Mechanical and morphological properties of DGEBA/SiO$_2$ reinforced with fiberglass at room temperature

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Abstract In this work some mechanical properties of epoxy resin (DGEBA)/silica oxide (SiO$_2$) reinforced with different weight percentage (5, 10 and 15) fiberglass investigated. A homogeneous solid colorless samples were prepared at room temperature using disposable stirrer. The study used the comparison of fiberglass different percentage concentration in order to improve strength and tenacity. Moreover, the effect of silica oxide presence in order to improve the interface surface. The results showed that (DGEBA) epoxy resin with 15% fiber glass has high tensile strength, impact and hardness. Furthermore, the addition of fiber glass improves the fracture toughness of the epoxy resin (DGEBA) and the amount of toughness. Besides, the presence of silica oxide within the sample structure led to greater coherence between the fiberglass and other parts of the composite, this is illustrated by SEM images for selected samples.

1. Introduction
Epoxy resins were firstly popularized in 1946 and broadly utilized as a part of the industry as a coating layer for basic applications, for example, overlays and composites, tooling, shaping, throwing, holding and others(1, 2). The capability of the epoxy ring to respond with an assortment of substrates gives the epoxy resins adaptability. Some of the epoxy resins are characterized as a high corrosion resistant add to have good thermal and mechanical properties, exceptionally good adhesion to different substrates, great electrical insulating properties, and processing capability under different conditions. The most commercial Epoxy is diglycidyl ether of bisphenol A (DGEBA) which is synthesized from colorless solid bisphenol A (Mw. 288) and epichlorohydrin solution. Numerous DGEBA commercial liquid resins take average molecular weights between 340 and 400. High molecular weight DGEBA can be obtained from low molecular weight resin via reacting with bisphenol A in the existence of a basic catalyst (3). In structural applications, epoxy resins are commonly brittle and notch touchy. Thus wonderful attempt has been focused on improving the toughness, fiberglass reinforcement is one of them(4, 5). The bonding between the fiberglass and the epoxy is important to enhance the matrix properties, particularly mechanical properties. The epoxy molecules in structural composites are identified as coupling agent because they form bonds with the dispersed phase and joined into the continuous matrix phase likewise. The popular category of composite material is the fiber that reinforced by polyester composites, where continuous thin fibers like a natural fiber, fibers of glass or carbon are embedded in the matrix of a polyester(6). In the last few decades, polymer-inorganic filler composites have involved respectable scientific and manufacturing interest to construct high-performance composites. The combination of the hybrid enhanced the modulus, strength and fracture toughness of the composites at the same time. Moreover, the purpose of addition silica
coupling agents to improve filler surface which is most common method to increase the adhesion between the matrix and the reinforcement (fibers) (7-9). In this work, epoxy matrix is hybrid with silica oxide (SiO$_2$) to improve the interface surface and the matrix reinforced by fiberglass to increase its potential applications. Some mechanical properties of reinforced composites in different percentages were studied.

2. Materials.
The common epoxy monomer (diglycidylether of bisphenol A – DGEBA) viscosity 9000 to 13000 cps used as basic epoxy resins and Triethylenetetramine hardener [CH$_2$NHCH$_2$CH$_2$NH$_2$]$_2$ from Parikh Chemicals, Ltd. Kanpur, India. Silica Oxide powder SiO$_2$ purity (99.5-99.8%), FeO$_3$ (0.008 to 0.01) % and moisture 0.33%, from TMMINDIA, Jaipur, India. Monofilament Polypropylene fibers (Sika Fiber) from Sika Egypt for Constraction Chemicals/ El Abour City/ Egypt.

3. Sample Preparation
The DGEBA epoxy resin and the TETA hardener were mixed gradually together using a disposable stirrer at room temperature in order to avoid making air bubbles. The blend was carried out for 20 minutes to get a homogeneous mixture so that the prepared samples have the same concentrations in all its part. Then the mixer was poured into the mould and left for 24 hours at room temperature. Finally, the samples were post cured at 100°C for 1 hour. All samples are solid colorless.

4. Results and Discussion
All mechanical tests are the average of three measurements and directed in the laboratory at room temperature.

4.1. Mechanical Test

4.1.1. Tensile
Three dumbbell-shaped samples were used in a tensile test with the dimensions of [(105±2)×(10±2)×(4±2)] mm in accordance with the ASTM D 638 standard. The load cell that used was 30KN, at a speed of 5 mm/min.
The applied tensile forces against relative elongation of the samples with variable fiberglass proportion in the samples are illustrate in Fig. 1. The Figure clarify a clear increase in the stress value with fiberglass percentage increasing for samples, where it started from 0.51 MPa for pure Epoxy to 19 MPa. with 15% fiberglass. The endpoint for each curve corresponds to the separation of the sample, so it is obvious, that the 15% fiberglass has the total top tensile performance, as ultimate stress strength at 15% is the greatest (Fig. 2). Through deformation increasing, the epoxy resin curve of ductility show deterioration, leading to a sudden fracture, after a sharp tensile force development. There is a clear augmentation of the strength in relation to the increasing amount of fiberglass added to a matrix(10).
The stress-strain curve for samples demonstrated in three different fiberglass concentrations in addition to pure epoxy and epoxy/silica oxide is typically semi-crystalline polymer curve. The yield stress clear on stress-strain curve within plastic deformation region for 10% and 15% fiberglass where it demonstrates improvement in fiberglass amount increasing. The breakdown in tensile curve for 15% fiberglass could attributed to fracture in fibers because of surface imperfections and short length fiber used, so minimizing the diameter of fiber make the fiberglass surface less defects so that might propagate throughout processing or under a load.
Generally, ultimate strength, stress and yield stress show an increase with fiberglass percentage increasing. This behaviour can be understood as a capability of fiber glass to give the structure greater
strength and endurance. Feature like this needs a link between fiberglass and epoxy structure, here the role of silica as a bonding agent in order to increase the link between the matrix parts. On this way, fiberglass amount increase gives the matrix greater attitude ability.

**Figure 1.** Stress – strain curve for all samples.

![Stress-strain curve](image1)

**Figure 2.** Effect of strain rate on ultimate tensile strength, yield stress.

The load - extension curve (stress-strain curve as seen in Figure 3) shows high modulus, especially at 15% fiberglass which is a sharp slope in the early linear region, this corresponds to a thermosets curve.

![Load-extension curve](image2)
As can be observed in Figures 3 for 10% and 15% fiberglass, there is a clear increase in the maximum limit of tensile strength when the percentage of fiberglass is augmented; this conduct was additionally seen by C. Liang(11, 12). A high- fiberglass/matrix adhesion happening in the sample phase is some of the main reasons for this conduct. The increased in the amount of fiberglass leads to high coherence degree between the sample components, demonstrating that there is increase in the transference of tension to dispersed-phase elements.(13).

The yield point (elastic limit) for 10% and 15% fiberglass appears clearly which indicates that there is a clear dividing line between elastic and plastic behaviour, while this division not obvious in 5% fiberglass. So 15% fiberglass reinforcement gave the sample greater strength to withstand mechanical factors(14).

\[ G_f = \frac{V_c}{B D} \]  
\[ K_c = \sqrt{E G_f} \]

Where:-

B: Width of the sample, m
D: Thickness of the sample, m
E: Modulus, Gpa

\[ K_c: \text{Fracture toughness}, \quad \text{Mpa m}^{0.5} \]

Notable variance in the impact strength of the samples can be seen with the increase in the percentage of fiberglass. The rate of impact strength has augmented by more than 175%. The exposure of epoxy based composite materials to a kind of impact loading conditions lead to absorb the energy in the plastic deformation process of the matrix, debonding at composite/fiberglass interface and in the breakage of reinforcing material. The absorption of the least amount of energy for the phenomenon to be clear and prominent leading to breakage. In case of small particles plaster like silica oxide are incorporated in the composite, crack length increases significantly during the fracture process. For the similar volume fraction of the plaster material, the smaller the plaster particles size, the larger be the surface area, therefore greater will be the upsurge in crack length leading to upsurge in energy absorption before breakage(15).

![Fracture toughness increases with fiberglass content](image)

**Figure 4.** Fracture toughness increases with fiberglass content.

4.1.3 Hardness Test

The hardness investigation results for all samples exist in Tables 2 and Figure 5. Three different points for each sample were tested and the average of the data was reported. The epoxy resin (DGEBA) with 15% of fiberglass shows higher hardness than that for the epoxy resin (DGEBA) with 5% and 10% of fiberglass. The presence of fiberglass in the structure of the sample led to more toughness in the sample and what helped to the cohesion of matrix components the presence of silica oxide. The position and the length of the fiberglass which led to a load distribution along the fiberglass making the step of elastic distortion long and more than a critical load for yielding not easy(16).
Table 1. Hardness values for three ratios of fiber glass content.

| Fiberglass percentage | Hardness values |
|-----------------------|-----------------|
| 0%                    | 20 28 24        |
| 5%                    | 38 24 30        |
| 10%                   | 39 35 42        |
| 15%                   | 58 72 60        |

Figure 5. Hardness (Average) vs. fiber glass content (%).

4.2. Characterization

4.2.1. Scanning Electron Microscope

Scanning electron microscope for cross section fractured surface of pure DGEBA epoxy resin, DGEBA epoxy resin with SiO$_2$ and 15% DGEBA/SiO$_2$ matrix illustrated in Fig. 6.a, b and c. A uniform morphological feature in pure epoxy zone indicate a single material (Fig. 9.a) while SEM images for 15% fiberglass show a high overlap between fiberglass and the matrix which leads to high cohesion between fiberglass and epoxy matrix. The presence of typical fiberglass improves mechanical properties if it is formed in a matrix. Nevertheless, the cohesion between fiberglass and the matrix structure must be existing to perform effectively in the polymer structure.

Fig. 9.b show silica oxide (SiO$_2$) good spread in epoxy structure. The presence of silica oxide increases the surface area which lead to growing the joining between epoxy and fiberglass as in Fig. 6.c. The plaster material characteristic of silica oxide assisted significantly the adhesion of fiberglass with the epoxy which has improved the mechanical properties [18].
Figure 6. a) SEM image of the fractured surface with 5µm scale bar (a) pure DGEBA epoxy resin. (b) DGEBA epoxy resin with SiO$_2$ (c) 15% DGEBA/SiO$_2$ matrix.

5. Conclusion
The present paper deliberates the effect of fiberglass different percentage concentrations, as well as a nonorganic silicon oxide on mechanical properties of DGEBA epoxy/fiberglass composite. The typically semi-crystalline polymerteensile strength curve show development with fiberglass amount increasing, this increase in line with impact factor which rose by 193%. Moreover, the results showed that the hardness increasing because of the silica oxide presence as a plaster material along with fiberglass percentage concentration increasing. The average modulus of elasticity increased 318% and 192% over pure epoxy resin after adding 50% load of 53-A and 12-A, respectively.

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