Influence of Aluminum Fine Powder Content on the Some Mechanical Properties of Epoxy and Polyester Composites

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Abstract: In this study, the effect of aluminum powders on the some mechanical properties of epoxy (EP) and unsaturated polyester (UPE) composites was investigated. Aluminum powders (Al) were added to polymers with (0, 1, 3 and 5) % weight percentages. Epoxy/Aluminum and unsaturated polyester/Aluminum composites were fabricated by the cast molding method. Maximum fracture forces, Maximum Extensions, Yield Points, Young Modulus, Tensile Strengths, flexural strength and ultimate compressive strength tests were performed on both composites. The results showed that the tensile strength of epoxy/Aluminum composites increased with increasing of additive percentage of Al powder, and the samples of EP/Al composite gained highest values of tensile strength (22.48 MPa) at ratio percent (5%). While the tensile strength of unsaturated polyester/Aluminum composites decreased with increasing of additive percentage of Al powder. Also the results showed that the samples of EP/Al composite gained highest values of flexural strength (58.63 MPa) at weight percentage (1%). While the samples of UPE/Al composite gained highest values of flexural strength (91.88 MPa) at weight Percentage (3%). Finally, the value of compressive strength decreased with increasing of additive percentage of Al powder in both of EP/Al and UPE/Al composites.

Keywords: tensile strength, flexural strength, ultimate compressive strength and aluminum powder.

1. Introduction

Polymer composites generally consist of two primary ingredients: Organic resin matrix- the organic resin matrix is High molecular weight monomer as epoxy resin, or polyester, which has wide applications due to its properties and Inorganic fillers particles as a reinforcement materials which vary from material to another; each on has its own distinctive characteristics, the particles can be either metallic or nonmetallic. Particulate composites consist of particles of one or more materials...
suspended in a matrix of another material's particles, which can be either metallic or nonmetallic as can the matrix [1]. The physical properties of the resin are affected by the weight percentage of filler in the resin composite, within particle limits. Percentage filler content of a resin composite may be expressed in terms of weight or volume fractions or percentage [2]. The hard particles in a particulate composite place a constraint on the plastic deformation of the matrix material between them, because of their inherent hardness relative to the matrix. The particles also share the load, but a much smaller one, which lies parallel to the direction of load. Thus, these particles are effective in enhancing the stiffness of the composite, but do not offer the potential for much strengthening. Hard particles, placed in brittle matrix, reduce the strength due to stress concentrations [3]. Many particle types of fillers are used to improve the physical properties of matrix materials such as mechanical, thermal and electrical conductivity. For example Al2O3 or alumina is one of the most versatile of refractory ceramic oxides and used in a wide range of applications [4, 5]. Epoxy polymers are widely employed as the basis for adhesive compositions, and as the matrix material for composites [6]. Such polymers possess many useful engineering properties, such as a relatively high modulus and strength, good creep resistance and good elevated-temperature properties. However, such epoxies are relatively brittle polymers with poor resistance to crack propagation [7]. Polyesters are one of the most versatile synthetic copolymers. Polyesters are produced in high volume that exceeds 30 billion pounds a year worldwide [8-10]. They are widely used commercially as fibers, plastics, composites and coatings applications, too [11-13].

Alaa A. Abdul-Hamead et al. [14] studied composite material properties of polyester material reinforced with iron weave wires with percentage (5,10,15 and 20)% and concluded that most physical properties have been improved after reinforcement by metals the value of mechanical properties will increase with increasing percentage of reinforcement. Sihama Issa Salih et al. [15] studied composite material properties of unsaturated polyester with metal powders. The unsaturated polyester resin was reinforced by two types of metal powders Copper (15.598 µm) and aluminum (21.533µm) at selected volume fraction of (0, 5, 10, 15, 20 and 25 %). And concluded that most physical properties include tensile properties (strength at fracture point, elastic modulus and elongation at at break), flexural strength and flexural modulus, impact properties and hardness have been improved and the values increased with increasing percentage of reinforcement.

Srivastava V. and Ansur V. [16] studied the effect of copper and aluminium particles on the mechanical properties of epoxy resin. Copper (Cu) and aluminium (Al) particles were added in the epoxy resin as filler with the variation of weight percentage (1%, 5%, 8% and 10%). The tensile strength, compressive strength, vicker’s hardness, friction coefficient and wear properties were evaluated and compared. The fracture behavior was investigated under scanning electron microscope. Experimental data from tensile tests were compared with Bigg’s equations. The results indicate that the tensile strength and wear loss gradually reduced with the increase of filler content. The hardness, compressive strength and coefficient of friction increased with an increase of weight percentage of Cu and Al fillers content.

A major aim of the this work was studied the effect of Al micro particle content on the mechanical properties of epoxy and polyester resins includes tensile properties (Maximum fracture forces, Maximum Extensions, Yield Points, Young Modulus and Tensile Strengths), flexural strength, flexural modulus and ultimate compressive strength of epoxy/aluminum and unsaturated polyester/aluminum micro composites.

2. Experimental Procedure

2.1. Materials

Unsaturated polyester resin (UPE) is a liquid with moderate viscosity which can be cured to the solid state by adding (Methyle Ethyle Keton Peroxide, MEKP) as a hardener, while cobalt octoate acts as a
catalyst to accelerate the solidification process. Epoxy resin (Sikadur-52) was used in this research; which characterized by a low viscosity and free flowing; ideally suited to a wide range of building and civil engineering applications where highly penetrative material is required. Aluminum fine powders (Strem Chemicals, USA) was used in this research.

2.2. Material Preparation

2.2.1. Preparation of Polymer Microcomposites

Epoxy resin was mixed with weight fractions 0, 1, 3, and 5% percentages of aluminum is shown in table 1. then stirred for approximately 1 h, the hardener was added with 2:1 ratio of (epoxy: hardener), then poured into a Teflon mold via cast molding method. The mixture was de-gassed in a vacuum oven for 30 min and cured at 50˚C for 3 hrs, the unsaturated polyester resin was prepared with weight fractions (0, 1, 3, and 5%) percentages of aluminum. Unsaturated polyester/aluminum microcomposites were prepared by the same manner of preparation of Epoxy/aluminum microcomposites.

| Code | Composition | Matrix Polymer(gm) | Reinforcement Al (gm) |
|------|-------------|--------------------|-----------------------|
| A0   | EP          | 100%               | 0%                    |
| A1   | EP/Al       | 99%                | 1%                    |
| A2   | EP/Al       | 97%                | 3%                    |
| A3   | EP/Al       | 95%                | 5%                    |
| B0   | UPE         | 100%               | 0%                    |
| B1   | UPE/Al      | 99%                | 1%                    |
| B2   | UPE/Al      | 97%                | 3%                    |
| B3   | UPE/Al      | 95%                | 5%                    |

3. Measurements

3.1. Tensile Test

Tensile testing is one of the more basic tests to determine stress – strain relationships. A Tinus Olsen machine model H50KT was used for this test which was carried out a crosshead speed of 5 mm / min. A simple uniaxial test consists of slowly pulling a sample of material in tension until it breaks. Test specimens for tensile testing are generally either circular or rectangular with larger ends to facilitate gripping the sample (ASTM D-638 for plastics). Figure 1. shows the tensile test specimens to carry the test. The typical testing procedure is to deform or “stretch” the material at a constant speed. The required load that must be applied to achieve this displacement will vary as the test proceeds. During testing, the stress in the sample can be calculated at any time by dividing the load over the cross-sectional area $\sigma = P/A$. The displacement in the sample can be measured at any section where the cross-sectional area is constant and the strain calculated by taking this change in length and dividing it by the original or initial length $\varepsilon = \Delta L/L_0$ [17].
3.2. Three – Point Bending Test

Three-point bending tests were carried out using a Tinus Olsen machine model H50KT of (5kN) full scale load capacity according to the ASTM D790-10 standard. The test specimen dimensions were (125 mm) long, (96 mm) support span and (10 mm) width, and the test speed was 0.5 mm/min. Flexural strength, flexural modulus, and elongation at break values were obtained and evaluated. Flexural stress was calculated according to Eq.

\[ \sigma = \frac{3FL}{2bd^2} \]  

(1)

where \( \sigma \) is the flexural stress [MPa], \( F \) is the load [N], \( L \) is the span [mm], \( b \) is the specimen width [mm] and \( d \) is the specimen thickness [mm].

Flexural modulus was calculated according to Eq.

\[ E_B = \frac{L^3m}{4bd^3} \]  

(2)

where \( E_B \) is the flexural modulus [MPa], \( L \) is the span [mm], \( b \) is the specimen width [mm], \( d \) is the specimen thickness [mm], and \( m \) is the slope of the linear region of the load-displacement curve.

Bending strain was calculated according to Eq.

\[ \varepsilon = \frac{6Dd}{L^2} \]  

(3)

where \( \varepsilon \) is the strain [mm/mm], \( D \) is the maximum displacement at the central point of the specimen, \( d \) is the specimen thickness [mm], and \( L \) is the span [mm]. [18]
3.3. Compression Test.

The compression test was done to calculate the compression strength for the samples under test. Hydraulic- piston type Ley Bold Harris No.36110, was used. In this instrument, the sample is fixed on a moving base, then the base is lifted up by a lever found in the instrument till the surface of the sample touches the upper surface of the instrument, then the pointer of the gauge is placed on zero level. The load is applied gradually to the longitudinally fixed sample, and then the reduction in the length of sample is determined via the fixed digital vernier, the increasing of the load continues till sample failure. The value of the maximum load represents the ultimate compression strength of the sample. Figure 2. shows the compression test specimens to carry the test.

![Figure 2. Compression test specimens.](image)

4. Results and discussion

4.1. Tensile Test

The values of tensile strengths, maximum fracture forces, maximum Extensions and yield points for epoxy specimen and (EP/Al) micro composites of all samples are summarized in table 2. The relationship between the tensile strength and aluminum content of (EP/Al) micro composites is shown in Figure 3. It is clear that the tensile strengths of micro aluminum composites increased with increasing Al content ratio. Maximum tensile strength was observed at 5 wt. % of Al (percentage), which is 22.48 MPa. Tensile strength of the polymer composite is also depending upon strength at the interface of matrix and filler material. The enhancement of the tensile strength of the micro composites was due to the homogeneous dispersion of the reinforcement material and the good interaction between the reinforcement and the matrix.

Table 2. Maximum fracture forces, Maximum Extensions, Yield Points, Young Modulus and Tensile Strengths of epoxy and EP/ Al composites.

| Sample   | Maximum Fracture Force (N) | Maximum Extensions (mm) | Yield Points (MPa) | Young Modulus (MPa) | Tensile Strengths (MPa) |
|----------|-----------------------------|-------------------------|--------------------|---------------------|-------------------------|
| EP       | 1087.366                    | 7.4                     | 20.28              | 135.2               | 20.28                   |
| EP / 1% Al| 1191                        | 7                       | 21.98              | 157                 | 21.98                   |
| EP / 3% Al| 987.5                       | 4.5                     | 20.65              | 229.4               | 20.65                   |
| EP / 5% Al| 1135                        | 4                       | 22.48              | 281                 | 22.48                   |

Also the Maximum fracture forces, Maximum Extensions, Yield Points, Young Modulus and Tensile Strengths of unsaturated polyester and UPE/ Al composites shown in table 3. It is clear from the results that the tensile strengths of micro-aluminum composites decreased with increasing Al content.
ratios. This could be that as the increasing Al content caused the weak adhesion between matrix and fillers and led to the decrease of the strength of the unsaturated polyester composite. The tensile test for specimens of EP/Al and UPE/Al micro composites with 1, 3 and 5% of aluminum powder showed that all specimens with Al micro particles suffer brittle fracture during the test course is shown in Figure 4.

**Table 3.** Maximum fracture forces, Maximum Extensions, Yield Points, Young Modulus and Tensile Strengths of unsaturated polyester and UPE/Al composites.

| Sample       | Maximum Fracture Force (N) | Maximum Extensions (mm) | Yield Points (MPa) | Young Modulus (MPa) | Tensile Strengths (MPa) |
|--------------|----------------------------|-------------------------|--------------------|---------------------|-------------------------|
| UPE          | 2252.991                   | 8.5                     | 33.05              | 197.06              | 33.05                   |
| UPE / 1% Al  | 602.5                      | 5                       | 11.82              | 118.2               | 11.82                   |
| UPE / 3% Al  | 567.5                      | 2                       | 12.43              | 310.75              | 12.43                   |
| UPE / 5% Al  | 542.5                      | 4                       | 12.45              | 156.75              | 12.45                   |

**Figure 3.** Tensile Strength variation with Al powder content in EP,UPE resins
4.2. Three – Point Bending Test.

The flexural strength (F.S) values of (EP/Al) and (UPE/ Al) composites are shown in table 4. Results showed that the flexural strength of epoxy/micro aluminum composites increased to (58.63MPa), when the Aluminum percentage increases from 0 to 1% as shown in figure 5. The increase in flexural strength is due to the dispersion of Aluminum and stronger interfacial bonding between the matrix and filler in the composites. An increase in flexural strength of epoxy/aluminium composites due to addition of reinforcing aluminium particles to epoxy. This implies that incorporation of Al micro composites in epoxy matrix enhanced the flexural strength of the developed composites, which implies that both the strength and rigidity of the composites were increased. The increase is linked to a good interfacial adhesion of the particles with the matrix which enabled effective load transfer from the matrix at the bending zones to the reinforcing particles within the entirety of the composites. This explanation is in agreement with literature[19]. When the Aluminum percentage is further increased by 3%, the flexural strength decreases to (47.92MPa), but still higher than the flexural strength value of the neat epoxy samples. When the Aluminum percentage is further increased by 5%, the flexural strength decreases to (45.01 MPa) lower than that of the neat EP/ Al (47.46MPa). Reduction is due to the agglomeration of Aluminium fillers in the composites.

The result also show that the strength of unsaturated polyester/micro aluminum composites decreased to (71.87MPa), when the Aluminum percentage increases from 0 to 1%. When the Aluminum percentage is further increased by 3%, the flexural strength increases to (91.88 MPa). The increase is linked to a good interfacial adhesion of the particles with the matrix which enabled effective load transfer from the matrix at the bending zones to the reinforcing particles within the entirety of the composites. When the Aluminum percentage is further increased by 5%, the flexural strength drop to (64.65MPa) lower than that of the neat UPE/ Al (74.71 MPa) due to the debonding between the reinforcement and the matrix.
Table 4. The effect of Al content (wt %) on the Flexural Strength, (F.S) of (EP/Al) and (UPE/Al) composites.

| Composition | Flexural Strength, F.S (MPa) |
|-------------|-----------------------------|
|             | Aluminum (Al) content (wt %) |
|             | 0%  | 1%  | 3%  | 5%  |
| EP/Al       | 47.46 | 58.63 | 47.92 | 45.01 |
| UPE/Al      | 74.71 | 71.87 | 91.88 | 64.65 |

Figure 5. Flexural Strength variation with Al powder content in EP, UPE resins

4.3. Compression Test.

The Compressive test is used to calculate the ultimate compressive strength of the composites that have (0, 1, 3, and 5) % of aluminum powder (Al) added to EP and UPE resins. The ultimate compressive strength (UCS) values of (EP/Al) and (UPE/Al) composites are shown in Table 5. Compression strength depends on the matrix properties of the material, reinforcement material, strength of binding across interfaces, volume fraction of reinforcement material. Figure 6. shows ultimate compressive strength variation with Al powder content in EP and UPE resins. In this figure, the ultimate compressive strength of the EP/Al composite samples decreased rapidly at the weight
percentage of Al was in the range of 0% to 1%. But the ultimate compressive strength increased slightly to a range of 1% to 3%. Then the ultimate compressive strength decreased slightly in a weight percentage range of 3% to 5%. The results of ultimate compressive strength still more much lower than the neat epoxy. The results also show the ultimate compressive strength of the UPE/Al composite samples decreased rapidly at the weight percentage of Al was in the range of 0% to 1%. Beyond this ratio, there is some rising in the strength of the composite until reach to the ratio 5% of Al micro particles. But results of ultimate compressive strength still more much lower than the neat unsaturated polyester. It is clear from the results that the ultimate compressive strengths of micro-aluminum composites decreased after the addition of Al content ratios in both of EP and UPE resins. This could be explained as the increasing Al content caused the weak adhesion between matrix and Al powder and led to the decrease of the strength of the epoxy and unsaturated polyester composites.

Table 5. The effect of Al content (wt %) on the Ultimate Compressive Strength of (EP/Al) and (UPE/Al) composites.

| Composition | Ultimate Compressive Strength, (UCS) MPa. |
|-------------|------------------------------------------|
|             | Aluminum (Al) content (wt %)              |
|             | 0%           | 1%           | 3%           | 5%           |
| EP/Al       | 36.90        | 28.57        | 30.04        | 24.49        |
| UPE/Al      | 67.92        | 24.17        | 29.74        | 38.14        |

Figure 6. Ultimate Compressive Strength variation with Al powder content in EP, UPE resins.
5. Conclusions

The primary objective of this experimental study was to prepare the composite from aluminum powder. The result shows that Epoxy and polyester resins are a good adhesive material which can use as a matrix with Al fine powder. These composites found to have good mechanical properties. There is enhancement in the flexural strength due to addition small amount of Al in epoxy composite. The highest flexural strength was observed at 3% of UPE/Al composite. Similarly highest flexural strength was observed at 1% Al of EP/Al composite. It is observed that addition of aluminum powder reduce maximum fracture forces, maximum extensions, yield points, and tensile strengths of UPE/Al composite possibly due to agglomeration. Generally, compressive strength will decrease with increasing aluminum weight percentage wt% to both of epoxy and polyester resins.

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