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Evaluation of the Fatigue behavior for the polymer matrix composite and hybrid composite

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Abstract

The characteristics of polymer materials which are containing ceramic particles has been investigated to find the information and data to give good expectation for composite behavior under fatigue damage. In this research epoxy resin reinforced by ceramic particles (Alumina, silicon carbide and graphite), with reinforcement particles size range between 36 and 45 Micrometer and 1 to 10 micrometer for graphite. The structure has been investigated under stress-strain and fatigue damage to evaluate the bound strength between the matrix and reinforcement phase. This examinations lead to discover new Techniques which is applied during preparation of the composite materials. Basically this methodology will reduce the porosity which develops during mixing and solidification process, as a result the bound strength between the polymer and the reinforcement will increase in another word the properties of the composite improve. The fatigue damage in the composites is complex because, it is combine between several damages, first matrix cracking and second debonding of the particles. The fatigue damage shows that pure epoxy give initial stress (26.2) MPa and its final failure is at 221 hundred thousand cycles in which the stress indicated is to be equal to 20 MPa. for the composite contain epoxy with aluminand slicon carbide, the initial stress is equal to (32.2) MPa and its final failure is at 910 hundred thousand cycles in which the stress indicated is to be equal to 23 MPa. In the case of graphite reinforcement it is clear there is reduction in the value of maximum stress.

The microstructure examination shows that the cracks stop at the reinforcement particles or goes around them. Crack propagation is thereby inhibited. This means that the fracture toughness of the composite increased

1. Introduction

The fatigue life was found to increase with decreasing stress level, and below a certain stress level, known as the fatigue limit, (failure dose not occur for any number of loading cycle), The mean stress level, defined as the average of the maximum and minimum stress on the cyclic loading, plays an important role on fatigue life. It was found that the cyclic life decreases with increasing mean stress for a given maximum applied stress level [1]

The Stress – Number of cycles curve method lead to an inaccurate prediction of the fatigue life of engineering components due to the large scatter of experimental results as influenced by specimen size and geometry, material and the nature of the fluctuating load. A better understanding of the fatigue phenomenon can be obtained by modeling the fatigue crack initiation and propagation processes. Crack initiation is analyzed at the microscopic level, while the continuum mechanics approach is used for crack propagation. It is generally accepted that, when a structure is subjected to repeated external load, energy is accumulated in the neighborhood of voids and microscopic defects which grow and coalesce, forming microscopic cracks. Eventually larger macroscopic cracks are formed. [2]

A macro-crack is usually referred to as a fatigue crack. The number of cycles required to initiate a fatigue crack is the fatigue crack initiation life. Following the initiation of a fatigue crack, slow stable crack propagation begins, until the crack reaches a critical size corresponding to the onset of global instability leading to catastrophic failure. Thus, the fatigue life of an engineering component may be considered to be composed of three stages: the initiation or stage I; the propagation or stage II; and the fracture or stage III, in which the crack growth rate increases rapidly. The fatigue crack propagation life, depending on the material, the amplitude of the fluctuating load and environmental conditions. [3]

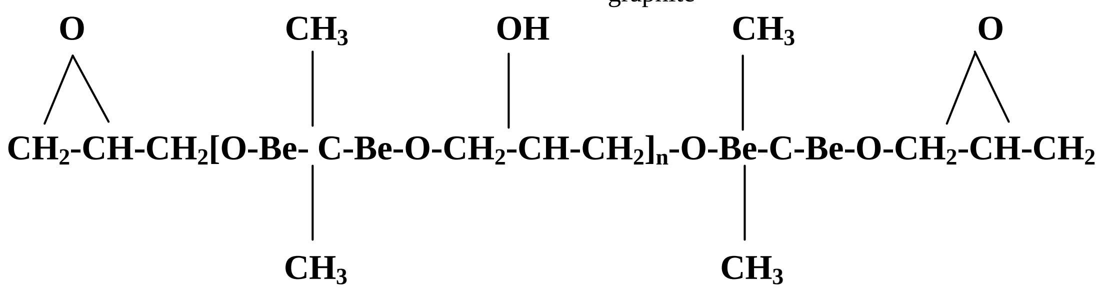
The failure of engineering components subjected to an aggressive environment may occur under applied stresses well below the strength of the material. Environmental conditions greatly influence the processes of local failure at the tip of a crack and cause subcritical crack growth and gradual failure of structural components

Failure under such conditions involves an interaction of complex chemical, mechanical and metallurgical processes. [2]. Composite materials have offered substantial improvements over metals for application to structures subjected to fatigue loads.. Metals exhibit simple failure mode which can be described as cracking caused by a single dominant fatigue crack, While the composites can exhibit one or a combination of failure modes, including particles breakage, delaminate, matrix cracking, interface de bonding, and void growth under fatigue loading. [4]

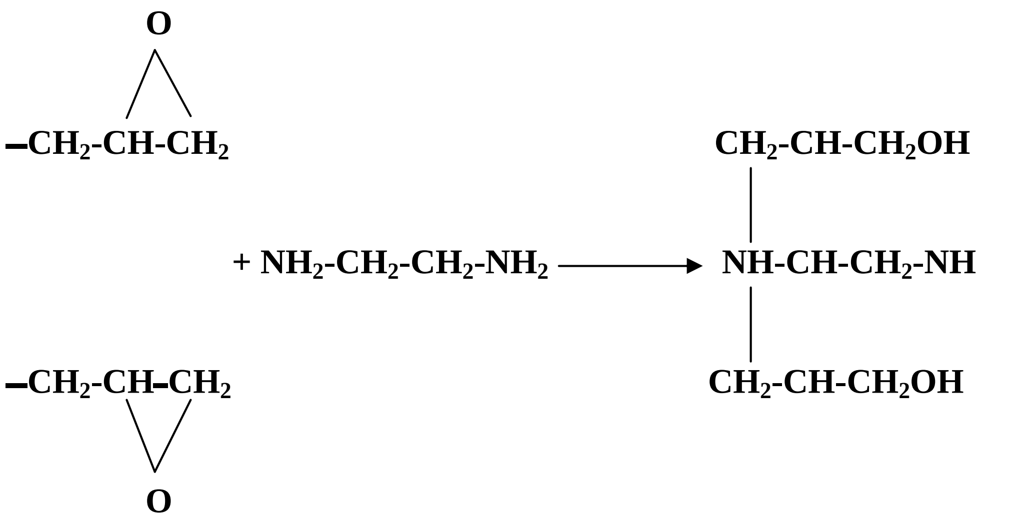
Any combination of these may be responsible for fatigue damage, which may result in reduced fatigue strength and stiffness. Material properties, specimen geometry, stacking sequence, load levels, loading rate, waveform types and frequency, time, and temperature are also critical variables in composite fatigue as they are in any fatigue study. Variation in any of these variables could result in different damage processes and damage evolution mechanisms. [5]

Materials:

The matrix material Conipox 77Z Epoxy type which is from thermosetting material combined with a hardener 3:1 ratio, which enables cross-links to be established between the epoxy molecules to produce a thermoset material and the rests are reinforced materials; (β-Alumina, α-Silicon Carbides, and Graphite) powder. Alumina, α-Silicon Carbides, and Graphite) powder. Alumina fine powder manufactured by E.Merck-Dramstadt, extra pure, Silicon carbide manufactured by Fluka AG Buchs S.G – Switzerland, Charcoal Animal Powdered, Pure. Graphite powder, Laboratory Chemical – India. The range of particle size for reinforcement material between (***36***μ***m*** to 45μ***m***) and 1 to 10 μ***m*** for graphite



Where: Be benzenening and n for degree of polymerization. When the epoxy is mixed with hardener the oxygen bond opened and the reaction binds two epoxy molecules by covalent bond.



Linear epoxy **Hardener** **Cross link epoxy**

2.2 Mixing process:

Mixing of reinforced materials particles with the matrix is an important process especially with the fabrication of hybrid composites contain two or three particulate materials. An electrical engineering mixer was used. The particles were put into the drum according the specified volume fraction and were mixed five to ten minutes, the mixing time increased with type of reinforcement and the volume fraction.

2.3 Vacuum process:

Combined resin with a hardener, produce reaction. This chemical reaction generates porosity in the structure of the composite especially around the ceramic particles. So that during solidification process the mixture was placed desiccators as shown in figure 2.1 to get rid of bubbles in the mixture

Figure 2.1 vacuum apparatus

Finally the samples placed in curing chamber at 30°C for 8-hr to complete solidification

3. Result and Discussions

3.1 Stress and Strain Curve

Four types of experimental data were investigated in this research firstly matrix materials (epoxy) secondly alumina with epoxy, thirdly alumina and silicon carbide with epoxy and finally alumina, silicon carbide and graphite with epoxy.

Stress strain relation curve was drawn for each specimen where stress is calculated from Equation $\sigma = P/A$, where P is the load from the load gage and A is the cross section area for the specimen, the curves for strain-stress relation is shown in Figure (3.1.1). All tensile specimens failed at the reduced section of the specimen where the cross-sectional area is minimum. The initial observation of the stress-strain curves shows that all PMC's are brittle in another meaning sudden failure occurs from ultimate tensile stress **(UTS)** to failure stress. Also it is very clear particles size, density, volume fractions and type of reinforcement materials affect the stress-strain curves [10].

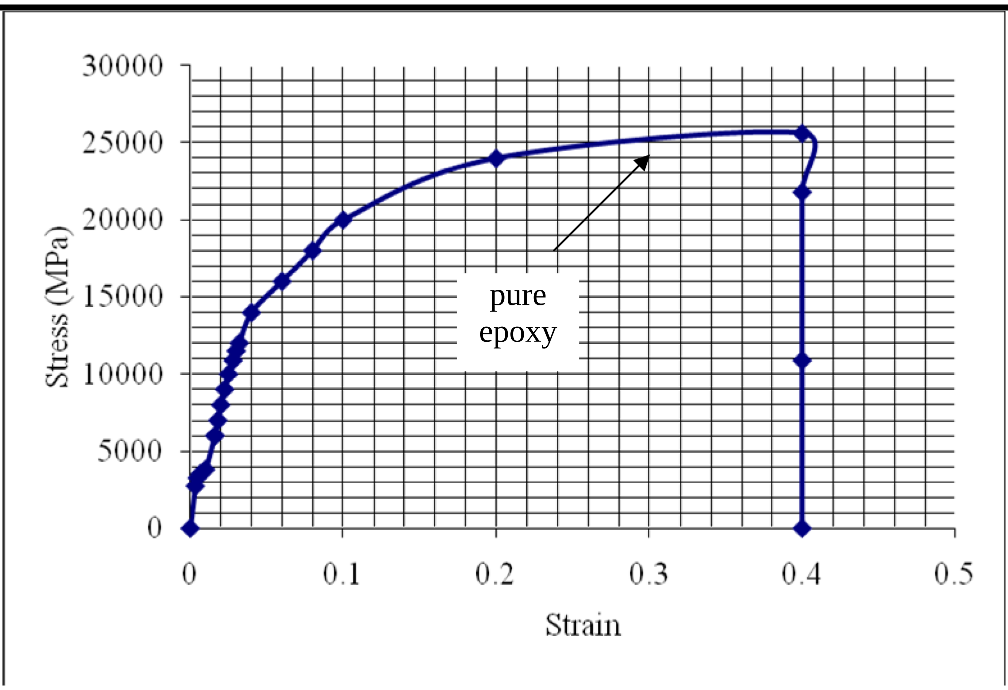


Figure 3.1.1 shows the relation between stress and strain for pure epoxy

The mechanical properties of polymers are specified with many of the parameters that are used for metals- that is modulus of elasticity, and yield and tensile strength. The simple stress-strain test is employed for the characterization of some of these mechanical parameters. Epoxy highly sensitive to the rate of deformation (**Strain rate**) as shown in figure (3.1.1). For a brittle polymer, which has been use in this research as much as it fractures while deforming elastically. The fracture process in polymers involves the breaking of intra-and intermolecular bonds. As a general rule, the mode of the fracture in thermosetting polymers is brittle. In simple terms associated with the fracture process is the formation of the cracks in regions where there is a localized stress concentration Covalent bonds in the network or crosslink structure are severed during fracture.

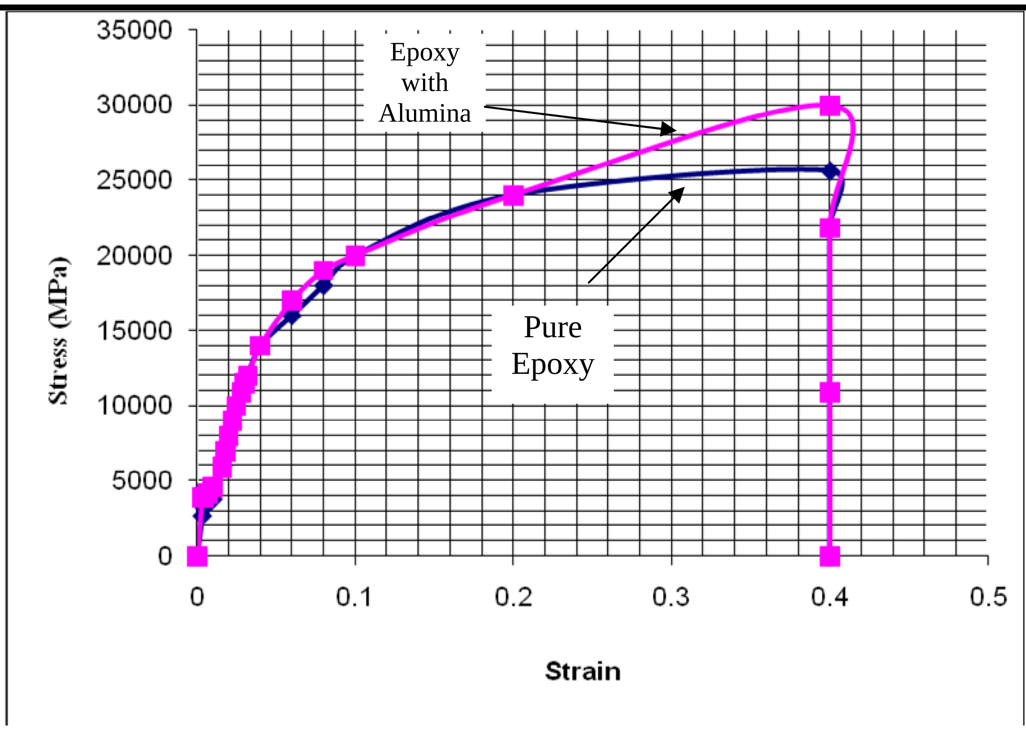


Figure 3.1.2 shows the relation between stress - strain for pure epoxy and epoxy reinforced with alumina

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Figure (3.1.2) represent the relation between stress-strain for Epoxy reinforced with alumina. It is clear from the figure above maximum value of stress increase from 260 for pure epoxy to 300 for epoxy with 5% alumina. The alumina particles provide the high stiffness, while surrounding polymer resin matrix holds the structure together. Particle-matrix interaction cannot be treated on the atomic or molecular level; rather, continuum mechanics is used. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of matrix phase in the vicinity of each particle. In essence, the matrix transfers some of the applied stresses to the particles, which bear a fraction of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix-particle interface.

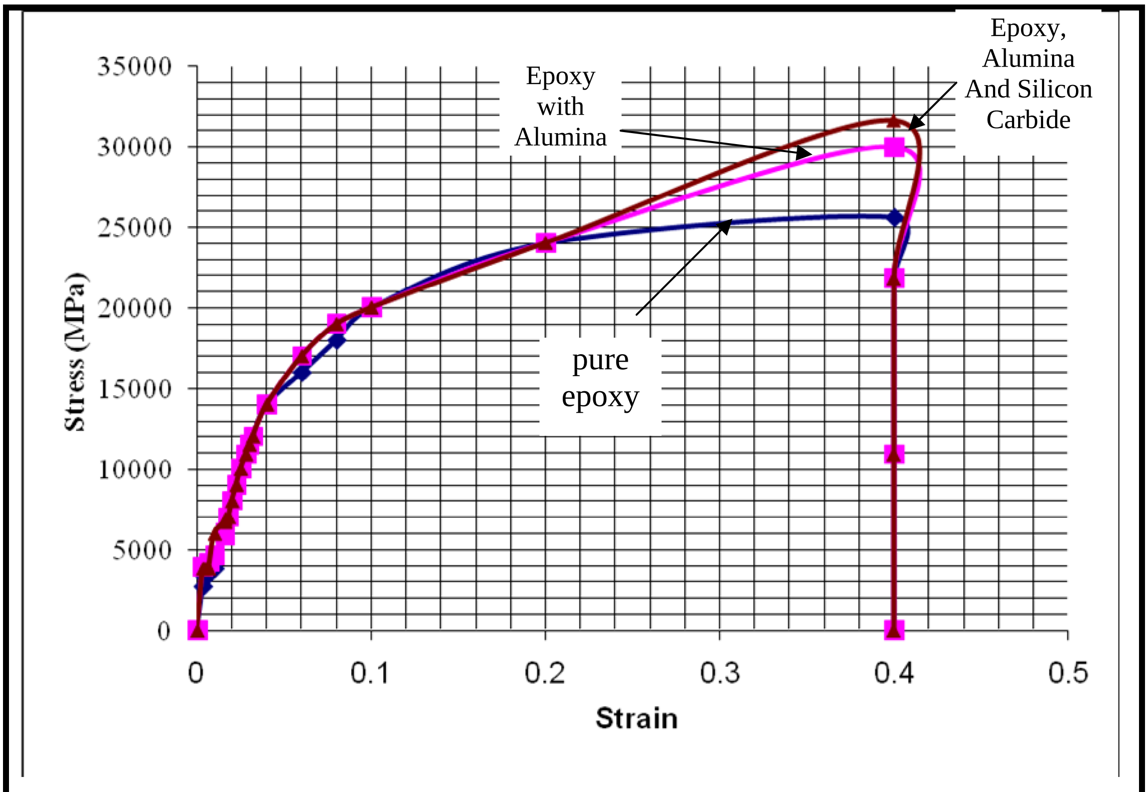

Figure 3.1.3 shows the relation between stress - strain for pure epoxy, epoxy reinforced with alumina and Hybrid composite (epoxy, alumina and silicon carbide).

Hybrids – polymer matrix composite

Hybrids-PMC's is investigated as shown in figure (3.1.3). Hybrid-PMCs are fabricated by:
A- Mixing (alumina and silicon carbide) with Epoxy
The stress increases by adding silicon carbide to reaching maximum value at **325.** These increments in stress are because of the silicon carbide particles are normally much smaller, with diameters between **1** and **10** μ ***m***, the Particles of the matrix interactions that lead to strengthening occur on the atomic or molecular level. The mechanism of strengthening is similar to that for precipitation hardening. Whereas the matrix bears the major portion of an applied load, the small dispersed particles hinder or impede the motion of dislocations. Thus plastic deformation is restricted such that, yield and tensile strength, as well as hardness, improve.

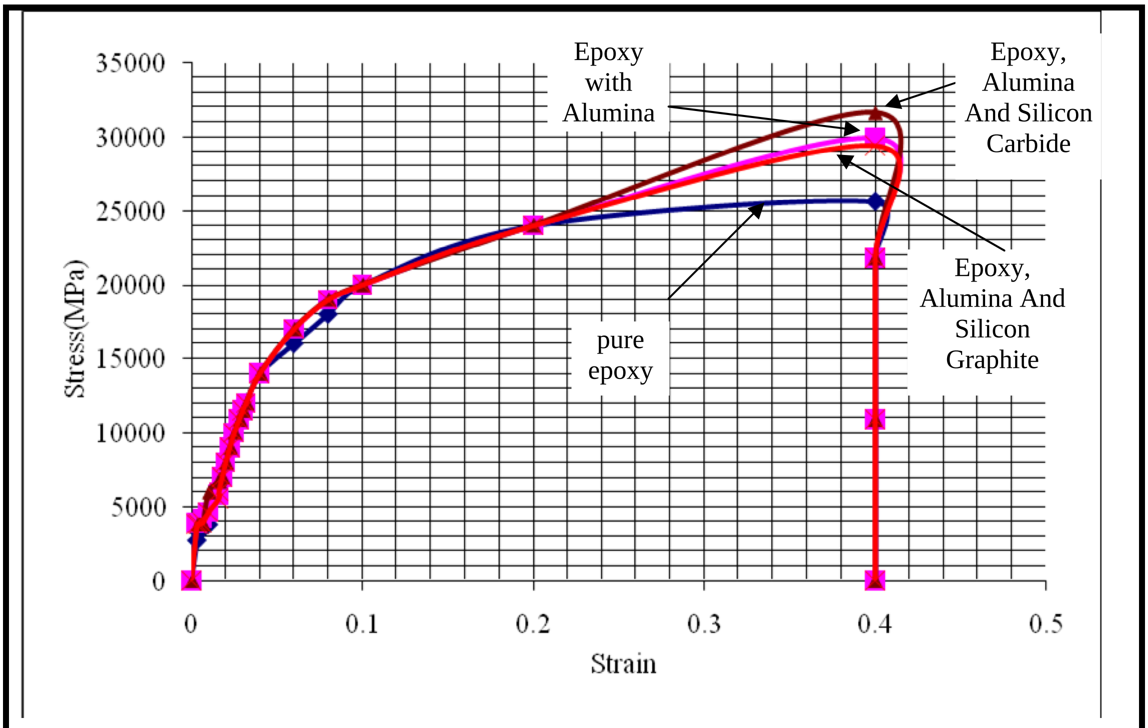

Figure 3.1.4 shows the relation between stress - strain for pure epoxy, epoxy reinforced with alumina and Hybrid composite (epoxy, alumina and silicon graphite).

B- Mixing (alumina and graphite) with Epoxy: Hybrid-PMCs is fabricated by mixing (alumina and graphite) with epoxy leads to drops in strain of Hybrid-PMCs and decrease in stress to reach till up to **(280MPa)** as shown in Figure 3.1-4, the reason for this behavior due to wettability of reinforcement by the matrix. *Wettability* refers to the ability of the liquid to spread on solid substrate. Frequently taken as a measure of wettability, are acontact angle of **0°** indicating perfect wettability and a contact angle of **180°** indicating no wettability. *Wettability* is only a measure of the possibility of attaining an intimate contact between liquid and solid. Good wetting is anecessary, but not sufficient, condition for strong bonding. Besides wettability, [11]. Other important factors such as chemical, mechanical, thermal and structural factors, affect the nature of the bonding between the reinforcement and matrix. As it happens, these factors frequently overlap, and it may not always be possible to isolate their effects. In ***PMC's***, the surfaces of particles are generally treated to promote chemical or mechanical adhesion with the matrix another reason Increase in fillers leads to decrease the movement of particles which causes decreasing in the transmitting stresses from matrix to fillers particles.[10]

3.2.Fatigue test

The Stress-number of cycles is the most important presentation method. For the fatigue effect on any kind of material whether is metal, ceramic, polymer or it is made from composite materials, in the figures below the relation between the stress and the number of cycles is presented, these figures are for different values of stress and for different composite materials.
Figure 3.2.1 represent the relation between the stress and number of cycles for the pure epoxy with, the initial stress is equal to (26.2) N/mm2 and its final failure is at 221 hundred thousand cycles in which the stress indicated is to be equal to 20

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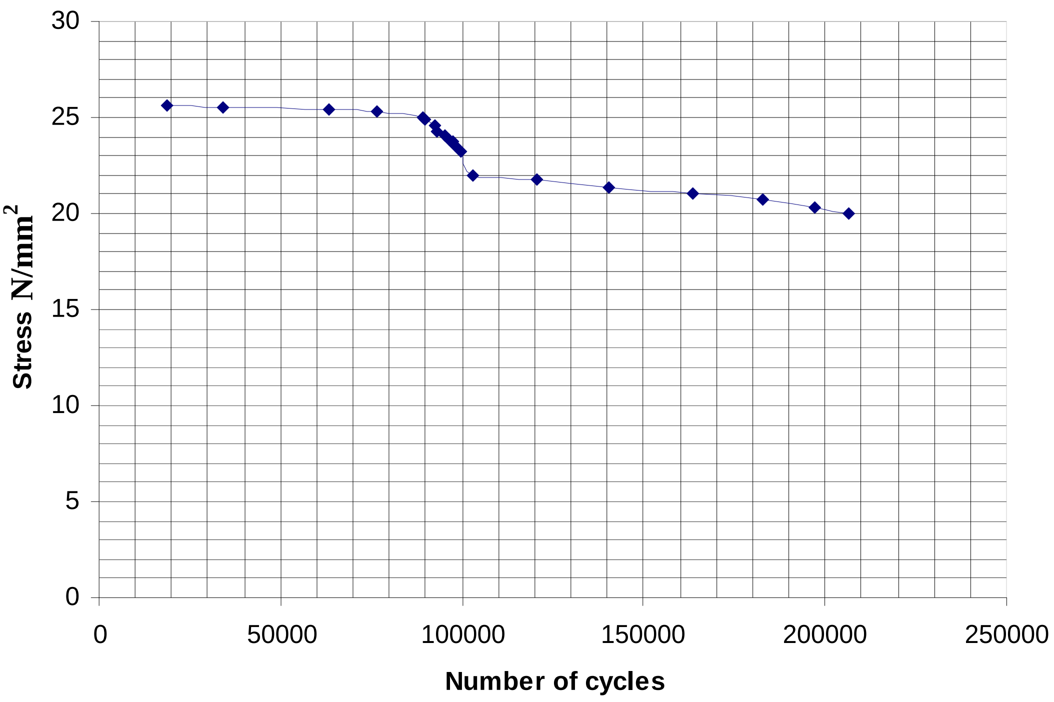

Figure 3.2.1 relation between the stress and number of cycles for the composite contain epoxy

Figure 3.2.2 represent the relation between the stress and number of cycles for the composite contain epoxy with alumina, the initial stress is equal to (29.2) N/mm2 and its final failure is at 187 hundred thousand cycles in which the stress indicated is to be equal to 23 MPa. From the result shown in figure 3.2.1and figure 3. 2.2 there is no noticeable difference in the value of maxim stress and number of cycles at which the material fail. But in the case of modules of elasticity there is noticeable change, for pure epoxy the module of elasticity was 908MPa but for the epoxy with 5% alumina the value increase up to 1.31 Gap

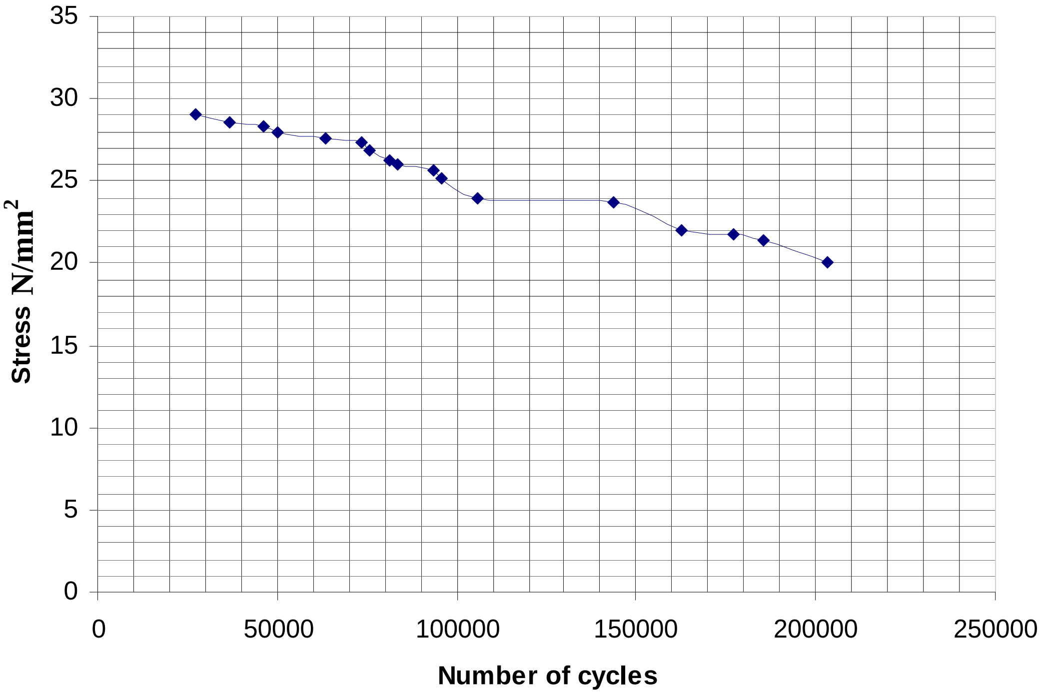

Figure 3.2.2 relation between the stress and number of cycles for the composite contain epoxy with alumina

Figure 3.2.3 represent the relation between stress and number of cycles of Epoxy alumina and silicon carbide, it is clear up to 100 thousand cycles rapid drop in the stress with number of cycles. And then the curve takes liner relation between stress and number of cycles up to 150 thousand. After that the decrease returns to be a rapid drop in the value of stress, until the final failure at the end of the 190 thousand cycles With silicon carbide the maximum stress increase and the number of cycles increase as will, this behavior due to strong interface between SiC and epoxy which allow the force to transmit from reinforcement to the matrix.

Figure 3.2.4 shows the behavior of Epoxy alumina with silicon carbide the specimen shows maximum stress of 29 Mpa and than the stress drop down rapidly until 110 thousand cycles then become stable. When the number of cycles reach 180 thousand the stress values drop rapidly again.

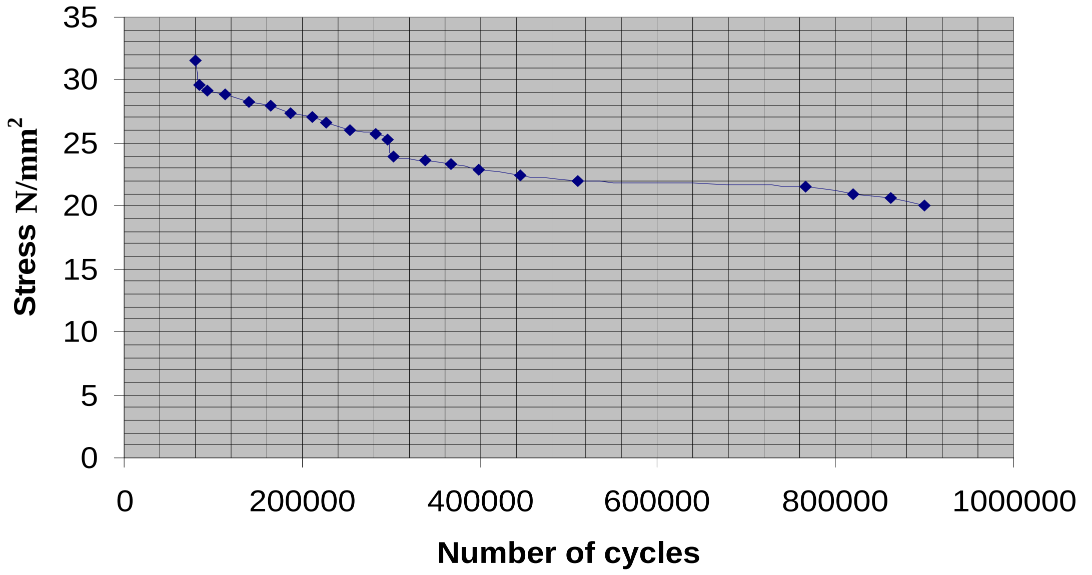

Figure 3.2.3 relation between stress and number of cycles of Epoxy alumina and silicon carbide

Figure 3.2.4 represent the effect of graphite in the composite, it is clear there is reduction in the value of maximum stress because of the pore wet ability between epoxy and silicon carbide. So that it is important to know the wet ability of the materials before use as discuss previously

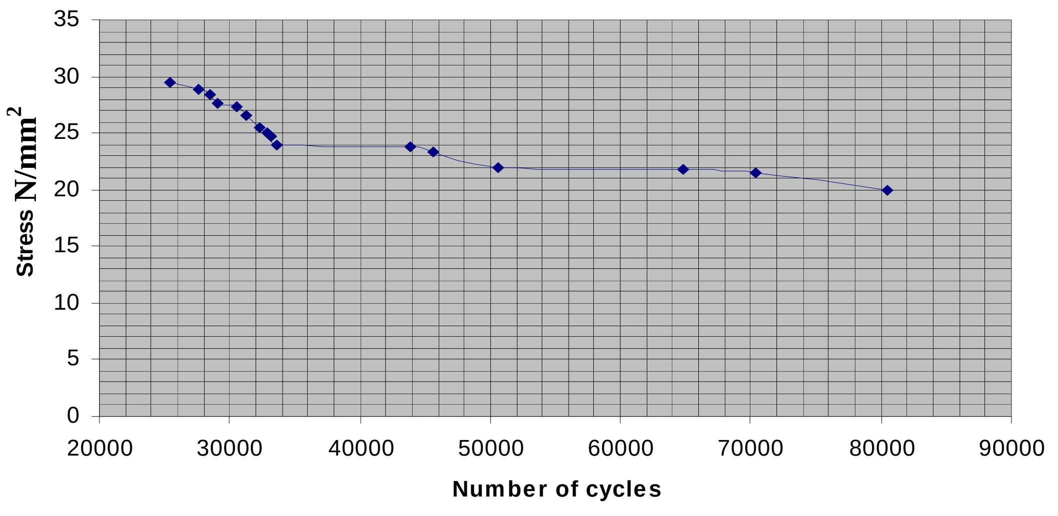

Figure 3.2.4 relation between stress and number of cycles of Epoxy alumina, silicon carbide graphite

It is clear from all the **S - N** curves, the stress decreases during the test in different percentages. During the first two thousand cycles there is rapid decreases in the stress which is represent the first region in which the fatigue life initiates the first damages, most of these damages are a transverse crack that takes place in the composite structure, as cycles increase the decrease in the stress takes new pattern and the decrease is less sharp than the first two thousand, and starts to take a linear decreasing.

After that the relation between stress and number of cycles returns to be a rapid drop in the value of stress up to the final failure at the end of the 600000 cycles, this behavior can be explained as that the damage in the first few thousand cycles was because of the transverse crack and then it starts to grow in the composite and starts to produce the particles matrix de bonding

3.3.1 Microstructure examination

It can be clearly seen that the composite have a very complex structure because of the use of the particle reinforcement. The distribution of reinforcement particles in the matrix, which is very important factor affected the properties of the composite so that it is important to make sure that maxing process give homogenous distribution.

The interface between the matrix and the reinforcement phase is responsible to transfer the force from the reinforcement to the matrix as shown. The effect of the particles on the fracture of the composite can be seen from the micrograph figure 3.3.1 which clearly shows that the cracks stop at the particles or goes around them. Crack propagation is thereby inhibited. This means that the fracture toughness of the composite increased by more than factor of x 2. The transverse cracks that take place in the particle matrix interface lead to damage in the first few thousand cycles and then it starts to grow in the composite and starts to produce particles matrix de bonding as shown in figure3.3.1.[6]

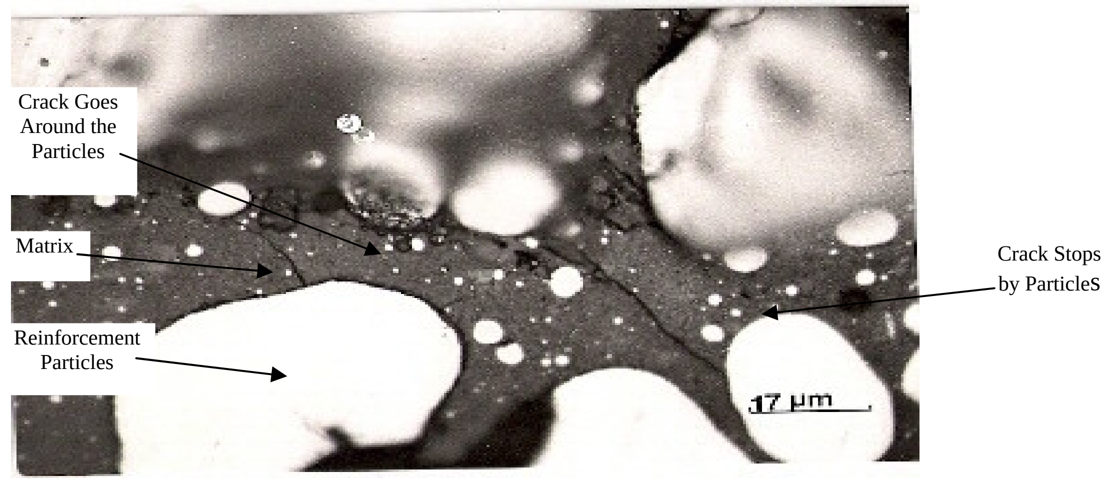

Figure 3.3.2 shows that the cracks stop at the particles or goes around particles

4.Conclusions

1- The fracture strengths of polymeric materials are low relative to those of metals and ceramics. As a general rule, the mode of the fracture in thermosetting polymers is brittle. In simple terms associated with the fracture process is the formation of the cracks in regions where there is a localized stress concentration.
2- Forcing particles tend to restrain movement of matrix phase in the vicinity of each particle. In essence, the matrix transfers some of the applied stresses to the particles, which bear a fraction of the load. The degree of reinforcement or improvement of mechanical behavior depends on strong bonding at the matrix-particle interface.
3- The **S - N** curves during cyclic loading, different regions inside a composite material have different micro-responses. The weaker matrix can act temporarily as a homogenous material like the conventional metal but only until some other constituent of the composite takes over in the deformation process. After sufficient matrix cracking the crack encounters the particle/matrix interface. Here the circumferential stiffness of the particles does not allow it to be broken by the crack, and hence the crack moves along the particle-matrix interface. This type of process eventually leads to damage called de

bonding, as shown in microstructure examination

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تقيم سلوك الإعياء للمواد المركبة والمواد الهجينة من البوليمر

د. عبد الرحمن نجم عبد

مدرس

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الخلاصة

إنّ خصائصَ موادِ Polymer التي تَحتوي جزيئاتَ خزفية درست لإيجاد المعلوماتِ والبياناتِ لإعْطاء التوقعِات الجيدِة لسلوكِ المواد المركّبة تحت اختبار الإعياءِ. في هذا بحثِ Epoxy لقد عزّزَ بالجزيئاتِ الخزفيةِ (أوكسيد ألمنيوم وكربيد وسيليكون وجرافايتِ)، بمدى حجمِ يتراوح بين ٣٦-٤٥ ميكرومتر و١-١٠ ميكرومترِ للكرافايت . حيث ان التركيب فحص تحت إجهادِ واختبار الإعياءِ لتَقييم قوّةِ الترابط بين مرحلةِ التعزيزَ والمصفوفة بحيث ان هذه الفحوص تُؤدّي إلى اكتشاف تقنيات جديدةَ التي تطبق أثناء تحضيرِ الموادِ المركّبةِ. وبصورة اساسية ان هذا عِلْم المنهج سَيُخفّضُ المسامية التي تُطوّرُ أثناء عمليةِ الخَلْط والتصليد. كنتيجة قوّة الترابط بين Polymer والتعزيز سَتَزيد من خصائص تحسين المركب.

اختبار الإعياءَ في المركّباتِ يكون معقد لأنها تتركب بين عِدّة أضرار، أولاً تكسر المصفوفة وثانياً إلتِصاق الجزيئاتِ. اختبار الإعياءَ في Epoxy الصافي يَعطي إجهاداً أولياً مقدارة MPa (٢٦.٢) وفشله النهائي في ٢٢١ مائة ألف دورة الذي فيه الإجهادِ سَيصْبَحُ مساويَ إلى 20 MPa بينما مركّبِ يَحتوي with EPOXY ALUMINAND SLICON CARBIDE ، الإجهاد الأولي مساويُ إلى MPa (٢٩.٢) وفشله النهائي في ٩١٠ مائة ألف دورة الذي فيه الإجهادِ سَيصْبَحُ مساويَ إلى MPa ٢٣ . في حالة تعزيز الجرافايتِ من الواضحُ ان هناك تخفيض في قيمةِ الإجهادِ الأقصى. الفحصَ المجهري يبين بأنّ الشقوقَ تَتوقفُ عند جزيئاتِ التعزيزَ أو يحيط بهما. وبهذا نمنع انتشار التشقق وهذا يَعْني بأنّ المقاومة ضد الكسرَ قد زادتْ في المركبات.