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# EFFECT OF H2SO4 ACID ON FATIGUE FAILURE PROPERTY FOR POLYMER MATRIX COMPOSITE

**Mohammed. Gh. Hammed*  Mohammed. S. Waheed** Balkees. M. Deya****

* College of dentistry, AL-Anbar University
**Applied science dept, University of technology.

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ABSTRACT

This research include the study of the fatigue property for the polymer and the composite materials, we using the epoxy resin as matrix for the reinforced materials that consist of artificial fibers (Kevlar, glass and PVC fibers) also aluminum powder for reinforcing.

The slates made of composite materials and hybrid composite materials for both volume fractions30% and 40% from the reinforced materials, where we made twenty one slates from the composite materials, all these slates cutting to samples with measurement (10x 70mm) in order to execute the fatigue test accordingly for the fatigue machine characteristics, these samples divided to several groups for both volume fractions 30% and 40%, these groups immersing in H2SO4 acid for fifty day to study the effect of this solution in the fatigue characteristic.

The test executed by two steps: - the first step include executing the fatigue testing for the dry samples and comparison these results with each other, the second step include the fatigue test for the samples after immersion in the solution (H2SO4 acid) for fifty day,. The results of fatigue test from the second step comparing with the results from the first group for both volume fractions 30% and 40%. The results and laboratory examinations for these samples show a decreasing in the number of fatigue cycles until the fail when the applied load or applied stress increase.

## Introduction

Fatigue failure of the phenomenon observed for the first time in (1800) when they began axes wagons in the railway line before the end of time specified in the service. These axes were made of ductile steel but suddenly showed something like breakage. Rankin has published a report in (1830) on the causes breakage unexpected points in the vertical axes of the railway line when it was assumed that the article has crystallized (take concrete form) becomes Fragile because of fatigue or fluctuating stress [1]. Fiber glass composites have been used in thousand of applications since their inception in the late 1930 s despite an incomplete understanding and characterization of their mechanical fatigue properties [2]. About 30% of all polymers produced each year are used in the civil engineering and building industries. Polymer offer many advantages over conventional materials including lightness resilience to corrosion and ease of processing. They can be combined with fibers or particals to form

* Corresponding author at: College of dentistry, AL-Anbar University, Iraq.E-mail address:

composite materials which have enhanced properties. Theoretically, any material that is not a pure substance and contains more than one component, may be classified among the composite materials, enabling them to be used as structural members and units polymer composites can be used in many different forms ranging form structural composites in the construction industry to the high technology composites of the aerospace and space satellite industries. Polymer composites were first developed during the 1940,s, for military and aerospace applications. Glass-reinforced plastics have been used in many other applications including pressure pipes, tank liners and roofs.

In the last decade, polymer composites have found application in the construction sector in areas such as bridge repair, bridge design, mooring cables, structural strengthening, and stand-alone components [3-5]. In polymer composites, the matrix may be thermoplastic or thermoset materials. Epoxy resin is thermoset materials, the structure of epoxy resin is characterized by the epoxy group [-CH-O- CH2-]. Also known as epoxide .epoxy resins of several families are now available ranging from viscous liquids to high melting solid. Among them, the conventional epoxy resins manufactured from epichlorohydrin and bisphenol A remain the major type used. There are a varicly of hardeners or curing a gents generally used for epoxy resins. The amine type compounds are often used in structural application. The hardening effect is achieved through the formation of cross-links between the resin polymer chain and the hardener, or by direct linkage among the epoxy groups [6-8]. Reinforced plastics based on epoxy resins have better mechanical strength, chemical resistance, electrical insulating properties and environmental stability than those made with conventional unsaturated polyester [9, 10]. The matrix of composite materials, commonly made of epoxy binds and protects the fibers from damage, and transfers the stresses between fibers [11, 12].

The fibers polymers are capable of being drawn into long filaments having at lest a (100:1) length-to-diameter ratio [5]. Fibers are the principal structural component in a fiber- reinforced composite material. They support the majority of the load acting on a composite structure. However, the properties of a composite laminate such as compressive strength and modulus, tensile strength and modulus, specific gravity, fatigue strength, electrical and thermal conductivities and cost are influenced not only by the amount of fiber, but also by the orientation of the fibers. The most commonly used fibers in composites are glass, polyvinylchloride (PVC) and aramid (Kevlar) fibers [13].

**Fatigue failure**

Fatigue is a form of failure that occurs in structures subjected to dynamic and fluctuating stresses (e.g.; bridge, aircraft and machine components). Under these circumstances it is possible for failure to occur at a stress level considerably lower than tensile or yield strength for a static load [14]. The term fatigue is used because this type of failure normally occurs after a lengthy period of repeated stress or strain cycling. Fatigue is important inasmuch as it is the single largest cause of failure in metals, estimated to comprise approximately 90% of all metallic failures; polymer and ceramics are also susceptible to this type of failure. Furthermore; it is catastrophic and insidious, occurring very suddenly and without warning [15]. Although less sensitive to fatigue, the increased use of composite materials has emphasized the fact that their fatigue behavior is more complex than that of metals. In a metal fatigue damage develops as a clearly defined sharp crack, the initiation and propagation of which can be reasonably well predicted by fracture mechanics analysis. In a composite material, fatigue damage can take the form of any, or all, of the following; delamination, matrix cracking, fiber failure, matrix crazing, fiber/ matrix debonding and void growth forming a discrete but complex damage zone. This is dependent upon variables associated with the testing conditions and the construction and composition of the material [16]. Fatigue testing is usually performed using sinusoidal loading. Thus the state of fatigue loading can be described a few parameters shown in figure (1). By specifying the maximum and minimum stress the other stress parameters can be easily determined such as stress range, $\sigma_r$, stress amplitude, $\sigma_a$, mean stress, $\sigma_m$, and fatigue stress ration, $R$.

$$\sigma_r = \sigma_{max} - \sigma_{min}$$

$$\sigma_a = (\sigma_{max} - \sigma_{min}) / 2$$

$$\sigma_m = (\sigma_{max} + \sigma_{min}) / 2$$

$$R = \sigma_{min} / \sigma_{max}$$

The $R$ value is an indication of the mode of fatigue loading.

The fatigue properties of composite materials depend on such factors as the interaction between the mechanical properties of the matrix and the reinforcement, the strength of the bond between the two, the volume fractions of the two, the direction and type of loading, the loading frequency and the temperature[18].

## Experimental procedure

Epoxy resin was used to fabricate the samples and the hardener material was added in order to solid it. This mixture are used to made the matrix, more over we used synthetic fibers and aluminum powder in order to reinforce the matrix to produce composite materials which are ready for test. Hand lay-up was used to produce composite materials. In this study, twenty one slated of composite materials were made.

## Cutting up of samples

Tow iron saws were used indented one smooth, the other in the rough cutting. Hacking was in accordance with the specifications used in the test, the samples were with the dimensions of (70 mm) length and (10 mm) width. The thickness depends on the number of layers in the sample fiber rating (number of layers of fibers), then was removed Pluses from the samples by using the iron rasp. Further refine and sleeking these samples by the private sleeking paper for this purpose. After obtaining samples standard has been working one hole in each sample, diameter (4 mm) at one edge, away from the present one side of the hole and longitude ribs presentation by (3 mm).

## Results and discussion

### Fatigue test for dry samples

This group include the prepare composite materials samples that have two volume fractions 30% and 40%, the fatigue test executed three times for each samples, then we calculate the average for the readings to know the number of fatigue cycles. In this group which contain non reinforced epoxy samples (E) and reinforced epoxy samples with aluminum (AE), the laboratory tests and the results show decreasing in the number of fatigue cycles even failure when the applied load on the samples increase as shown in the fatigue test tables (2). In (E) samples, the applied load are (3.2, 4.1, 4.8 N), that cause deflection equal to (12, 15, 18 mm) and the number of cycles equal to ( 3753, 1379, 358) cycle respectively, that because most of polymer materials specially epoxy having long molecular chains which cross linked with each other when it become hard. The resistance of these materials depends on direction, regularity and cross linkage degree for molecular chains. The external forces play active role in the effect on cross linkage chains strength. Applied the external load on epoxy materials will effect on nature and direction the cross linkage polymer chains and that causing broken the polymer chains when high loads applied. Moreover, when the external loads increase, the deflection increase too and that depend on longitudinal the chains clearly, ditto the applied load on the samples cause applied inner stress on the molecules chains for polymer materials. The increase in the applied loads cause increase the deflection and that cause increase the effect range for tension and compression forces, that will accelerate formation of primary cracks in polymers because the high increasing in the inner energy, so the collapse occur in the which have thermal inconstancies energy higher than chemical bonds energy, then the fraction will occur. The fraction will be brittle because there is no reinforced materials prevent the cracks from diffusion. The (AE) samples have no defection higher than (6 mm) as shown in the table (2). When the samples reach the higher deflection, will fail before execute the test that because material brittle, when we compared these samples with non reinforced epoxy samples (E) samples, we find that (AE) samples have elastic less than the elastic of the epoxy samples, so the number of fatigue cycles for these samples less than the number of fatigue cycles in non reinforced epoxy samples, also the fraction will be brittle compare with epoxy samples because of nature, shape and size of aluminum powder molecules, where the cross linkage process between aluminum powder and polymer material will be high and the samples elastic will be little for both volume fractions 30% and 40%, the elastic will decrease in these samples when aluminum reinforced ratio increase from 30% to 40%. In the figure (2) show the microscopic pictures for these samples before and after executing the fatigue test.

(PE) and (PAE) samples have high elastic because of its little thickness (0.25 mm), when we apply a load equal to (1.2 N), the deflection will be (18 mm) as shown in the table (2) and the number of fatigue cycles will be little for the samples which have defections equal to (12, 15). We could not calculate the cycles number for these samples that have the higher deflection (18 mm) because of the high elastic and the little coherence between PVC fibers and the matrix, therefore we could not rotating the samples because of its little thickness or the cycles number will be little and the samples will fail at test start. The samples will suffer from bend since the test start and that causing turning off the machine; therefore we couldn't test the samples. On other side, the samples which have little deflection (12, 15mm) have little cycles number, where these samples fail and separate in to two parts or more and for both volume fractions. It's important to know that the higher value for fatigue cycles number for the samples from type (PAE) samples are (4091) cycle. The figure (3) shows the microscopic pictures for the samples before and after testing and for both volume fractions 30% and 40%.

The results and microscopic examinations for (KE) samples with volume fraction 30% and 40% show that these samples have high cycles number, so we could not obtain the fatigue limit until fail. Where these samples have cycles number (5x106) cycle with out failure, the test executed with deflections equal to (12 and 15mm), but when the deflection on horizontal line is equal to (18 mm) for (KE) samples for both volume fractions 30% and 40%, the cycles number will equal to (1185262) cycle for the samples with volume fraction 30% and the cycles number will equal to (83365) cycle, the two samples didn't separate because of coherence strength between Kevlar fibers and the matrix, where Kevlar fibers have high strength and tensile resistance. The fatigue machine turn off at these cycles number because the samples suffer from bend because applied periodic changing sinusoidal load and the cracks will diffuse in the matrix, there fore the sample will fail, as shown in the table (2).

The figure (4) shows the microscopic pictures for these samples before and after testing. The cracks will diffuse in the matrix just after finish the test, these cracks will be surface and can inter to the matrix, therefore the samples do not separate in to two parts because Kevlar fibers play important role in stoppage the cracks and that will give high strength for the composite materials that applied to changing loads with the time and the fatigue life will increase.

The dry samples from types (GE, GAE, KAE, GPAE, GKAE and KPAE) for both volume fractions 30% and 40% have unknown fatigue limit, where they reach to (5x106) cycle without fail except (KPAE) sample, this sample failure at cycles number equal to (350511) cycle and separate into two parts.

**Fatigue testing for immersed samples in acidic solution**

In this test, H2SO4 was used with normality (1N) to immerse the samples for (50) day to know the effect of this acid on the composite materials and fatigue property, the results and laboratory examination for these samples show that the number of fatigue cycles until the fail decrease when the applied load on the samples increase.

In the non reinforced epoxy samples (E) when the applied load on the samples increase from (3.0N) to (3.7N) then to (4.3N), the deflection equal to (12, 15, 18 mm) respectively, and the number of fatigue cycles are (1879, 164, 75) cycle respectively as shown in table (3). When we comparing these results with the results of dry samples as show in the tables (2) and (3), we find the number of fatigue cycles for immersed samples in H2SO4 less than in the dry samples, because the effect of H2SO4 acid on the samples, the acid molecules penetrate in the samples by diffusion and occupy the gaps among the polymer chains, therefore the cross linkage among these chains impair and the samples fail at the testing start. In (AE) samples for both volume fraction 30% and 40% we could not obtain deflection higher than (6 mm) as in other samples form the same types that immersed in other solutions because the low elastic for (AE) samples. The testing and laboratory examination for these samples show the number of fatigue cycles until fail few, most of the samples with deflection (4 and 6 mm) failed at the testing start except (AE) samples with volume fraction 30% and deflection (4mm) where the number of fatigue cycles until fail magnitude (75) cycle and (AE) samples with volume fraction 40% and the same deflection that have number of fatigue cycles equal to (110) cycle, therefore when the reinforced ratio for the samples increasing, the fatigue life increasing too and the resistance for external condition will be better. The figure (5) show the microscopic pictures for (E) and (AE) samples before and after fatigue testing, the fraction region brittle because the brittleness the samples and these samples required low fraction energy.

At testing the samples from types (PE, PAE and GAE) for both volume fractions 30% and 40% we could not execute the fatigue test because most of the samples after the immersion in H2SO4 suffer from torsion, bending and difference their dimensions as shown in the figure (6).

The laboratory examinations of (KE, GKAE and KPAE) samples show that we could not calculate the fatigue limit for the deflections (12, 15 mm), where the number of fatigue cycles equal to (5x106) cycle without fail except the (KE) samples with volume fraction 30% and deflection (15 mm) where the number of fatigue cycles until the fail are (573966) cycle, when the applied load on these samples increase, the deflection will be (18 mm). The number of fatigue cycles until the fail for (KE) samples with volume fraction 30% are (950) cycle and for (KE) samples with volume fraction40% are (1050) cycle, whichever when the reinforced ratio increasing, the mechanical properties for these samples will be better and their resistance for the fatigue will increase too.

The (GKAE) samples with deflection (18 mm) and volume fraction 30% have number of fatigue cycles equal to (378415) cycle, the samples separating to two parts, either the (GKAE) samples with volume fraction 40% have number of fatigue cycles until the fail equal to (877492) cycle. The (KPAE) samples with volume fraction 30% and deflection (18 mm) have number of fatigue cycles equal to (351521) cycle, either (KPAE) samples with volume fraction 40% have number of fatigue cycles equal to (675352) cycle, when the reinforced ratio increasing, the resistance of fatigue foe these samples will increase. When we comparing the results for immersed samples in H2SO4 with the results for the same dry samples we find that the number of fatigue cycles for immersed samples in H2SO4 acid less than the number of fatigue cycles in the same dry samples, that because of the effect of the acid on the samples, where the acid molecules diffuse in the composite materials and impair the cross linkage between the reinforced materials and the matrix by effecting on the interface of the composite (between the reinforced materials and the resin), so the resistance of these samples decrease and fail quickly, the figure (7) show the microscopic pictures for these samples before and after the testing, the cracks diffuse through the samples and the reinforced fibers slinking at the fracture region, where the samples separated into two parts, also the color of the samples changing after immersing in H2SO4 acid for (50) day from dark grey to light grey.

The results and the laboratory results for other samples from types (GE, KAE and GPAE) for both volume fraction 30% and 40% that immersed in H2SO4 acid show that these samples have unknown number of fatigue cycles, where the number of fatigue cycles reach (5x106) cycle without fail.

The comparing between these samples with the same dry samples we find that the number of cracks and the extending magnitude in the immersed samples bigger than in the same dry samples.

**Conclusion**

1- The number of fatigue cycles until the fail for the composite materials decreasing when the applied load on the sample increasing for the both volume fractions 30% and 40%.
2- The samples from types (KE, GE, KAE, GAE, GKAE, GPAE and KPAE) have not known fatigue life limit at the deflections (12, 15mm) for both volume fractions 30% and 40%, where the number of fatigue cycles until the fail equal (5x106) cycle.
3- The samples from type (KE) failed at the deflection (18mm) and with number of fatigue cycles less than (5x106) cycle because of the high flexibility and little thickness for these samples, therefore the fatigue machine turn off because of bending and torsion the samples during the test, but the samples did not separate because of the high strength of the Kevlar fibers.
4- The flexibility for all samples increasing when the samples immerse in the solutions for fifty days because of absorption of these solutions.
5- The flexibility for the (AE) samples are low for both volume fractions 30% and 40%, where we could not execute the test at the higher deflection that greater than (6mm) because the samples failed and separated to two parts when we apply the load to reach to the high deflections.
6- The samples from the types (PE, PAE) that immersed in H2SO4 acid suffer from deformation and difference in the shapes and dimensions, that prevent execute the fatigue and hardness testing for

both volume fractions 30% and 40%. 7- The slinking of the reinforced fibers in the fraction region for immersed samples in the solutions bigger than the slinking of the reinforced fibers in dry samples, also the length of the slinking fibers in immersed samples in the solutions is bigger than in dry samples too.

8- The Kevlar fibers can transport the stress as easy as along the fiber, therefore the resistance of the Kevlar fibers bigger than the glass and PVC fibers.

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**Table (1) shows the weights of each fibers, aluminum powder and matrix, also show volume fractions for reinforced materials**

| Sample type | Fiber weight (g) | Al Powder weight (g) | Epoxy weight (g) | Volume fraction |
|---|---|---|---|---|
| Pvc | 1.5566 | ---- | 2.0128 | 40% |
| Kevlar-Al | 5.0284 | 9.4282 | 13.5311 | 40% |
| Al | ---- | 31.1380 | 21.6236 | 40% |
| Pvc-glass-Al | 18.1030 | 20.2459 | 29.0566 | 40% |
| Glass-Al | 19.8013 | 20.7222 | 29.7401 | 40% |
| Kevlar-glass-Al | 23.0664 | 28.2682 | 40.5699 | 40% |
| Kevlar | 5.0398 | ---- | 6.5621 | 40% |
| pvc-glass-Al | 17.7826 | 19.8686 | 44.3563 | 30% |
| Pvc-Al | 1.5661 | 2.9160 | 6.5100 | 30% |
| Kevlar-Al | 5.0195 | 9.4114 | 21.0110 | 30% |
| Kevlar-pvc-Al | 6.5856 | 12.3276 | 27.5216 | 30% |
| Kevlar | 3.5906 | ---- | 7.2723 | 30% |
| Al | ---- | 22.9027 | 24.7406 | 30% |
| Glass-Al | 18.2289 | 19.0767 | 42.5862 | 30% |
| Kevlar-glass-Al | 20.7996 | 26.0018 | 58.0492 | 30% |
| Epoxy | ---- | ---- | ---- | ---- |
| Glass | 17.1062 | ---- | 12.4318 | 40% |
| Pvc-Al | 1.5546 | 2.8947 | 4.1542 | 40% |
| Kevlar-pvc-Al | 6.5197 | 12.2041 | 17.5149 | 40% |

| | | | | |
|---|---|---|---|---|
| Glass | 16.6155 | --- | 18.7837 | 30% |
| Pvc | 1.5800 | --- | 3.1780 | 30% |

**Table (2) shows fatigue failure for dry samples**

| Sample type | Fatigue failure (Vf)=30% | | | | Fatigue failure (Vf)=40% | | | |
|---|---|---|---|---|---|---|---|---|
| | Thickness (mm) | Load (N) | Deflection (mm) | Cyclic no. (N) | Thickness (mm) | Load (N) | Deflection (mm) | Cyclic no. (N) |
| E | 1.5 | 3.0 | 12 | 1879 | ---- | ---- | ---- | ---- |
| E | 1.5 | 3.7 | 15 | 164 | ---- | ---- | ---- | ---- |
| E | 1.5 | 4.3 | 18 | 75 | ---- | ---- | ---- | ---- |
| AE | 2.2 | 3.3 | 4 | 28 | 2.0 | 3.5 | 4 | 110 |
| AE | 2.2 | 3.8 | 6 | ---- | 2.0 | 3.8 | 6 | ---- |
| AE | 2.2 | ---- | 8 | ---- | 2.0 | --- | 8 | ---- |
| GE | 0.95 | 1.7 | 12 | 5X106 | 1.0 | 1.9 | 12 | 5x106 |
| GE | 0.95 | 2.2 | 15 | 5X106 | 1.0 | 2.3 | 15 | 5x106 |
| GE | 0.95 | 2.9 | 18 | 5X106 | 1.0 | 3.0 | 18 | 5x106 |
| KE | 0.5 | 1.3 | 12 | 5X106 | 0.8 | 1.6 | 12 | 5x106 |
| KE | 0.5 | 1.7 | 15 | 573966 | 0.8 | 1.9 | 15 | 5x106 |
| KE | 0.5 | 2.2 | 18 | 950 | 0.8 | 2.3 | 18 | 1050 |
| PE | ---- | ---- | 12 | ---- | --- | --- | 12 | ---- |
| PE | ---- | ---- | 15 | ---- | --- | --- | 15 | ---- |
| PE | ---- | ---- | 18 | ---- | --- | --- | 18 | ---- |
| GAE | 1.1 | ---- | 12 | ---- | 1.5 | 3.1 | 12 | 5x106 |
| GAE | 1.1 | ---- | 15 | ---- | 1.5 | 3.7 | 15 | 5x106 |
| GAE | 1.1 | ---- | 18 | ---- | 1.5 | 4.4 | 18 | 5x106 |
| KAE | 0.9 | 1.3 | 12 | 5X106 | 1.1 | 1.4 | 12 | 5x106 |
| KAE | 0.9 | 1.7 | 15 | 5X106 | 1.1 | 1.7 | 15 | 5x106 |
| KAE | 0.9 | 2.1 | 18 | 5X106 | 1.1 | 2.1 | 18 | 5x106 |
| PAE | ---- | ---- | 12 | ---- | --- | --- | 12 | ---- |
| PAE | ---- | ---- | 15 | ---- | --- | --- | 15 | ---- |
| PAE | ---- | ---- | 18 | ---- | -- | --- | 18 | ---- |
| GPAE | 1.5 | 3.1 | 12 | 5X106 | 2.0 | 3.7 | 12 | 5x106 |
| GPAE | 1.5 | 3.7 | 15 | 5X106 | 2.0 | 4.3 | 15 | 5x106 |
| GPAE | 1.5 | 4.5 | 18 | 5X106 | 2.0 | 5.2 | 18 | 5x106 |
| GKAE | 1.5 | 6.1 | 12 | 5X106 | 2.25 | 8.9 | 12 | 5x106 |
| GKAE | 1.5 | 7.5 | 15 | 5X106 | 2.25 | 10.5 | 15 | 5x106 |
| GKAE | 1.5 | 9.0 | 18 | 378415 | 2.25 | 12.5 | 18 | 877492 |
| KPAE | 1.25 | 2.1 | 12 | 5X106 | 1.25 | 2.1 | 12 | 5x106 |
| KPAE | 1.25 | 2.7 | 15 | 5X106 | 1.25 | 2.6 | 15 | 5x106 |
| KPAE | 1.25 | 3.2 | 18 | 351521 | 1.25 | 3.0 | 18 | 675325 |

**Table (3) shows fatigue failure for immersed samples in $H_2SO_4$ acid**

| Sample type | Fatigue failure (Vf)=30% | | | | Fatigue failure (Vf)=40% | | | |
|---|---|---|---|---|---|---|---|---|
| | Thickness (mm) | Load (N) | Deflection (mm) | Cyclic no. (N) | Thickness (mm) | Load (N) | Deflection (mm) | Cyclic no. (N) |
| E | 1.5 | 3.2 | 12 | 3753 | ---- | ---- | ---- | ---- |
| E | 1.5 | 4.1 | 15 | 1379 | ---- | ---- | ---- | ---- |
| E | 1.5 | 4.8 | 18 | 358 | ---- | ---- | ---- | ---- |
| AE | 1.6 | 2.7 | 4 | 527 | 2.2 | 3.7 | 4 | 62 |
| AE | 1.6 | 3.5 | 6 | 283 | 2.2 | ---- | 6 | ---- |
| AE | 1.6 | ---- | 8 | ---- | 2.2 | ---- | 8 | ---- |
| GE | 0.9 | 2.1 | 12 | 5x106 | 0.85 | 1.6 | 12 | 5x106 |
| GE | 0.9 | 2.7 | 15 | 5x106 | 0.85 | 2.2 | 15 | 5x106 |
| GE | 0.9 | 3.0 | 18 | 5x106 | 0.85 | 2.7 | 18 | 5x106 |
| KE | 0.75 | 2.0 | 12 | 5x106 | 0.7 | 1.2 | 12 | 5x106 |
| KE | 0.75 | 2.4 | 15 | 5x106 | 0.7 | 1.6 | 15 | 5x106 |
| KE | 0.75 | 2.6 | 18 | 1185262 | 0.7 | 1.8 | 18 | 83365 |
| PE | 0.25 | 1.0 | 12 | 62 | 0.2 | 0.8 | 12 | 72 |
| PE | 0.25 | 1.4 | 15 | 22 | 0.2 | 0.9 | 15 | 44 |
| PE | 0.25 | 1.6 | 18 | ---- | 0.2 | 1.1 | 18 | 19 |
| GAE | 1.2 | 4.4 | 12 | 5x106 | 1.2 | 4.7 | 12 | 5x106 |
| GAE | 1.2 | 5.6 | 15 | 5x106 | 1.2 | 5.9 | 15 | 5x106 |
| GAE | 1.2 | 6.9 | 18 | 5x106 | 1.2 | 6.9 | 18 | 5x106 |
| KAE | 0.8 | 1.9 | 12 | 5x106 | 1.0 | 2.0 | 12 | 5x106 |
| KAE | 0.8 | 2.1 | 15 | 5x106 | 1.0 | 2.2 | 15 | 5x106 |
| KAE | 0.8 | 2.6 | 18 | 5x106 | 1.0 | 2.9 | 18 | 5x106 |
| PAE | 0.25 | 1.3 | 12 | 235 | 0.3 | 1.1 | 12 | 4091 |
| PAE | 0.25 | 1.5 | 15 | 38 | 0.3 | 1.3 | 15 | 28 |
| PAE | 0.25 | 1.7 | 18 | 22 | 0.3 | 1.6 | 18 | 27 |
| GPAE | 1.5 | 5.6 | 12 | 5x106 | 1.6 | 6.5 | 12 | 5x106 |
| GPAE | 1.5 | 6.7 | 15 | 5x106 | 1.6 | 7.7 | 15 | 5x106 |
| GPAE | 1.5 | 7.6 | 18 | 5x106 | 1.6 | 9.1 | 18 | 5x106 |
| GKAE | 1.5 | 8.9 | 12 | 5x106 | 1.9 | 7.8 | 12 | 5x106 |
| GKAE | 1.5 | 10.5 | 15 | 5x106 | 1.9 | 9.3 | 15 | 5x106 |
| GKAE | 1.5 | 11. | 18 | 5x106 | 1.9 | 10. | 18 | 5x106 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **8** | | | | **0** | | |
| **KPAE** | **1.25** | **4.7** | **12** | **5x106** | **1.0** | **2.7** | **12** | **5x106** |
| **KPAE** | **1.25** | **5.7** | **15** | **5x106** | **1.0** | **3.0** | **15** | **5x106** |
| **KPAE** | **1.25** | **6.9** | **18** | **350511** | **1.0** | **3.5** | **18** | **5x106** |

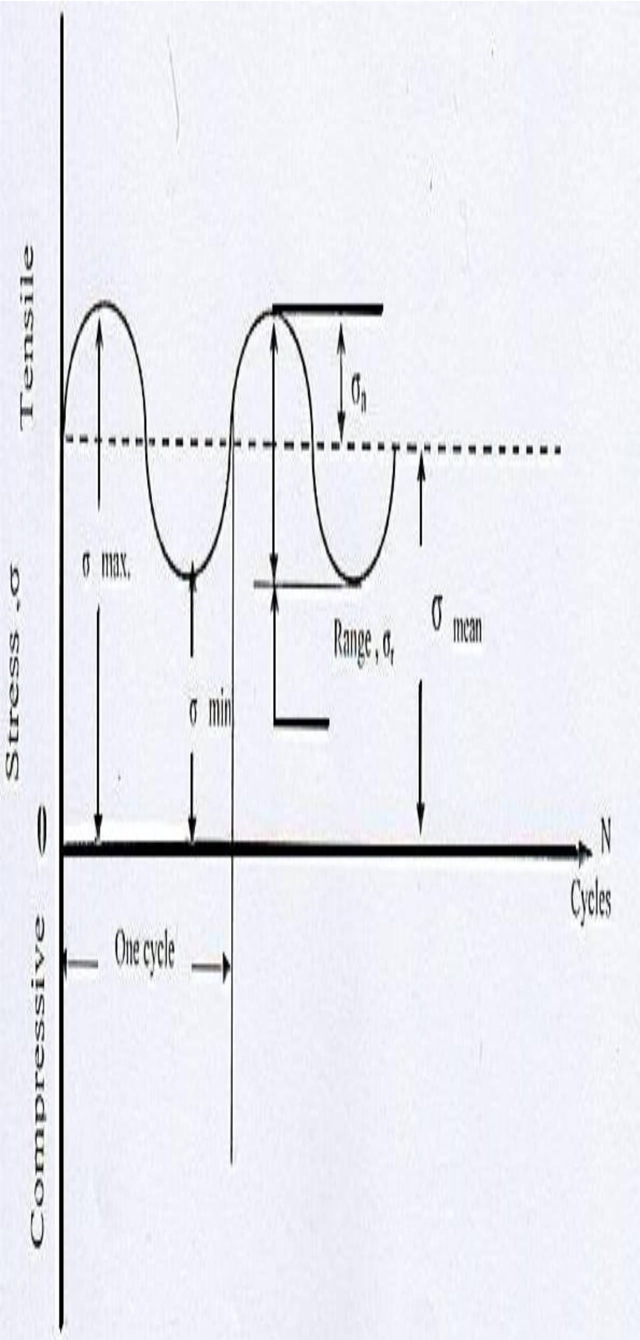
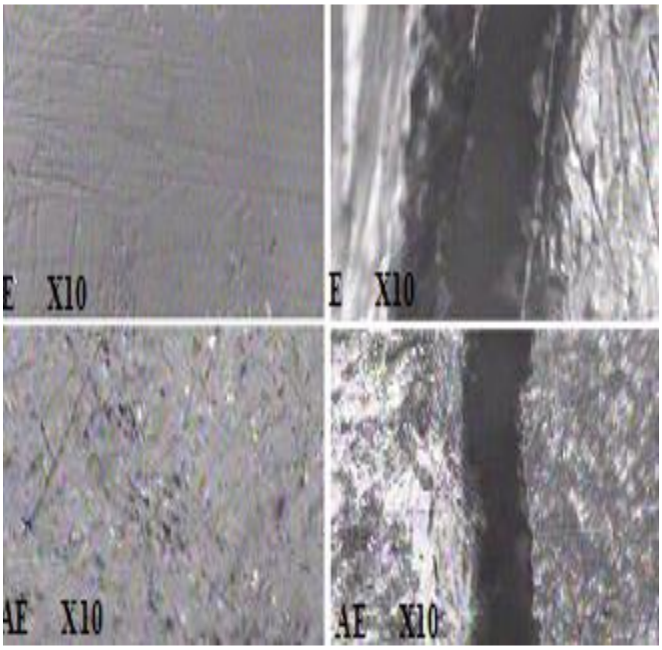
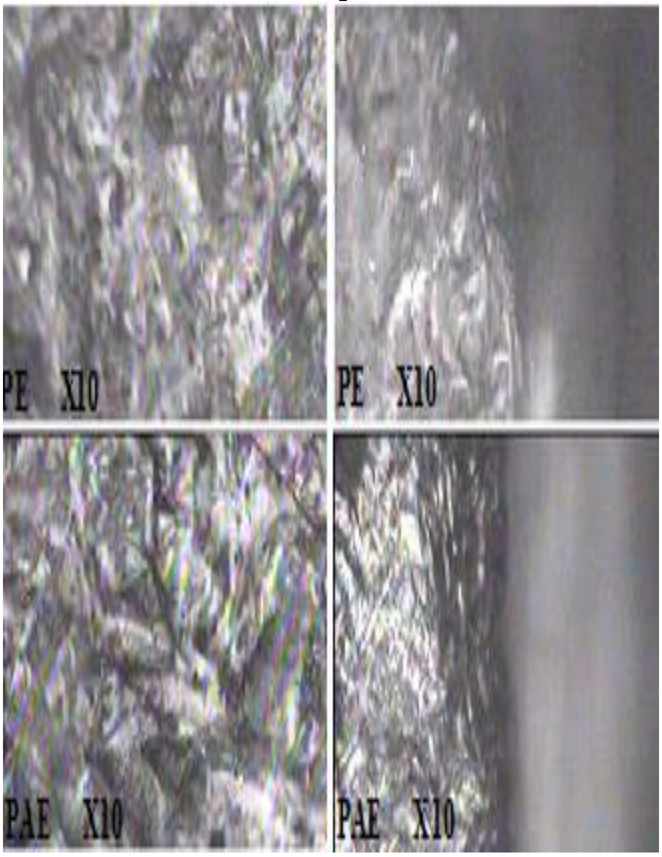



**Figure (1) Sinusoidal loading for fatigue testing [17].**



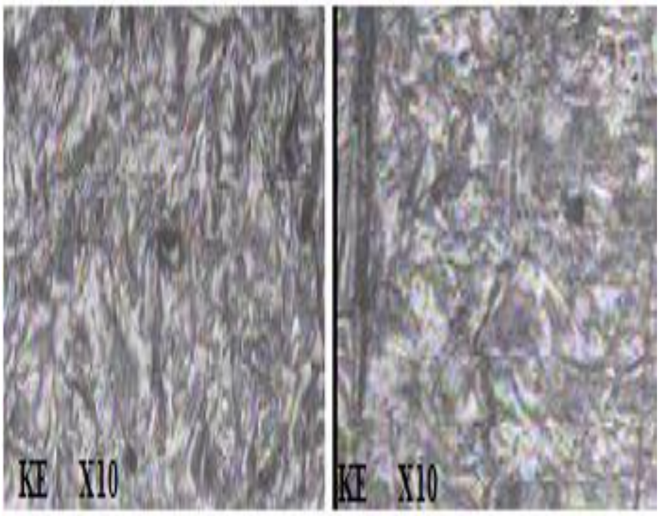

**(a) before (b) after**

**Figure (2) shows the microscopic pictures for these samples**



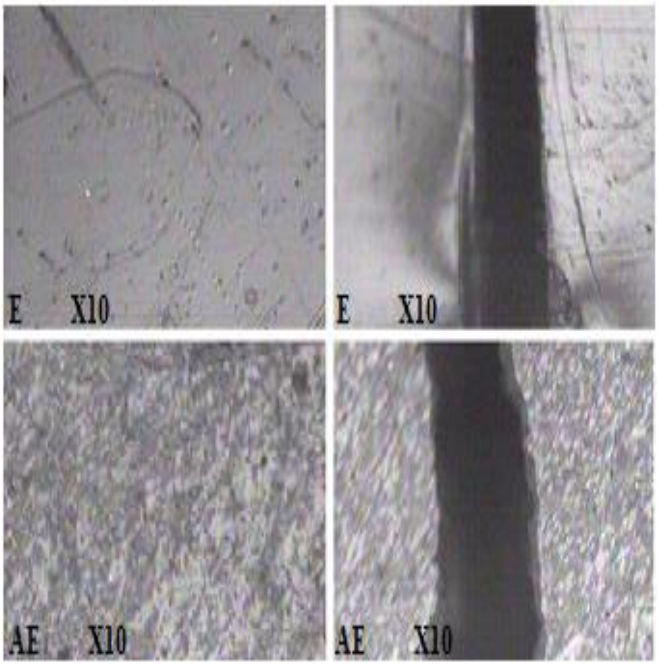

**(a) before (b) after**

**Figure (3) shows the microscopic pictures for (PE) and (PAE)**




**(a) before (b) after**

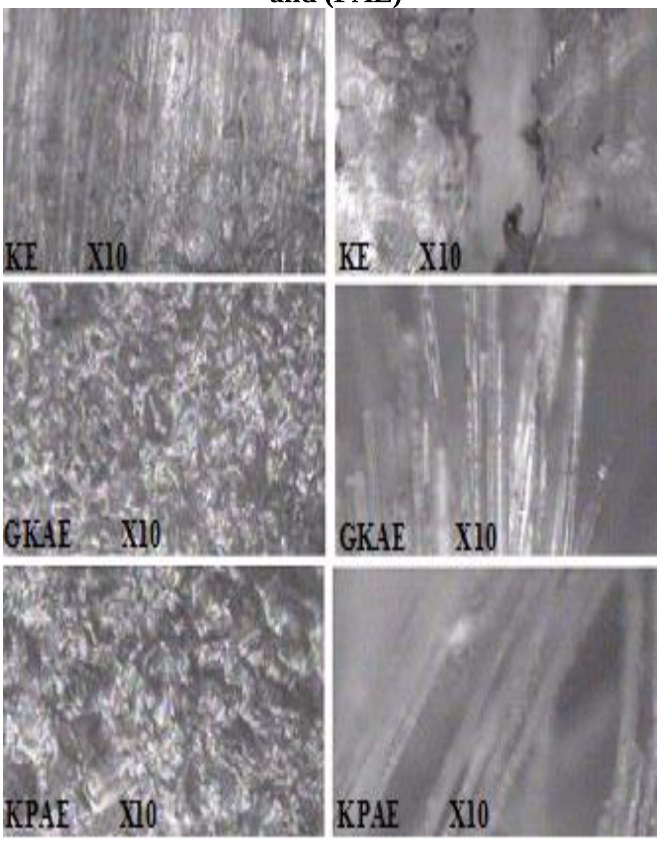
**Figure (4) shows the microscopic pictures for (KE)**




**(a) before (a) after**

**Figure (5) show the microscopic pictures for (E) and (AE) samples**

**Figure (6) shows photographic picture for (PE) and (PAE)**




**(a) before (a) after**

**Figure (7) show the microscopic pictures for (KE, GKAE and KPAE) samples**

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# تأثير حامض الكبريتيك على خاصية الكلال لمتراكبات الايبوكسي

محمد غازي حمد　　محمد سعيد وحيد　　بلقيس محمد ضياء

**الخلاصة**

تضمن البحث دراسة خاصية الكلال للمواد المتراكبة البوليمرية ، حيث استخدم راتنج الايبوكسي كمادة رابطة لمواد التدعيم والتي تتكون من الالياف الصناعية (الياف الكفلر والزجاج و PVC) وكذلك تتضمن مسحوق الالمنيوم لغرض التدعيم ايضا.

صنعت الواح من المواد المتراكبة والمواد المتراكبة الهجينة وبالكسرين الحجميين 30% و 40% من مواد التسليح ، حيث تم تصنيع (21) لوحا من هذه المواد. هذه الالواح قطعت الى عينات بالقياسات (10x70mm) لكي يتم فحص الكلال لها وتبعا لمواصفات الجهاز المستخدم ، هذه العينات قسمت الى عدة مجاميع لكلا الكسرين الحجميين ومن ثم غمرت في محلول حامض الكبريتيك المخفف ذي التركيز (1N) لمدة خمسون يوما لدراسة تأثير هذا الحامض على خاصية الكلال للمواد المتراكبة .

اجري فحص الكلال بمرحلتين :- المرحلة الاولى اجراء فحص الكلال للعينات وهي جافة ومن ثم مقارنة نتائج الفحص فيما بينها . اما المرحلة الثانية فقد نفذ فحص الكلال للعينات بعد غمرها بالمحلول الحامضي لمدة خمسون يوما وقد تم مقارنة النتائج الحاصل عليها في هذه المرحلة مع نتائج المرحلة الاولى ولكلا الكسرين الحجميين من التسليح . اظهرت النتائج والفحوصات المختبرية للعينات ان هناك تناقصا في عدد الدورات الى حد الكلال عند زيادة الحمل او الاجهاد المسلط عليها .