Improvement fatigue life of polymer matrix composite by reinforcement with carbon nanotubes

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Abstract. This work, cover an improvement in fatigue life polymer matrix composite reinforcement with Carbon Nanotubes (MWCNT), by adding the reinforcements of Carbon Nanotubes to increase the fatigue strength. Three different percentage volume fractions added to the polymer matrix 3%, 5% and 7% to investigate which composition is more efficient and powerful in mechanical application. The investigation was conducted experimentally deals with fabricated the tensile and fatigue specimens and evaluate the mechanical properties and the fatigue strength using the different volume fractions of Carbon Nanotubes and numerically by using Ansys software. Experimental results are compared with those obtained numerically using the finite element technique adopting. The comparison has shown a good agreement between the two techniques with a maximum discrepancy of (6.4%). Also, the results indicate that the reinforcement of the polymer by Carbon Nanotubes increase the fatigue limit, as the volume fraction increase the improvement of fatigue life increased.

Keywords: Fatigue composite, Carbon Nanotubes (MWCNT) reinforcement, Mechanical Properties.

1-Introduction

Reinforcing polymers by Carbon Nanotubes advance the nanotechnology technique that have led to development a new class of composite materials known as Carbon Nanotubes (CNTs) reinforced polymers. The high aspect ratio and low density, together exceptional mechanical, electrical and thermal properties, render Carbon Nanotubes (CNTs) as a good reinforcing agent for polymers. In generally, structures in the working live are subjected to several dynamic loads, then, the stresses induced in the structure are usually dynamic stresses. Fatigue in structure components represents a very dangerous phenomenon due to cyclic loading. In current researches and studies an attempt is made to reduce the risk of this problem. Fatigue life can be studied by using different techniques depending on different effects such as the type of materials used in manufacturing the structure. Fatigue analysis is based on stress-life, strain-life or crack growth with various parametric studies of reinforcement of composite materials, as Carbon Nanotubes (CNTs) reinforcement. V. K. Srivastava et al. (1987) [1], investigated the fatigue life of hybrid composite materials used in aerospace structure by using ultrasonic technique. It was shown that the fatigue life of composite materials is decreased with increasing the attenuation of ultrasonic. In addition, this research presented the mode of failure for composite materials by using scanning electron-microscopy. V. V. Ganesh et al. (2004), [2], presented the effect of particle orientation on tensile strength and fatigue behavior for anisotropic composite metal materials. The investigation showed that the increase of SiC particle leads to increasing the mechanical properties and fatigue behavior of composite metal materials. In addition, the research indicated that the orientation of particle leads to an increase the anisotropic of composite. In (2010), [3] C. M. Manjunatha et al. investigated the tensile fatigue characterization of composite materials reinforcement by glass fiber material. Where, the...
composite material is combined from two epoxy resin materials types and reinforcement with glass fiber. The epoxy resin materials used is neat epoxy and other epoxy is hybrid epoxy. The research showed that the fatigue behavior of composite materials has a hybrid epoxy which was best for the composite materials with neat epoxy resin materials. Sato et al. [4] investigated that the total main crucial factor is to transmit the properties of CNTs into composites in which a polymer is the matrix with appropriate processing method.

The fatigue characterization and mechanical properties for composite materials with various reinforcement effect for fiber and powder types and volume fraction were studied, with multi applications as in prosthetic foot, vibration, buckling application and other application of composite materials, In years 2010 to 2017 [5], [6] the researchers showed that the best volume fraction and the best fiber types could be used to evaluate the best mechanical properties and fatigue characterization. Thus, in this work, a modified mechanical properties and fatigue behaviors of composite materials by reinforcement with Carbon Nanotubes (CNTs) are studied. The aim of this work is study the effect of (CNTs) on mechanical properties of Polymer composite which definitely have potential to be used in aerospace structure applications.

2-Experimental Work
The main purpose of the experimental work aims to evaluate the mechanical properties of composite materials, combined from polyester resin materials reinforcement with Carbon Nanotubes (CNTs) materials and to calculate the fatigue limit life of the materials. The work covers the preparation of the specimens for tensile and fatigue test. The tensile and fatigue specimens are made with various volume fractions of Carbon Nanotubes (CNTs) materials with polyester resin materials volume fraction as shown in Table 1. The density of material used can be obtained by using the Archimedes law as follows, [7] and [8]. The densities used in this work are as follows,

1. Polyester resin material polyester resin $\rho_r \approx 1100 \text{ kg/m}^3$.
2. Carbon Nanotubes reinforcement material $\rho_c \approx 1400 \text{ kg/m}^3$.

| Specimen Number | $\forall_r$ (%) | $\forall_c$ (%) |
|-----------------|-----------------|-----------------|
| S1              | 97              | 3               |
| S2              | 95              | 5               |
| S3              | 93              | 7               |

| Table 1. Volume Fraction of Polyester Resin and Carbon Nanotubes (CNTs) |

Where:

$\forall_c$: Volume fraction of Carbon Nanotubes
$\forall_r$: Volume fraction of risen materials

Therefore, the weight required to manufacture the specimens are can be calculated as follows, [9] and [10],

1. Weight of resin materials $W_r = (\text{Length} \times \text{Width} \times \text{High}) \times \rho_r \times \forall_r$
2. Weight of reinforcement powder $W_c = (\text{Length} \times \text{Width} \times \text{High}) \times \rho_c \times \forall_c$

The tensile test specimens are prepared according to ASTM standard (D 638) type III with dimension as shown in Figure 1, [11], and the testing is achieved by using Tetometric tensile machine. The mechanical properties evaluated are modulus of elasticity and strength for composite materials with various volume fractions for the specimens shown in table 1, for various Carbon Nanotubes reinforcement percentage volume fraction 3% to 5% and 7% and with various polyester resin percentage volume fractions 93%, 95% and 97%. The mechanical properties are calculated from the average value.
for five specimens for each volume fraction specimens tested. The mechanical properties, as modulus of elasticity and strength of composite materials specimens, are used as input data in the numerical technique by using Ansys Software (Ver. 15) to evaluate the numerical results of fatigue strength and the number of fatigue cycles of fabricated composite materials.

The fatigue limit life of composite materials with effect of various Carbon Nanotubes reinforcement and volume fraction are calculated for the specimens shown in Table (1), in this work 12 specimens for each volume percentage volume fraction of reinforcement effect were used to construct the strength against the number of load cycles, dimension as shown in Figure (2), [12].

![Figure 1. Tensile specimen dimensions](image1)

![Figure 2. Fatigue specimen dimensions](image2)

### 3-Numerical approach

Ansys software that based on finite element analyses is used to find the fatigue strength number of cycles plot for the validity of the experimental work and a parametric study is achieved using this technique. The output results of Ansys include the fatigue strength with number of cycle for specimens shown in Table 1, to evaluate the results of the fatigue specimens. The finite element mesh and the number of elements are selected depending on the mesh generation curve of fatigue strength with number of element, [13]. The value of fatigue strength is stable with variable the number of elements, then the number of element selected are about (231956), for various specimens. The fatigue strength-number of fatigue cycle relation for each specimen of polymer composite materials is obtained.

### 4-Results and Discussion

The evaluated results in this work show the effect of reinforcement by Carbon Nanotubes materials on the mechanical properties and fatigue life limit, as strength and number of cycle, with various percentage volume fractions of Carbon Nanotubes and polymer resin. Where, the results are evaluated by using experimental technique, to evaluate the mechanical properties and fatigue limit life of composite materials, and numerical technique, by using finite element method with Ansys software, to evaluate the fatigue limit life of composite materials. Then, comparison the fatigue results evaluated experimentally, with fatigue results, evaluated by numerical technique, has shown an agreement of fatigue. Therefore, the found results are:

| Specimen Number | Modulus of Elasticity, E (GPa) | Strength, \( \sigma_u \) (MPa) |
|-----------------|-------------------------------|--------------------------------|
| S1              | 21.3                          | 160.4                          |
| S2              | 24.6                          | 164.5                          |
| S3              | 27.7                          | 175.8                          |
1- Tables 2, record the results of experimental work consist of modulus of elasticity and strength for produced composite materials.

2- Figure 3 and 4 represent the effect of percentage volume fraction of Carbon Nanotubes on strength of composite and modulus of elasticity respectively.

3- Figure 5, shows the comparison between for different percentage volume fractions with fatigue cycle.

4- Figure 6, Figure 7 and Figure 8, represent the comparison between experimental and numerical approach for fatigue Strength cycle for different percentage volume fractions 3%, 5% and 7% of Carbon Nanotubes respectively.

**Figure 3.** Effect of percentage volume fraction of Carbon Nanotubes on strength of composite

**Figure 4.** Effect of percentage volume fraction of Carbon Nanotubes on Modulus of elasticity
Figure 5. Comparison between different percentage volume fractions with fatigue cycle

Figure 6. Comparison between experimental and numerical fatigue strength cycle for composite materials reinforced with 3%.

Figure 7. Comparison between experimental and numerical fatigue strength cycle for composite materials reinforced with 5%.
5-Conclusions
The analysis noticeably indicates that CNT plays a major function in improve mechanical properties of polymer composite, from presented job that the effect of reinforcement Nanotubes for different percentage volume fraction on the strength and fatigue life of composite materials. Where, the investigation of its effect is presented by an experimental work, and then, comparison the results with numerical, by using Ansys. The experimental work is a good approach that can be used to evaluate the strength and fatigue life of composite materials with various Carbon Nanotubes reinforcement. The comparison between experimental and numerical technique gives a good agreement of fatigue results with various parameters effects of reinforcement powder, with a maximum discrepancy of about (6.4%), and reinforcement with Carbon Nanotubes materials cause an increase in the strength of resin materials, and then, increasing the strength of composite materials. The fatigue strength and life are increased with reinforcement the composite materials by Carbon Nanotubes. Thus, the fatigue characterizations are increase with increasing Carbon Nanotubes percentage volume fraction.

6-Acknowledgement
The support of the Al-Nahrain University, Mechanical Engineering Department is gratefully acknowledged.

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