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Mechanical and Thermal Behavior of Epoxy Composites with Carbon Black

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Abstract

General background: Polymer composites are widely developed to meet structural and functional demands through tailored fillers. **Specific background:** Epoxy matrices combined with particulate carbon black offer tunable mechanical strength and thermal transport. **Knowledge gap:** The coupled compressive response and heat conduction behavior across varied carbon black loadings, including recovery phenomena, remains insufficiently clarified. **Aims:** This study examines compressive strength and thermal conductivity of epoxy composites containing 0–9 wt% carbon black fabricated via hand lay-up. **Results:** Compressive strength peaked at 5 wt% carbon black, attributed to improved interfacial bonding and stress transfer, while higher contents reduced strength due to agglomeration. An unusual elastic-like recovery under compression occurred without catastrophic failure. Thermal conductivity increased monotonically, reaching a maximum at 9 wt% as conductive pathways developed. **Novelty:** The identification of pseudo-elastic recovery alongside opposing optima for mechanical strength and thermal transport provides a distinctive structure–property relationship. **Implications:** These findings guide composition selection for lightweight components requiring balanced load-bearing capacity and heat dissipation.

Highlights

- Peak compressive strength achieved at 5 wt% carbon black.
- Elastic-like recovery observed under compressive loading.
- Thermal conductivity rises steadily with filler content.

Keywords: Epoxy Composites; Carbon Black; Compressive Strength; Thermal Conductivity; Particle Reinforcement

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Introduction

Composite materials are materials consisting of more than one material that are designed to make properties better than if they were each individual material.[1-3] Composite materials are composed of two parts, the first part is the base material (matrix) and the second part is additives, the composite materials are plastic-based (polymeric) that are characterized by ease of fabrication, low density, and other good physical properties[4, 5]. Ceramics-based overlays are highly tolerant to high temperatures, so ceramic-based overlays are widely used in the manufacture of turbine blades, and because they resist oxidation, they are used in aerospace, rocket nozzles, or precision electronics.

The mechanical behavior of micro-reinforced supermaterials is the result of the interaction of the properties of the constituent phases of the superstructure, which are represented in the following [8-10]:

- Base Article
- Reinforcement material
- Interface

A. Used Materials

The materials used in the manufacture of research samples are composed of the base material polymer (epoxy resin) and the reinforcement material, which is a fine ceramic material (carbon black), which is as follows:

1. The Matrix Material

In this research, the Jordanian epoxy resin (Quick mast 105) originated par excellence from Fosroc Company was used, which is in the liquid state and can be polymerized and converted to the solid state by adding hardener of the same type of resin, as the solider is distinguished by being a light liquid with low viscosity, density and transparent yellow color, the ratio of the hardener to the resin is (3:1) as the table (1) shows) Some of the properties of the epoxy used. The duration of the resin to harden is more than (3) hours at room temperature, as it is left for two weeks to complete the treatment (Full Curing), and then the samples are cut within the standard specifications of the tests used in the research. The epoxy used is characterized by its low density and low viscosity, and it has a high adhesive property. High Chemical Resistant.

Property	
Compressive strength BS 6319	>72N/mm2 @ 7days @20°C
Flexural strength BS 6319	> 60 N/mm2 @ 35°C
Tensile Strength BS 6319	> 25 N/mm2
Pot life :	85 minutes @20°C
Specific gravity :	1.04
Viscosity:	1.0 poise @ 35 °C
Min. application Temperature	5°C

Figure 1. Table 1 shows some of the properties of epoxy (Quick mast 105).

2. Reinforcement Material

In this research, a reinforcement material (carbon black) with weight ratios (0%, 1%, 3%, 5%, 7%, 9%) with a granular size of mμ(75) and the manufacturer of carbon black (Degussa) was used in the form of a random powder.

3. Specimens Preparation

The Hand lay-up molding method was adopted using a mechanical mixer in the process of preparing samples, and this method was chosen without other complex methods for easy manufacturing in this way and the possibility of manufacturing

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models of different sizes according to the required size and dimensions, and the cost is lower than the rest of the manufacturing methods, two types of molds were used, one square for test samples (thermal conductivity) and the other cylindrical for compression test samples. The following is a description of each of them:

4. The process of preparing samples is carried out in several steps, which are as follows:

5. First Step: Prepare the templates

It includes the preparation of a special mold for the casting process, which is a sheet of glass that represents the base of the mold coated with transparent thermal paper (in order to prevent the adhesion of resin to the glass plate and to make it easier to remove the manufactured pieces), where the board is placed at a high level of evenness (as the surface is ensured by a leveling scale), and the sides of the mold consist of glass rulers of the required thickness coated with thermal adhesive favlon as an insulating material to ensure that the resin does not stick to the glass rulers as the shape becomes The template as shown in Figure (1).

As for the cylindrical mold, a cylindrical tube with a length of (4 cm) and a diameter of (2 cm) of polyvinyl chloride (PVC) was used, as shown in Figure (2).

Figure 2. Showing the square template

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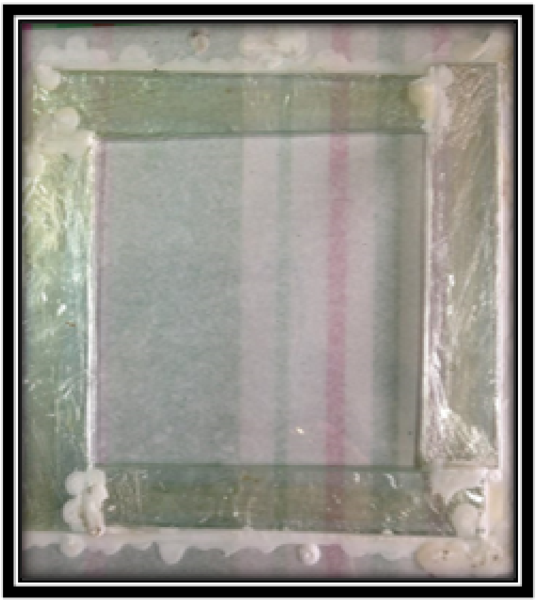

Figure 3. Showing the cylindrical mold

6. Second Step: Preparation of Samples

The method of preparing and pouring samples is summarized in the following steps:

1. A quantity of epoxy material is weighed according to the size of the designed mold and the solidifier is added in a ratio of (3:1).

2. A quantity of reinforcement (graphite and carbon black minutes) is weighed according to the required weight fraction.

3. After that, the process of mixing the reinforcement and the base material begins at room temperature, and the mixture is mixed continuously and slowly to avoid the occurrence of bubbles during the mixing process, and the mixing lasts for (10-15) minutes for the cylindrical mold with a dimension of (4x2 cm, (20-30) minutes for the rectangular mold with a dimension of (12x12) Poison until the mixture is homogeneous and notice that the mixture starts to warm up, which is a sign that the reaction process has begun, it is important for the mixture to have a certain process viscosity to protect the particles from sedimentation.

4. The liquid mixture is poured in the form of a torrent in the middle of the mold (to avoid the occurrence of air bubbles in the mold that causes the failure in it), as it flows to all areas of the mold continuously and regularly until the mold is filled to the required level, and here the mold must be completely flat.

5. The cast is left in the mold for (24) hours to harden definitively before taking it out of the mold, then after taking it out, it is left for (15) days, and this process is important to complete polymerization.

The samples are cut according to the approved specifications for each test using a band saw with soft teeth to ensure that there is no vibration during compression cutting and thermal tests, and the smoothness of the saw teeth will work to avoid deformities that may occur during cutting, while the dimension adjustment stage is done using a smoothing device and then the polishing process is done with zero degree smoothing sheets. Two samples were prepared for each test and for each of the aforementioned ratios to obtain high accuracy of the results.

7. Compression Test Samples

The compression test samples were prepared in its standard dimensions and according to the American specifications (ASTM-D 695 with a length of 40 mm) and a diameter of (20 mm), as shown in Figure (3).

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Figure 4. A sample of compression test samples is shown.

8. Thermal conductivity test samples

The samples were cut with a diameter of (40 mm) and a thickness of (4 mm) and these samples were specific to the Lee's Disc used in the examination as shown in Figure (4) .

Figure 5. A sample of thermal conductivity test samples is shown.

9. Compression Test

Figure (5) shows the relationship between compression strength and reinforcement ratios (0,1,3,5,7,9) The results showed that the compressive strength of the composite recorded the highest compressive strength of the epoxy-black carbon composite at 5%, which indicates that in this ratio, we have obtained the best adhesion and cohesion of the interface between the base material and the reinforcing material ;The compression durability increases with the durability of the interface [12, 13].

During the compressibility test, we found a distinctive phenomenon in behavior, as the samples during the examination took the elastic behavior in the occurrence of longitudinal cracks in the direction of the compression stress without the complete breakage of the material (we can say that the material did not fail) in order to return the material to its initial shape before the examination after removing the effector, except for the existing cracks, and thus this case may be useful for making flexible supports for special cases, as the manufactured material works the work of the elastic spring. This phenomenon allows us that the produced material may fall into the classification of smart materials, and this behavior is rare in polymeric materials or polymer-ceramic composites [14].

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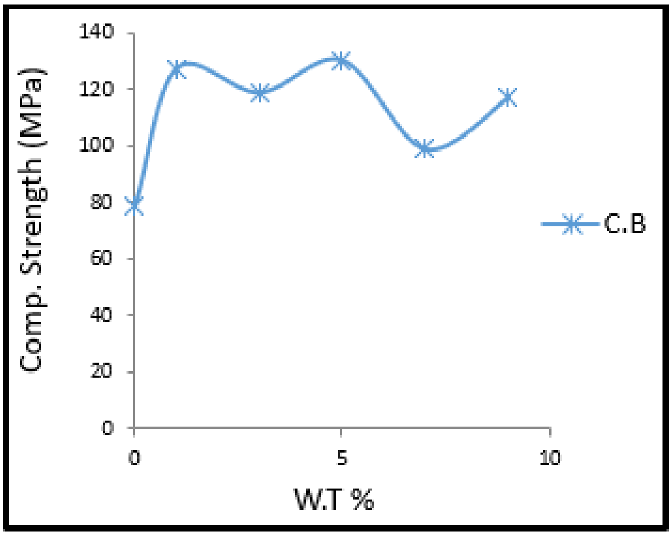

Figure 6. The relationship between compressive strength and reinforcement ratios of the epoxy-carbon black composite is shown.

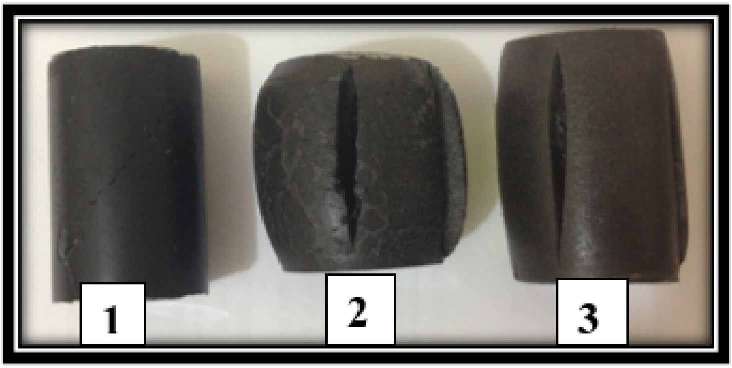

Figure 7. It shows the mentioned phenomenon : 1. Before shedding. 2. The sample itself after shedding force. 3. The sample is the sameafter a period of time

B. Thermal conductivity test

Figure (7) shows the relationship between the coefficient of thermal conductivity and the reinforcement ratios (0,1,3,5,7,9) and the results showed that the thermal conductivity coefficient recorded values that increase with the increase of the reinforcement ratios and the highest value was at 9% This indicates that an increase in the percentage of added minutes leads to an increase in the likelihood of thermal conductivity due to an increase in the amount of the material (additive), which has a higher conductivity than the base material, which in turn leads to an increase in thermal conductivity [15, 16].

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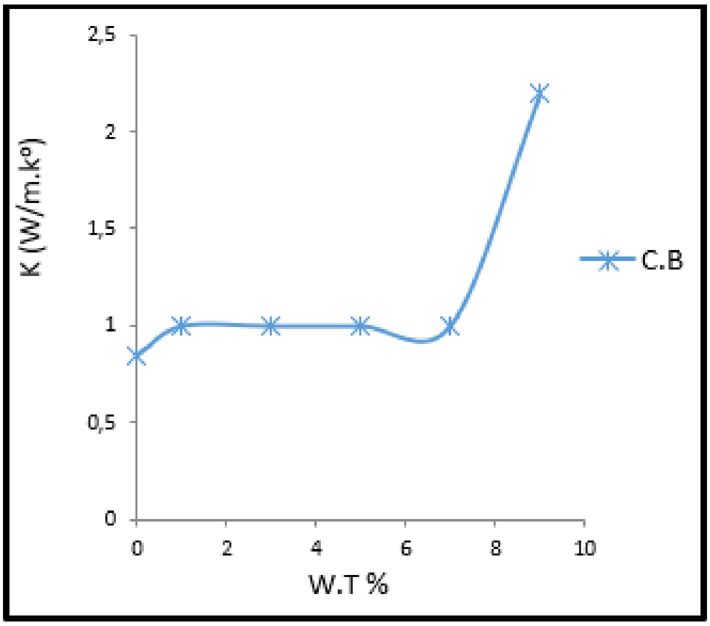

Figure 8. Shows the relationship between the thermal conductivity coefficient and the reinforcement ratios

Conclusion

The present work investigated the effect of carbon black particle reinforcement on the compressive strength and thermal conductivity of epoxy composites. The experimental results confirmed that the incorporation of carbon black significantly influences the performance of the epoxy matrix. An optimal reinforcement content of 5 wt% was identified, at which the composite exhibited the highest compressive strength due to improved interfacial bonding and uniform stress distribution. A distinctive elastic-like behavior under compressive loading was observed, where the specimens recovered their original shape after unloading despite the presence of longitudinal cracks, indicating a potential classification of the material as a smart or pseudo-elastic composite. In contrast, the thermal conductivity of the composites increased monotonically with increasing carbon black content, reaching its maximum at 9 wt%, as a result of enhanced heat transfer pathways within the composite structure. Overall, the results demonstrate that epoxy–carbon black composites can be engineered to achieve a balance between mechanical strength and thermal conductivity, making them promising candidates for applications requiring lightweight materials with improved thermal and mechanical performance.

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