Effect of Shot Peening on the Endurance Limit of Fiber Glass Composite Material

Ahmed N. Al-Khazraji * and Mahdi N. M. Shareef **

Abstract - shot peening is one of the common cold processes that used to improve the fatigue life of the metals. But, studying the effect of this process on the variation in properties of composite material is still insufficient. This work was investigated the effect of shot peening experimentally on fiber glass (E type) with polyester with volume fraction of 33 %. The results showed that the best improvement obtained in the endurance limit was at 6 min shot peening time with a percentage of 25 % more than that of without shot peening. While the improvement in mechanical properties was obtained by 5 %. The verification of experimental results was done using ANSYS.14 workbench with a good agreement in behavior between the experimental and numerical.

Keywords— Composite Material, Endurance Limit, Fatigue, Fiber Glass, Shot Peening.

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1. Introduction

Most components in practice of engineering machines and industries are subjected to fatigue loading such as automobile parts, train wheels, bridges, airplanes, and many of industrial machines that working for more than million cycles. Many of these machines components constructed from a composite material. So, studying these material and the loading on it is of great important. Shot peening is one of the important processes, which is create the compressive residual stresses on the surface which is prevent the components from propagation of cracks especially in the metals. Many studies dealt with the traditional metallic materials. But, studying the effect of shot peening process on the fiber glass composite material still insufficient. This paper mainly focus on this point. The main aim of this study is to estimate the fatigue life under the effect of shot peening process for composite materials of fiber glass reinforcement. Due to the importance of this study, many experimental researches done in the past. These researches deals with the effect of shot peening on the Metal Matrix Composites (MMC). J. Lu, and et al. [1], studied the effect of shot peening on the residual stresses of a MMC of Aluminum alloys (2124 and 6061) as matrix and different Silicon Carbon (SiC) in form of whiskers and particulates as fiber whose volume fraction range from 15% to 40%. The results showed that the residual stresses are compressive and isotropic which are beneficial for the fatigue life. S. Tohriyama, and et al. [2], investigated the influence of shot peening on fatigue life for two types of MMC of A6061 Aluminum alloy reinforced with Silicon Carbide Whisker (SiCw) and A2024 Aluminum alloy reinforced with Silicon Carbide Particle (SiCp) with a volume fraction of 20% produced by squeeze casting and powder metallurgy respectively. The peening time was (15 sec), shot diameter (105-250 μm), and coverage of (300%). The results showed that the shot peening improves the low cycle side fatigue strength of SiCp/2024 but the high cycle side fatigue strength lowered. And for SiCw/6061 composites, fatigue strength was not improved by shot peening. Hill S. and et al. [3], investigated the influence of shot peening on the fatigue performance of MMC under rotating bending loading conditions with a stress ratio of $R = -1$. The metal matrix composites are shown to respond favorably to shot peening for a given set of parameters. Their results showed that fatigue strength of shot peened specimens were higher than for unpeened specimen at the same number of cycle to failure. Weizhi Luan and et al. [4], investigated the influence of shot peening at time of (1 min) on the surface mechanical properties of the TiB_2/6351Al composites. The matrix proof stress ($\sigma_{0.2}$) of the shot peened surface had been increased by 27 % and the whole strength increment was about 21%. They concluded that the shot peening is an effective method to improve the surface strength of the TiB_2/6351Al composite.

2. Experimental Work

2.1. Preparation the Specimens for Testing

The experimental work deals with;

(1) Preparation the specimens by Hand Lay-Up molding method,

(2) Preparation of tensile test specimens according to standard of ASTM D 3039 [5]. and

(3) Preparation of fatigue test specimens according to machine specifications [6] as shown in Figure 1.

2.2. Tensile Test

The type of used tensile test machine was microcomputer controlled electronic universal testing machine WDW-100E. Tensile tests were done before and after

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shot peening and for all treatment times. Two specimens were tested for each case and taking the average value to satisfy an additional accuracy.

2.3. Fatigue Test

The type of fatigue testing machine used in this work was HI-TECH alternating bending fatigue (HSM20) with constant amplitude as shown in Figure 2. The specimens were subjected to deflection perpendicular to the axis of specimens at one side of the specimens, and the other side was fixed, developing bending stresses as a cantilever beam which can be determined directly from the following equation;

$$\sigma = \frac{1.5\,E\,t\,\delta}{l^2} \qquad (1)$$

Where;

σ : is the maximum alternating stress (MPa),
E : the modulus of elasticity (GPa),
t : thickness of specimens (4 mm),
δ : the deflection measured by dial gauge (mm),
l : the effective length of specimen (60 mm).

A series of tests are commenced by acting a specimen to the stress cycling and the number of cycles to failure is counted. This procedure is repeated on other specimens at progressively decreasing stress amplitudes. As a result, the surfaces of the specimens are under tension and compression stresses when the specimen fluctuated. All the tests done at constant stress amplitude loading with $R = -1$. The obtained data were plotted as stress S versus the logarithm of the number N of cycles to failure for each of the specimens.

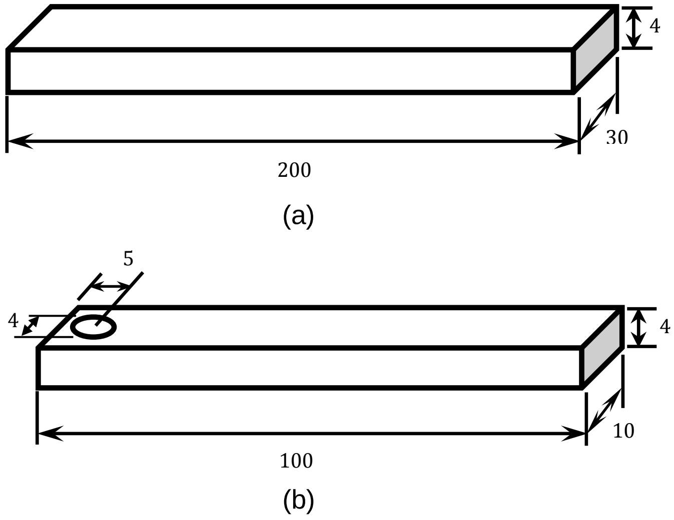


Fig.1: Schematic diagram for [all dimensions in mm]
(a) Tensile test specimens (ASTM D 3039)
(b) Fatigue test specimens.

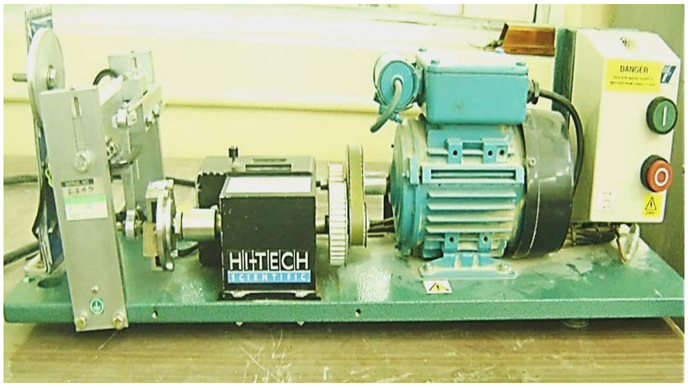


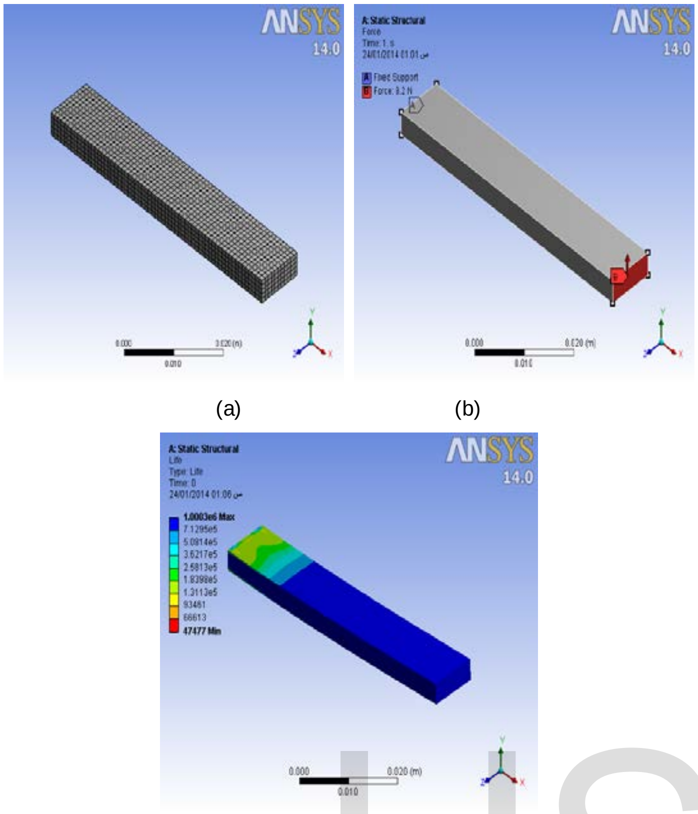
Fig.2: Fatigue testing machine.

2.4. Shot Peening

Shot peening process was used in this paper, to study the variation of mechanical properties and fatigue behavior of fiber glass composite material (E-glass with polyester of 33 % volume fraction). The shot peening is accomplished by machine of Sintokogio LTD, model STB-OB. In this machine, the motor rotates an impeller which bombard the shots towards the specimens at 1435 r.p.m motor rotational speed with one jet of shots at an average speed of 70 m/s. The material of the shooting balls is a low carbon steel with average diameter of 1.2 mm and coverage of 80-100 %. The peening machine consist of rotary cylinder with inside diameter of 590 mm and depth of 740 mm in which the specimens is placed. The time used for shot peening (SPT) was three different times of (2, 4 and 6 min) on the prepared specimens. 26 specimens were subjected to shot peening at that times divided to 6 specimens for tensile test (2 specimens for each SPT) and 20 specimens were used for fatigue test.

3. Numerical Analysis

The Finite Element Method (FEM) with aid of ANSYS.14 Workbench software is used as a numerical tool to verify the shot peening effect on the fatigue behavior in the fiber glass composites. The solid-45 element with 8 nodes was used in this work. The meshing process has been done by choosing the volume and the number of elements in each body, as shown in Figure (3-a). The total number of elements in each specimen was 3465 element with 17208 node. The load in the ANSYS workbench software will be at one side, and the other side was fixed support, as shown in Figure (3-b). All the material properties required in numerical analysis are imported from the experimental tests results. The resultant fatigue life was obtained for each specimen as shown in Figure (3-c). The obtained fatigue lives were compared with the experimental results as shown in Figure 7.



(a) (b)

(c)

Fig. 3: The model specimen
(a) Mesh (b) Applying load (c) Fatigue life.

4. Results and Discussion

The tensile test properties were changed due to the submission the fiber glass composites to the shot peening. The mechanical properties before and after shot peening process can be listed in Table 1. The mechanical properties improved gradually where the maximum improvement was about 5 % at SPT of 6 min with respect to the unpeened specimens (0 min). The increment in the mechanical properties values with the shot peening due to the generate compressive residual stresses at the surface.

The results of fatigue tests can be divided into two part. The first related with the base fiber glass composites without any treatment by shot peening. The second part deals with the treated fiber glass composites by shot peening at the three times. The fatigue behavior were illustrated as *S-N* curves as shown in Figure 4 for base material without shot peening and Figure 5 for shot peened material at every time compared with the unpeened case. From these two figures, the fatigue life estimation equations were determined by using the power law regression [7];

$$\sigma_a = A \times N^{-b} \qquad Basquin\ equation \qquad (2)$$

Where;

σ_a : is the fatigue stress amplitude (MPa),

N : is the number of cycles to failure (MPa),

A and b : are constants depend on material.

Table 1: Mechanical properties for fiber glass reinforced polyester composites before and after shot peening.

SPT (min)	Mechanical properties	Fiber orientation	
		Longitudinal	Transversal
0	$\sigma\ ult\ (MPa)$	383	10
	$E\ (GPa)$	22.17	10.943
2	$\sigma\ ult\ (MPa)$	390	10.2
	$E\ (GPa)$	22.575	11.16
4	$\sigma\ ult\ (MPa)$	394	10.32
	$E\ (GPa)$	22.8	11.293
6	$\sigma\ ult\ (MPa)$	401	10.38
	$E\ (GPa)$	23.212	11.36

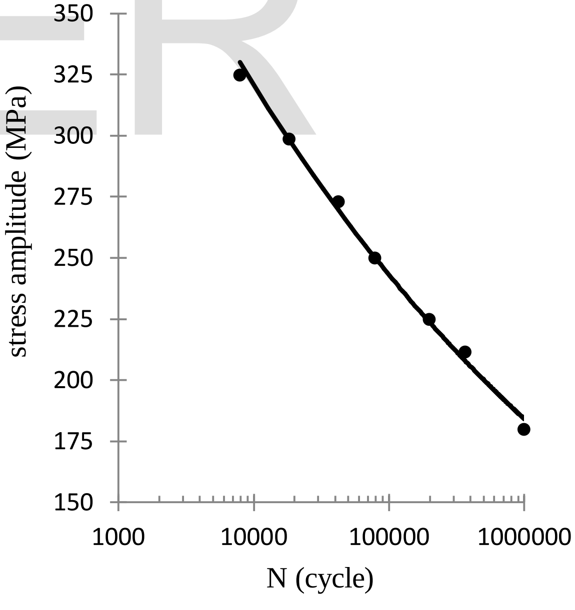


Fig. 4: Semi-log S-N curve for unpeened specimens.

The value of endurance limit is not clearly obvious on the *S-N* curve; therefore the endurance limit can be calculated by using fatigue life estimation equation at 10^6 cycles. The estimated equations are listed in Table 2.

It can be seen from Figure 5 that the shot peening treatment verified an increase in the fatigue life in all cases as compared to the unpeened *S-N* curves across the whole range of stress amplitudes, as well as an increase in the endurance limit. The endurance limit increase with increasing the shot peening time by a percentage of about 12.4 %, 19.92 % and 25.052 % for shot peening time of 2, 4 and 6 min respectively with respect to the unpeened case as shown in Figure 6. The maximum percentage of increasing in endurance limit is about 25 % at 6 min as compared with the unpeened endurance limit. The value of endurance limit for the all cases are listed in Table 3.

Fibers are the main load carrying material in composites and as the number of load carrying elements increases in a material, its strength increases. The reason of increasing in the fatigue properties values with the shot peening may be due to generate a compressive residual stresses at the surface of the specimens.

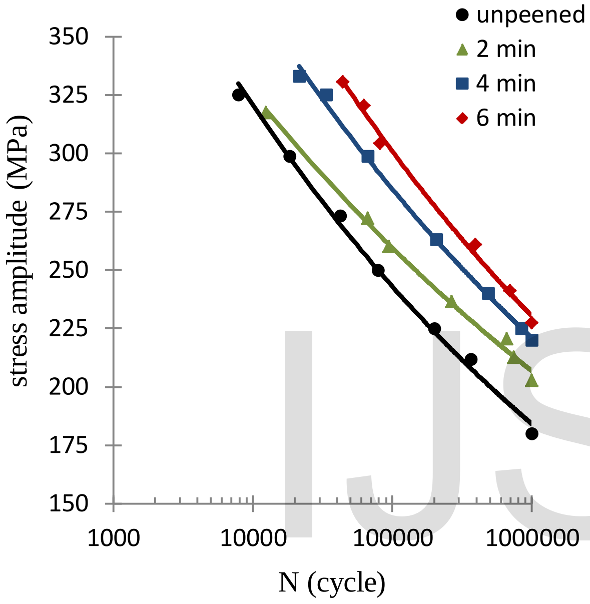


Fig. 5: Semi-log S-N curves before and after shot peening.

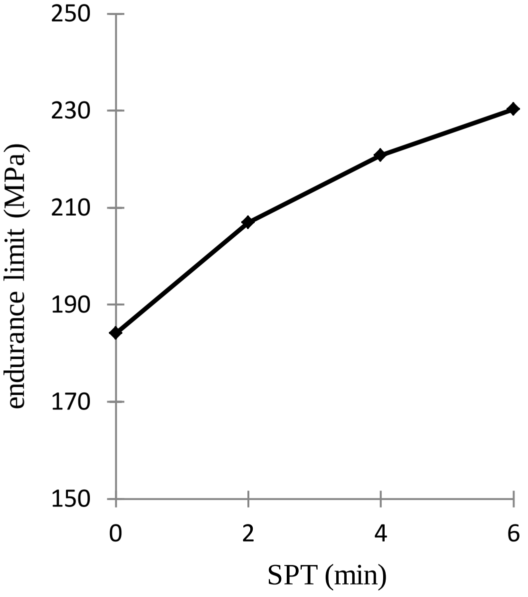


Fig. 6: Relationship between endurance limit and SPT.

The experimental results were compared with the numerical data as shown in Figures (7-a),(7-b),(7-c) and (7-d). The numerical endurance limit can be obtained from the numerical *S-N* curve equation at 10^6 cycle. Percentage error of endurance limit between the experimental work and numerical analysis were calculated as follow;

$$Error = \frac{\sigma_{e\,(exp)} - \sigma_{e\,(num)}}{\sigma_{e\,(exp)}} \times 100\% \qquad (3)$$

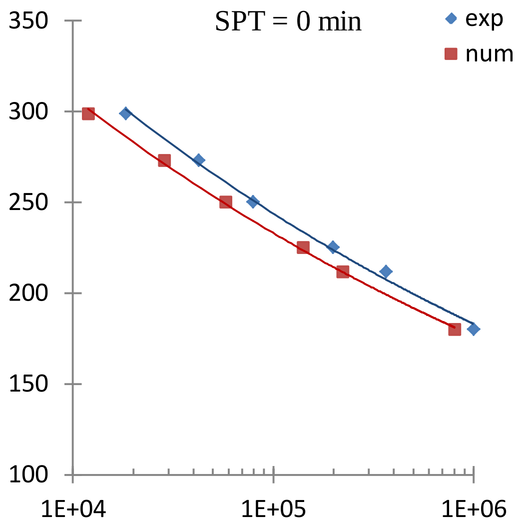
It is clear from the Figures (7-a),(7-b),(7-c) and (7-d), that the experimental and numerical *S-N* curves is too converging. So, the comparison obtained an agreement in behavior between the experimental work and numerical data. The maximum percentage error of endurance limit does not exceed 5 %. The comparison between the experimental and numerical fatigue life estimation equations are tabulated in Table 2. And a comparison of experimental and numerical endurance limit and the percentage error between them are tabulated in Table 3.

Table 2: Experimental and numerical S-N equations.

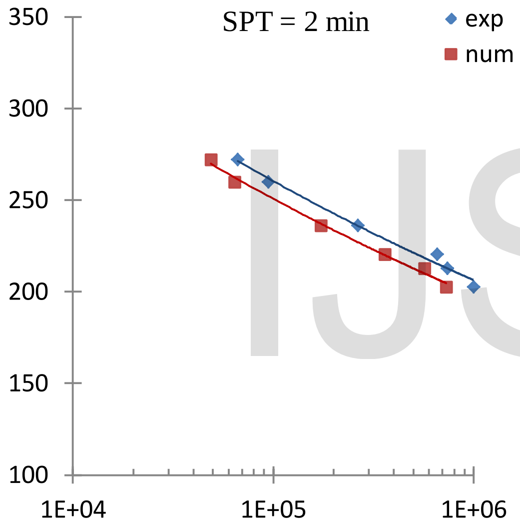
SPT (min)	Exp. S-N equation	Num. S-N equation
0	$\sigma = 972.972\, N^{-0.1205}$	$\sigma = 939.12\, N^{-0.121}$
2	$\sigma = 808.112\, N^{-0.0986}$	$\sigma = 812.123\, N^{-0.1021}$
4	$\sigma = 1012.02\, N^{-0.1102}$	$\sigma = 1026.45\, N^{-0.1147}$
6	$\sigma = 1146.55\, N^{-0.1162}$	$\sigma = 1099.96\, N^{-0.1158}$

Table 3: Experimental and numerical endurance limit

SPT (min)	Exp. $\sigma_e\ (MPa)$	Num. $\sigma_e\ (MPa)$	Error %
0	184.12	176.5	4.14
2	206.953	198.16	4.25
4	220.794	210.444	4.68
6	230.245	222.11	3.53



(a)



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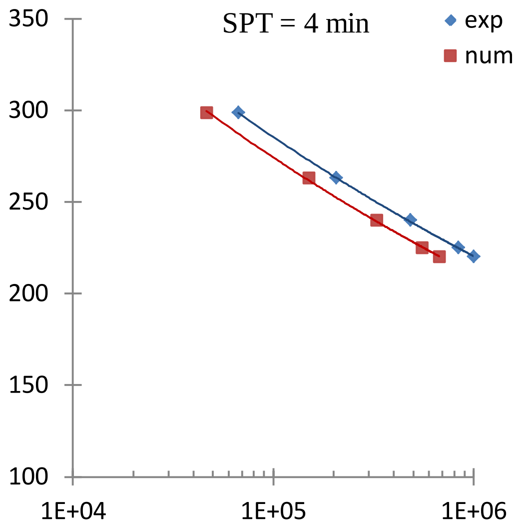

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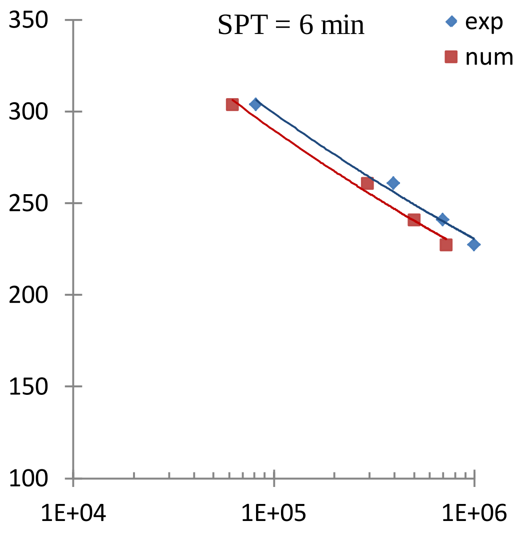

(d)

Fig. 7: Semi-log S-N curves comparison between experimental and numerical data at SPT of (a) 0 min (b) 2 min (c) 4 min (d) 6 min.

5. Conclusions

The main conclusions drawn from this paper are;

1. Increasing the shot peening time increases the endurance limit of fiber glass composites with maximum increasing of about 25 % at 6 min shot peening time to a value of about 230.245 MPa compared with 184.12 MPa for the unpeened case.
2. The *E*-glass fiber composites increased in mechanical properties with increasing shot peening time by a percentage of about 5 %.
3. The numerical results (by finite element method with aid of ANSYS.14 workbench) showed a good agreement with the experimental results where the maximum error does not exceed 5 % for endurance limit for all cases.

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