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Characteristics and Properties of Epoxy/Polysulfide Blend Matrix Reinforced by Short Carbon and Glass Fibers

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Abstract

In this research, binary blends have been prepared from epoxy resin (EP) and different weight percentages of polysulfide rubber (PSR) (0%, 2.5%, 5%, 7.5 and 10%), and then compression, impact, and hardness tests were evaluated. The experimental results showed that the addition of polysulfide rubber in the epoxy resin decreased the compressive strength, Young's modulus, and hardness, while increased the impact resistance. It was found that the weight percentage 5% of polysulfide was the best percentage, which gives the best mechanical properties for the blend matrix. The advantage of this blend matrix is that, it mediates between the brittle properties of epoxy and the flexible properties of a blend matrix with the highest percentage of PSR. Short fibers (Carbon & Glass) with different volume percentage (2.5%, 5%, 7.5%, and 10%), were used to reinforce the best blend matrix obtained separately and randomly, and then the same mechanical tests conducted on these composites. The experimental results showed that the addition of fibers increased the compressive strength, Young's modulus, impact resistance and hardness. It was also observed that the composites materials reinforced with carbon fibers have significantly higher mechanical properties values than the composites materials reinforced with glass fibers.

Keywords: Composite Materials, Epoxy, Polysulfide, blend, fibers.

1. Introduction

Epoxy resins are belong to the principal polymer under the term thermosetting resins. Epoxy resins are widely used as structural adhesives, matrices in fiber-reinforced composites, and coatings for metals because of their excellent properties such as high tensile strength and modulus, easy processing, good thermal and chemical resistance, and dimensional stability [1].

However, like other thermoset resins, the crosslinking character of cured epoxies produces a highly undesirable property: they are relatively brittle, having poor resistance to crack initiation and growth. This lack of toughness severely effects the performance of these thermoset in Almost all applications. To address this defect, it has been used a technology that permits some thermosets to be toughened by the addition of a second elastomeric phase, such as artificial rubber. This helped to flexibilize the brittle thermoset matrix and increase the fracture energy [2-3].

Improving fracture toughness will lead to significantly improved performance when used as is, and will also improve the damage initiation threshold and long term reliability for fiber reinforced composites. There are different reactive liquid elastomers which are used to modify or toughen epoxy resins [4]. Liquid polysulfide elastomer is one of the most important reactive modifiers for epoxy resin. Polysulfide modified epoxy adhesive systems are widely used in the construction, electrical and transportation industries. Since polysulfide is a very flexible elastomer, addition of liquid polysulfide elastomer to epoxy resin gives good flexibility and impact strength to epoxy matrix [5]. However, the addition of polysulfide rubber to modify epoxy systems disrupts the most desirable properties of epoxy resin. They reduce the elastic modulus and tensile strength, and the glass transition temperature (Tg) [6].

The weak fracture toughness of many thermosets frequently limits their application areas in which they can be used. Considerable efforts had been made in the past to improve fracture toughness of polymers through chemical modification or by incorporation of special additives such as liquid rubbers, elastomers, plasticizers, or fibers reinforcing agents. In the case of thermoset resins, which are normally liquid in uncured state, fibers reinforcement has become an important means of increasing the strength, modulus and impact toughness of such resins. Fibers reinforcement used usually with thermosets as short fibers. Common types of short fibers are carbon and glass [7-8].

This paper discusses the effects of combining the benefits of adding polysulfide rubber and two various types of short fibers to the epoxy matrix to develop improved matrix material with the aim of attaining good adhesive strength without compromising the other desired mechanical properties of the epoxy resin. The objective of this

study is to examine the influence of polysulfide elastomer and fibers concentration on the morphology and mechanical properties of fiber reinforced rubber-modified epoxy system.

2. Experimental Procedure

2.1 Materials

The blend matrix system consists of epoxy resin and polysulfide rubber. Epoxy is thermoset resin containing of two or more epoxide group, which are composed of oxygen atom linked with two atoms of carbon. Epoxy group linked chemically with the other molecules to form three-dimensional cross-linked thermoset structures. The type of epoxy used in this research is (Quickmast 105® (DCP)) manufactured by commercially produce from Quick Mast company .The hardener from the same company mixed with the epoxy resin in the ratio of 3:1, and the interaction between them occurs at room temperature, the name of this interaction is (Addition reaction), and epoxy properties are shown in table (1). As for polysulfide rubber, which are a class of chemical compounds containing chains of sulfur atoms, provided as a white dough, where it turns into a form of elasticity by adding PbO_2 (Black dough) in the ratio of 1:16 with a density ratio (1.35) gm/cm3as, and polysulfide rubber properties are shown in table (2). Reinforcement materials must provide two main advantages, which are: high strength and low ductility to improve the matrix material, where the most common methods of reinforcement is reinforcing by fibers. Carbon and glass fibers have been used to reinforce the blend matrix. It cut to lengths ranging between (10-14 mm) with diameter limits of (10-14 μm) produced by (Grace cemfiber company). Table (3) shows the physical and mechanical properties of carbon and glass fibers.

Table 1: Physical and mechanical properties of epoxy resin [9].

Test method	Typical results
Compressive strength (Mpa)(min.)	70.0 at 20 °C
Tensile strength (Mpa)(min.)	30.0 at 35 °C
Flexural strength (Mpa)(min.)	63.0 at 35 °C
Young modulus in compression (Gpa)	16
Hardness (shore D)(min.)	72
Impact strength (Charpy) KJ/m^2	4.4
Density (g/cm^3)	1.004

Table 2: Physical and mechanical properties of polysulfide rubber [10].

Test method	Typical results
General chemical structure	-50 to 95
Service temperature (°C)	1:16
Mixing ratio	1.35
Density (g/cm^3)	292
Tg (°C)	22 - 39
Hardness (Shore A)	126 - 412
Ultimate elongation (%)	0.74 - 0.91
Tensile strength (Mpa)	-50 to 95

Table 3: Mechanical and physical properties of carbon and glass fibers [11].

Typical results	Fiber	
	Carbon	Glass
Young's modulus GPa	105	13
Density g/cm^3	1.8	2.55
Tensile strength GPa	2.4	2
Poisson's ratio	0.20	0.22
Thermal conductivity W/m.K	76	230

2.2 Molds and specimens preparation

Composites tend to be high-adhesion, so it should use molds made from materials have moderate strength and toughness, therefore glass has been used to prepare molds. The mold used in this work prepared with dimensions of (16 × 8 × 1.2) cm. as shown in figure (1). The mold must be cleaned and lubricated the inside walls of mold with Vaseline and nylon paper (Fabloon) to prevent the adhesion between the mold and polymeric material. This will ensure to get regular distribution, smooth surface, and no defects. The mixture poured in the mold by Hand lay-up molding from one side only to eliminate the entrapment of air. After the solidification process completed within 24 hours in the room temperature, the molded extracted from the mold, then it was cut into a standard specimen dimensions according to ASTM standard for the mechanical test. Table (4) shows the standard dimensions of specimens.

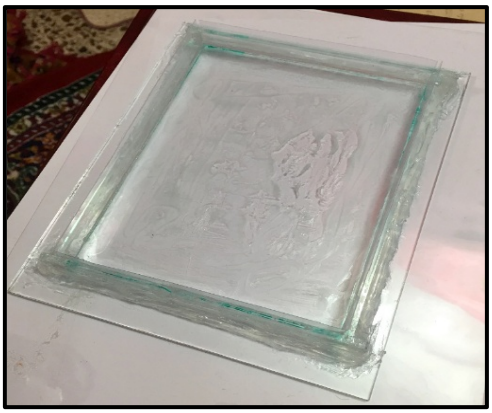
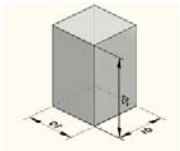
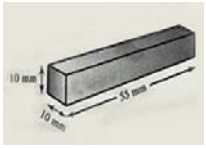


Figure 1: The shape of the mold.

Table 4: Samples dimension and standard specification for testing specimens.

Test type	Test specimen specification	Standardization code
Compression test		ASTM-D695
Impact test		ASTM-256-78
Hardness test		ASTM-D2240

2.3 Composites preparation

Two stages of composites were prepared in this research. The first stage included preparing samples of epoxy resin and different blend matrices of epoxy-polysulfide. The weight percentages of polysulfide rubber in the matrix resin were (0%, 2.5%, 5%, 7.5%, and 10%).The polymeric blend matrix presented by mixing the resins of both epoxy and polysulfide rubber without their hardeners via magnetic stirrer model (No 690/1) shown in figure (2), for 3-4 hours until it became homogenous. Hardeners of epoxy and polysulfide were added in the mixture of resins. The final mixture blended for a half hour by manual mixing. After the mixture became homogeneous enough, it poured into the mold and it left in room temperature for completing the solidification. After the molded cut into standard samples، the mechanical tests conducted on them. From the obtained results of mechanical tests, the best percentage of polysulfide will be identified.

The second stage included reinforcing the best blend matrix of epoxy-polysulfide (the blend matrix with the best percentage of polysulfide) from the previous stage, by different volume percentages of short fibers (Carbon& Glass) separately and randomly. The volume percentages of fibers were (2.5%, 5%, 7.5%, and 10%). Fibers added with the obtained blend matrix into the mold with good distribution and mixing. The same mechanical tests conducted on the second stage samples. In this work, it was tested 150 samples for all the mechanical tests. Two samples for every single test was tested, then took the average value of the obtained results.

Figure 2: Magnetic starrier.

2.4 Mechanical tests

2.4.1 Compression test

Compression test was conducted to measure the compressive strength of materials using testomertic CO.Ltd WDW-200E. The compressive strength is the material resistance to the maximum compressive stress without crushing. The sample with size of (10 × 10 × 20) mm^3 according to ASTM-D695 were starched at a constant load speed of 2 mm/min. From the stress-strain curve, the compressive strength of samples was identified. Figure (3) shows compression test instrument.

Figure 3: Compression test instrument.

2.4.2 Impact test

Impact test was conducted using impact test instrument type of Izod which is produced by (Testing Machines .INC.,AMITYVILLE, New York), to determine the impact resistance of materials, where was used hammer which its energy is 5 joule to conduct the test. Standard size of samples is (10 × 10 × 55) mm^3 according to ASTM-D256-87. Figure (4) shows Izod impact test instrument. Impact resistance is calculated from this relationship:

I.S= U/A

Where U: is the fracture energy (kilo Joule) is determined form Izod impact test instrument.

A: is the cross-sectional area of the specimen (m^2).

Figure 4: Izod impact test instrument.

2.4.3 Hardness test

Hardness test was conducted using Shore D hardness instrument for measuring the hardness of the polymeric materials. It is a device similar to the compass, where it contains a needle in the middle. Testing method included, placing the device vertically on the sample to measure the hardness. The needle touched and implanted the surface of sample and waited for three seconds, then hardness value took from the device. The effective pressure according to (DIN 53505) is (5kp) for shore D hardness. Three results have taken in different places and then took the average value. Figure (5) shows shore D hardness instrument.

Figure 5: Shore D hardness instrument.

3. Results and discussion

Results of the two stages that have been obtained from the mechanical tests will be discussed and represented in graphic curves in order to identify the mechanical properties of materials.

3.1 Stage I: Epoxy and epoxy-PSR blends

The results of the first stage will be discussed to identify the effect of adding different percentage of polysulfide rubber on the mechanical properties of a matrix resin of epoxy. This helps to identify the best percentage of polysulfide that gives best mechanical properties to the blend matrix. This blend matrix will be a matrix material to the second stage.

3.1.1 Results of compression test

Compression tests were conducted on the prepared sample from epoxy resin before and after adding polysulfide rubber with different weight fractions (2.5%, 5%, 7.5% and 10%), in order to determine the compression strength and Young's modulus.

Figure (6) shows the compression stress-strain curve of epoxy resin, where it has been found that the ultimate stress was 74.5 Mpa and Young's modulus 3.2 Gpa.

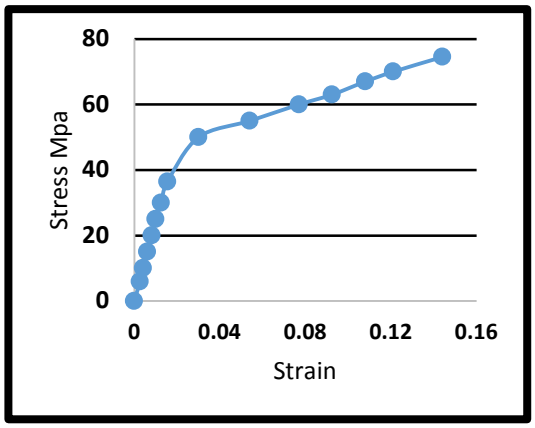


Figure 6: The compression stress-strain curve of epoxy resin.

As for the samples of epoxy-polysulfide blends, the experimental results shown in figure (7) showed that, the compressive strength decreased with the increase of PSR percentage. Therefore, when blending (2.5%, 5%, 7.5%, 10%) of PSR with epoxy resin caused a decrease in compressive strength by about (-3.74%, -11.37, -19.3%, -25.32%) than epoxy resin value. The smaller rubber particles incorporated into the epoxy matrix will reduce the strength and flexibilizes the brittle thermoset matrix, and thus result in low compressive strength of the blend matrix, which is incapable to carry high axial loads. Also, the nature of elastic properties of polysulfide rubber include low compressive strength that will weaken the cross linkage network of the blend matrix.

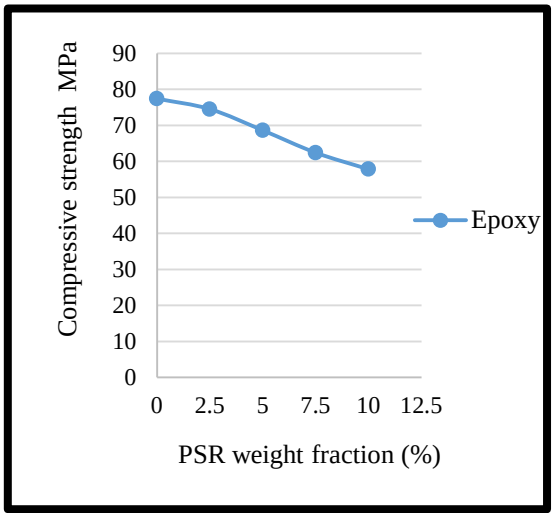


Figure 7: Effect of PSR weight fraction on compressive strength.

It was also noticed that adding more polysulfide rubber leads to reduction in modulus of elasticity, as shown in figure (8). Therefore, blending (2.5%, 5%, 7.5%, 10%) of PSR with epoxy resin caused a decrease in Young's modulus by about (-12.5%, -18.75, -34.37%, -53.12%) than epoxy resin. The reason behind this reduction is the low strength properties of PS that will affect the mechanical properties of the blend material including the Young's modulus.

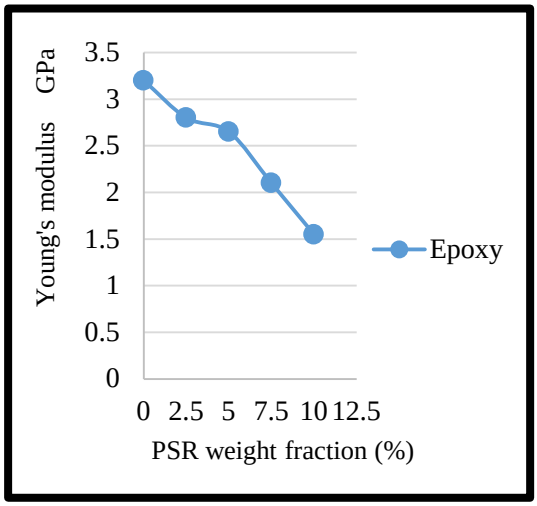


Figure 8: Effect of PSR weight fraction on Young's modulus**.**

3.1.2 Results of impact test

The experimental results shown in figure (9) showed that the impact resistance increased with the increase of PSR percentage. Therefore, blending (2.5%, 5%, 7.5, 10%) of PSR with epoxy causes an increase in impact resistance by about (25.53%, 40.42%, 60.02%, 75.53%) than epoxy resin value. This is due to the fact that polysulfide rubber has the ability to improve the flexibility of the blend matrix, therefor the resultant blend matrix has the ability to absorb and dissipate the impact energy load before fracture.

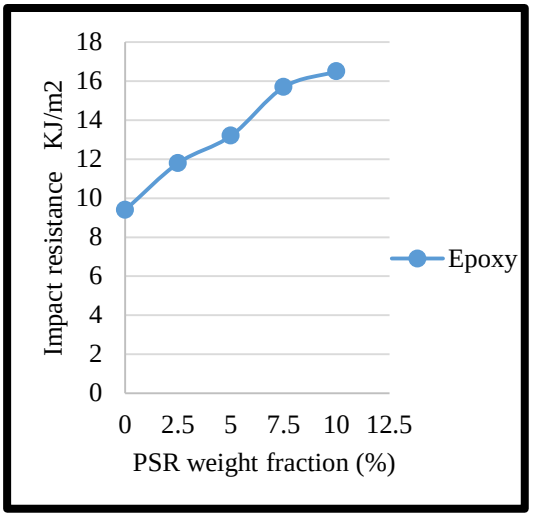


Figure 9; Effect of PSR weight fraction on Impact resistance**.**

3.1.3 Results of hardness test

The experimental results shown in figure (10) showed that the hardness decreased with the increase of PSR percentage. Therefore, blending (2.5%, 5%, 7.5%, 10%) of PSR with epoxy causes a decrease in hardness by about (-9.46%, -20.27%, -24.32, -29.73%) than epoxy resin value. The small dissolved particles of PSR in the phase of epoxy make the blend matrix incapable to resist the penetration loads and scratches. In addition, PSR particles that have been dissolved in the epoxy phase create domains of rubber particles between the cross-links, which reduced the cross-linking density.

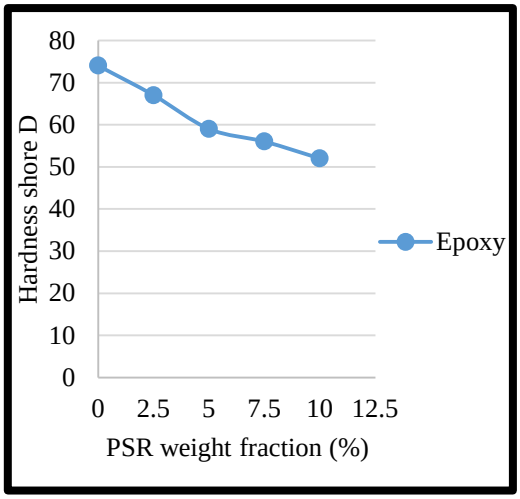


Figure 10: Effect of PSR weight fraction on hardness.

3.2 Stage II: Epoxy-polysulfide blend/ Fibers

In previous tests of epoxy-polysulfide blends, it was found that the best percentage of polysulfide give best mechanical properties to the blend matrix was 5%. The advantage of this blend matrix is that; it mediates between the brittle properties of epoxy and the flexible properties of a blend matrix with highest percentage of PSR. This stage will discuss the effect of adding different percentage of fibers (carbon and glass) on the mechanical properties of the obtained blend matrix.

3.2.1 Results of compression test

The experimental results shown in figure (11) showed that, the compression strength increased with the increase of carbon and glass fiber percentage. There, addition (2.5%, 5%, 7.5%, 10%) of carbon and glass fibers with (epoxy/5% PSR) blend matrix increased compression strength by about (8.6%, 13.99%, 21.72%, 28.86%) for carbon fibers composites and (3.8%, 10.24%, 14.86%, 21.57%) for glass fibers composites. This is due to the fact that, fibers reinforcement allows transferring some of the stress from the blend matrix to the fibers. Fibers will carry the maximum part of the subjected load, and thus increase the compressive strength. It was also noted that composite materials reinforced with carbon fibers have significantly higher compressive strength than the composite materials reinforced with glass fibers.

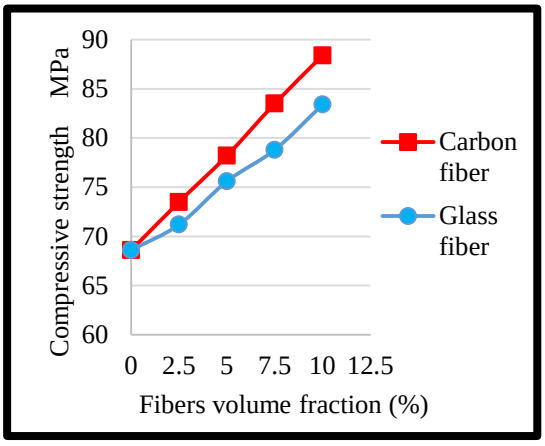


Figure 11: Effect of fibers volume fraction on compressive strength.

It was also noticed through these results that carbon fibers composites have highest Young's modulus values than glass fibers composites, as shown in figure (12). Therefore, addition (2.5%, 5%, 7.5%, 10%) of carbon and glass fiber with (epoxy/5% PSR) blend matrix increased Young's modulus by about (19.23%, 34.61%, 61.53, 88.46%) for carbon fibers composites and (11.53%, 19.23%, 38.46%, 65.38%) for glass fibers composites. This is due to the fact that, a carbon fiber has higher Young's modulus value than glass fiber, where each of them affect the value of Young's modulus of the composite materials.

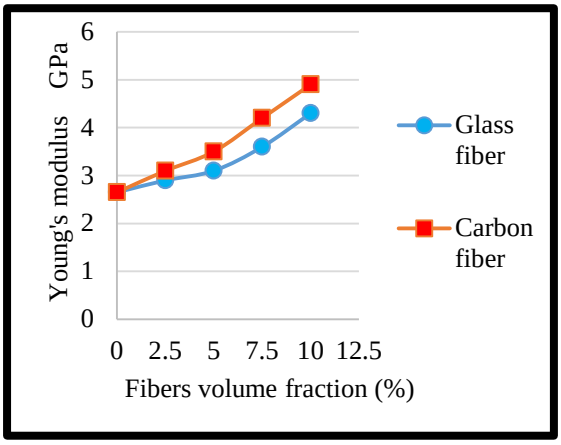


Figure 12: Effect of fibers volume fraction on Young's modulus.

3.2.2 Results of impact test

The experimental results shown in figure (13) showed that the impact resistance increased with the increase of carbon and glass fiber percentage.

The addition (2.5%, 5%, 7.5%, 10%) of carbon and glass fibers with (epoxy/5% PSR) blend matrix increased impact resistance by about (39.39%, 95.35%, 123.48%, 150.76%) for carbon fibers composites and (23.49%, 59.84%, 84.85%, 110.61%) for glass fibers composites. This is due to the fact that, fibers will carry the maximum part of the impact energy subjected on the composites, and thus increase the impact resistance of composites. It was also noted that composite materials reinforced with carbon fibers have significantly higher impact resistance than the composite materials reinforced with glass fibers.

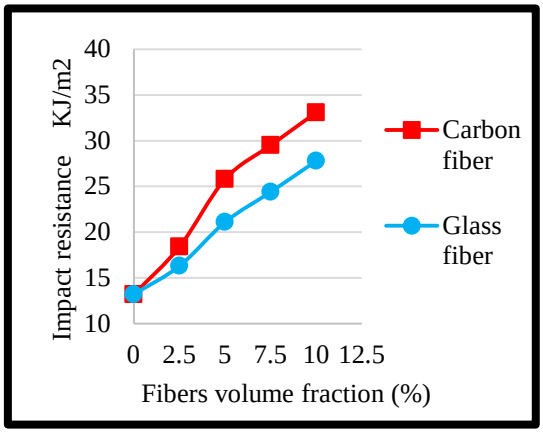


Figure 13: Effect of fibers volume fraction on impact resistance**.**

3.2.3 Results of hardness test

The experimental results shown in figure (14) showed that the hardness increased with the increase of carbon and glass fiber percentage. The addition (2.5%, 5%, 7.5%, 10%) of carbon and glass fibers with (epoxy/5% PSR) blend matrix increased hardness about (10.16%, 15.25%, 22.03%, 25.42%) for carbon fibers composites and (6.78%, 11.86%, 16.95%, 20.33%) for glass fibers composites. This is due to the fact that, the subject load will be distributed on the deployed fibers in the blend matrix, and thus leads to decrease the penetration rate on the composite materials surface, and increase its hardness. In addition, the increase in the hardness in the composites is the indication of good bonding between blend matrix and fibers. It was also noted that composite materials reinforced with carbon fibers have significantly higher hardness values than the composite materials reinforced with glass fibers.

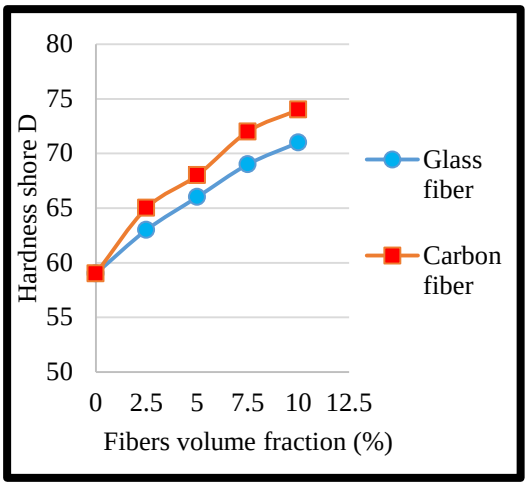


Figure 14: Effect of fibers volume fraction on hardness.

4. Conclusions

The most important conclusions that have been reached from this research summarizes as follows:-

1- Blending polysulfide rubber with epoxy decreased ultimate strength, modulus of elasticity and hardness. While, it improved impact resistance.
2- The best percentage of polysulfide that give the best mechanical properties to the blend matrix was 5%. The advantage of this blend matrix is that; it mediates between the brittle properties of epoxy and the flexible properties of a blend matrix with highest percentage of PSR.
3- The compressive strength of the blend matrix increased with the increase of fibers reinforcement percentage. Carbon fiber composites have significantly higher compressive strength vlaues than glass fiber composites with equivalent volume fraction of fibers reinforcement. The highest value of compressive strength obtained when blending (10%) of carbon fiber with (epoxy/5% PSR) blend matrix, which is (28.86%) than that of the blend matrix.
4- The modulus of elasticity of the blend matrix increased with the increase of fiber reinforcement percentage. Carbon fiber composites have significantly higher modulus of elasticity values than glass fiber composites with equivalent volume fraction of fibers reinforcement. The highest value of compressive strength obtained when blending (10%) of carbon fiber with (epoxy/5% PSR) blend matrix, which is (88.46%) than that of the blend matrix.
5- The impact resistance of the blend matrix increased with the increase of fibers reinforcement percentage. Carbon fiber composites have significantly higher impact

resistance values than glass fiber composites with equivalent volume fraction of fibers reinforcement. The highest value of compressive strength obtained when blending (10%) of carbon fiber with (epoxy/5% PSR) blend matrix, which is (150.76%) than that of the blend matrix.

6- The hardness of the blend matrix increased with the increase of fibers reinforcement percentage. Carbon fiber composites have significantly higher hardness values than glass fiber composites with equivalent volume fraction of fibers reinforcement. The highest value of compressive strength obtained when blending (10%) of carbon fiber with (epoxy/5% PSR) blend matrix, which is (25.42%) than that of the blend matrix.

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بعض الخصائص الميكانيكية لمتراكبة خليط الايبوكسي-بولي سلفايد المدعم بألياف الكربون والزجاج القصيرة

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الخلاصة

في هذا البحث, تم تحضير خلطات ثنائية من راتينج الايبوكسي مع عدة نسب وزنية مختلفة من مطاط البولي سلفايد (0% , 2.5% , 5% , 7.5% , 10%), ومن ثم تم اجراء عليها اختبار الانضغاط, اختبار الصدمة, واختبار الصلادة. النتائج التي تم الحصول عليها أظهرت بأن الزيادة في نسبة البولي سلفايد تؤدي الى نقصان في قيمة الاجهاد الأقصى, معامل يونج, والصلادة وبينما تؤدي الى زيادة قيمة مقاومة الصدمة. افضل النتائج الميكانيكية التي تم الحصول عليها عند خلط 5% من مطاط البولي سلفايد مع الايبوكسي. تم استخدام الياف قصيرة من الكربون والزجاج مع عدة نسب حجمية مختلفة (2.5%, 5%, 7.5%, 10%) لتدعيم الخليط الأمثل الذي تم الحصول عليه بشكل منفصل وعشوائي, ومن ثم تم اجراء نفس الاختبارات السابقة عليها. النتائج المستحصلة أظهرت بأن الزيادة في نسبة الالياف تؤدي الى زيادة في قيمة الاجهاد الأقصى, معامل يونج, مقاومة الصدمة, والصلادة. وقد لوحظ ايضاً بأن المواد المتراكبة المدعمة بواسطة الياف الكربون أعطت قيم عالية من الخواص الميكانيكية مقارنة بالمواد المتراكبة المدعمة بواسطة الياف الزج.