Improvement Fatigue Life and Strength of Isotropic Hyper Composite Materials by Reinforcement with Different Powder Materials

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Abstract— In this paper, an improvement is suggested to increase the fatigue life of the isotropic materials combined from glass short fibers and polyester resin materials by adding the reinforcements of powder materials to increase the fatigue strength. Two types of powder materials were investigated, carbon and glass with and without powder reinforcement. The investigation was conducted experimentally and numerically. The experimental program covers the manufacturing the tensile and fatigue samples and evaluate the mechanical properties and the fatigue strength using the different volume fractions and types of powders. The experimental results are compared with those obtained numerically using the finite element technique adopting Ansys program. The comparison has shown a good agreement between the two techniques with a maximum discrepancy of (9.46%). Also, the results indicate that the reinforcement of the composite material by powder materials increase the fatigue limit. Also, the improvement of fatigue life by using the carbon powder is better than that obtained by using the glass powder.

Index Term— Fatigue, Fatigue Composite, Powder Reinforcement, Isotropic Composite Fatigue.

I. INTRODUCTION
Generally, structures in the live are subjected to dynamic load, 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 are based on stress-life, strain-life or crack growth with various parametric studies of reinforcement by powder materials, as powder, particle or fiber 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. Jody N. Hall et al. (1994), [2], investigated the fatigue characterizations of reinforcement aluminum alloy with effect of particle and matrix parameters. Where, the research investigation included the effects of particle size and volume fraction on the same mechanical properties and fatigue behavior of aluminum alloy reinforcement with SiC particle. In addition, the research included the evaluation of the effect of particle size on maximum stress intensity on tip of crack. The conclusion of this work was that the strength and fatigue of materials are increased with the increasing the volume fraction of particle, and also, it is increased with decreasing the particle size., V. V. Ganesh et al. (2004) [3], 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 metallic materials. In addition, the research indicated that the orientation of particle leads to an increase the anisotropic of composite. In 2010, C. M. Manjunatha et al. [4] 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. In 2012, A. Glage et al. [5] presented the effect of ceramic powder on the fatigue behavior of composite materials with low cycle fatigue. The composite materials are combined form stainless steel matrix and reinforcement with ceramic powder reinforcement. Thus, the investigation included the evaluation of the effect of ceramic powder on deformation structure under low cycle fatigue of different matrix materials. In 2014, Tateoki Izuka et al. [6] presented the effect of MgAl2O4 reinforcement particle on the mechanical and microstructure properties of aluminum composite materials. The effect of particle size on the mechanical properties and fatigue characterization of aluminum alloy were investigated in this work. The evaluated results showed that the tensile strength and fatigue characterization of aluminum alloy are modified with reinforcement with MgAl2O4 particle. 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 [7 to 33] 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 different powder materials types are studied. Most composite materials used in the previous work were reinforced by fiber only. Therefore, in this work the powder reinforcement is used to modify the mechanical properties of matrix materials to increase the mechanical properties and the fatigue behaviors of composite materials.

II. EXPERIMENTAL WORK

The main purpose of the experimental work aims to evaluate the mechanical properties of composite materials, combined from polyester resin materials and reinforcement with two materials are short glass fiber and glass or carbon powder reinforcement 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 samples are made with various volume fractions of short fiber and different powder materials types, for various polyester resin materials volume fraction as shown in Table I. The density of material used can be obtained by using the Archimedes law as follows, [34 and 35]. The densities used in this work are as follows,

1. Polyester resin material \( \rho_{\text{polyester resin}} \approx \rho_r \approx 1100 \text{ kg/m}^3 \).
2. Carbon powder reinforcement material \( \rho_{\text{carbon powder}} \approx \rho_p \approx 1550 \text{ kg/m}^3 \).
3. Glass powder reinforcement material \( \rho_{\text{glass powder}} \approx \rho_p \approx 2500 \text{ kg/m}^3 \).
4. Glass short fiber reinforcement material \( \rho_{\text{short fiber}} \approx \rho_{sf} \approx 2100 \text{ kg/m}^3 \).

Therefore, the weight required to manufacture the samples can be calculated as follows, [36 and 37],

1. Weight of resin materials = \( w_r = \text{Length} \times \text{Width} \times \text{High} \times \rho_r \times V_r \)
2. Weight of reinforcement powder = \( w_p = \text{Length} \times \text{Width} \times \text{High} \times \rho_p \times V_p \)
3. Weight of resin materials = \( w_{sf} = \text{Length} \times \text{Width} \times \text{High} \times \rho_{sf} \times V_{sf} \)

The experimental work can be divided to two parts, as,

II.1. Mechanical Properties

The tensile test samples are prepared according to ASTM standard (D 638-97), [38], and the testing is achieved by using universal tensile machine, shown in the Fig. 1. The mechanical properties evaluated are strength and modulus of elasticity for composite materials with various volume fractions for the samples shown in Table I, for various powder reinforcement types for volume fraction from 0% to 20% and short fiber reinforcement volume fraction from 10% to 40% with various polyester resin volume fractions. The mechanical properties are calculated from the average value for five samples for each volume fraction sample tested.

The tensile samples are prepared from the division the plate sample as shown in Fig. 2.a, into five samples, as shown in Fig. 2.b. The required weight for each volume fraction materials of samples made can be evaluated by using Eq. (1).

Also, the manufacture of the tensile samples requires a higher pressure on the sample which is achieved by using the block as shown in Fig. 3. Finally, the mechanical properties, as strength and modulus of elasticity of composite materials samples, are used as input data in the numerical technique by using Asys program (Ver. 13) to evaluate the numerical results of fatigue strength and the number of fatigue cycles of hyper composite materials.

Table 1

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>( V_{sf} ) (%)</th>
<th>( V_p ) (%)</th>
<th>( V_r ) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( S_1 )</td>
<td>30</td>
<td>10</td>
<td>60</td>
</tr>
<tr>
<td>( S_2 )</td>
<td>5</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>( S_3 )</td>
<td>0</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>( S_4 )</td>
<td>20</td>
<td>10</td>
<td>70</td>
</tr>
<tr>
<td>( S_5 )</td>
<td>5</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>( S_6 )</td>
<td>0</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>( S_7 )</td>
<td>10</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>( S_8 )</td>
<td>10</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>( S_9 )</td>
<td>0</td>
<td>90</td>
<td></td>
</tr>
</tbody>
</table>

\( V_{sf} \): Volume Fraction of Short Fiber  
\( V_p \): Volume Fraction of Powder Fiber  
\( V_r \): Volume Fraction of Risen Materials

Fig. 1. Tensile Test Machine.
II. Fatigue Limit Life

The fatigue limit life of composite materials with effect of various powder reinforcement types and volume fraction are calculated for the specimens shown in Table 1. In this respect 12 samples for each volume fraction of reinforcement effect were used to construct the strength against the number of load cycles. The preparation of samples is shown in Fig. 3. The fatigue samples are made by dividing the fatigue plate sample, with dimension (length of plate = 16 cm, width of plate = 20 cm, and thickness of plate = 15 mm) with dimension as shown in Fig. 4, [39]. The Fatigue machine is shown in Fig. 5.
III. NUMERICAL INVESTIGATION
The finite element 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 program include the fatigue strength with number of cycle for samples shown in Table 1, to evaluate the results of the fatigue sample. The finite element mesh is shown in Fig. 6. The number of elements are selected depending on the mesh generation curve of fatigue strength with number of element, as shown in Fig. 7, [40]. The value of fatigue strength is stable with variable the number of elements, then the number of element selected are about (226194), for various samples. The fatigue strength-number of fatigue cycle relation for each sample of hyper composite materials is obtained.

IV. RESULTS AND DISCUSSION
The results evaluated in this work show the effect of reinforcement by powder materials on the mechanical properties and fatigue life limit, as strength and number of cycle, of hyper composite materials with various volume fraction of fiber and powder materials and different powder reinforcement types, as glass and carbon powder materials. 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 program, 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 divided to multi part, as,

1. Evaluate the strength and modulus of elasticity for composite materials by experimental work, as shown in Tables II and III.
2. Comparison between experimental and numerical fatigue results, and then, calculate the present error, as in Fig. 8.
3. Evaluate the fatigue strength-fatigue cycle relation of hyper composite by numerical work, as shown in Fig. 9.
4. Evaluate the fatigue strength and life cycle of composite materials for various powder and short fiber volume fraction and different powder materials types, by numerical work, as shown in Figs. 10 to 12.
Therefore, Tables II and III, shows the effect of different types of powder reinforcement and various volume fraction fiber and powder on the mechanical properties of hyper composite materials. From Tables II and III, it can be seen that the increase of reinforcement powder leads to increase the strength and modulus of elasticity of composite materials. Also, the value of mechanical properties for composite materials reinforcements with carbon powder materials are more than the value of mechanical properties of composite materials reinforcement with glass powder materials. Also, the comparison between the experimental and numerical results of fatigue-life relation is shown in the Fig. 8. The figure shows that the good agreement between experimental and numerical results for fatigue strength and life with maximum does not exceed (10%) with various volume fraction of powder and short reinforcement fiber and different powder materials types, as glass and carbon reinforcement powder materials, as shown in Fig. 8.1 to 8.III, respectively.

Therefore, the effect of reinforcement powder types and volume fraction on the fatigue strength-fatigue number of cycle relation is shown in Fig. 9. This Fig shows the fatigue strength-number of fatigue cycle relation with various short reinforcement volume fractions. Thus, from the figure it can be seen that the fatigue strength is increased with increasing of reinforcement powder volume fraction or increasing the short reinforcement fiber, as shown in Figs. 10 and 12. But, the increase of strength fatigue of composite materials reinforcement with carbon powder are greater than fatigue strength of composite materials reinforcement with glass powder, as shown in Fig. 12. In addition, the effect of powder and short fiber reinforcement on the fatigue life has the same effect on the fatigue strength, as shown in Figs. 11 and 12. Where, the fatigue life of composite materials are increased with increasing the reinforcement powder or short fiber, in addition to, the fatigue life for composite materials reinforcement with carbon powder materials are greater than the fatigue life of composite materials reinforcement with glass powder. Thus, The reason that leads to increase the fatigue life or strength for composite materials with reinforcement powder or short fiber, due to the high strength for reinforcement materials, then, due to the increase of the strength for matrix materials of composite materials used. Therefore, the mechanical properties, fatigue strength and limit cycle of hyper composite materials are increased with increasing the strength of reinforcement powder, and it is increased with increasing the volume fraction of reinforcement powder. Thus, the mechanical properties and fatigue characterization (strength and fatigue cycle) for composite materials reinforcement with carbon powder are more than the composite materials reinforcement with glass powder. The strength of carbon powder is more than the strength of glass powder. Also, the effect of short fiber is more than the effect of powder reinforcement, at same volume fraction, then, the increase of mechanical properties and fatigue characterization by reinforcements with short fiber are more than the increase of its by reinforcement with powder materials.

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Modulus of Elasticity (MPa)</th>
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<tr>
<td></td>
<td>Glass Powder</td>
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<tr>
<td>S1</td>
<td>16.27</td>
</tr>
<tr>
<td>S2</td>
<td>15.14</td>
</tr>
<tr>
<td>S3</td>
<td>14.68</td>
</tr>
<tr>
<td>S4</td>
<td>11.94</td>
</tr>
<tr>
<td>S5</td>
<td>11.08</td>
</tr>
<tr>
<td>S6</td>
<td>10.31</td>
</tr>
<tr>
<td>S7</td>
<td>7.26</td>
</tr>
<tr>
<td>S8</td>
<td>6.41</td>
</tr>
<tr>
<td>S9</td>
<td>5.13</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Glass Powder</td>
</tr>
<tr>
<td>S1</td>
<td>134.51</td>
</tr>
<tr>
<td>S2</td>
<td>131.12</td>
</tr>
<tr>
<td>S3</td>
<td>126.99</td>
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<tr>
<td>S4</td>
<td>110.98</td>
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<tr>
<td>S5</td>
<td>106.92</td>
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<tr>
<td>S6</td>
<td>103.75</td>
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<tr>
<td>S7</td>
<td>99.42</td>
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<tr>
<td>S8</td>
<td>94.35</td>
</tr>
<tr>
<td>S9</td>
<td>90.67</td>
</tr>
</tbody>
</table>

![Fatigue Strength vs. Number of Cycle](image)

a. $\nu_p = 0\%$, Glass Reinforcement Powder

![Fatigue Strength vs. Number of Cycle](image)

b. $\nu_p = 5\%$, Glass Reinforcement Powder

![Fatigue Strength vs. Number of Cycle](image)

c. $\nu_p = 10\%$, Glass Reinforcement Powder
Fig. 8. I. Different Powder Reinforcements Volume Fraction and Types with 10% Short Reinforcement Fiber.

a. $\forall p = 0\%$, Glass Reinforcement Powder
b. $\forall p = 5\%$, Glass Reinforcement Powder
c. $\forall p = 10\%$, Glass Reinforcement Powder
d. $\forall p = 0\%$, Carbon Reinforcement Powder
e. $\forall p = 5\%$, Carbon Reinforcement Powder
f. $\forall p = 10\%$, Carbon Reinforcement Powder

Fig. 8. II. Different Powder Reinforcements Volume Fraction and Types with 20% Short Reinforcement Fiber.

a. $\forall p = 0\%$, Glass Reinforcement Powder
b. $\forall p = 5\%$, Glass Reinforcement Powder
c. $\forall p = 10\%$, Glass Reinforcement Powder
d. $\forall p = 0\%$, Carbon Reinforcement Powder
e. $\forall p = 5\%$, Carbon Reinforcement Powder
f. $\forall p = 10\%$, Carbon Reinforcement Powder
Fig. 8. III. Different Powder Reinforcements Volume Fraction and Types with 30% Short Reinforcement Fiber.

Fig. 8. Comparison between Experimental and Numerical Results for Fatigue-Cycle Relation of Composite Materials.

Fig. 9. Fatigue Strength-Cycle Relation for Hyper Composite Materials with Different Powder Reinforcement Volume Fraction and Types Effect, for Various Short Fiber Volume Fractions.
I. Glass Reinforcement Powder

II. Carbon Reinforcement Powder

Fig. 10. Fatigue Strength for Hyper Composite Materials with Various Short Fiber Volume Fractions.

I. Glass Reinforcement Powder

II. Carbon Reinforcement Powder

Fig. 11. Fatigue Life Cycle for Hyper Composite Materials with Various Short Fiber Volume Fractions.

I. Fatigue Strength of Hyper Composite Materials.

a. Fatigue Strength, $V_{sf}=10\%$

b. Fatigue Strength, $V_{sf}=20\%$

c. Fatigue Strength, $V_{sf}=30\%$

a. Fatigue Life Cycle, $V_{sf}=10\%$
The presented work shows the effect of reinforcement powder types and volume fraction on the strength and fatigue life of hyper composite materials. Where, the investigation of its effect is presented by an experimental work, and then, comparison the results with numerical work, by finite element method. Therefore, the following conclusions, are listed:

1. The experimental work is a good approach and can be used to evaluate the strength and fatigue life of hyper composite materials with various powder reinforcement volume fraction and types effect.

2. 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 (9.46%).

3. The reinforcement with powder materials caused 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 powder materials. Thus, the fatigue characterizations are increase with increasing powder volume fraction.

4. The reinforcement with powder materials has a high strength and cause an increase of fatigue characteristics. Therefore, the fatigue characterizations of composite materials reinforcement with carbon powder are more than the fatigue characterizations reinforcement with glass powder material.

5. The effect of short fiber is more than the effect of powder reinforcement. Therefore, the increase of fatigue characterizations, for composite materials, with short fiber volume fraction is more than the increase of fatigue characterizations, for composite materials, with same powder volume fraction.

**REFERENCES**


