MECHANICAL PROPERTIES OF COMPOSITE MATERIALS BASED ON EPOXY RESIN REINFORCED LOW CARBON STEEL

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ABSTRACT

This work aims to prepare a composite material based on epoxy resin reinforced by fiber and dust particle from low carbon steel with various volume fractions and so, studying their effect on tensile and flexural strength.

Fibers from low carbon steel, with 0.20 mm in diameter and low carbon steel dust particles were used as reinforcement with a volume fraction of (0.8, 2.4, 4.0, 6.2, and 8.3 %).

The results showed that the tensile strength increases as volume fraction increases, for both cases. But the reinforcement by dust particles has more tensile strength than fiber reinforcement. For example, at volume fraction 0.8 %, the tensile strength of fiber composite was 135 MPa, whereas tensile strength of dust particles was 158 MPa.

Also the results of flexural test show that the flexural strength increases as volume fraction increases, for both cases, but in low carbon steel dust particles / epoxy composite, the flexural strength reaches a maximum value 417.23 MPa at volume fraction 8.3 %. This value is higher than that of low carbon steel fiber / epoxy composite.

الخواص الميكانيكية لمادة مركبة ذات أساس من راتنج الإيبوكسي المقواة بالفولاذ الواطيء الكاربون

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الخلاصة

يهدف هذا البحث لتحضير مادة مركبة ذات أساس من راتنج الإيبوكسي والمقواة بألياف و دقائق من الفولاذ الواطيء الكاربون بكسر حجمي مختلف وكذلك دراسة تأثيره على مقاومة الشد والانحناء. تم استخدام ألياف من الفولاذ الواطيء الكاربون وبقطر (0.20 mm) ودقائق غبارية من الفولاذ الواطيء الكاربون كمادة تقوية بكسور حجمية (0.8 ، 2.4 ، 4.0 ، 6.2 ، و 8.3 %).

أظهرت نتائج الفحص أن مقاومة الشد تزداد بزيادة الكسر الحجمي لكل من التقوية بالألياف والدقائق الغبارية، لكن التقوية بالدقائق الغبارية كانت أفضل من الألياف. كمثال على ذلك عند كسر حجمي % 0.8 كانت قيمة مقاومة الشد بالنسبة للدقائق الغبارية حوالي 158 MPa بينما بالألياف 135 MPa وعند نفس الكسر الحجمي.

كذلك بالنسبة لاختيار الانحناء فان مقاومة الانحناء تزداد بزيادة الكسر الحجمي، لكلا الحالتين، لكن في مادة راتنج الإيبوكسي المقواة بدقائق غبارية فإن مقاومة الخضوع وصلت قيمة عليا هي 417.23 MPa عند كسر حجمي % 8.3. وهذه القيمة أعلى من التقوية بالألياف.

1-INTRODUCTION

Composite materials are formed by blending two materials in distinct phases causing a new material with different properties from either parent. (Newell, J., 2007)

Composite materials can be classified by the type of material used for the matrix, the four primary categories of composite are polymer matrix composite (PMCs), metal matrix composites (MMCs), ceramic matrix composites (CMCs), and carbon/carbon composites (CCCs). At this time, PMCs are the most widely used class of composites. However, there are important applications of the other types, which are indicative of their great potential in mechanical engineering application. (Carel, 2007)

Composites may also be classified on the basis of the type of reinforcement they employ, particle reinforced composites, short fiber (discontinuous fiber) or whisker reinforced composites, and continuous fiber or sheet reinforced composites. (Chawla, K. Kumar, 1999)

There are two major classes of polymers used as matrix materials, thermoplastic and thermosetting polymers. Thermoplastics soften when heated and harden when cooled-processes that are totally reversible and may be repeated whereas thermosetting polymer having cured (or hardened) by a chemical reaction; will not soften or melt when subsequently heated. Epoxies are one type of thermosetting polymer that are more expensive and have better mechanical properties and resistant to moisture than the polyester and vinyl resin. (Callister, 2007)

At the present, epoxy resins are widely used in various engineering applications, such as electrical industries, and commercial and military aircrafts industries. In order to improve their processing and product performances and to reduce cost, various fillers are introduced into the resins during processing. (Huang Z.M., 2000)

In a study, modified epoxy resin with carboxyl-terminated polybutadiene presented improved impact resistance and outstanding mechanical performance in terms of flexural and tensile properties because of the presence of rubber particles homogeneously dispersed inside the epoxy matrix. This modified system also resulted in an improvement of mechanical properties of the corresponding carbon fiber based composites. (Goncalz, V, 2010)

In another study, empty fruit bunch was selected as the fiber and epoxy as the matrix, the tensile and flexural properties showed a decreasing trend as the fiber loading was increased. The highest tensile properties was obtained for the composite with low fiber loading and there were no significant effect for addition of more than 5 V_f% to the flexural properties.

The aim of the present work is to examine the effect of low carbon steel fiber and low carbon steel dust particles on epoxy resin and consequently on tensile and flexural strength of composites.

2- EXPERIMENTAL WORK

2-1 Materials Used

In this work, the epoxy resin used has the number 105 as a specification, manufactured by Ayla Construction Chemicals under license from DCP, England, with a density 1.4 g/cm^3. It was used as the matrix, and low carbon steel (unidirectional continuous fiber with 0.20 mm in diameter; measured using a digital caliper with an accuracy ± 0.02 mm, and dust particles; both were bought from local markets) as the reinforcement. Figure 1 shows the structure and properties of an epoxy resin. **Table 1** shows typical properties for materials used.

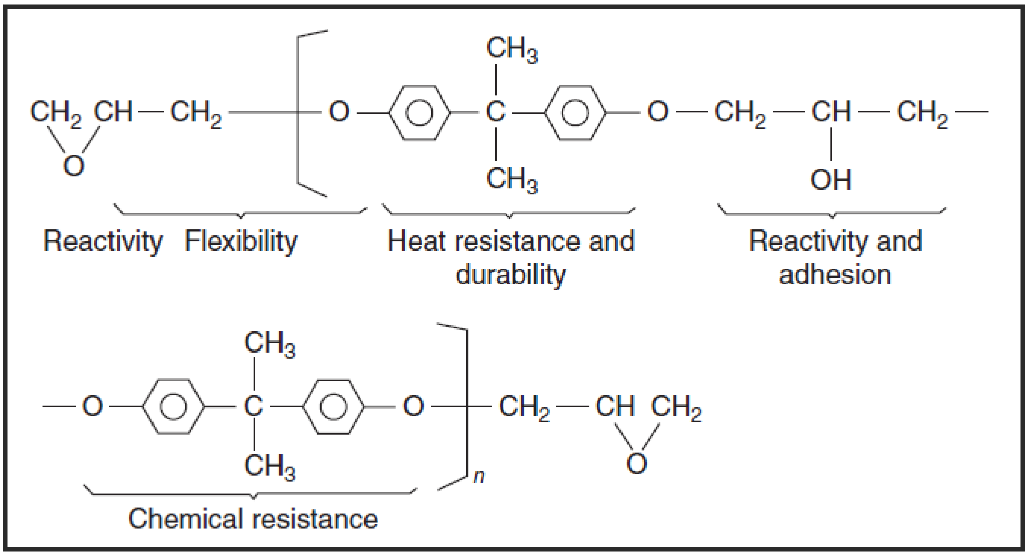


Figure 1 The structure and properties of an epoxy resin (Petrie, E. M, 2006)

2-2 Preparation of Samples

In this work, the moulds were made from carbon steel for both tensile and flexural tests. The ratio between epoxy resin and hardener for this study was 4:1 by weight. Initial epoxy and hardener were mixed together based on the weight percentage to form a matrix. The best way to prepare the curing process to produce a standard quality specimen test was by mixing the epoxy and hardener for approximately 10 minutes. The curing time was around 20-24 hours until the composites dried evenly if applied at the room temperature condition of 25-30 °C.

For specimens reinforced by fibers, the fibers were wet with prepared epoxy (to get a good bonding between fibers and matrix) and then distributed and fixed in the mould. Then the epoxy was mold gradually in the mould. The mould

All the specimens reinforced by dust particles were prepared by preparing the epoxy firstly, and leaving it for 2 hours until the curing began to form, and then the dust particles were wet by the epoxy to keep them from sinking during curing. Then they were mixed with the epoxy by hand for 5 minutes. **Table 2** shows the volume fraction and the number of fiber.

2-2-1 Tensile Specimen Test Preparation

For tensile test, the moulds were made according to ASTM D638 with dimensions of (width = 11 mm, thickness = 6 mm and with gage length $L_{\circ}$ = 60.5 mm), and then the test samples (number of specimens for each type of fiber and dust is 5 samples with one pure epoxy sample) were prepared by taking the fiber and dust by weight percentage and then calculating the fiber volume fraction according to the following relation. (Agarwal, Bthagwan D., *etal*, 1980):

$$V_f = \frac{\rho_m \times W_f}{\rho_f \times W_m + \rho_m \times W_f} \quad (1)$$

Where:

ρ_m = matrix density (g/cm3)

ρ_f = fiber or particle density(g/cm3)

W_m = mass of the matrix (g)

W_f = mass of the fiber and particle (g)

Figure (3) shows the tensile test specimens.

2-2-2 Flexural Specimen Test Preparation

For flexural test, the mould was made according to ASTM D790. The specimen dimensions were 127 mm length, 12.7 mm width and 3.2 mm thickness. The testing processes were carried out using WP 310 universal material tester (**fig. 2**). For both tensile and flexural test, cross head speed of 1 mm/min was used, and then the test samples were prepared, taken also by weight percentage (number of specimens for each type of fiber and dust are 5 samples with one pure epoxy sample).

From test, the breaking load has been recorded to be used in the following equation to obtain the flexural strength:

$$\sigma_F = \frac{3FL}{2bd^2} \quad (2)$$

Where:

σ_f = flexural strength (MPa),

F = load at fracture (KN),

L = distance between support points (mm),

b = specimen's cross-section-width (mm),

d = specimen's cross-section-height (mm).

3- RESULTS AND DISCUSSION

3-1 Tensile Strength Test

The results are demonstrated in **table 3** and **fig. 5**. It can be clearly noticed that the tensile strength is directly proportional to fiber or dust volume fraction. The tensile strength reaches its maximum value (172 MPa) at a fiber volume fraction of 8.3 % and a maximum of (173 MPa) at the same volume fraction of the dust. An increment ratio of 41 % can be noticed compared with the virgin epoxy. At a low volume fraction (V_f = 0.8 %), there is a noticeable difference between the tensile strength of the two reinforcements, where reinforcing with the dust shows a larger tensile strength with a ratio of 1.172 %. This is because the fine particle fillers are setting on the molecular compaction chains giving a high molecular compaction. So it can be said that reinforcing with a steel dust is more suitable than that with a steel fiber to get a composite material with a higher specific strength.

Studies proof that the reinforcement by fibers gives better results than other reinforcements and this occurs only at volume fraction range between (30-70%). (Haydar A. Hussain, etal, 2008). But in this work, the volume fraction used was lower than this range because the reinforcement's materials have high density so the increment in volume fraction leads to an increment in composite weight and this is not the purpose of using composite materials (low weight).

3-2 Flexural Strength Test Results

From **table 4**, it can be noticed that the flexural strength of virgin epoxy is about 117 MPa. **Table 4** and **fig. 6** show that the flexural strength value enhanced from 117 MPa to 400.21 MPa at 8.3% fiber volume fraction, whereas its value reached 417.23 MPa at 8.3 particle volume fraction. This can be attributed to the imperfect alignment of the fibers. Also the efficiency of stress transferred between resin and fiber decreased from the weak interfacial regions. (Khalil etal. 2007)

For the reinforcement with particles, dust particles are set on the molecular chain reducing the applied stress on the matrix and the molecular chain becomes more compacted.

4 – CONCLUSIONS

1. The tensile strength and flexural strength of low carbon steel fiber and dust particles reinforced epoxy composites have been measured.
2. The tensile and flexural strength increased as the volume fraction increases for both reinforcements.
3. The σ_f and σ_T of epoxy composite reinforced by dust particles hads a larger increment ratio of 1.172 %, and1.1% respectively than that of epoxy composite reinforced by low carbon steel fibers.

Table 1 Typical Properties of Materials used. (Callister, W. D, 2007) & (Mark,J.E.,1998)

Materials used	Density (g/cm^3)	Tensile modulus (GPa)	Tensile strength (MPa)	Flexural strength (MPa)
Epoxy resin	1.4	2.41	24-90	34-200
Low Carbon steel	7.85	207	440	345

Table 2 The fiber volume fraction, and number of fibers for reinforcement used in this work

Number of specimen	Fiber volume fraction (V_f%)	Number of fiber used

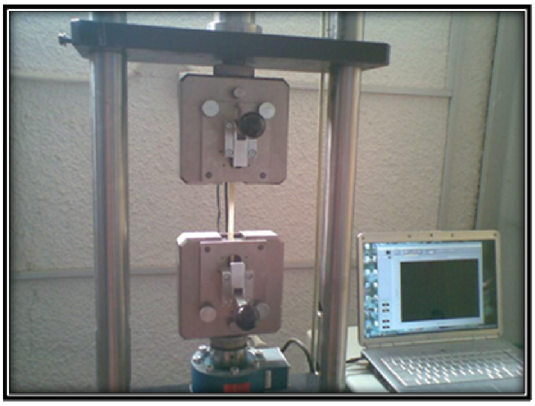
1	0	0
2	0.8	1
3	2.4	4
4	4.0	6
5	6.2	8
6	8.3	10

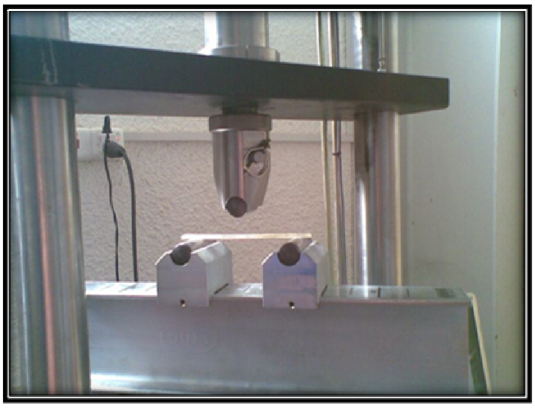
Table 3 tensile test results

No. of specimen	V_f	σ_T (MPa) low carbon steel fiber / epoxy resin	σ_T(MPa) low carbon steel particles / epoxy resin
1	0	70	70
2	0.8	135	158.32
3	2.4	157	160.83
4	4	160	170.23
5	6.2	169	172
6	8.3	172	173

Table 4 Flexural test results

No. of specimen	V_f	σ_f (MPa) low carbon steel fiber / epoxy resin	σ_f (MPa) low carbon steel particles / epoxy resin
1	0	117	117
2	0.8	127.23	137.86
3	2.4	165.13	182.92
4	4	231.5	249.1
5	6.2	348.06	362.02
6	8.3	400.21	417.23





(a) (b)

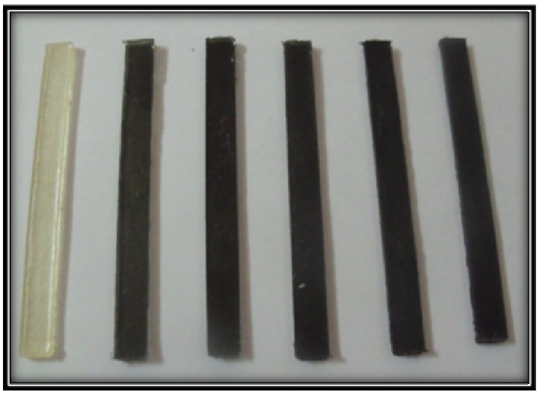
Figure (2) WP 310 Universal material tester:

(a) Tensile test,
(b) Flexural test.

(a) (b)

Figure (3) Tensile strength test's specimen before fracturing:

(a) Reinforced by fiber,
(b) Reinforced by dust particles.



(a) (b)

Figure (4) Flexural strength test's specimen before fracturing:

(a) Reinforced by fiber,
(b) Reinforced by dust particles.

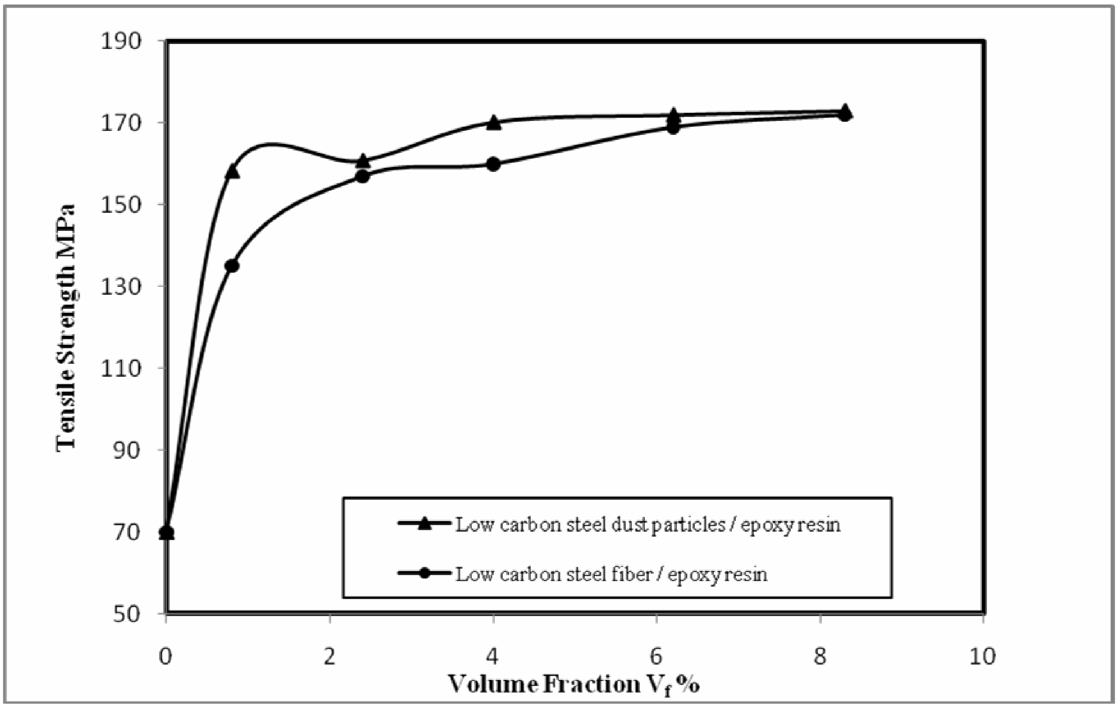


Figure (5) Tensile strength of low carbon steel (fiber and dust particles) / epoxy resin composite

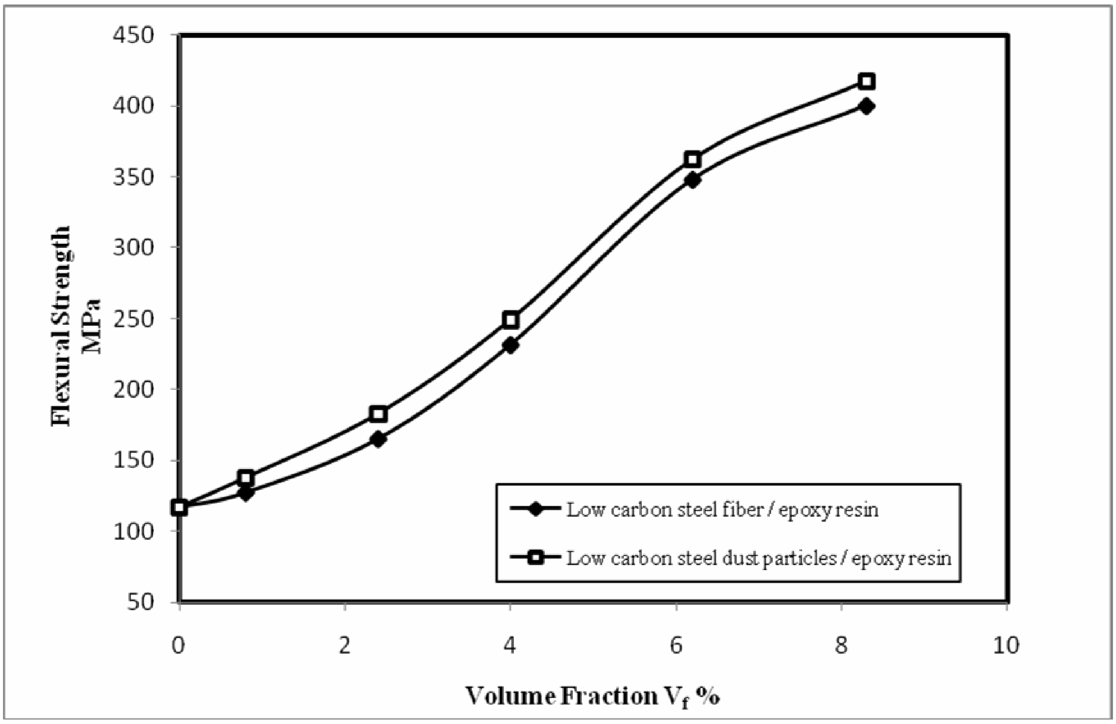


Figure (6) Flexural strength of low carbon steel (fiber and dust particles) / epoxy resin composite

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