

Mechanical properties of a hybrid composite material (epoxy-polysulfide rubber) reinforced with fibres

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Abstract. This study investigated the mechanical properties of a hybrid polymer matrix composite material (PMCs) prepared from 98 wt% epoxy resin and 2 wt% polysulfide rubber reinforced with two types of fibres, glass fibres and carbon fibres, which were used in the form of a plain woven material with a volumetric fracture of 20%. Mechanical tests were conducted for the composite materials before and after reinforcement with these fibres to ascertain the effect of adding fibres on the mechanical properties of the composite material. The fibre effect was evident in improving all studied properties, especially tensile strength and impact strength.

1. Introduction

Many modern technologies require materials with uncommon combinations of properties not found in the classical ceramics, metals, alloys, and polymeric materials of traditional engineering. This particularly applies to applications used underwater, and in aerospace and transportation [1]. Generally, a composite material consists of a form of reinforcement (particles, flakes, fibres, or fillers) embedded in a matrix (metal, polymer, or ceramic). The matrix holds the reinforcement together to obtain the desired shape while the reinforcement improves the overall mechanical properties of the matrix [2]. Composites containing two or more types of reinforcement in a matrix are called hybrid composites. The development of composite materials containing more than one type of fibre reinforcement (hybrid composites) has been motivated by their ability to combine the advantageous features of various reinforcement systems to improve performance as well as reduce weight and cost [3]. Polymer is the most common matrix material used in such composite materials due to its strength and stiffness, which although naturally lower than those of metals and ceramics, can be improved by reinforcing with other materials; additionally, the processing of polymer matrix composite does not require high pressure and temperature [4]. Polymer matrix composites (PMCs) are thus the most widely used synthetic composites [5]. The use of polymers without reinforcement as structural material is limited by its low levels of mechanical properties, but reinforcing the polymers with strong fibres allows the fabrication of polymer matrix composites [6] that offer greater strength and stiffness along with resistance to corrosion. Their frequency of use is thus related to their low cost, high strength, and simple manufacturing principles [7]. This work aims to evaluate the mechanical properties of a hybrid composite material and to obtain the effect of adding fibres on the properties of this composite material.



2. Fibre-Reinforced Composites (FRC)

Fibres are a significant class of reinforcement materials, and the main use of fibres in composite materials is to improve the mechanical and physical properties of the matrix resin with their high strength to weight ratio. Fibre materials are characterised by high tensile and compression strength and high elastic modulus. They impart these properties to the composites to which they are added by being the most subjected to loads, thus improving the stiffness of such composites [8,9]. The mechanisms of failure of fibre-reinforced composite materials include delamination, longitudinal matrix splitting, inter-laminar matrix cracking, fibre pull-out, and fibre fracture [10]. Fibre reinforcement can include ceramic fibre such as carbon and glass fibres, polymeric fibre such as Kevlar fibre, or metal fibre in the form of wires such as copper wire and steel wire [11]. Glass fibre is widely used to strengthen polymeric materials, and this can be in the form of a Woven Roving, distributed along the resin material, in the form of a Chopped Strand, distributed in random form, in the form of a Glass Fabric, or in the form of threads and tapes. This material has many useful characteristics, including a high melting point, good chemical resistance, and high tensile strength [12]. Carbon fibre is another widespread fibre type used in industrial applications because it gives the best properties when used to strengthen polymer composite materials. Some of the most important characteristics of carbon fibre are its high stiffness, good strength in tension and compression, and good resistance to creep, corrosion, and fatigue [13].

3. Experimental procedure

The materials used in this work were

3.1. Epoxy Resin (ER):

This was Sikadur®-52 Injection Type N, which consists of two parts, a resin and a hardener. The recommended mix is 3 g of epoxy resin to 1 g of hardener. Table (1) shows the properties of the epoxy resin

Table 1. The properties of epoxy resin [14].

Properties	Values
Tensile Strength	37 MPa (at 23 °C)
Flexural Strength	61 MPa (at 23 °C)
Compressive Strength	52 MPa (at 23 °C)
Density	1.1 g/cm ³ (at 20 °C)
Viscosity	430 mPa.s (at 20 °C)

3.2. Polysulfide Rubber (PSR):

The polysulfide used in this research was polyseal PS PG, which consists of two parts, a resin and a hardener. The recommended mix was 16 g of polysulfide resin to 1 g of hardener. Table (2) shows the properties of the polysulfide rubber.

Table 2. The properties of polysulfide rubber h [15].

Properties	Values
Specific Gravity	1.35
Tensile Strength	8.3 MPa
Flexural Strength	550%
Young's Modulus	3.7 to 5 MPa
Compressive Strength	20 to 100 MPa

3.3. Carbon fibres:

The type of carbon fibres used were Carbon UD Stockinette from the Tenax Company, England. The carbon fibre was used in the form of a plain woven bi-directional (0° to 90°) material. Table (3) shows the properties of the carbon fibres.

Table 3. The properties of carbon fibres [16].

Properties	Values
Tensile strength	5,600 MPa
Elongation	1.9%
Tensile modulus	290 GPa
Density	1.81 g/cm ³
Tensile strength	5600 MPa

3.4. Glass fibres:

The type of glass fibres used in this work were woven E- glass fibres from the Tenax Company, England. Table (4) shows the properties of these glass fibres.

Table 4. The properties of glass fibres [17,18].

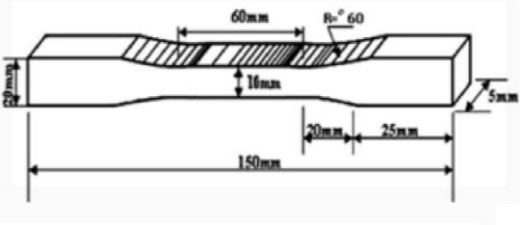
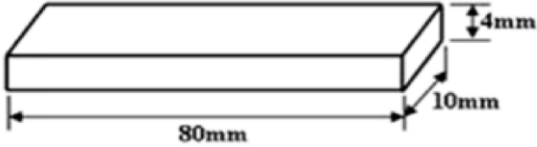
Properties	Values
Compressive strength	1,080 MPa
Tensile strength	3,445 MPa
Young modulus	72.5 GPa
Percentage elongation	4.3
Poisson's ratio	0.22
Density	2.58 g/cm ³

In this study, epoxy resin was mixed at 98 wt% with polysulfide rubber at 2 wt%. The mixing was continuing for 2 hours at room temperature to obtain a homogeneous blend with no bubbles. The epoxy-polysulfide blend was reinforced by cutting and weighting the fibres; using a volumetric friction of 20% and the rules of mixtures, the weight ratio of the fibres could thus be determined from the total weight of the blend. The method used was to pour an amount of the blend into the mould before adding the first layer of fibre, then adding another amount of the blend, continuing this process to develop a composite material reinforced with three layers of fibres. Table (5) shows the samples created in this way. The composite materials were left at room temperature for 24 hours before being extracted from the moulds and placed in the drying oven at 60°C for 8 hours to complete the process of solidification and to eliminate any stresses that may have formed during the process of reinforcement. Finally, the samples were cut according to the standard specifications for each test. Table (6) shows the standard dimensions of samples used in the work.

Table 5. The type of samples in this work.

No. of samples	Properties
A1	Epoxy (98 Wt%)+polysulfide (2 Wt%)
A2	A1 reinforced with two layers of carbon fibres and one layer of glass fibres
A3	A1 reinforced with two layers of glass fibres and one layer of carbon fibres

Table 6. Dimensions for testing samples.

Type of tests	Samples dimensions
Tensile test	
Hardness test	
Impact test	

Three types of tests were conducted on the prepared samples:

1. Tensile Strength

Tensile resistance is a measure of the material's ability to resist the static forces that try to pull at and break the material. Tensile strength was calculated using equation (1) [19]:

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

where

σ : Tensile strength (N/m²).

F: Applied load (N).

A: Cross section area of sample (m²).

The tensile test was carried out according to the standard specifications (ASTM-D638) using a tensile machine (computer controlled universal testing machine) of model WDW-50.

2. Hardness test

Hardness is an important surface mechanical property which can be defined as a material's resistance to penetration or plastic deformation [20].

The hardness test was carried out according to the standard specifications (ASTM-D2240) using a Shore D hardness instrument model TH210 designed for measuring the hardness of polymeric materials. The Shore D is a device similar to a compass that measures the hardness of polymeric materials by means of the depth of indentation or penetration on a scale of 0 to 100. The device has a needle in the middle with a 1.4 mm diameter and a 30° conical point.

3. Impact test

The impact strength test is a practical method that gives an accurate indication of the strength of the material and its resistance to breaking under stress at high speed, Impact strength was calculated using equation (2) [21]:

$$I.S = Uc/(A) \quad (2)$$

where

I.S: Impact strength (J/m^2).

Uc: Energy necessary to break the sample (J).

A: Cross section area of sample (m^2).

Impact testing was carried out according to the standard specifications (ASTM- 256) by using a Charpy impact test instrument of model IMI, which is designed to measure the impact fracture energy of polymeric materials.

4. Results and Discussions

4.1. Tensile Strength

The experimental results for tensile strength shown in figure (1) demonstrate that the tensile strength increased after reinforcement with carbon and glass fibres. The addition of 20% carbon and glass fibres to a 98% epoxy-2% polysulfide rubber blend matrix leads to an increase in tensile strength to 493 MPa for sample A2 and 374 MPa for sample A3. The composite material began to elongate linearly in response to the stress exerted as the loading continued, with the deviation of the matrix material reaching the point of submission while the fibres continued to lengthen and resist until resistance collapsed. When the matrix material broke down, the composite material failed completely. Fibres bear a large part of the load, which increases the tensile strength of the composite material; however, the composite materials reinforced with two layers of carbon fibres and one layer of glass fibres (A2) have higher tensile strength than the composite materials reinforced with two layers of glass fibres and one layer of carbon fibres (A3).

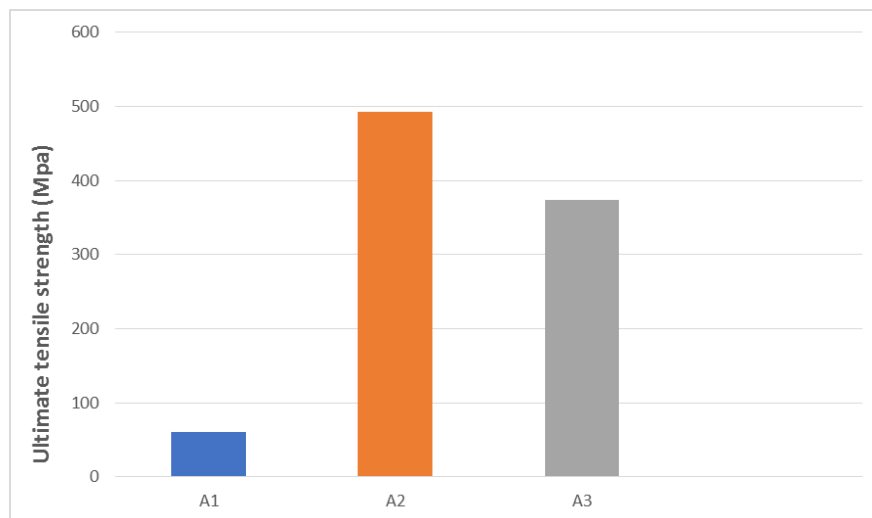


Figure 1. Ultimate tensile strength of the composites.

4.2. Hardness

The experimental results for hardness shown in figure (2) suggest that the hardness increased after reinforcement with carbon and glass fibres. The addition of 20% carbon and glass fibres to a 98% epoxy-2% polysulfide rubber blend matrix led to an increase in hardness to 82.45 for sample A2 and to 82.66 for sample A3. The load was distributed on the fibres, thus decreasing the penetration rate on the composite material's surface and increasing its hardness. The increase in the hardness in the composites is an indication of good bonding between blend and fibres, reducing the movement of the blend molecules.

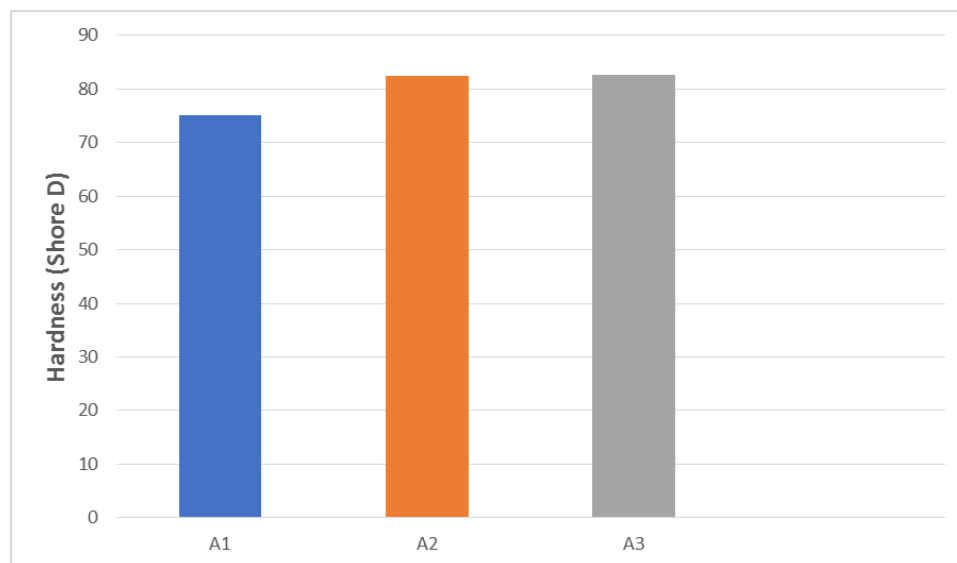


Figure 2. Hardness values of the composites.

4.3. Impact Strength

The experimental results of impact strength shown in figure (3) demonstrate that the impact resistance increased after reinforcement with carbon and glass fibres. The addition of 20% carbon and glass fibres to a 98% epoxy-2% polysulfide rubber blend matrix led to an increase in impact resistance to 207.434 KJ/m² for sample A2 and to 156.341 KJ/m² for sample A3. Fibres will carry the bulk of the stress and work to distribute stress over a larger volume, reducing the possibility of concentration of stress in a particular area as well as acting as an obstacle to breaking and thus preventing the growth of small cracks that may occur as a result of impact. It was noted that the composite materials reinforced with two layers of carbon fibres and one the layer of glass fibres (A2) had higher impact resistance than the composite materials reinforced with two layers of glass fibres and one layer of carbon fibres (A3).

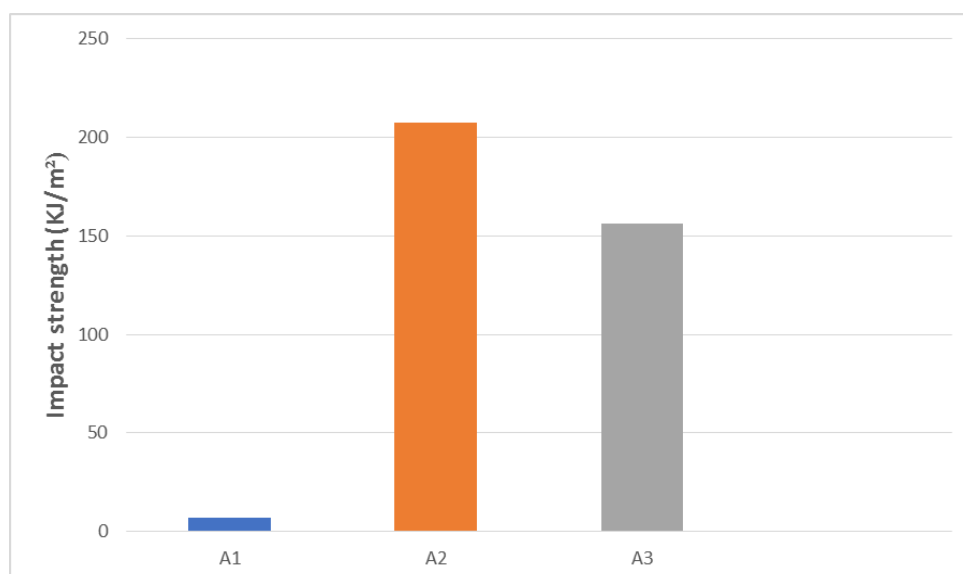


Figure 3. Impact strength of the composites.

5. Conclusions

The results obtained can be summarised as follows:

1. The increase in the tensile strength of sample A2 was very clear, as shown in figure (1), due to the high mechanical properties characteristic of carbon fibre. Its tensile strength in particular is very high, thus giving the composite material a high tensile strength.
2. Sample A3 was characterized by a high hardness value due to the presence of two layers of glass fibres in addition to a middle layer of carbon fibres. This characteristic gave the sample an increase in the value of hardness because the glass fibres have a high density compared with the carbon fibres as seen in tables (3) and (4).
3. The obvious increase in the values of mechanical properties, especially tensile strength and impact strength, when using fibres of glass and carbon with a low percentage of polysulfide (2%) offers a great opportunity to use this type of composite material in various mechanical applications, especially those requiring lightweight and high specification parts. This would allow it to be used as an alternative to iron or metal parts where light weight is important in the design of the part, for example in cars, aircraft, and pipes.

Acknowledgments

The authors wish to acknowledge the assistance and encouragement of their colleagues in the Materials Engineering Department, Applied Sciences Department, University of Technology, Baghdad, Iraq. Special thanks are given for the work by technical staff in this University.

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