled with graphite. Zhang et al [7] found that reduction in friction coefficient was possible by addition of more than 5wt% MoS_2, and decrease in wear rate was observed by the addition of more than 10wt% MoS_2.

Bijwe and Indumathi [8] have reported on influence of fibers and solid lubricants on the low oscillating wear of polyetherimide composites. 10% inclusion of glass fiber inclusion showed higher wear resistance. Suresha et al [9] 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 [10] reported effect of particle addition and fibrous reinforcement on epoxy-matrix composites for sliding conditions. The study revealed that the Coefficient of friction (COF) of epoxy resin (EP)/PTFE was approximately 30% lower than EP. Singhal and Chawla [11] reported that the addition of 2 wt% of glass fiber increased compressive strength (104.7 N/mm2) and impact strength (4.2 J). Satheesh et al. [12] 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 [13] 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. Guo et al. [14] reported the tribological and mechanical properties of epoxy with hybrid filling. The results showed that a small amount of oil loaded microcapsules, grafted nano SiO_2 and short carbon fibers into the epoxy lead to improved tribological and mechanical properties.

Zhang et al. [16] reported the mechanical behavior of unidirectional flax and glass fiber reinforced hybrid composites. It was found that the tensile modulus of HFRP (Hybrid fiber reinforced polymer) followed the ROM (rule of mixture) very well. Tensile strength and modulus of short randomly oriented hybrid-natural fiber was found out experimentally and predicted using Rule of Hybrid Mixture (RoHM) by Venkateshwaran et al. [17]. The results showed RoHM follow the same trend as the experimental properties. Joshi et al. [18] carried mechanical characterization of borosilicate glass (0 to 32 vol%) reinforced epoxy matrix composites experimentally and using RoHM. The results showed 4-fold increase in hardness for 32 vol% composite and it was correlated closely with modified rule of mixture.

It is clear from the literature, that glass fiber play important role in improving strength and stiffness of polymer composites. Solid lubricants like molybdenum disulphide (MoS_2), graphite and PTFE can be used to improve tribological property of polymer composites. It was found experimentally that wear rate can be reduced by adding solid lubricants. Some researchers used RoHM along with experimental results to compare the results.

The present paper describes the mechanical characterization of the composites consisting of epoxy as matrix material, E-glass fiber as reinforcing element, graphite and bronze as fillers and compares the results with RoHM.

2. MATERIALS AND METHODS

A. Materials

The materials used for manufacturing the polymer composites are listed in Table 1 with their size in the micrometer and densities in g/cc. Epoxy resin CY230 was used as a matrix and chopped E-glass fiber was used as reinforcement. The fillers, graphite and sintered bronze 85/15 were also obtained from local vendors in Maharashtra, India. The curing agent selected was HY951. Table 2 shows the elemental content of glass fiber, graphite and sintered bronze in volume percentage. The glass fiber content was kept constant as 10 and 15 volume percentage fro two group of compositions and the fillers, graphite and sintered bronze were varied between 10 vol% to 20 vol% for first group and 5 to 15 volume percentage for second group.

TABLE 1. Materials properties

Sr No	Material	Size in microns	Density (g/cc)
1	Epoxy resin	--	1.1383
2	short-glass fiber	14	2.62
3	Graphite	20	2.15
4	Sintered Bronze	47	5.3

B. Fabrication of Composites

In this study, all the specimens used were fabricated considering ASTM standards of test specimens. Glass fiber reinforced, graphite and sintered bronze filled epoxy matrix composite specimens were by pressure die moulding.

The glass fibers were washed with the help of acetone for better adhesion with matrix material. This mixture of composite was stirred for about 30 minutes. The homogeneous mixture was poured into 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 110^{0}C with mould under clamp pressure, 24 hours at room temperature and post curing: 30 minutes at 160^{0}C followed by 12 hours curing at room temperature. The same cycles were followed for all samples 1 to 6. The test specimens were then cut according to ASTM standards. Five replicates of each composition 1 to 6 were fabricated and average results were recorded.

Table 2 Constituents of composites

Sr No	Composite designation	Composition (vol%)			
		Resin	**GF***	**GR***	**SBR***
1	G10/B20	60	10	10	20
2	G15/B15	60	10	15	15
3	G20/B10	60	10	20	10
4	G5/B15	65	15	5	15
5	G10/B10	65	15	10	10
6	G15/B5	65	15	15	5

*GF: Glass fiber, GR: graphite, SBR: Sintered bronze

C. Rule of Hybrid Mixture

For a hybrid composite consisting of four single composite systems the modulus of the composite can be evaluated from RoHM equation 1 by neglecting the interaction between four systems as follows

$$E_c = E_m V_m + E_{br} V_{br} + E_{gr} V_{gr} + E_f V_f \qquad (Eq.1)$$

Where, E_c , E_m, E_{br}, E_{gr} *and* E_f…..are elastic modulus of the hybrid composite, matrix material, bronze, graphite and E-glass fiber. And V_m, V_{br}, V_{gr} *and* V_f are the relative volume fraction of matrix, bronze, graphite and E-glass fiber. It should also be considered that the expressions listed below are valid for the assumed system

3. MECHANICAL CHARACTERIZATION

Tensile tests were carried out on rectangular specimens using ASTM D 3039 standard at a crosshead speed of 2 mm/min. All the specimens were flat and rectangular in cross section having a thickness of 3mm carrying tabs at the ends. Density, impact strength and hardness were calculated as per Archimedes Principle, ASTM: D 256 and ASTM: D 785 standards respectively. All the tests were carried out for five specimens and average results obtained were taken for each sample 1-6 (G10/B20, G15/B15, G20/B10, G5/B15, G10/B10 and G15/B5)

Figure 1 shows representative photographs of the tensile test specimens of composites in five replicates.

FIGURE 1. Photograph of tensile test specimen

4. RESULTS AND DISCUSSION

A. Tensile properties of PMC

The tensile properties of the glass fiber reinforced, graphite and bronze filled composites were tested experimentally and RoHM and the results were plotted against the volume percentage of glass fiber, graphite and bronze as shown in figure 3. From the graph, it can be seen that for fixed 10 vol% of glass fiber, with increase in the graphite content from 10 vol% to 20 vol%, the tensile modulus reduced from 4.8GPa to 3.67GPa while tensile strength was found to be lowest i.e. 39.58MPa for G15/B15 composites. On the other hand for fixed 15 vol% of glass fiber, with graphite content of 5 to 15 vol% and bronze content of 15 to 5 vol%, the tensile strength increased almost two fold (72.56 MPa) and the tensile modulus was maximum (5.256 GPa), for composition G15/B5. It can be noted that the increased volume percentage of E-glass fiber showed remarkable improvement in mechanical properties. The increased tensile property of G10/B20 composite was attributed to the increased volume percentage of bronze and/or decreased volume percentage of graphite. It can also be noted that the decrease in graphite filler has a positive effect on tensile properties. It might be due to the mechanical properties of the bronze and/ or graphite filler.

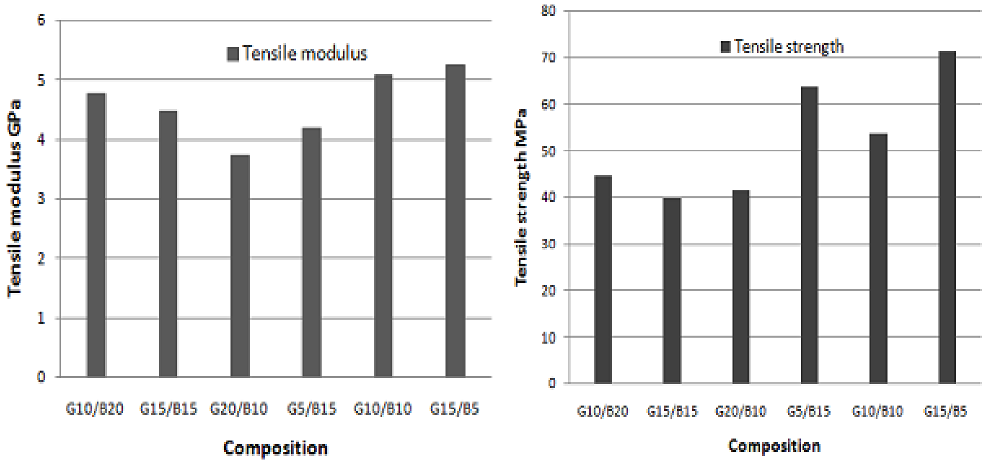

FIGURE 3. Tensile modulus and strength of composite

Figure 4 (a) (b) shows the comparison of tensile modulus by experimental and RoHM method for two group of compositions and figure 5 (a) (b) shows the comparison of tensile strength by experimental and RoHM method for two group of compositions.

B. Density of PMC

Figure 6 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 the theoretical density of 2.078 g/cc.

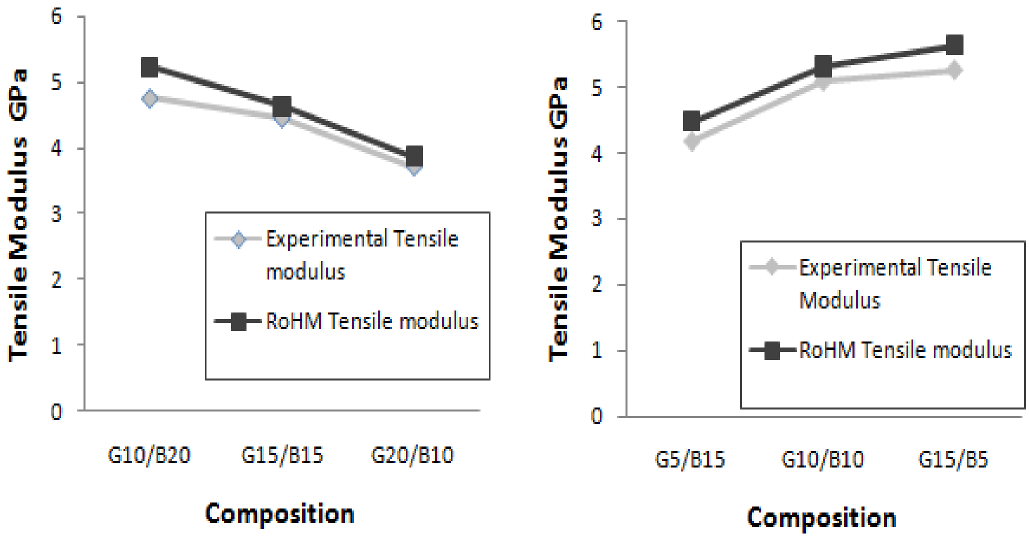

FIGURE 4. Comparison of experimental and RoHM tensile modulus (a) For fixed 10 vol% of Glass fiber (b) For fixed 15 vol% of Glass fiber

The measured densities for fixed 15 vol% glass fibers with 5-15 vol% of graphite and 15-5 Vol% of bronze filled composite were closer to theoretical density. On the other hand, for the composite with fixed 20 vol% of glass fiber, percentage void volume found was 4.33%. This might be due to compacting of glass fibers and insufficient surface wetting of glass fibers at these compacting regions. Compacting of glass fiber occurs due to high loading and improper dispersion as the mixing was done manually.

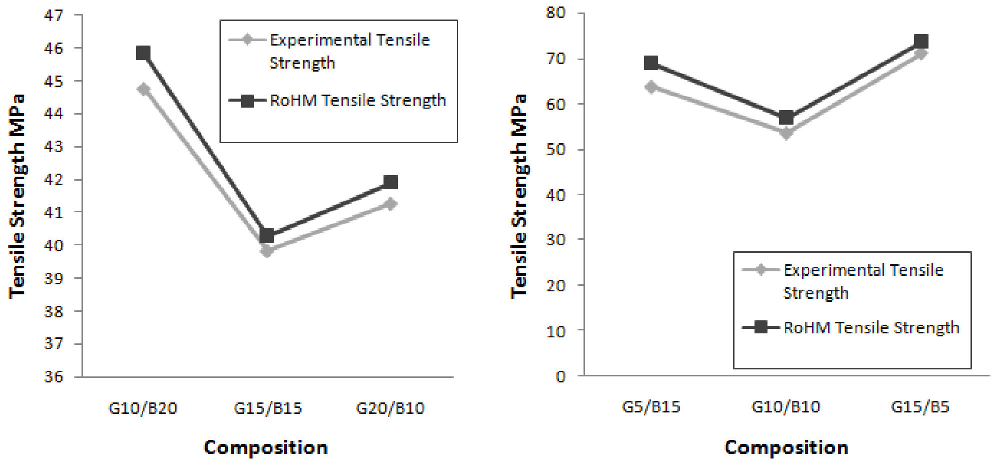

FIGURE 5. Comparison of experimental and RoHM tensile strength (a) For fixed 10 vol% of Glass fiber (b) For fixed 15 vol% of Glass fiber

Theoretical density was computed by rule of mixture using the equation 2.

$$(\rho_c)_{th} = \frac{\rho_m V_m + \rho_{br} V_{br} + \rho_{gr} V_{gr} + \rho_f V_f}{V_c} \qquad (Eq\ 2)$$

Where $(\rho_c)_{th}$ was theoretical density, ρ_m, ρ_{br}, ρ_{gr} and ρ_f were densities of matrix material, bronze, graphite and e glass fiber respectively. Similarly V_c is the total volume of the composite and V_m, V_{br}, V_{gr} and V_f were volume of matrix material, bronze, graphite and e glass fiber respectively. The experimental density was calculated using the Archimedes Principle. The declining trend in density might be because of the increased percentage of graphite filler.

Figure 7(a) and (b) shows randomly distributed glass fibers filled with graphite and bronze particulates in the epoxy matrix composite can be seen in fig. 7(a). Figure 7(b) clearly shows clustering of glass fiber. This might be the reason of lower measured density. The inclusion of two fillers having different mechanical properties led to formation of voids also. Figure 8 show the cohesiveness of the composite with complete bonding of the fillers with epoxy resin. This is responsible to achieve better mechanical properties.

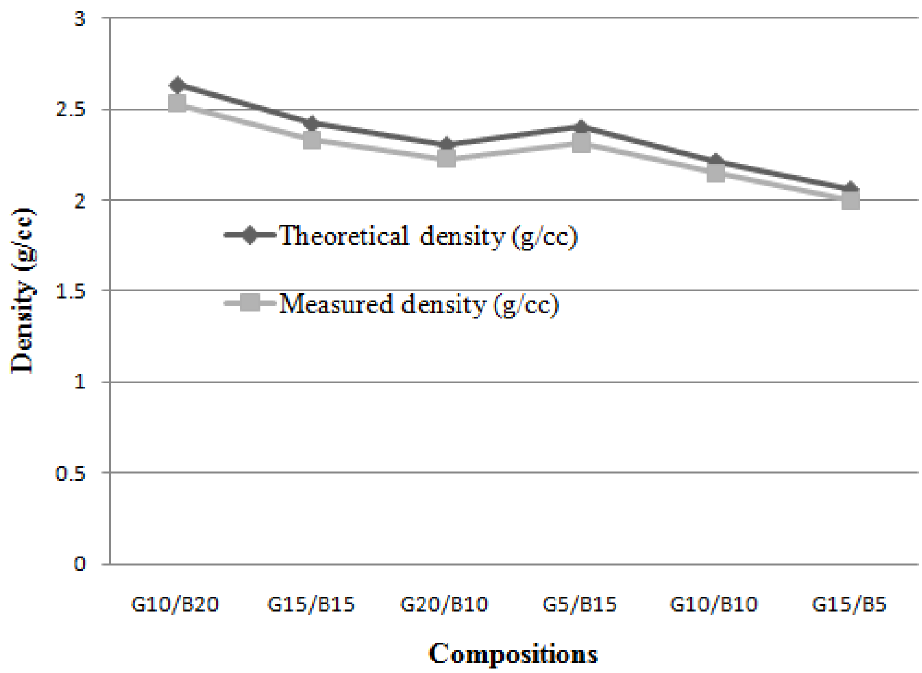

FIGURE 6. Theoretical and measured density

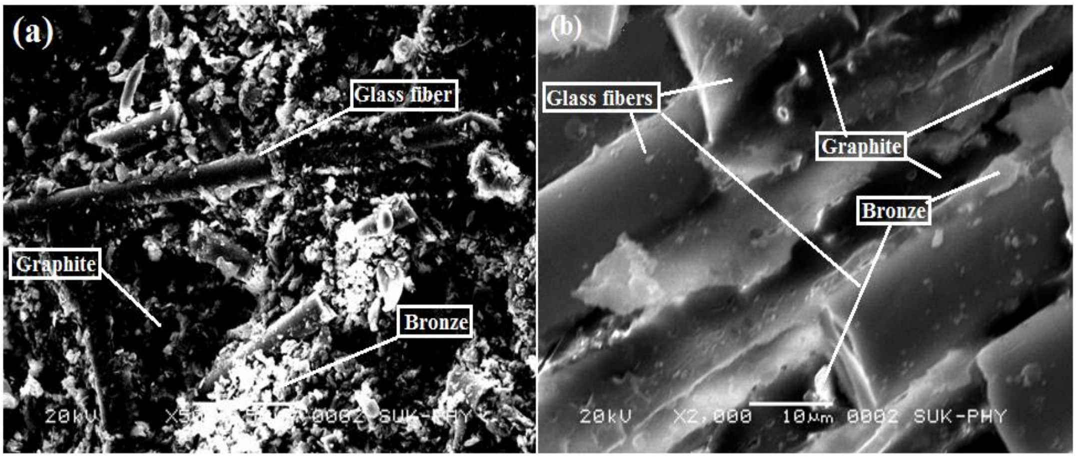

FIGURE 7. SEM images of composites (a) G10/B20 (b) G15/B5

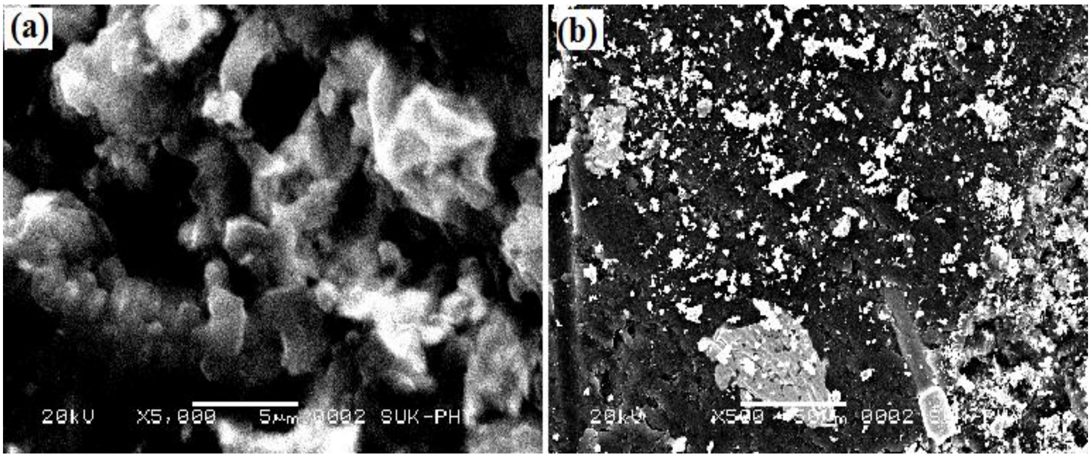

FIGURE 8. SEM images of composites (a) G20/B10 (b) G15/B15

Figure 7-8 shows SEM images of glass fiber reinforced and graphite, bronze filled epoxy composite.

5. CONCLUSION

Glass fiber reinforced graphite and bronze filled polymer composites have been developed and are characterized. In our work, the focus is on mechanical characterization. Two different fillers have been used to improve strength of glass fiber reinforced epoxy resin. The increasing volume percentage of bronze showed improved tensile property and density while increasing the volume percentage of graphite shows decreasing trend of tensile property and density. At the same time the increased volume percentage of graphite showed an increasing trend of hardness. As per the experimental results of tensile, density, impact and hardness tests the glass fiber, graphite and bronze have an effect on fiber-filler-matrix interaction in the composites.

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