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Study the Effect of Different Reinforcements on the Damping Properties of the Polymer Matrix Composite

Ibtihal Abed Al-Razaq* **Mustafa Ziyara Shamukh****

, Department of Mechanical Engineering / University of Technology*

**E-mail: mutafaziara@outlook.com

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Abstract

In this research, damping properties for composite materials were evaluated using logarithmic decrement method to study the effect of reinforcements on the damping ratio of the epoxy matrix. Three stages of composites were prepared in this research. The first stage included preparing binary blends of epoxy (EP) and different weight percentages of polysulfide rubber (PSR) (0%, 2.5%, 5%, 7.5% and 10%). 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. The second stage included reinforcing the best blend matrix of epoxy-polysulfide (the blend matrix with the best percentage of polysulfide resulted 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%). The third stage included reinforcing the blend composites with highest percentages of carbon and glass fiber, by different weight percentages of nano-particles (Red mud& Fly ash) separately. The weight percentages of particles were (0.5%, 1%, 1.5%, and 2%). The experimental results showed that blending polysulfide rubber with epoxy increased the damping ratio. As for reinforcement materials, they decreased the damping ratio, where glass fiber composites have significantly higher damping ratio than other composites.

Keywords: *Composite Materials, Epoxy, Polysulfide, damping ratio, fibers, nano-particles.*

1. Introduction

Damping is an influence within or upon an oscillatory system that has the effect of reducing, restricting or preventing its oscillations, where this system is under cyclic stress. The damping properties of composites are a function of the adhesion between the filler and the matrix. Good filler-matrix interaction reduce energy dissipation via damping. The proportion of damping that occur in the oscillating system can be expressed by a factor called damping ratio. The damping ratio is a measure describing how dissipating an oscillating system after a disturbance, where the oscillating system exhibit oscillatory behavior when it disturbed from its position of static equilibrium [1-2].

The use of composite materials in many structural applications due to their high specific stiffness and strength has attracted interest in methods for improving the damping performance of these structures. It has been found that the damping of composites depends on the micromechanical properties of the constituent materials, which are represented by the matrix material and additives. The composite damping exhibits an opposing trend to stiffness and flexibility that gained by the addition of reinforcements, being increase with added flexible properties, and decrease with stiff properties. Thus there is a need to develop integrated mechanics models for the analysis of structural components which are capable of describing the global structural response by correlating the damping characteristics of the structural components to the parameters of the basic constituent materials (matrix material and reinforcements) [3-4].

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 [5].

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 [6-7].

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 [8]. 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 damping properties, flexibility and impact strength to epoxy matrix [9-10]. 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), while improving damping properties [11].

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 and particles reinforcements have 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 [12-13].

Composites with particles as reinforcement are likely to overcome the cost barrier for wide spread applications in roadway products, automotive, and small engine applications. Among various types of particles used, fly ash and red mud are the most inexpensive and low-density reinforcements available in large quantities as solid waste. Particles reinforcement used to improve various properties of selected matrix materials, including stiffness, strength and wear resistance and reduce the density [14-15].

This paper discusses the effects of combining the benefits of adding polysulfide rubber and two types of reinforcements (fibers and particles) to the epoxy matrix and study their effect on the damping properties of the thermoset matrix.

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/cm^3. 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. The most common methods of reinforcement are reinforcing by fibers and particles. 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. Nano-particles of red mud and fly ash were used as a reinforcement material in this research. Table (4) shows the physical and mechanical properties of red mud and fly ash particles.

Table 1,
Physical and mechanical properties of epoxy resin [16].

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 [17].

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 [18].

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

Table 4,
Mechanical and physical properties of red mud and fly ash particles [19-20].

Typical results	**Particles**	
	Red mud	**Fly ash**
Young's modulus GPa	30	25
Density g/cm^3	3.26	2.4-2.8
Poisson's ratio	0.341	0.45-0.65
Diameter µm	0.7-0.9	1.5-2.5

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. Glass has been used in this research to prepare the molds. The mold prepared with dimensions of (16 × 8 × 1.2) cm^3, as shown in Figure (1). The mold must be cleaned and lubricated the inside walls of the 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 be completed within 24 hours in the room temperature, the molded extracted from the mold, then it cut into a standard specimen dimensions.

Fig. 1. The shape of the mold.

2.3. Composites Preparation

Three 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. The use of the magnetic stirrer in the preparation of composites to reduce the bubbles arise during the mixing process. 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 damping test conducted on them using logarithmic decrement method and integrated system of devices and software programs. From the obtained results of the first stage, 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 third stage included reinforcing blend composites with highest percentages of carbon and glass from the previous stage, by different weight percentages of nano-particles (Red mud& Fly ash) separately. The weight percentages of particles were (0.5%, 1%, 1.5%, and 2%). Particles mixed with the obtained blend matrix (the blend matrix with the best percentage of polysulfide from the first stage), and then fibers added with this mixture into the mold. The same practical steps of the first stage conducted on the second and third stages.

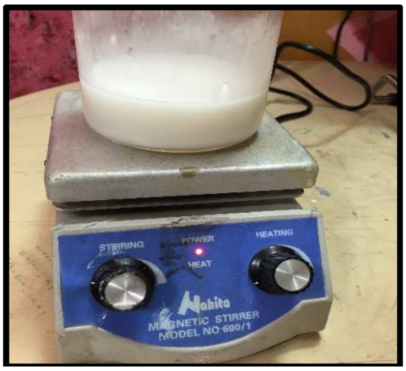

Fig. 2. Magnetic starrier.

2.4. Damping Test

A damping capacity of composites was determined at a laboratory temperature (22 ± 2) C°, using logarithmic decrement method and integrated system of devices and software programs as shown in Figure (3). The composite samples (length 145 mm, width 45 mm, thickness 10 mm) were used as cantilever beams. Figure (4) shows the specimen of the damping test.

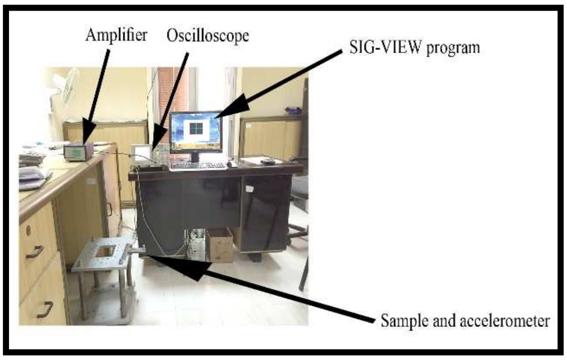

Fig. 3. Damping test setup with assembled sample.

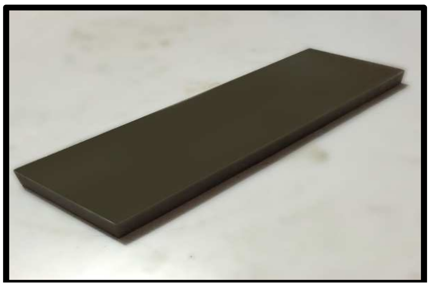

Fig. 4. Damping test specimen.

2.4.1. Damping System Devices

(a) Accelerometer

An accelerometer is a device that measures the motion response of vibrating system. This apparatus is of type (KISTLER -4371) with sensitivity 9.8 mV/g as shown in Figure (5).

Accelerometer are extensive used for measuring vibration, as well to record earthquakes, the velocity and displacement are obtained by integration from the record of accelerometer.

Fig. 5. The accelerometer.

(b) Amplifier

The amplifier device that used in this research is of type (Nexus 7749), as shown in Figure (6).

The amplifier used to increases the power of a signal that received from the accelerometer, and then give the resultant signal to the digital storage oscilloscope.

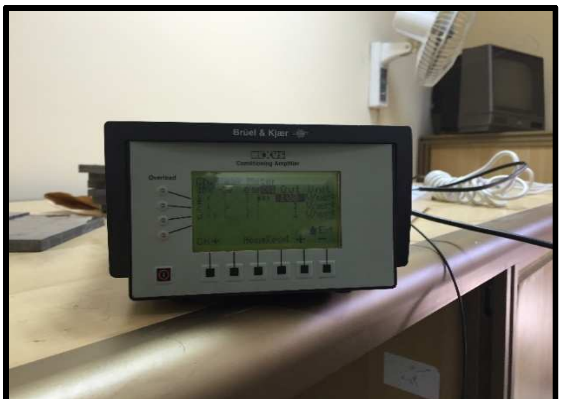

Fig. 6. The amplifier device.

(c) Oscilloscope

The oscilloscope device is a type of electronic test instrument used for displaying the received signal from amplifier. The oscilloscope that used in this research is of type (GDS-810) with maximum frequency 100 MHz. It contains a screen to display the oscillating wave that received from the amplifier as a sign wave, as shown in Figure (7).

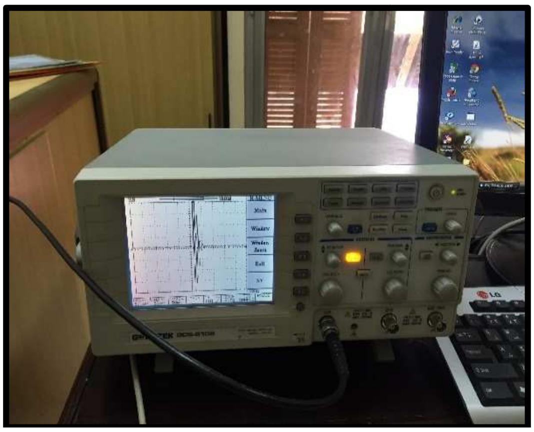

Fig. 7. The oscilloscope device.

2.4.2. Measurement of Damping

There are various methods to measure the damping ratio of an oscillating system, which depending on the response of the system expressed as a function of time or frequency, and that meaning time-response methods and frequency-response methods. The examples of the time-response methods are logarithmic decrement method, hysteretic loop method, and step-response method, while the examples of the frequency-response methods are Bandwidth method and Magnification-factor method.

2.4.2.1. Logarithmic Decrement Method

This is probably the most popular time-response method used to determine damping ratio. When a single-degree-of-freedom oscillatory system with viscous damping is excited by a disturbance or impulse input, where its response takes the form of a time decay. Figure (8) shows the logarithmic decrement method. The damping ratio can be estimated from a free-decay recorded wave using equations below:

$$\delta = ln\frac{X1}{X2} = \frac{2\pi\zeta}{\sqrt{1-\zeta^2}} \qquad \ldots(1)$$

then the damping ratio can be obtained from the equation below:

$$\zeta = \frac{\delta}{\sqrt{4\pi^2+\delta^2}} \qquad \ldots(2)$$

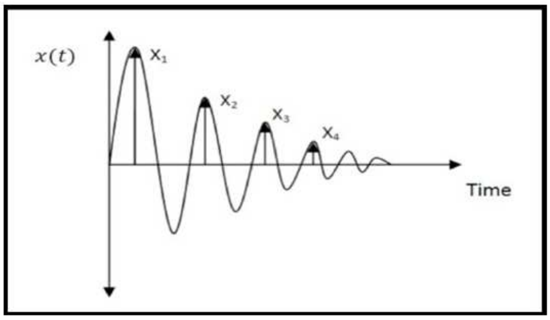

Fig. 8. Logarithmic decrement method.

2.4.3. Method of damping test

The specimen was treated as self-supporting materials with cantilever beam configuration with sufficient length for fixing the beam. The accelerometer fixed in the upper surface of the free edge of the specimen, as shown in figure (9). The specimen were subjected to impulse force by a test hammer. Impulse testing of the dynamic behavior of mechanical structure includes beating the test sample with the force-instrumented hammer, and measuring the resultant motion by accelerometer, which is used to measure the motion response, and then transfer it to the amplifier device to increases the power of a signal that received from the accelerometer, and then give the resultant signal to the digital storage, which displays the received signal from amplifier. The oscilloscope has been connected with a computer by using the serial connection, which adjusts the signal and convert the acceleration into displacement information. The resultant signal from the oscilloscope appears on the computer by using SIG-VIEW program, where using logarithmic decrement method to calculate the damping ratio from the response signal obtained from SIG-VIEW program.

Fig. 9. The setup of the specimen for damping test.

3. Results and Discussion

The results of the three stages that have been obtained from the damping test will be discussed and represented in graphic curves in order to identify the properties of materials.

3.1. Stage I: Epoxy and epoxy-PSR blends

The experimental results shown in figure (10) showed that the damping ratio increased with the increase of polysulfide percentage. Therefore, when blending (2.5%, 5%, 7.5%, 10%) of PS with epoxy caused an increase in damping ratio about (21.59%, 53.41%, 72.72%, 102.27%) than epoxy resin value. Due to low mechanical properties of polysulfide rubber, the addition of polysulfide with the brittle thermoset matrix increased the flexibility and improves the damping properties of the blend matrix. The resultant blend matrix will be able to dissipate and absorb the kinetic energy, where this mean reduction in vibration's amplitude and increase in damping ratio.

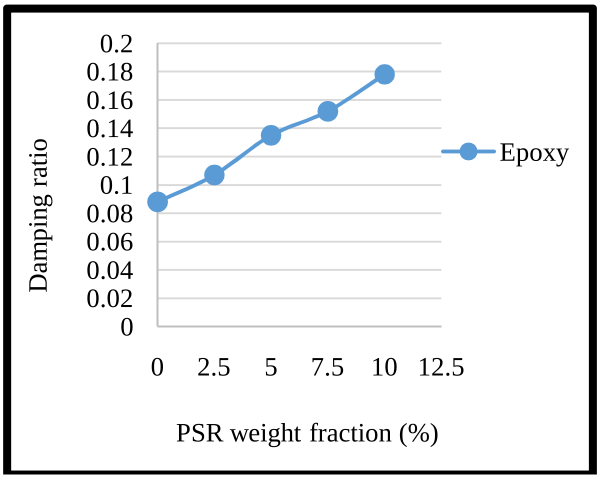

Fig. 10. Effect of PSR weight fraction on damping ratio.

3.2. Stage II: Epoxy-PSR blend matrix/ Fibers

The experimental results shown in figure (11) showed that, the damping ratio decreased with the increase of carbon and glass fiber percentage. The addition of (2.5%, 5%, 7.5%, 10%) of carbon and glass fibers with (epoxy+5% PSR) blend matrix decreased the damping ratio by about (-19.25%, -29.62%, -41.22%, -50.37%) for carbon fibers composites and (-14.07%, -22.96%, -32.59%, -39.25%) for glass fibers composites. This is due to the fact that, the good fibers distribution in blend matrix led to better adhesion between fibers and the blend matrix, which affect the toughness increment of composites and resulted in less sliding between interfaces, and thus leads to dissipate less energy and decrease damping ratio. It was also noted that the glass fibers composites have significantly higher damping ratio than carbon fibers composites with equivalent volume fraction of fibers reinforcement.

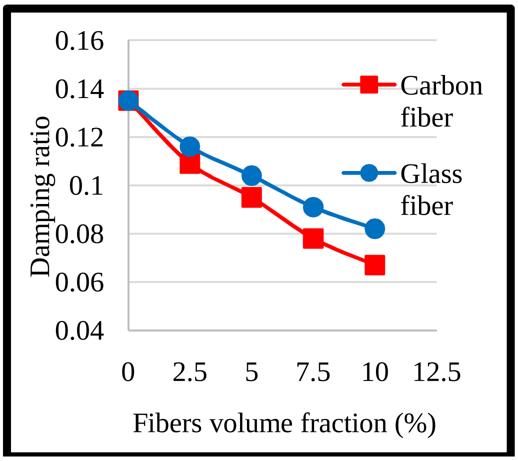

Fig. 11. Effect of fibers volume fraction on damping ratio.

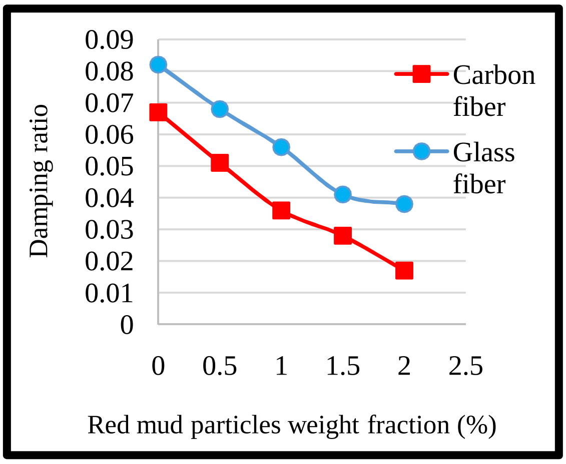

Fig. 12. Effect of red mud particles weight fraction on damping ratio.

3.3. Stage III: Epoxy-PSR blend matrix-fibers/ Particles

The experimental results shown in figures (12) and (13) showed that, the damping ratio decreased with the increase of red mud and fly ash particles percentage. The addition of (0.5%, 1%, 1.5%, 2%) of red mud particles with (epoxy+ 5% PSR+ 10% carbon and glass fibers) decreased the damping ratio by about (-5.97%, -23.88%, -37.31%, -50.74%) for carbon fiber composites and (-9.75%, -23.17%, -30.48%, -43.90%) for glass fibers composites. For fly ash particles, the addition of (0.5%, 1%, 1.5%, 2%) of fly ash particles with (epoxy+5% PSR + 10% carbon and glass fibers) decreased the damping ratio by about (-23.86%, -46.26%, -58.20%, -74.62%) for carbon fiber composites and (-17.07%, -31.70%, -50%, -53.65%) for glass fibers composites. This was due to the fact that, the good particles distribution in the blend matrix led to better adhesion between particles and the blend matrix, which affected the stiffness increment of composite materials and resulted in less sliding between interfaces, and thus leads to dissipate less energy and decrease the damping ratio.

It was also noted that glass fiber composites reinforced with fly ash particles have significantly higher damping ratios than other composites of this stage with the equivalent weight fraction of particles reinforcement.

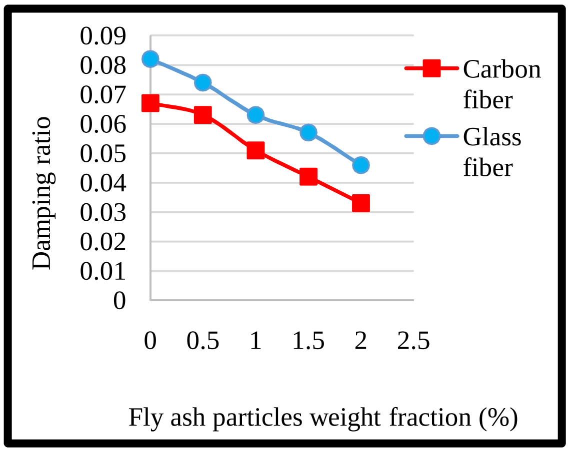

Fig. 13. Effect fly ash particles weight fraction on damping ratio.

4. Conclusions

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

1- The damping ratio of the blend matrix increased with the increase of polysulfide percentage, where the blend matrix with 10% of polysulfide has significantly higher damping ratio than other blends.
2- The weight percentage 5% of polysulfide has been selected as 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.
3- The damping ratio of the blend matrix decreased with the increase of fibers percentage. Glass fibers composites have significantly higher damping ratio than carbon

fibers composites with equivalent volume fraction of fibers reinforcement.

4- The damping ratio of the blend composites decreased with the increase of particles percentage. Glass fiber composites reinforced with fly ash particles have significantly higher damping ratios than other composites with equivalent weight fraction of particles reinforcement.

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دراسة تأثير مواد التدعيم على خواص التخميد لمادة متراكبة ذات أساس بوليمري

ابتهال عبد الرزاق محمود*　　　مصطفى زيارة شامخ**

**، ** قسم الهندسة الميكانيكية/ الجامعة التكنولوجية*

**البريد الالكتروني: mustafaziara@outlook.com

الخلاصة

تم في هذا البحث دراسة خصائص التخميد لمواد متراكبة بأستخدام طريقة التناقص اللوغاريتمي لحساب نسبة التخميد. تم اعداد المواد المتراكبة المستخدمة في هذا البحث بثلاث مراحل. المرحلة الاولى تضمنت اعداد خلطات ثنائية من الايبوكسي وعدة نسب وزنية مختلفة من مطاط البولي سلفايد (٠%، ٢.٥%، ٥%، ٧.٥%، و ١٠%). لقد وجد ان النسبة الوزنية ٥% لمطاط البولي سلفايد كانت أفضل نسبة والتي تعطي خصائص ميكانيكية جيدة لخليط المادة الأساس. ما يميز هذا الخليط المتراكب الناتج كونه يتوسط بين الصفات الهشة للأيبوكسي والصفات المرنة لخليط متراكب ممزوج مع اعلى نسبة بولي سلفايد. المرحلة الثانية تضمنت تدعيم افضل خليط المتراكب (الخليط المتراكب ذو النسبة المثلى من مطاط البولي سلفايد المختارة من المرحلة السابقة) ، بنسب حجمية مختلفة من الياف الكربون والزجاج القصيرة (٢.٥%، ٥%، ٧.٥%، و ١٠%) كلٍ على حدا وبتوزيع عشوائي. المرحلة الثالثة تضمنت تدعيم الخلائط المتراكبة مع اعلى نسبة الياف كربون وزجاج، بنسب وزنية مختلفة من الدقائق النانوية المتمثلة بالطين الأحمر والرماد المتطاير بشكل منفصل. النتائج العملية أظهرت بأن خلط مطاط البولي سلفايد مع الايبوكسي أدى الى زيادة نسبة التخميد. اما بالنسبة لمواد التدعيم، فأنها أدت الى نقصان نسبة التخميد، حيث ان متراكبات الياف الزجاج أظهرت قيم اعلى لنسبة التخميد مقارنة بباقي المتراكبات.