Structural properties of Epoxy – polysulfide copolymer reinforced with silicon carbide powder

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ABSTRACT
Most structural materials are designed to have light weight and high strength and tensile modulus. Epoxy is a commonly used thermoset polymer in construction, machinery, aerospace having light weight, adhesive, stable and low cost. Considering mechanical properties Epoxy have excellent bonding performance, superior thermal and chemical resistance, and easy processability. While the large internal stress, poor brittleness, poor impact resistance and high crosslinking density are the main defect in Epoxy properties. To enhance the brittleness and impact strength Epoxy is blended with polysulfide but reinforced with SIC to enhance tensile modulus and wear resistance. The polysulfide blending percentage is 6% wt. and the reinforcing SIC particles percentage is 1-2% wt. To evaluate the enhancement in Epoxy properties, mechanical tests (Tensile, Flexural and Wear) were performed. Tensile test results showed an increase in tensile strength when 1% SiC was applied, while flexural test results showed a little difference between the two reinforcement percentages in the beginning of the test then an increase of 1% SiC flexural strength was observed. Wear rate enhanced obviously when 2% SIC was applied.

KEYWORDS
Epoxy, polysulfide, mechanical properties, SiC.

INTRODUCTION
The excellent mechanical properties of SiC powder is the main cause why this material become a promising suggestion for ceramic, metal, and polymer–matrix composites reinforcement. One of the most important engineering polymers is Epoxy. It has found many applications in adhesives and electronics encapsulation materials. In aerospace, automobile, and civil engineering applications, Epoxy composites are used as structural parts due to their high mechanical strength [1]. Because of Epoxies high cross-link density being rather brittle and tend to fracture upon loading. Silicon carbide (SiC) have many good mechanical characteristics such as high mechanical strength and hardness, good thermal conductivity, high thermal stability, and superior chemical stability to oxidation in extreme conditions [2]. The Epoxy development of composite based on SiC powder enhancing thermal and mechanical properties. Due to their much larger strength over their bulk counterparts and strong interfacial bonding, SiC is suitable to reinforce Epoxy. A recent study on SiC reinforced Epoxy showed an improvement in wear resistance in addition to other mechanical properties compared to pure Epoxy resin [3].

Particles reinforced Epoxy composites mechanical behavior have been investigated by many researchers:-

Adnan Nemaa et.al. reinforced Epoxy polysulfide with different weight percent (0.2–0.6 wt.%) of MWCNTs to enhance mechanical properties. An increase in tensile strength and young modulus was noticed. SEM and FESEM were used to study the dispersion of MWCNTs in the matrix and understanding the morphology of the nano composite [4]. Vijayan Poornima, produced SiC nano fiber which is used to reinforce Epoxy. The composite was prepared by ultra-sonication and high shear mixing . A comparison of the two methods was made considering dispersion and flexural properties. The superior dispersion in ultra-sonication yielded an improvement in flexural strength and modulus. The weight percent of SiC was 0.25 phr that have good dispersion which in turn led to good improvement in mechanical properties [5]. Ekhlas Eden investigated the improvement in mechanical properties (tensile, hardness, flexural and wear) of Epoxy polysulfide reinforced with Alumina. The results showed an increase in composite properties up to 30% Alumina then a decrease in mechanical properties was
noticed when 40% Alumina was applied [6]. Chisholm et al. studied loading of 1.5% SIC nano particles to Epoxy. A 20 -30% increase in mechanical properties was obtained. The results showed that the addition of fine particles led to an increase in surface energy which enhance crystallinity and cross-linking of the polymer. This enhancement causing composite improvement in stiffness and strength. [7]

Rodgers et al. explored infusion of many weight percent of SIC nano particles to Epoxy. The increase by 12 °C for 1 wt. % SIC nano composite in the measured Tg is due to the increase in cross-linking density of Epoxy resin causing a restriction in molecular mobility. While a decrease by 8 °C of 1.5 wt.% SIC nanocomposite compared with neat Epoxy can be explained by a reduction in cross linking or curing degree because of the increase in viscosity[8]. A.A. Karim prepared a composite made of glass fibers and carbon fibers as reinforcement and 98 wt.% Epoxy, 2 wt.% polysulfide rubber as matric. The fibers were in the form of woven materials with 20% volumetric fracture. an increase in tensile strength and impact strength was noticed in the obtained results [9]. Romli et al. studied mechanical performance of coir / Epoxy loaded with fibers considering curing time. Tensile properties affected by fiber loading and curing period while compressive properties have no effect [10].

AIMS OF THE STUDY

1- Enhancing brittleness and impact strength of Epoxy by blending it with Polysulfide.
2- Improving the wear resistance and tensile strength of the copolymer blend by reinforcing with SiC particles.
3- Evaluating the blending method by studying the obtained blend properties.
4- Evaluating the composite properties by doing mechanical tests.
5- Studying the possibility of using the composite in structural application

MATERIALS AND METHOD

The first component of matrix is 92-93% wt. of Epoxy with mechanical properties as reported in table [1]. The second matrix component is 6wt.% of polysulfide that have mechanical properties listed in table [2]. The reinforcement is 1-2 wt.% silicon carbide particles with mechanical properties listed in table [3]. SiC particles were mixed with Epoxy resin using ultrasonic device for 30 minutes to have good dispersion [11-12]. Polysulfide resin added to mixtures and sonicated for 15 minutes to ensure that all the components are mixed well. Epoxy hardener and polysulfide hardener then added to the reinforced blended copolymer. The composite was poured into the mold that made of Perspex according to ASTM specifications. After curing process is complete (approximately after three days) the solidified composite was stayed in oven for 2h. at (60 C) to complete the curing process.[13]

Table 1. Mechanical properties of Epoxy [9].

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength</td>
<td>37 Mpa (at 23 °c)</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>61 Mpa (at 23 °c)</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>52 Mpa (at 23 °c)</td>
</tr>
<tr>
<td>Density</td>
<td>1.1 Kg/liter (at 20 °c)</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties of polysulfide [9].

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.35</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>8.3 Mpa</td>
</tr>
<tr>
<td>Failure strain</td>
<td>550%</td>
</tr>
<tr>
<td>Young modulus</td>
<td>3.7-5 Mpa</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>20-100 Mpa</td>
</tr>
</tbody>
</table>

Table 3. Alumina structural properties [6].

<table>
<thead>
<tr>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
</table>
Porosity | 0.2-3  
---|---
Density | 3.75-3.95  
Thermal expansion coefficient 10-6 1/k | 0.775  
Specific heat j/gk | 4.3  
Thermal conductivity W/mk | 30-40  
Young modulus Gpa | 410-380  
Shear modulus Gpa | 164-158  
Fracture toughness Mpa√m | 3-6  
Hardness HV1 | 1500-2000

EXPERIMENTAL TEST

In order to evaluate the obtained composite some mechanical tests was performed including:-

Tensile Test

Controlled electro-mechanical testing device was used to measure tensile strength. ASTM D638 samples were loaded with a constant load of 30 kN and a speed of 5 mm/min for a span length of 50 mm until the specimen fractured. Stress-strain curve of the samples was obtained and the tensile strength and deformation at fracture were calculated. Three samples of composite were investigated. Fig. (1) Show ASTM D638 samples dimensions of tensile test [14].

![Figure 1. Samples dimensions of tensile test according to ASTM](image)

Flexural Test

An object strength upon loading with flexural load before breaking is the flexural strength. Instron Universal Testing Machine (Tinus Olsen, U.K., model HKT 50 KN) with a speed of cross head equal to 5 mm / minute in a span length of 50 mm was used to execute the test. ASTM D 790 samples was cut from composite sheet with 4mm, 12-14 mm, and 96 mm as thickness, width and length respectively. The average of three tested samples was taken to have best accurate results, Fig. (2) show the flexural test specimen dimensions [15].

![Figure 2. Flexural test specimen](image)

Wear Test

A pin on disk apparatus was used to determine the materials sliding wear in laboratory. Under nominally nonabrasive conditions materials are tested in pairs. Two specimens are required, one of them is the rediused tip pin which is perpendicular to the other. The second is the circular and flat disk. A rigidly held ball is a common first specimen or the pin. Either the pin or the disk is revolved about the disk center by the machine. In the two
case the circular path on the surface of the disk is obtained considering adjusted disk plane. 2 – 10 mm is the specimen diameters range while the disk diameter range is 30 – 100 mm with 2- 10 mm thickness. for calculating volume losses of radius R pin and a flat disk considering one specimen to be weared equation below should be considered[16].

Pin volume loss (mm3 ) = \( \frac{\pi (\text{wear scar diameter, mm})^4}{64(\text{sphere radius, mm})} \)  

Using the pin on disk apparatus the angular velocity of the disk is 900 rpm which is made of alloy steel having 55 HRC hardness. The differences in weight of tested samples before and after test (represents the slide wear loss) was calculated using a 0.1 mg accuracy digital electronic balance. A different loads were exerted on the specimen(10,20,30 and 40) in a constant time period of 10 minutes for each load. Wear rate (mm3/N.m) was expressed by evaluating the volume loss [17]

\[ w = \frac{\Delta m}{2ntrn/60} \]  

Where w is the specific wear rate  n is the angular disk velocity (rpm), r is the sliding radius in cm, Δm is the mass loss in (g), t is test duration in (s)[papery][18]

RESULTS AND DISCUSSIONS

Using the mechanical tests to estimate the composite properties such that:-

Tensile test results of reinforced blend shown in fig. (3). it can be noticed that adding 1 %SIC to the blend cause an enhancement in tensile strength and tensile strain compared to that of the blend of epoxy polysulfide. While increasing the reinforced particles of SIC to 2% led to a reduction in the tensile strength and strain compared to blend and 1% SIC. This reduction may be attributed to the bad dispersion of the reinforced particles and particles weak adhesion and agglomeration with voids[19]. If the particles don’t dispersed well areas with different properties will exist causing a defect in overall properties of the composite.

Figure 3. Tensile stress – strain curve of SIC reinforced epoxy polysulfide.

Figure 4 below show flexural test results. Analyzing the curves showed that both 1% SIC and 2% SIC have almost the same behavior in the beginning of the test. Then an increase in flexural strength of 1% SIC is noticed compared to that of 2% SIC when the test persist. SiC/Epoxy have strong adhesion at interface and lower flexural strength is observed at higher wt. % of SiC due to agglomeration [20]
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Figure 4. Flexural stress strain curve of reinforced composite

Studying Figure 5 below showed that wear rate increase with the increase in applied load. while increasing SIC to 2% cause an enhancement in wear rate compared to that of 1% SIC. This enhancement may be explained according to hard nature of SIC particles that resist the removing effect during the test [21].

CONCLUSION

1- Because Epoxy highly cross linked it have low tensile strength, impact strength and flexural strength.
2- Polysulfide have good flexibility compared to Epoxy.
3- SiC have good mechanical properties considering wear resistance, tensile and flexural strength.
4- An observed enhancement in Epoxy brittleness and impact strength was observed when polysulfide is applied.
5- SiC cause an enhancement in flexural strength and wear rate.
6- Studying the composite application in engineering structures.
REFERENCES


