# The effect of Carbon fibers and powder addition on the alternating fatigue behavior of unsaturated polyester resin

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## Abstract
In this research, our concentration was to studies the effect of weight fraction of the reinforcement materials(carbon continuous fibers and carbon powder) on the behavior of alternating bending fatigue behavior of the unsaturated polyester matrix(polymeric composite) .
The result of this study, reveals that the variation of the weight fraction percentage of reinforcement materials could be affected the fatigue resistance of the composite produced .
It have been noticed that increases in the weight percentage fraction of carbon continuous fibers, contributed effectively to improve the fatigue resistance, this reflects the longer fatigue life of the composites, that increase in the fatigue life could be approach to more than (180) times, in the case of using carbon continuous fibers, at the stress level (9MPa), and the percentage of weight fraction (6wt%) .
The result obtained of fatigue test in the case of using carbon powder, suggests that the fatigue life depend on the percentage of weight fraction, as the results also reveals some improvement in fatigue life three times and half longer for the weight fraction (2,5wt%), of carbon powder, but the higher weight fraction (6wt%), reduced the fatigue life to a two third compared to un reinforced base matrix .
**Kay Words:** Composite materials, Polyester, Carbon Fiber, Carbon Powder, Bending fatigue (alternating) ,Fatigue behavior .

## Introduction
In recent years, polymer composite materials have developed more rapidly than metals in structural applications such as aircrafts, automobiles, ships, civil infrastructure, chemical processing equipment and sporting goods and other engineering industries [1] . They are used alternatively instead of metallic materials because of their low density, high strength and rigidity [2] .
In contrast to metals, where fracture process is well known to result from nucleation and subsequent growth of single dominant crack; the reinforced composites is characterized by the initiation and progression of multiple failures of different modes. Consequently, there are many potential failure modes for composites than for metallic materials and hence have to be analyzed in detail for better understanding of its failure [3] . Carbon Fiber Reinforced Plastic (CFRP) are extensively used in numerous industrial applications because of some outstanding physical, thermal and mechanical properties which are realizable with the combination of fiber and matrix resin, particularly lightweight, high stiffness and strength, good fatigue resistance, excellent corrosion resistance and dimensional stability compared with metallic materials [4] . Carbon powder are most often added to polymers to improve tensile and compressive strength, abrasion resistance, toughness, dimensional and thermal stability, and other properties .
because these inexpensive material replace some volume of the more expensive polymer, the cost of the final product is reduced [5] .
Carbon fibers have mainly been used in aerospace applications together with epoxies or high temperature thermoplastics, whereas polyesters have found use in large volume and low-cost applications with primarily glass fibers as reinforcement . The combination of carbon fibers and polyester matrix is becoming more important as the cost of carbon fibers is decreasing, and due to the development of new composites manufacturing technologies [6] .
As the composite structures which today are made from glass fiber and unsaturated polyesters become larger and more complex, with higher demands on the material properties .
There will be need to use carbon fibers in aerospace, automobiles and marine applications . One such example is rotor blades for wind turbines, where the addition of carbon fibers is required to retain low deflections during loading for larger designs.
Another example where carbon fiber and polyester is a possibility is hulls for advanced ships, primarily for high speed naval surface vessels, i.e. large structures where specific stiffness is an important property [7].
Most of the composites materials which are used in wind turbine blades are subjected to a cycle loading during the service condition that mostly cause fatigue damages[2][8] . In a picture of cracks starting and growing and eventually, the fan blade is broken [9] .
The mechanisms of composite materials under cycling loading and their fracture behaviors are really complex, for this reason, the study which has been done to identify the fatigue behavior under the cycling loading is essential for using composite materials safely [10] .
More ever, The fan blades which made from composites are subjected to the gravitational force, a centrifugal force and a wind force . A wind force has a relatively low frequency and a high amplitude and it is the most dominant force on the fatigue damage. This also generates alternating bending stresses (tension–compression) [11] .

Fatigue damage results in a change of strength, stiffness and other mechanical properties of composite material .
damage phenomena under various loading conditions are significantly different for polymeric composites .
In many fatigue studies, the fatigue performance of materials is analyzed by investigating the relationship between the fatigue load (S), either applied stresses, and the fatigue life(number of cycles to failure (N))[12] .Therefore usability of these materials can be decided in a better way by knowing their fatigue behaviors. For this aim, generally S–N diagrams are used [13] .
This work focuses on the preparation kinds of polymeric composite materials prepared from the unsaturated polyester resin as matrix reinforced by :

1. continuous carbon fibers .
2. carbon powder .

The aim of this study, is to investigate :

- The effect of selected weight fractions (1.25%,2.5% ,3.7%, 4.9%, 6%) of the carbon fibers and powder on the mechanical properties such (Fatigue behavior),of the prepared composite materials, which done at room temperature .
- The failure mechanism of the composite materials under-cyclic loading and their fracture behavior .

## Experimental

### Materials

The matrix used in this study was an unsaturated polyester resin. Manufactured by accompany of(SIR Saudi Arabia), it is type of thermosetting Polymer, Viscous Liquid, transparent and pink, table(1) gives some properties of this resin [14] :

**Table (1)some properties of Unsaturated polyester [14]**

| DENSITY ($GM/CM^3$) | FRACTURE TOUGHNESS (MPA) | TENSILE STRENGT H (MPA) | PERCENT ELONGATI ON (EL%) | MODULUS OF ELASTICIT Y (GPA) | COMPRESSIO N STRENGTH (MPA) | BENDING STRENGT H (MPA) |
|---|---|---|---|---|---|---|
| 1.2 | 0.6 | 41.4-89.7 | < 2.6 | 2.06-4.11 | 100 | 125 |

It is convert to solid by mixing (2%) of methyl ethyl ketone peroxides (MEKP) as hardener with (0.4%) Cobalt actuate as accelerator to solidification . This mixing is done for each (100%) of un saturated polyester resin at room temperature .

### Carbon fibers

Composite materials made by using carbon fibers for reinforcing plastic resin matrices are characterized by alight weight, very high strength and high stiffness. These properties make the use of carbon–fibers-plastic composite materials especially attractive for aerospace applications .
In this research carbon fibers used as continuous which is immersed in the form of regular manner into the resin. Carbon fiber surpass many characteristics one of these which is given in table(2)[15] .

**Table (2) some properties of Carbon fibers [15]**

| Density ($gm/cm^3$) | Young's Modulus (GPa) | Tensile Strength (GPa) | Tensile Elongation (%) |
|---|---|---|---|
| 1.8 | 230 | 2.48 | 1.1 |

### Carbon powder

Carbon powder are used in composite materials to reduce material costs, improve mechanical properties to some extent, toughness, high heat resistance, high sound and electric insulation, great chemical resistance and in some cases to improve process ability[5] . This powder added in a resin, gradually and slowly with the hardener and accelerator in a beaker at room temperature .

### Composites Preparation

1- Hand-lay-up and open mould techniques was used in a laboratory to prepared the carbon continuous fiber reinforced polyester (CCRP) composite and carbon powder reinforced polyester (CPRP) composite .
2-The glass mould used was cut and cleaned, according to (HSM20) for the fatigue tests.
3-The mould has initially been polished with release agent to prevent the composites from sticking on the mould upon removal .
4-The weight percent of the fiber or powder in the composite was ranging (1.25 – 6), which was calculated by Eq.(1) :

$$\text{Wt \% of the fibers in the composite} = \frac{\text{Weight of fibers}}{\text{Weight of polyester} + \text{weight of fibers}} \times 100\,\% \quad (1)$$

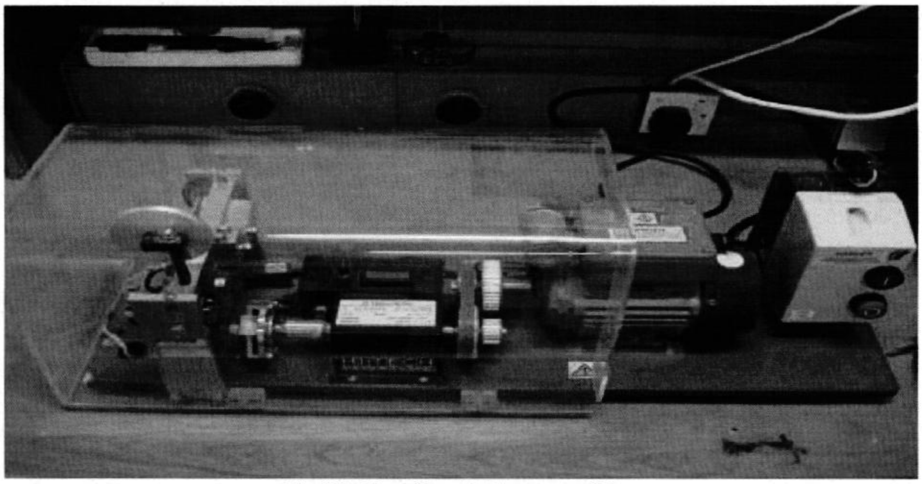
5- The (CCRP)with weight fraction as mention before were impregnated with resin by pouring the resin on the fibers from one corner to the mould after putting fibers into the mould, to avoid the bubble formation which causes cast damage. The uniform pouring was continued until the mould was filled to the fixed level. Then the fibers put into the mould. After then the other resin were uniform pouring to the mould .
6- The carbon powder (CP) and the matrix (including the accelerator and the hardener) were mixed at room

temperature continuously and slowly to avoid bubbling during mixing .
The process was continued for (5) minutes until the mixture became homogeneous, then the mixture was poured from one corner into the mould which was continued until the mould was filled to the required level .
7- Samples was then pressed in a ($3.33 \times 10^5 \frac{N}{m^2}$) and left in the mould for (24) hrs at room temperature to solidify, then, taken out of the mould and kept in the air for another (24) hrs .

## Mechanical tests

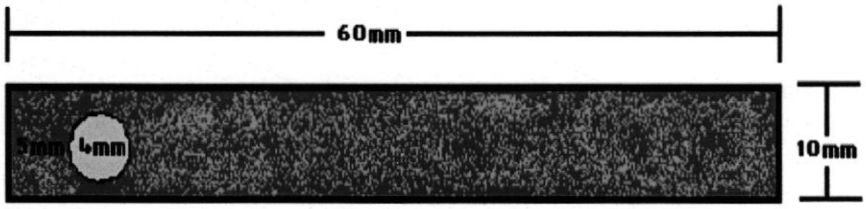
## Fatigue test

The bending fatigue testing machine type (HSM20)as shown in figure (1) made by (Hi–Tech)British company .



**Fig(1): Bending fatigue machine**

This machine is used special sample, which prepared according to the manual, as shown in figure (2).




**Fig(2): Sample of fatigue test**

The practical test frequency was kept constant, test temperature was room temperature about(20C°).
By neglected the gravitational and centrifugal forces, the maximum load can be calculate by Eq.(2)[5] :

$$\sigma_{max} = -\sigma_{min} = \frac{6\,PL}{BT^2} = 3\,P \qquad (2)$$

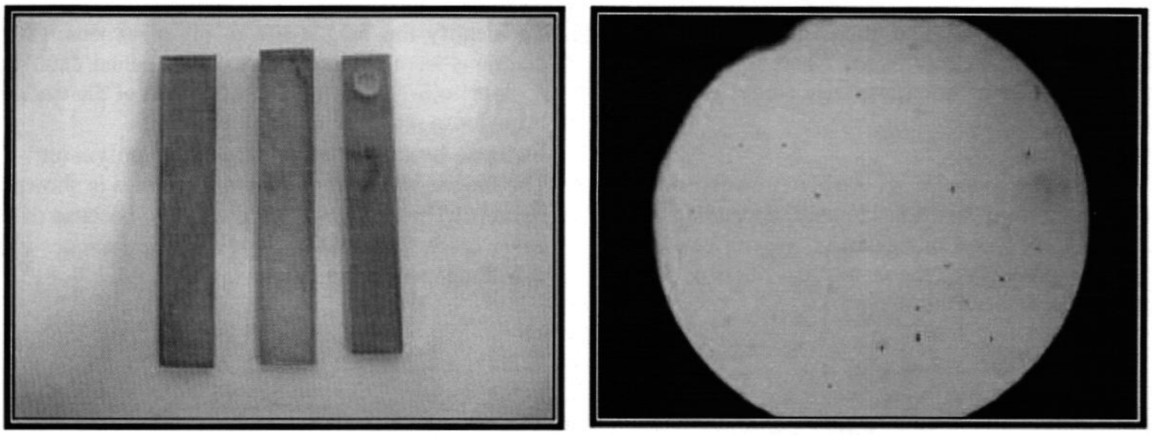
Where :
$\sigma_{max,min}$: is the maximum and minimum strength value(MPa),respectively.
P : is the applied load (N) .
L : is the distance from the applied load point to the fracture area (mm) .
B : is the sample width (mm) .
T : is the sample thickness (mm) .
The machine is designed to apply constant amplitude reverse loads with (R= -1), where,(R) is the ratio of the minimum stress to maximum stress applied to the samples .

$$R = \frac{\sigma_{min}}{\sigma_{max}} \qquad (3)$$

The bending stresses are equal to each other, i.e.($\sigma_{max} = -\sigma_{min}$). the fatigue tests were carried out until the specimen fracture and the(S–N)curves were plotted from the test results of all composites.

## Result and discussion

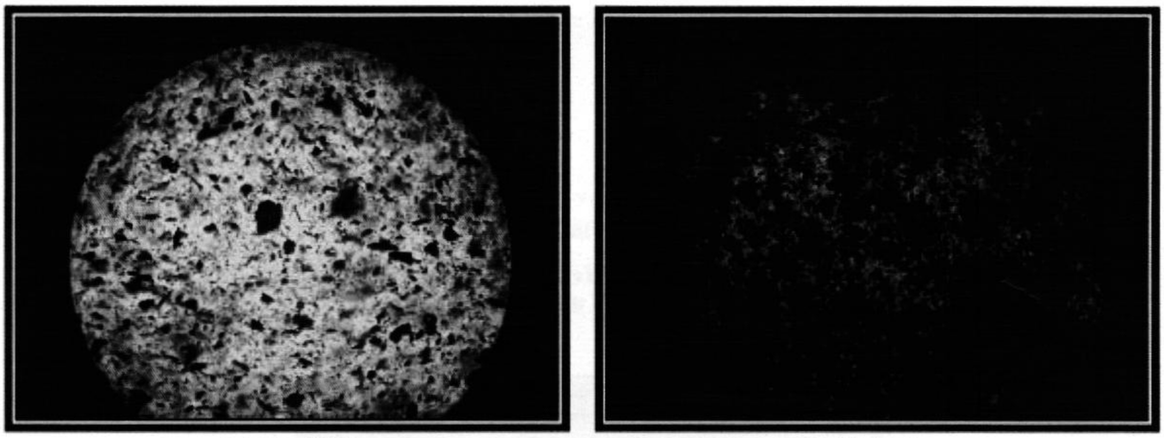
In order to study the effect of reinforcements on improved fatigue behavior and to gain a better understanding of the underlying crack propagation mechanism in the polymer matrix, optical microscopic pictures of fractured surfaces were considered for analysis .
In optical microscope analysis, it has been found that the standard sample or the non reinforced polyester sample was transparent and pure as we shown in figure (3) .



**100X**

**Fig.(3): Microstructure of the standard sample**

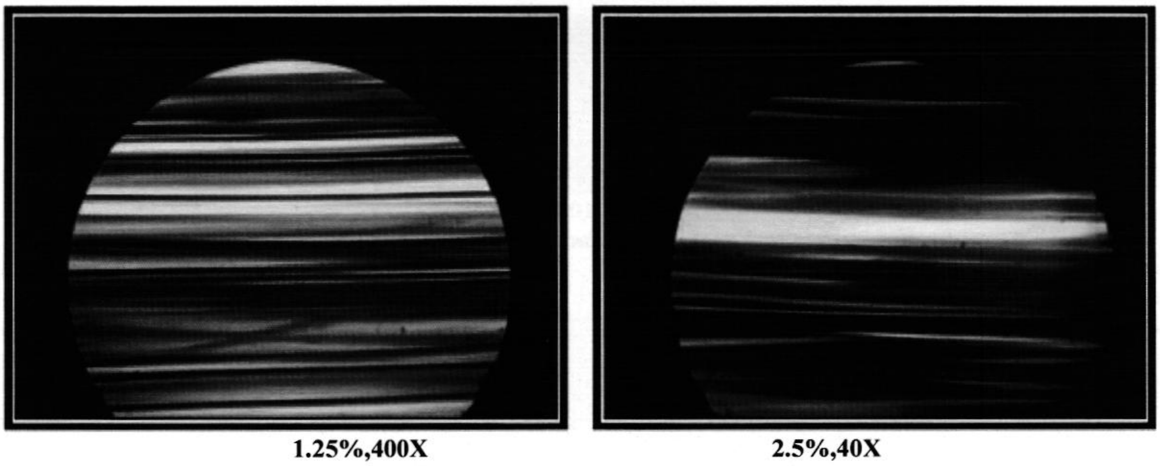
In the case of reinforced samples, it has been noted that the carbon particles are distributed randomly inside the matrix, as shown in figure (4) .



**1.25%,40X** **2.5%,40X**

**Fig.(4): Microstructure of different weight fraction of carbon powder composite**

Figure (5) shows the optical micrographs of the surface sectional of a little random distribution of carbon fibers in the matrix, this due to the fast solidification of the resin, during prepared process .



**1.25%,400X** **2.5%,40X**

**Fig.(5): Carbon continuous fibers composite microstructure**

On the other hand, the increasing of the weight fraction of carbon continuous fibers or powder will lead to increase of nontransparent (fogy) of prepared composites .

## Fatigue test

The fatigue properties of carbon powder or fiber composites were vary considerably, depending on the chemical, structural composition, growth conditions, the adhesion between the matrix and fibers or powder and the direction of the fibers .

To identify the fatigue life of all specimens, (S–N) diagrams were obtained from experimental data. The composite(S-N) plot gave a better idea of the material behavior in response to fatigue loading .

## Fatigue behavior of unsaturated polyester

The fatigue behavior of standard samples is shown in figure(6);The specimen failed quickly, because of the entire crack formation and growth sequence occurred at fast manner during fatigue test .

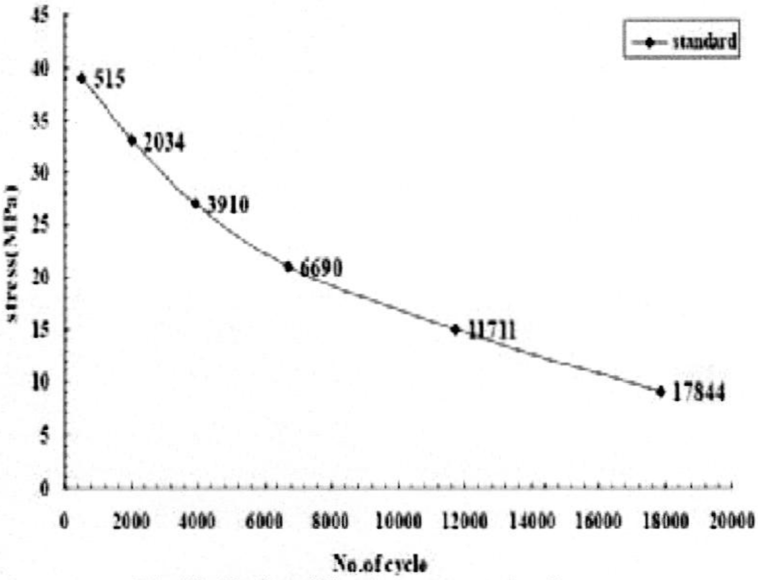


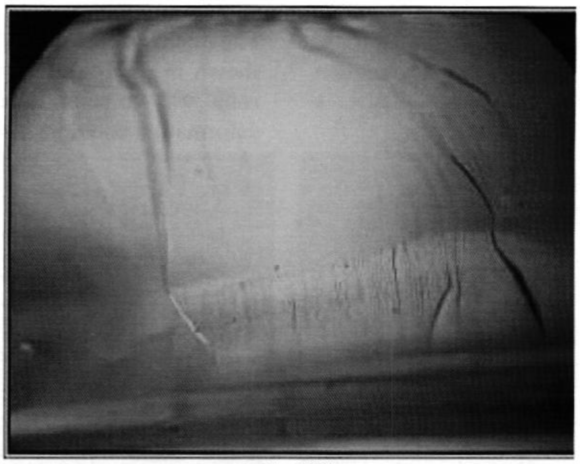

**Fig.(6): Fatigue life of unsaturated polyester**

The brittle nature of the fracture region of a typical sample cracked in fatigue testing is shown Figure (7).

**0%,104X**

**Fig.(7): Fractured surface of standard sample**

The samples failed in a brittle sharp edge with catastrophic manner, which cover the whole width of the specimen and no crack or damage was seen to form on the surface before eventual failure. The typical cross-section of the fractured specimen after cyclic fatigue test presents is shown in figure (8) . It indicates the point of crack initiation followed by striations and beach marks that map instantaneous positions of crack tip during fatigue crack propagation.



**0%,60X**

**Fig.(8): Fractured cross-section of standard sample**

Fatigue behavior of carbon continuous fiber composite All specimen used in this study were failed with the applied load levels, as shown in figure (9) .

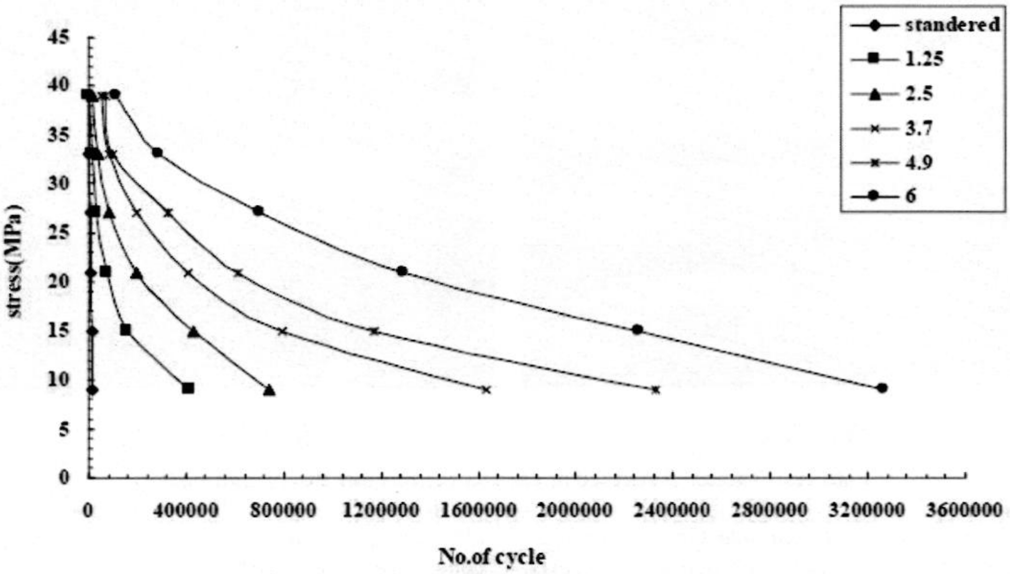



**Fig.(9): Fatigue life of carbon continuous fibers composite**

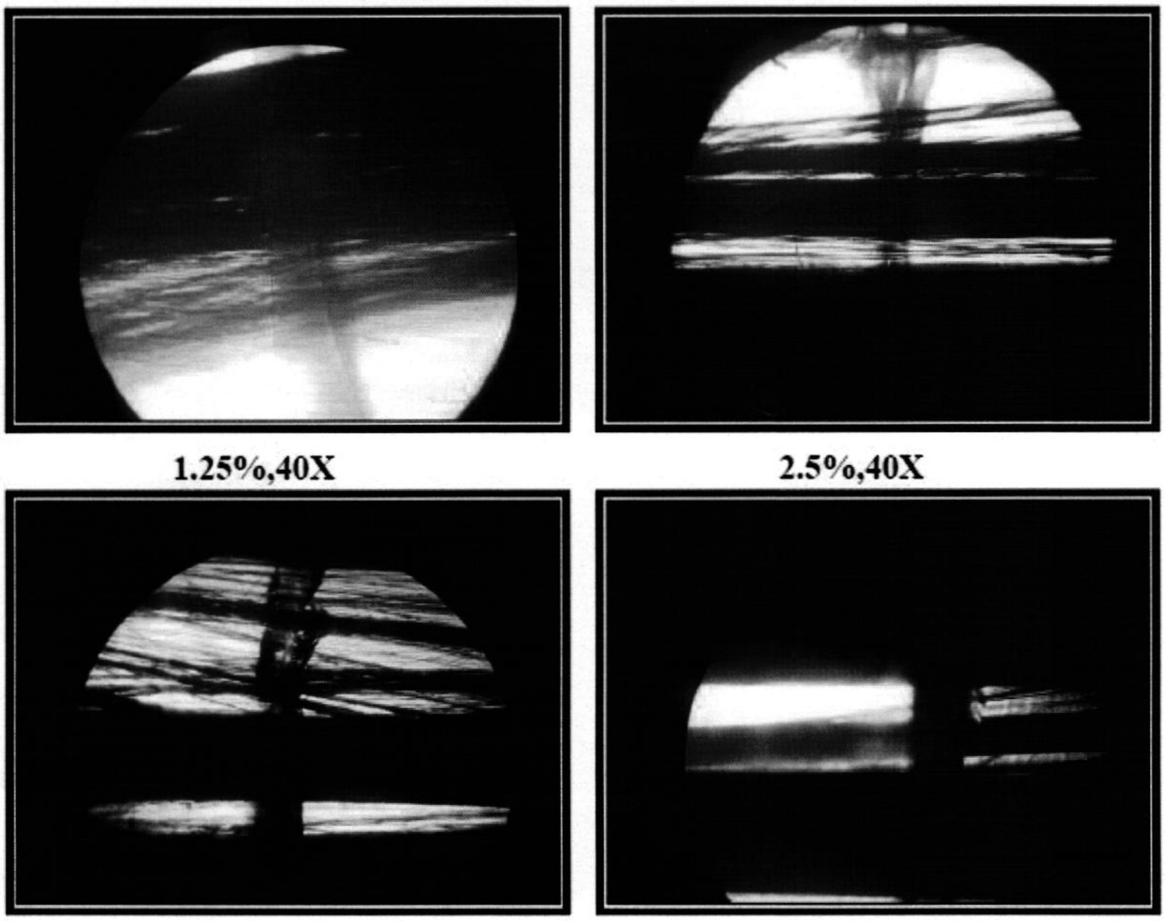
It is clear that the number of cycle up to failure for this composites decrease with increasing of the applied stress (load) . of the weight fraction of the reinforcement materials. This improvement approach (183) times than the standard sample at fatigue stress (9MPa) and concentration and (6%) weight percent of carbon fibers because of the fibers bear most of the applied load, as shown in table (3) .This improvement is observed in all sample, which means that this composites showed a better resistance against fatigue failure .

**Table (3): Fatigue life improvement of carbon continuous fibers composite**

| WEIGHT FRACTION(WT%) | FATIGUE STRENGTH(MPA) | FATIGUE LIFE(NO.OF CYCLE) | TIMES OF IMPROVEMENT |
|---|---|---|---|
| 0 | 9 | 17844 | 0 |
| 1.25 | 9 | 413195 | 23 |
| 2.5 | 9 | 742033 | 41.5 |
| 3.7 | 9 | 1630266 | 91 |
| 4.9 | 9 | 2327510 | 130.5 |
| 6 | 9 | 3265445 | 183 |

More ever, Results, Figure (9) showed that these composites suffered to gradual stiffness degradation with increasing fatigue cycles until they failed in a ductile fashion .

The microscopic test of the sample surface presents is shown in figure (10) . It is obvious that the fracture zone was a semi ductile type and some plastic deformation could be observed .

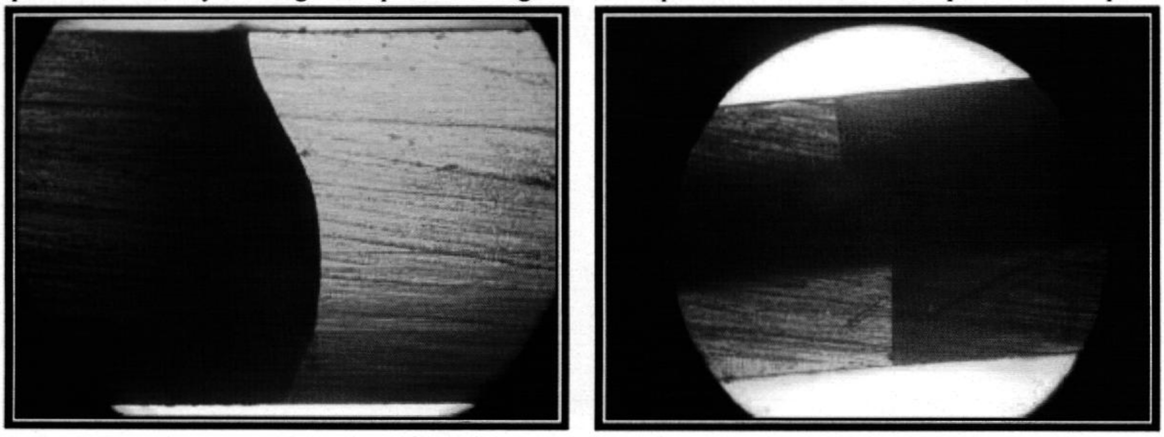


**1.25%,40X** **2.5%,40X**

**3.7%,40X** **6%,40X**

**Fig.(10):Fractured surface of carbon continuous fibers composite**

On the other hand, the typical side view of the test specimen's after acyclic fatigue are presents in figure (11); which it shows that the fracture surfaces of this composites as observed under optical microscope .



**2.5%,52X** **3.7%,100X**

**Fig.(11): Side view of fractured surface of carbon continuous fibers composite**

As indicated from figures the damage appear on the outer surface which act as sharp notches. Then the crack extend into the interior of the specimens which stopped by the presence of the stiff carbon fibers which act as a shield against crack extended for some time then this crack is start to propagate from another region along the longitudinal fibers .

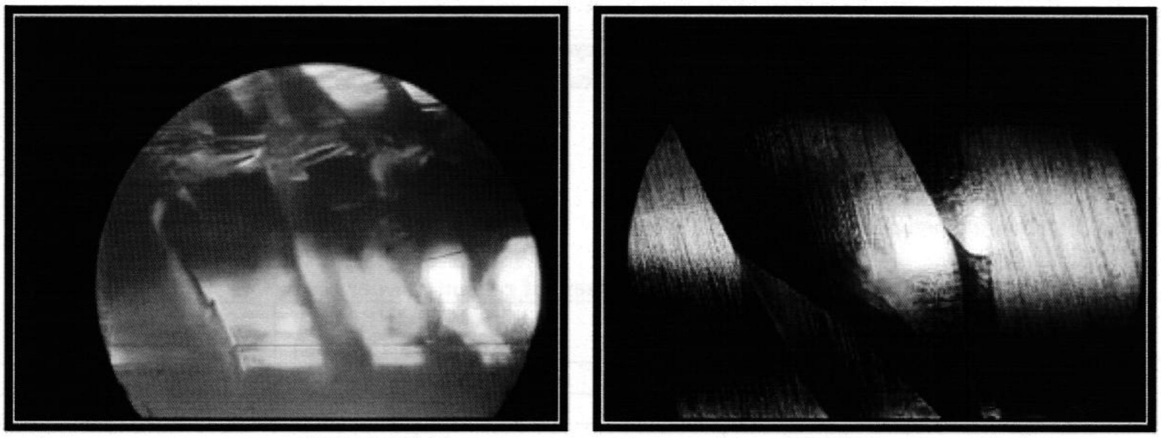
The cracks are, in most cases, oriented in a direction normal to the principal stress orthogonal to the fibers direction, exceed the strength of the matrix, but do not always cover the whole width of the specimen .

propagation of the cracks near the interface between fibers and matrix will produce High interface stresses generate interface cracks that cause the partial delamination within the fibers and finally partial pull out. Then the fibers may be partially break and cause the final break of the polyester bulk with out the carbon fibers, which means that there's a strong interfacial bonding between fiber and matrix, which means that the Fibers bearing most of the applied load from all direction .

Because of the arrangement(orientation)of fibers distribution is not equal, these will lead to random distribution of the load upon the fibers and matrix. Consequently, this will creature weak parts in this composite. the crack will produced, as a result of concentrated all type of stresses at this parts.

Transverse matrix- fiber separation generally starts at the upper fibers. the rigidity and flexibility of the upper and lower fibers decrease at the highest levels of the cycling bending process(tension-compression). thus, elasticity and stiffness will reduce by passage of time under cycling loading .

Microscopic examination of the fracture surface revealed stepped damaged structure at different locations, as shown in Figure (12) .



**2.5%,100X** **6%,48X**

**Fig.(12): Step fractured of carbon continuous fibers composite**

These damage zones produce stress concentrations which can lead to instabilities in the nearby fiber and matrix. Also, it has been viewed that the fiber misalignment/fiber waviness has led to the local shear instability and that the applied compressive-tension load accentuated shear stresses already developed around these initial defects, which weakened the surrounding matrix .The broken fibers can also transferred the load, producing stress concentrations in neighboring not broken fibers. These stress concentrations are a key mechanism to dictate the growth of damage zones which will predominantly depend on fiber strength, interface properties .

The unbroken fibers cannot bear the applied fatigue load, so they generate further strain to the matrix which is weakened and become unstable with continuous loadings (No.of cycle and stress) consequently, the sample failed or broken from different places, as shown in the last figure .

**Fatigue behavior of carbon powder composite**

Figure (13) shows a plot of fatigue stress level vs. number of cycles to failure for this composite. This plot permit to show the influence of the constituents on the fatigue life of the carbon powder composite.

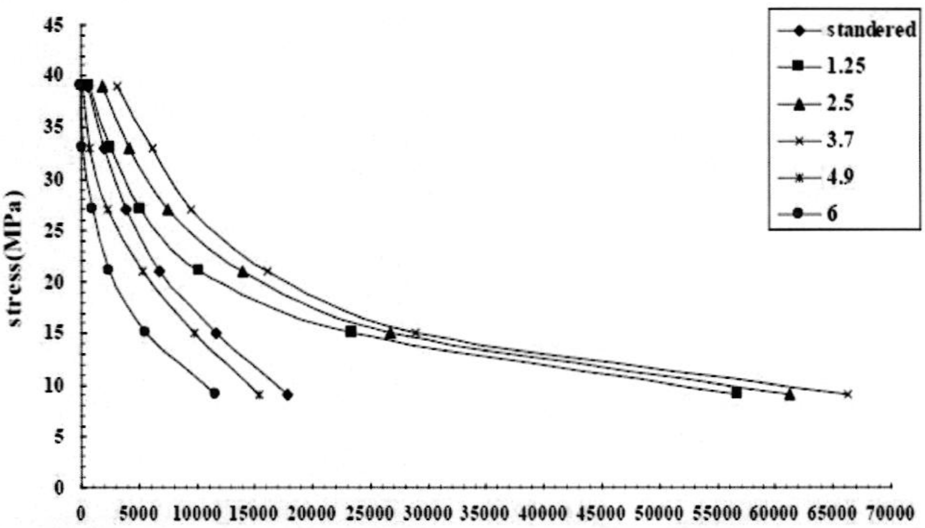


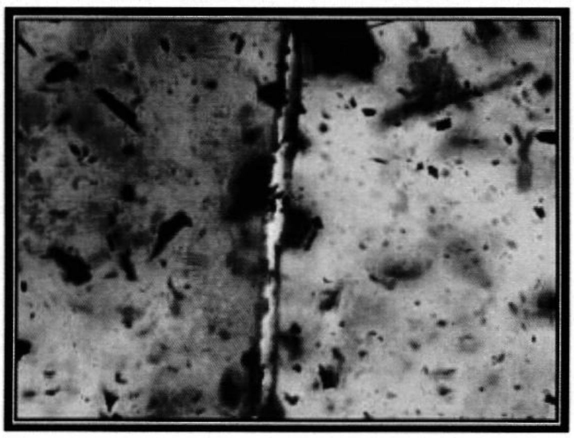

**Fig.(13): Fatigue life of carbon powder composite**

From figures (13), it can be observed that, at the weight fraction of carbon powder of (4.9%,6%) .Composites show a decrease in the fatigue life values as compared with non-reinforced composites, but at the lower weight fraction of carbon powder(1.25%, 2.5%,3.7%) . The fatigue life (fatigue resistance) was improved by (3,3.4,3.7) times, respectively, as shown in table (4). It means that, not all addition of carbon powder improved the fatigue behavior of un saturated polyester .

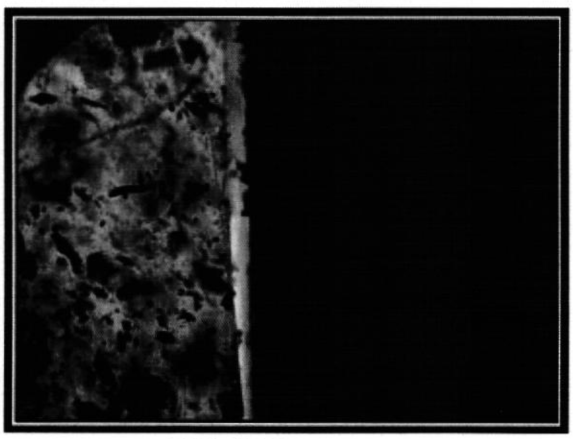
**Table(4):Fatigue life improvement of carbon powder composite**

| WEIGHT FRACTION(WT%) | FATIGUE STRENGTH(MPA) | FATIGUE LIFE(NO.OF CYCLE) | TIMES OF IMPROVEMENT |
|---|---|---|---|
| 0 | 9 | 17844 | 0 |
| 1.25 | 9 | 56762 | 3 |
| 2.5 | 9 | 61219 | 3.4 |
| 3.7 | 9 | 66236 | 3.7 |
| 4.9 | 9 | 15320 | -0.8 |
| 6 | 9 | 11652 | -0.6 |

The pictures in figure(14),show that the fracture surfaces of the composites at different filler loadings .



**1.25%,260X**



**2.5%,150X**

**Fig.(14): Fractured surface of carbon powder composite**

As a filler loading increase, these will lead to create of cluster agglomeration of carbon particles in random region inside the matrix which act as a cutter of polymeric chain that bind molecules of polymer matrix to each other, this will create a week point in different region inside the matrix, consequently, the sample will become more brittle with increasing of carbon loadings. thus, fracture surface become more brittle with a sharp edge. Which was the reason of the earlier failure of the test samples .

More ever, at a result of weak debonding between filler and matrix, figures showed some debris(broken particles) (patches)of carbon at the fracture edge .
The crack propagation is impeded by the presence of carbon particles oriented perpendicular to the path of crack. this particles act as stress concentrators as, more often than not, the crack was found to initiate again from this particles. The crack then has to change its propagation direction, its rate of extension is reduced since the present plane of propagation may not be necessarily the plane which experiences the stress level required for further crack growth .

## Optimum Concentration

In this test, all specimen were used at a constant applied load which equal to (21MPa).Figure (15),illustrates the effect of the weight fraction of the composite materials on the number of cycles .

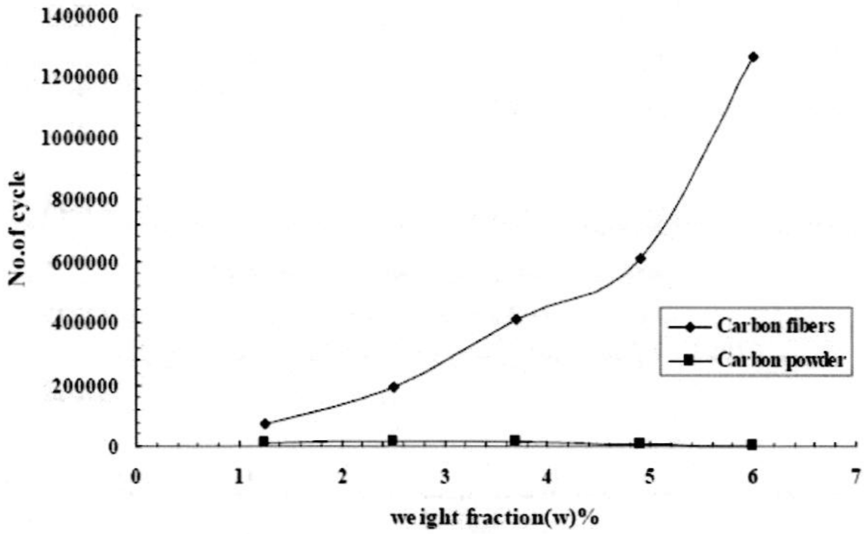



**Fig. (15): Optimum concentration of composite materials test**

In the case of carbon continuous fibers composites, it is clearly seen that, increasing the weight fraction of this types of fibers lead to an increase of fatigue life, which approach to (1265063) cycle of carbon continuous fibers composites at a weight fraction(6%) of carbon fibers which consider as the optimum concentrations of fibers in this composites . But, fatigue life was reduced to about of (2372) cycle at (6%) of fibers concentration in the case of carbon powder .
On the other hand, optimum concentration of powder in this composites is (3.7%)at a fatigue life of (16148) cycle .

## Conclusion

According to the results obtained we can conclude the following :

1. Using carbon continuous fibers as a reinforcement materials can increase considerably, the alternating bending fatigue resistance of unsaturated polyester (matrix) to produce composite materials .
2. All addition of carbon continuous fibers to unsaturated polyester can improve the fatigue life of this composite .
3. In the case of using carbon powder, as a reinforcement materials, the results indicated to some small improvement in fatigue resistance for the low percentage weight fraction, as a higher weight fractions could lead to some reduction in fatigue life .
4. It seems that the geometrical form and the area of the reinforcement materials could play an important rule of binding energy for the composite produced .

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# تأثير إضافة ألألياف ومسحوق الكاربون على سلوك الكلال ألتناوبي لراتنج البولي استر غير المشبع

**مؤيد عبد الله محمد ألنعيمي ، إدريس عيدان غدير العبيدي**

*قسم الفيزياء ، كلية العلوم ، جامعة الموصل ، الموصل ، العراق*

**( تاريخ الاستلام: 6 / 3 / 2013 ---- تاريخ القبول: 30 / 7 / 2013 )**

**الملخص**

في هذا البحث تم التركيز على دراسة تأثير نسب مواد التقوية (ألياف الكاربون المستمرة ومسحوق الكاربون) على سلوك الكلال الانحنائي ألتناوبي لمادة الأساس البوليمرية نوع البولي أستر غير المشبع .

أظهرت نتائج الدراسة أن التغير في النسب الوزنية المئوية المضافة يؤثر على مقاومة الكلال ألتناوبي، حيث وجد أن زيادة النسب الوزنية المئوية للألياف الكاربونية المستمرة ، أسهمت في تحسين مقاومة الكلال ألتناوبي وذلك بزيادة عمر الكلال للمواد المتراكبة المحضرة وبعدد يصل إلى أكثر من مئة وثمانين مرة للألياف الكاربونية المستمرة عند حمل الإجهاد (9MPa) وبتركيز (6wt%) ، بينما أظهرت نتائج فحص الكلال بإضافة مسحوق الكاربون ، أن عمر الكلال يعتمد على النسبة الوزنية المضافة ، كما أظهرت النتائج أن إضافة (2.5wt%) من مسحوق الكاربون يسهم في زيادة عمر الكلال بمقدار ثلاث مرات ونصف تقريبا، في حين أن رفع النسبة الوزنية إلى (6wt%) يؤدي إلى تناقص عمر الكلال بمقدار الثلثين بالمقارنة مع المادة الاساس .

**الكلمات المفتاحية** :المواد المتراكبة، بولي استر، ألياف الكاربون، مسحوق الكاربون، الكلال الانحنائي (ألتناوبي) ، سلوك الكلال .