Effect of Reinforcement Materials and Immersion Mediums on Mechanical Properties of Epoxy Composites

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Abstract: In this research, a non-reinforced epoxy and its composites which reinforced by fiber glass, polypropylene fiber and micro-silica oxide powder, with volume fraction (20%) were prepared, using a hand lay-up molding method. Impact strength, Surface hardness, and Bending strength tests were carried out for the specimens before and after immersion in tap water and ethanol. Before immersion, the results showed that adding fiber glass and polypropylene fiber to the polymer improved the mechanical properties while silica particles decreased it. On the other hand, water absorption of the substance led to a negative effect on the mechanical properties of the composite material. The effect of ethanol was the highest.

Keywords: Epoxy, Fiber glass, Polypropylene, Silica Oxide, immersion mediums, mechanical properties.

1. Introduction.

Development of modern science and technology require the need to find new materials instead of metals and ceramics, these materials are called composites which have a light weight, high strength, electrical and thermal insulation, in addition to their resistance to the environmental conditions, to be suitable for industrial uses [1]. Composite materials consist of matrix material, which represents the continuous phase, reinforcement material [Reinforcement Phase] which stands most of the stress applied on the composite material, leading to improve its mechanical properties, and the third phase is the interface region located between the matrix and reinforcement material [2]. The composite material resistance for the applied stress mainly depends on the elasticity modulus and the strength of the reinforcement fibers and particles. The amount of reinforcement materials in the composites is known by the volume fraction [3]. The bending resistance of the material is its ability to endure the vertically applied bending forces on its longitudinal axis. The stress resulting from applying the bending load combines two types of stress, compression and tensile stress [4].

2. Experimental Procedures.

2-1. Samples preparation: Epoxy resin type (sikadur 52) made by Sika company, was used as matrix material. It is a thermoset polymer, transparent viscous liquid, adhesion, little shrinkage, and it turns to hard material by adding a hardener with a mixing ratio 1:2 in laboratory temperature. Fiber glass, polypropylene fibers, and
Micro-silica oxide were used as reinforcement materials with volume fraction 20%. The weight of reinforcement materials was calculated according to the following relations.

\[ W_c = W_f + W_m \]  
\[ V_f = \frac{1}{1 + \left( \frac{1 - \psi}{\psi} \right) \left( \frac{\rho_f}{\rho_m} \right)} \]  
\[ \psi = \left( \frac{w_f}{w_c} \right) \times 100 \% \]

\( \psi \): Weight fraction  
\( w_c, w_f, w_m \): weight of the composite, reinforcement, and matrix materials respectively (g).  
\( \rho_f, \rho_m \): Density of reinforcement and matrix material respectively (g/cm³).  
\( V_f \): Volumetric fraction (%)  

Hand Lay-Up molding method was used in preparing the following samples:
1. Un-supported epoxy, 2. EP+ F.G, 3. EP+ P.P.F, 4. EP+ SiO₂

**-Impact test:** The following tests were done for the samples:
Charpy test, type shock monitor, was used to determine the impact strength of the material. Specimens were cut according to the standard specifications (ISO-179), impact strength was calculated using eq.4.

\[ I.S = \frac{E_c}{A} \]  
\( I.S \): impact strength (MPa), \( E_c \): energy of fracture (J), \( A \): cross section area (mm²)

**-Hardness test:** To investigate the surface hardness of the composite materials, the duroment hardness (type Shore – D, TH210 Equipment device), was used to perform a hardness test.

**-Bending Test:** Three points bending test was done to investigate the ability of the composite material to resist the applied load, which illustrate the nature of the material.
Flexural strength of the samples is calculated according to eq.5.

\[ F.S = \frac{3PL}{2bd^2} \]  
\( F.S \): flexural strength (N/mm²),  
\( P \): maximum load (N), \( L \): the space between the two pillars (mm)  
\( b \): sample width (mm), \( d \): Sample thickness (mm)

**3. Results and Discussions**

**Impact strength:** Tables (1 & 2) and figures (1 & 2) provide that reinforcing the polymer by fibers increase the resistance of composite material to impact, and that was in case of fiber glass higher than polypropylene fibers, while reinforcing by silica oxide reduced the impact resistance. Fibers bear the major part of the stress applied on the composite material more than particles, and prevents cracks diffusions and act as bumpers of fracture and increase the material cohesion and thus increases the impact strength [5]. On the other hand, adding silica particles to the polymer gave it the brittleness properties because of ceramics particles were
known so as a brittle material and it may provide points to focus stresses and micro cracks positions and their diffusions in composite material which case impact reduction [6].

After immersion in water and ethanol, a decrease in the impact resistance of all specimens was observed. Diffusion of water and its penetration through the composite material, especially through the polymer and voids created during the manufacturing process causes swelling and formation of stresses within the material, which leads to weak it and failure. On the other hand, absorption of water and ethanol causes plasticization of the matrix material as a result of the breakdown of the hydrogen bonds between the polymeric chains, the material loses its ductility and becomes brittle and thus its resistance to shock decreases [7]. Ethanol effects was higher than the water.

Surface Hardness: Tables (3 & 4) and figures (3 & 4) show that adding fibers and silica oxide to the polymer improved the surface hardness of the composite material specially the fiber glass and silica particles because of their higher hardness and ability to endure stresses and plastic deformation [8].

After immersion in water and ethanol, surface hardness of the polymer and composites was decreased with the length of the immersion period. Water and ethanol penetration into the interface region and the voids leads to a breakdown of the bonds between the polymer chains thus weakening the cohesion of the composite material and its resistance to scratching and the surface hardness decreases. The ethanol effects was greater than that of water because ethanol is a corrosive chemical solutions[9],[10].

Table 3: variation of surface hardness vs immersion time in H2O

Flexural Strength: Tables (5 & 6) and figures (5 & 6) illustrate that adding the fibers to the polymer increased the resistance of the composite material to bending, specially the glass fibers, which are characterized by high strength. On the other hand, adding silica particles decreased the flexural strength. The silica particles are characterized by brittleness, which makes the composite material brittle thus reducing the flexural strength [11].

After water and ethanol immersion, the flexural strength decreased in varying degrees for all samples in proportion to immersion time, as a result of the penetration of solutions inside the composite material and their negative effect. The effect of ethanol was greater than that of water, because ethanol is a corrosive chemical solutions [9],[10].

4. Conclusions.

From the obtained results, the following can be concluded; Supporting the polymers with glass and polypropylene fibers improve the impact strength, surface hardness and flexural strength of the composite material; While micro-silica oxide particles decrease the impact and flexural strength of the composite material; Exposure of the polymer and composite to water and ethanol negatively affects the mechanical properties of the material depending on the type of solution, the duration of immersion, and the type of reinforcement material.

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Table 1: variation of impact strength vs immersion time in H$_2$O

| Sample | Immersion Time (Week) | 0   | 2   | 4   | 6   | 8   |
|--------|-----------------------|-----|-----|-----|-----|-----|
| EP     |                       | 24.443 | 21.222 | 18.052 | 14.882 | 11.7123 |
| EP+F.G |                       | 46.033 | 36.181 | 31.549 | 22.704 | 20.98 |
| EP+P.P.F |                   | 24.972 | 15.356 | 12.348 | 12.275 | 8.066 |
| EP+SiO$_2$ |                 | 8.384 | 6.687 | 5.184 | 4.825 | 4.721 |

Fig.1: variation of impact strength vs immersion time in H$_2$O

Table 2: variation of impact strength vs immersion time in ethanol

| Sample | Immersion Time (Week) | 0   | 2   | 4   | 6   | 8   |
|--------|-----------------------|-----|-----|-----|-----|-----|
| EP     |                       | 24.442 | 19.822 | 15.252 | 10.682 | 6.1132 |
| EP+F.G |                       | 46.033 | 32.673 | 23.549 | 19.70 | 15.027 |
| EP+P.P.F |                  | 24.972 | 17.877 | 15.514 | 14.516 | 12.903 |
| EP+SiO$_2$ |                | 8.384 | 7.503 | 5.706 | 4.825 | 5.5 |
Fig. 2: variation of impact strength VS immersion time in ethanol

Table 3: variation of surface hardness vs immersion time in H\(_2\)O

| Sample       | 0   | 2   | 4   | 6   | 8   |
|--------------|-----|-----|-----|-----|-----|
| EP           | 79  | 74  | 70.3| 66.60| 62.8|
| EP+F.G       | 83  | 81  | 81  | 80  | 78.1|
| EP+P.P.F     | 78  | 77.6| 77  | 77  | 76.9|
| EP+SiO\(_2\) | 83.7| 82.7| 82.2| 82  | 82  |

Fig. 3: variation of hardness strength vs immersion time in H\(_2\)O
Tab.4: variation of surface hardness vs immersion time in Ethanol

| Sample  | Immersion Time (Week) |
|---------|-----------------------|
|         | 0        | 2        | 4        | 6        | 8        |
| EP      | 79       | 69.4     | 60.5     | 51.68    | 42.8     |
| EP+F.G  | 83       | 74.2     | 73.5     | 68.8     | 68       |
| EP+P.P.F | 77       | 60.5     | 59.1     | 64       | 62.7     |
| EP+SiO₂ | 83.7     | 69       | 66       | 65.8     | 65.2     |

Fig.4: variation of hardness strength VS immersion time in Ethanol

Table 5: Variation of flexural strength vs immersion time in H₂O

| Sample  | Flexural Strength(N/mm²) |
|---------|--------------------------|
|         | Immersion Time (Week)    |
| EP      | 0        | 2        | 4        | 6        | 8        |
|         | 81.5     | 70.9     | 60.414   | 49.05    | 36.68    |
| EP+F.G  | 116.185  | 100.338  | 91.894   | 81.7     | 77.664   |
| EP+P.P.F | 88.63    | 46.941   | 45.150   | 39.86    | 39.278   |
| EP+SiO₂ | 49.165   | 40.746   | 38.392   | 35.375   | 33.660   |
Fig. 5: Variation of flexural strength vs immersion time in H$_2$O

Table 6: Variation of flexural strength vs immersion time in ethanol

| Sample        | Flexural Strength (N/mm$^2$) |
|---------------|------------------------------|
|               | Immersion Time (Week)        |
|               | 0   | 2   | 4   | 6   | 8   |
| EP            | 81.5 | 11.53 | 11.53 | 11.53 | 11.53 |
| EP+FG         | 116.185 | 90.66 | 59.059 | 45.528 | 31.967 |
| EP+P.P.F      | 88.63 | 49.165 | 35.375 | 33.584 | 11.892 |
| EP+SiO$_2$    | 49.165 | 30.732 | 20.7 | 17.542 | 9.281 |

Fig. 6: Variation of flexural strength VS immersion time in ethanol