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MECHANICAL BEHAVIOR OF EPOXY RESIN REINFORCED WITH VARYING GRAPHITE PARTICLE SIZES

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Abstract:

The effect of adding graphite particles on the mechanical properties of epoxy-based material was studied using different particle sizes of (75, 53, 45) μm for graphite, with weight percentages of (0, 1, 3, 5, 7, 9)%. Fatigue tests showed that the epoxy-graphite composite recorded the highest value at 3% for all particle sizes. The highest value was at the particle size of 45 μm, followed by 53 μm and 75 μm. Compressive tests recorded the highest compressive strength value for the epoxy-graphite composite at 7% for particle sizes 45 μm and 53 μm. The highest value for the 75 μm particle size was at 5%.

Introduction

Introduction:

Polymer-based composite materials are considered modern materials that play an important role in most engineering and technological applications. The fabrication of materials with specific properties that meet certain design needs has attracted engineers' attention for several years. For example, aircraft engineers are constantly searching for material compositions that have low density but are strong, rigid, impact-resistant, abrasion-resistant, and not easily corroded. This combination of properties cannot be easily combined in a specific or single material but can be obtained in composite materials [1]. Composite materials are materials consisting of more than one substance designed to make the properties better than if each material were separate [2]. They consist of two parts: the first is the matrix material, and the second is the additives. Composite materials with a polymer base are characterized by ease of manufacturing, low density, and other good physical properties [3].

The mechanical behavior of particle-reinforced composite materials results from the interaction of the properties of the phases constituting the composite material, represented by the following [4]:

- The matrix material
- The reinforcing material
- The interfacial surface

Materials and Methods

First: (Epoxy Resin)

Epoxy resin belongs to the group of thermosetting resins, which are characterized by the inability to reshape them by heat into a solid material due to the formation of long polymeric chains interlinked with each other, known as cross-linking. Epoxy resin contains two or more epoxide groups, which consist of an oxygen atom bonded to two carbon atoms, as shown in Figure (1). The epoxy group chemically bonds with other molecules to form a three-dimensional network with cross-linking through the curing process [5].

Epoxy resin is characterized by relatively high hardness and chemical resistance, as well as possessing high specific adhesion capability due to the chemical structure of this resin, represented by the ether, hydroxyl, and polar groups that give high strength and adhesion and impart strength and hardness to the material. Therefore, it is used in applications that require high functional performance. These resins react with hardeners during curing, and the reaction is not accompanied by the emission of water or the release of any secondary products, making the volumetric shrinkage very small (less than 2%). Consequently, the resin acquires high strength and mechanical properties. Additionally, cured epoxy resins possess high toughness due to the bonding between cross-linking points [6, 7].

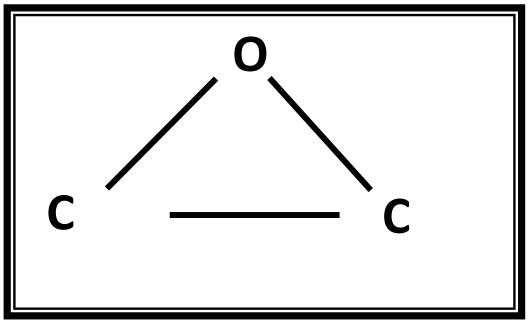


Figure 1 Epoxide Groups

Second: (Graphite Particles)

Graphite is a crystalline form of carbon with a distinctive crystalline structure different from diamond. It is more stable than diamond at ambient temperature and pressure. Its crystalline structure consists of layers of carbon atoms arranged hexagonally. Within the layers, each carbon atom is bonded to three coplanar neighboring atoms via covalent bonds. The fourth electron is bonded by weak van der Waals forces existing between the layers. It is used as heating elements in electric furnaces. Its features include[8]:

- High resistance and good chemical stability at high temperatures in a non-oxidizing atmosphere.
- High thermal conductivity.
- Low coefficient of thermal expansion.
- High gas absorption capacity.

Methodology:

Base Material

In this research, Quick mast 105 epoxy resin of Jordanian origin, licensed from Fosroc company, was used. It is in liquid state and can be polymerized and converted to solid state by adding a hardener of the same resin type. The hardener is characterized by being a light liquid with low viscosity and density and a transparent yellow color. The ratio of hardener to resin is (1:3). The used epoxy is characterized by low viscosity, low density, high adhesion property, and high chemical resistance.

Reinforcing Material

In this research, graphite particles were used as reinforcing material to be added to the base material (epoxy resin) in weight percentages of (0, 1, 3, 5, 7, 9)% with three particle sizes (45, 53, 75) μm. The graphite was manufactured by Sigma-Aldrich in powder form.

Sample Preparation

The hand lay-up molding method was adopted using a mechanical mixer in the sample preparation process. This method was chosen over other complex methods due to its ease of manufacturing, the ability to produce samples of different sizes according to the required dimensions, and lower cost compared to other manufacturing methods. Two types of casting molds were used: a square one for fatigue test samples and a cylindrical one for compression test samples.

A quantity of epoxy is weighed according to the designed mold size, and the hardener is added at a ratio of (1:3). Then, an amount of reinforcing material (graphite particles) is weighed according to the required weight fraction. The mixing process of the reinforcing material and the base material begins at room temperature, and the mixture is stirred continuously and slowly to avoid bubbles during the mixing process. The mixing continues for (10-15) minutes for the cylindrical mold with dimensions (2x4) cm, and (20-30) minutes for the rectangular mold with dimensions (12x12) cm until the mixture is homogeneous, noting the beginning of the temperature rise of the mixture, which is an indication of the start of the reaction process.

It is important for the mixture to have a certain practical viscosity to protect the particles from precipitation. The liquid mixture is poured as a stream in the center of the mold (to avoid air bubbles in the casting that cause failure) as it flows to all areas of the mold continuously and regularly until the mold is filled to the required level. Here, the mold must be perfectly level. The casting is left in the mold for (24) hours to harden completely before removing it from the mold, then after removal, it is left for (15) days, and this process is important to complete the polymerization. After that, the samples are cut according to the adopted specifications for each test using a band saw with fine teeth to ensure no vibration during cutting of fatigue samples, and the smoothness of the saw teeth will work to avoid deformations that may occur during cutting. The dimension adjustment stage is done using a smoothing device, and then the polishing process is done with zero-degree smoothing papers. Two samples were prepared for each test and for each of the aforementioned ratios to obtain high accuracy of results.

Mechanical Tests:

Compression Resistance

Compression resistance is defined as the maximum stress that a rigid material resists under vertical pressure. This resistance is measured by the force applied per unit area of the initial cross-section of the test sample. The compression test of the material is considered one of the tests that complete the picture of the strength of the polymer and its ability to withstand conditions of use. Many materials may be brittle in tension but appear ductile in compression, so we find that the compression test is

often used to determine the yield strength as well as the compression resistance [9]. This test is widely used to test brittle materials such as glass, concrete, rock, cast iron, and thermosetting polymers, because these materials have more strength in compression than in tension[10, 11] . The shape of the test samples used is cubic or cylindrical. The equation used to calculate the compressive strength is [12]:

$\sigma = F/A$ .....(1)

Where:

σ: Compressive strength (MPa)

F: Applied load (N)

A: Cross-sectional area of the sample (mm^2)

Compression Test Samples:

Compression test samples were prepared with standard dimensions according to American specifications (ASTM-D 695) with a length of (40 mm) and a diameter of (20 mm), as shown in Figure (2).

Figure 2 Sample of Compression Test

Fatigue Test

Fatigue is considered one of the types of failure that occurs in engineering parts that suffer from dynamic and fluctuating stress, such as in aircraft, ships, bridges, and other engineering parts [13]. The phenomenon of fatigue was observed in 1800 when the axles of carriages on the railway line began to fail before their specified service time ended. In 1870, the German engineer (Wohler) was able to conduct the first practical research on how to identify the failure of steel material under fluctuating loads by studying the number of cycles of variable stress time and knowing the endurance limit [14].

Fatigue Test Samples

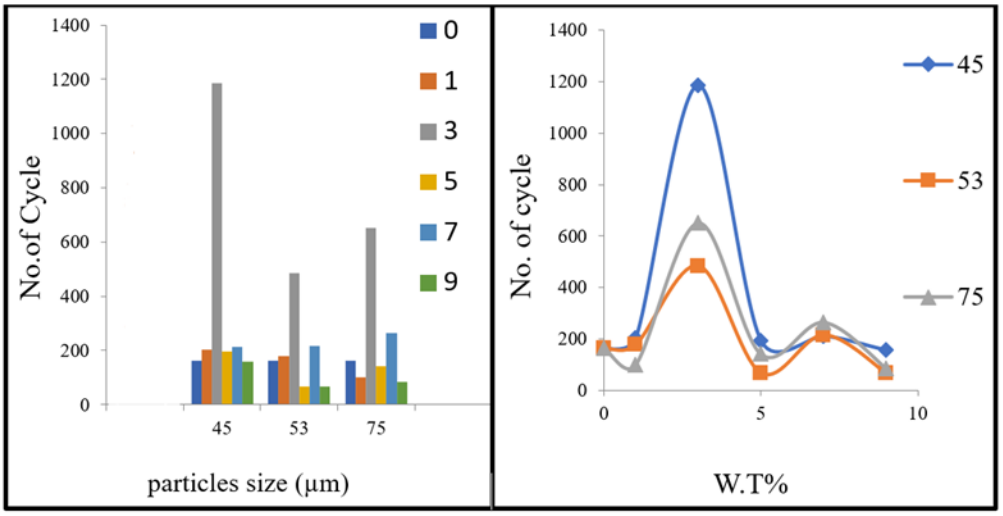
Fatigue test samples were prepared with standard dimensions according to American specifications (ASTM-D 790) with a length of (100 mm), width of (10 mm), and thickness of (4 mm), as shown in Figure (3).

Figure 3 Fatigue Test Samples

Results and Discussion

The results of mechanical tests, represented by (compression test and fatigue test) for epoxy-graphite composites with reinforcement percentages of (0, 1, 3, 5, 7, 9)% and three particle sizes (45, 53, 75) µm, showed the following:

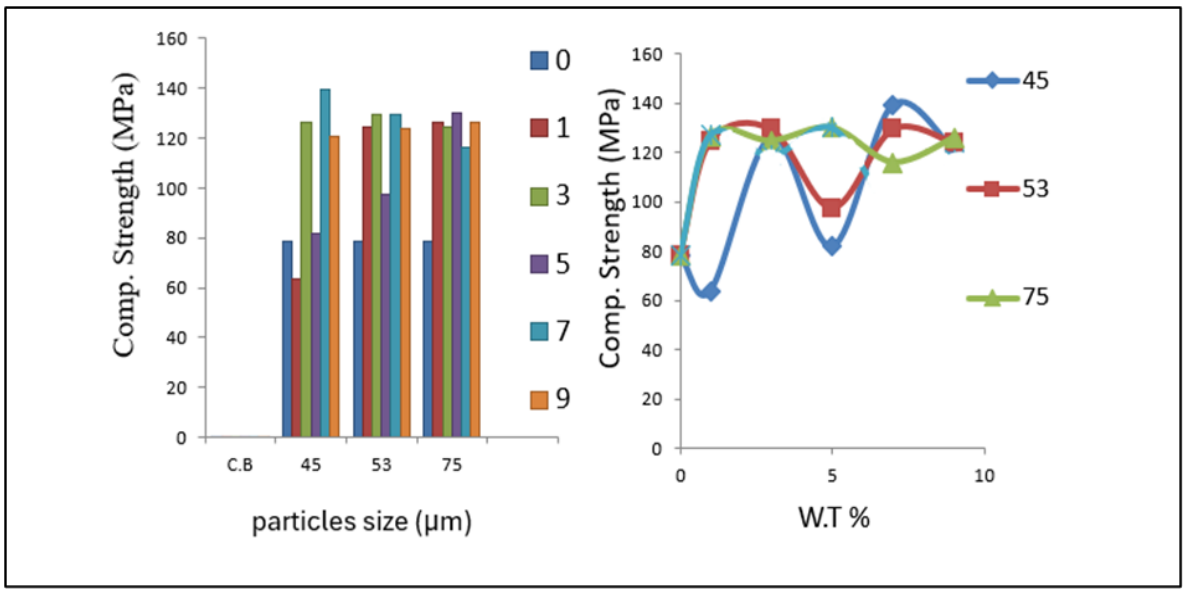
The highest fatigue value was at 3% for both sizes, with the highest value at the particle size of 45 µm, followed by sizes (53, 75) µm. This indicates that small particle sizes at low percentages have shown the best adhesion state between the base material and the reinforcing material [15]. This is illustrated in the figures below (4) and (5).



(a) (b)

Figure 4 (a) Shows the relationship between the number of cycles and particle size for all composites at a fatigue stress of 25.5 MPa (b) Shows the relationship between the number of cycles and reinforcement percentages for all composites at a fatigue stress of 25.5 MPa

The results showed that the highest compression strength was recorded at a 7% reinforcement ratio for the particle sizes of 53 µm and 45 µm. However, for the particle size of 75 µm, the highest compression strength was observed at a 5% reinforcement ratio. This can be attributed to the effect of the interparticle distances, which are larger for smaller particle sizes, leading to an increase in the regions rich in the matrix material [16].



(a) (b)

Figure 5 (a) The relationship between compression strength and particle size for composites is illustrated (b) The relationship between compression strength and reinforcement ratios for all composites is illustrated.

Through compression testing, a distinctive phenomenon was observed in the behavior of the samples. During the test, the samples exhibited elastic behavior, showing longitudinal cracks in the direction of the compression stress without complete material fracture (we could say that the material did not fail). After removing the stress, the material returned to its original shape before the test, except for the existing cracks. This characteristic could be useful for creating flexible supports for special cases, as the manufactured material behaves like an elastic spring. This phenomenon suggests that the produced material could be classified as a smart material, a behavior that is rare in polymer materials or polymer-ceramic composites. Figure (8) illustrates the phenomenon.

1 2 3

Figure 6 Figure (8): Illustrates the aforementioned phenomenon through photographic images, showing:

1. **An epoxy-graphite sample with a particle size of 75 µm before applying force, with a 7% reinforcement ratio.**
2. **The same sample after the test.**
3. **The same sample after a period of time has passed.**

Conclusion

This research has shown that incorporation of graphite particles has a direct impact on the mechanical behaviour of epoxy-based composites. It was found out that the size and weight percentage of the graphite particles greatly affect the behavior of the composite when subjected to mechanical load.

Fatigue testing demonstrated that the best grain size of graphite is 45 μm and the maximum fatigue strength was achieved at 3%wt. This means that the smaller the size of the graphite particles and moderate level of reinforcement the better the adhesion between the epoxy matrix and the graphite particles thus improving the fatigue strength. However, a higher fatigue strength was observed at a lower reinforcement of the largest particle size (75 μm) which indicates that the larger particles may not have a good dispersion within the matrix.

Compression tests also provided evidence of the effect of particle size and reinforcement ratio. The maximum compressive strength was achieved at 7% of reinforcement for 45 and 53 μm particle sizes while for 75 μm particle size, the compressive strength was maximum at 5% reinforcement. This means that the small sized particles to provide a better dispersion within the matrix hence giving the material the much-needed strength against compression.

Also, the specific mechanical property of the epoxy-graphite composites is the elastic behavior when they are subjected to compression, and after deformation, the material comes back to its initial state, which may be useful for applications in flexible support structures. This property, which is not typical for polymer-ceramic composites, creates new opportunities for the development of the so-called multifunctional materials that have both high flexibility and high strength**.**

References

1. W. D. Callister Jr and D. G. Rethwisch, Materials science and engineering: an introduction. John wiley & sons, 2020.
2. R. J. Tilley, Understanding solids: the science of materials. John Wiley & Sons, 2004.
3. G. Piatti, "Advances in composite materials," (No Title), 1978.
4. N. Chawla and Y. L. Shen, "Mechanical behavior of particle reinforced metal matrix composites," Advanced engineering materials, vol. 3, no. 6, pp. 357-370, 2001.
5. A. Tobolsky and H. Eyring, "Mechanical properties of polymeric materials," The Journal of chemical physics, vol. 11, no. 3, pp. 125-134, 1943.
6. L. Tong, A. P. Mouritz, and M. Bannister, 3D fibre reinforced polymer composites. Elsevier, 2002.
7. M. Bhatnagar, "A Textbook of Polymers [Chemistry and Technology of Polymers],(Processing and Applications)," Volume II, S. Chand & Company Ltd, 2004.
8. B. Kwiecińska and H. Petersen, "Graphite, semi-graphite, natural coke, and natural char classification—ICCP system," International Journal of Coal Geology, vol. 57, no. 2, pp. 99-116, 2004.
9. C. Wu, F. Xu, H. Wang, H. Liu, F. Yan, and C. Ma, "Manufacturing technologies of polymer composites—a review," Polymers, vol. 15, no. 3, p. 712, 2023.
10. L. Li et al., "Mechanical behavior and modeling of grinding force: a comparative analysis," Journal of Manufacturing Processes, vol. 102, pp. 921-954, 2023.
11. P. C. Powell and A. I. Housz, Engineering with polymers. CRC Press, 2023.

12. K. Voit, O. Zeman, P. Gappmaier, K. Wriessnig, and R. Adamcova, "Influence of Measurement Uncertainty in the Determination of Selected Rock Parameters—A Realistic Approach," Materials, vol. 16, no. 8, p. 3045, 2023.
13. T. Biswal, T. R. Sethy, and P. K. Sahoo, "Epoxy Foams," in Polymeric Foams: Fundamentals and Types of Foams (Volume 1): ACS Publications, 2023, pp. 161-181.
14. X. Liu and M. Ma, "Cumulative fatigue damage theories for metals: review and prospects," International Journal of Structural Integrity, vol. 14, no. 5, pp. 629-662, 2023.
15. C. H. Kumar, A. Bongale, and C. Venkatesha, "Factors affecting the fatigue behavior of Fiber-Reinforced polymer matrix composites," Journal of The Institution of Engineers (India): Series C, vol. 104, no. 3, pp. 647-659, 2023.
16. H. S. Hammood, A. S. Mahmood, and S. S. Irhayyim, "Effect of graphite particles on physical and mechanical properties of nickel matrix composite," Periodicals of Engineering and Natural Sciences, vol. 7, no. 3, pp. 1318-1328, 2019.