Al-Khwarizmi Engineering Journal

Al-Khwarizmi Engineering Journal, Vol. 10, No. 3, P.P. 1- 12 (2014)

Comparison of Fatigue Life Behavior between Two Different Composite Materials Subjected to Shot Peening at Different Times

Ahmed N. Al-Khazraji* **Mahdi N. M. Shareef****
,Department of Machine and Equipment Engineering/ University of Technology*
*E-mail: Dr_ahmed53@yahoo.com
**E-mail: Mahdi.numaan@yahoo.com

(Received 24 march 2014; accepted 15 June 2014)

Abstract

This paper investigated the fatigue life behavior of two composite materials subjected to different times of shot peening (2, 4 and 6 min).The first material prepared from unsaturated polyester with E-glass reinforcement by 33% volume fraction. While, the second one was prepared from unsaturated polyester with aluminum powder by2.5% volume fraction. The experimental results showed that the improvement in endurance limit was obtained (for the first material) at 2, 4 and 6 min shot peening times where the percentage of maximum improvement was 25% at shot peening time of 6 min. While, the endurance limit of the second material decreased at shot peening times of 2, 4 and 6 min where the percentage of maximum reduction was 29 % at shot peening time of 6 min. The verification of experimental results was done using ANSYS.14 workbench with a good agreement in behavior between the experimental and numerical.

Keywords: *Fatigue Life, Endurance Limit, Composite Materials, Shot Peening Time, Polymer Matrix Composites.*

1. Introduction

Composite materials became an important materials due to wide use in practical application, such as airplane, spacecraft, automotive industries and other applications because it have low weight and high strength compared with the traditional metals and alloys. For this reason, many researchers studied how to improve the mechanical and fatigue properties of these materials. One of the methods used to create the compressive residual stresses was the shot peening to obtain surface improvement for the conventional metals and alloys. Some researchers studied the effect of shot peening on the metallic matrix composite materials, but studying the effect of shot peening on polymeric matrix composite materials still very little and insufficient. So, this paper mainly focuses on this point.J. Lu, et al. [1], studied the effect of shot peening on the residual stresses of a metal matrix composites (MMC) of Aluminum alloys (2124 and 6061) as matrix and different Silicon Carbide (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, 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. 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 et al. [4], investigated the influence of shot peening at time of (1 min) on the surface mechanical properties of the TiB2/6351Al 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 TiB2/6351Al composite.

2. Experimental Work

2.1. Materials Selection

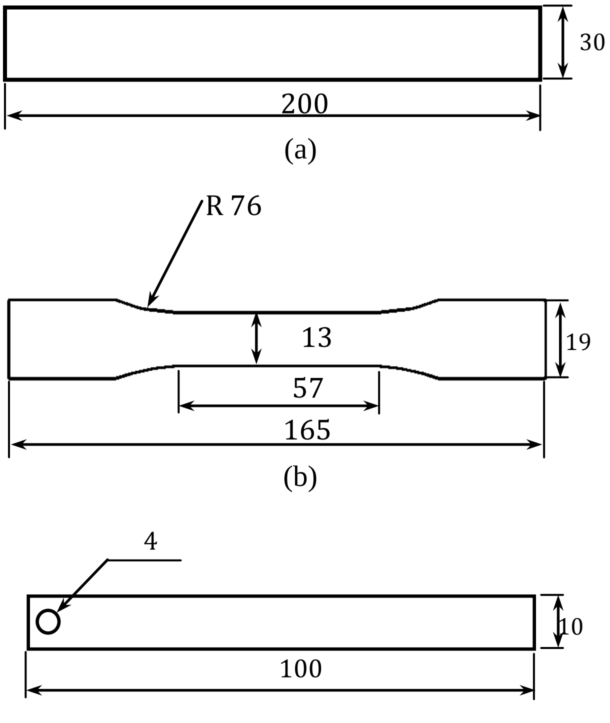
In this paper, two types of polymer matrix composite materials were prepared, the first was constructed from unsaturated polyester (UP) as a matrix and fiber glass (E-glass type in form of long (continuous)) as a reinforced material. The combination of the second one was unsaturated polyester reinforced by powder of Aluminum.

2.2. Preparation the Specimens for Testing

The preparation of testing specimens were done as follow;

1. Preparation the specimens by Hand Lay-up molding method according to standard of ASTM D 5687 [5].
2. Preparation of tensile test specimens according to standard of ASTM D 3039 [6]and ASTM D 638 [7] for fiber glass composites and aluminum powder composites, respectively as shown in Figures (1-a) and (1-b).
3. Preparation of fatigue test specimens according to machine specifications [8] as shown in Figure (1-c). Where the thickness of all tensile and fatigue specimens is 4 mm.

The unsaturated polyester resin was mixed with the hardener (Methyl Ethyl Keton Peroxide, MEKP) by a percentage of 2 %. For fiber glass composites, the composite plates was constructed by placing the fibers one above the other with the resin mixed well to spread them by using mould of $(110 \times 260 \times 4)$ mm. This process was repeated with a constant volume fraction of 33%. For aluminum powder composites (with a particle size of (50 - 100 μm)), the powder was added slowly (with constant volume fraction of 2.5%) into the mixture and mixing it for more than 5 min to be homogeneous until a rise in the temperature of mixture will result as an indication to the beginning of the interaction process. The mixture was poured into the mould. The inside wall of the mould was covered by a layer of transparent Fablon paper to avoid the adhesion of the resin with the mould. After that, a heavy load for pressing the mixture was put after pouring mixture in the mould to prevent any interaction between mixture and environment. After that, the sample stay in the mould for a period of 24 hour at room temperature and after that period, samples are extracted from the mould. To produce the test samples, the plate was cut into the appropriate dimensions using a tipped cutter which is very fine to ensure no vibration during cutting the samples and to avoid distortions that may occur during the process.



(a)

(b)

(c)

Fig. 1. Schematic diagram for [all dimensions in mm] with thickness of 4 mm for all specimens (a) Tensile test specimens (ASTM D 3039) [6], (b)Tensile test specimens (ASTM D 638) [7], and (c)Fatigue test specimens[8].

2.3. Shot Peening

Shot peening process was used in this paper, to study the variation in fatigue behavior for polymer matrix composite materials which are;
(1) unsaturated polyester resin reinforced by 33 % E-glass fiber, and
(2) unsaturated polyester resin reinforced by 2.5 % aluminum powder.

The shot peening is accomplished by machine of Sintokogio LTD, model STB-OB as shown in Figure (2). 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. Both tensile and fatigue specimens were subjected to shot peening at that times.

2.4. Tensile Test

The type of used tensile test machine was microcomputer controlled electronic universal testing machine WDW-100E as shown in Figure (3). Tensile tests were done before and after shot peening and for all shot peening times. Two specimens were tested for each case and taking the average value to satisfy an additional accuracy.

2.5. 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 (4). 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;

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

Where;

σ : is the maximum alternating stress (MPa),
E : the modulus of elasticity (GPa),
t : thickness of specimens (4 mm),
δ : the deflection of free end side of the specimen 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. 2. Shot peening machine.

Fig. 3. Tensile testing machine.

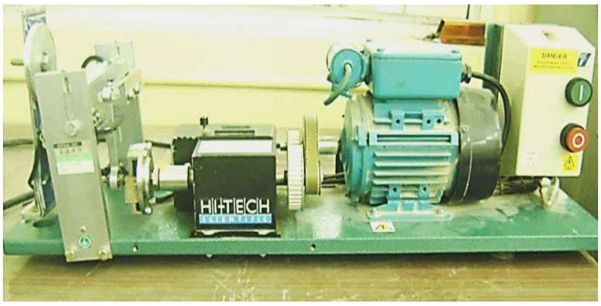
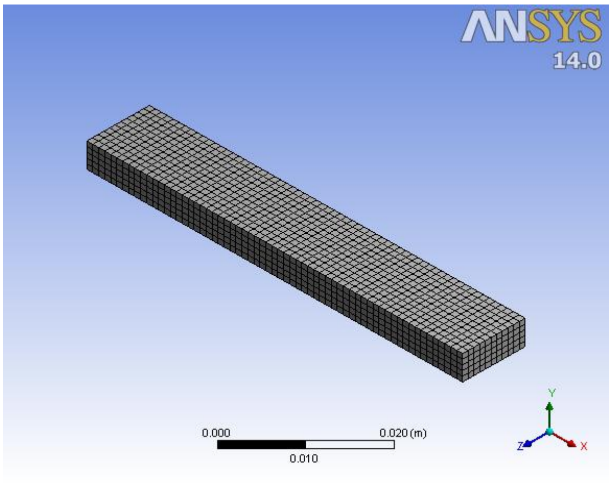


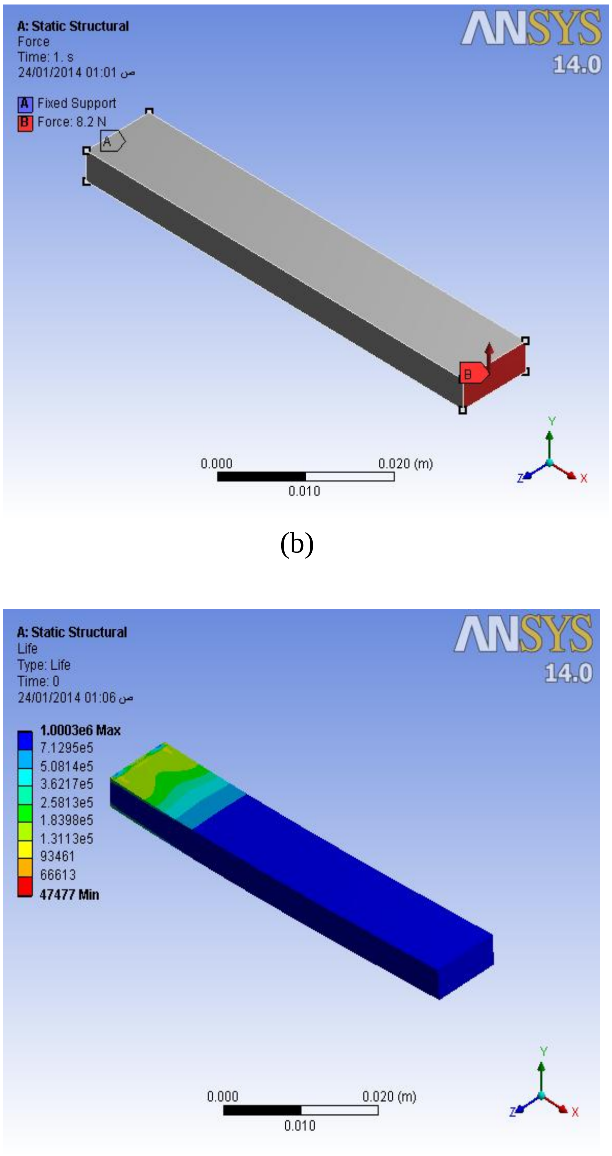
Fig. 4. Fatigue testing machine.

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 polymer matrix composite materials. 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 (5-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 (5-b). All the material properties for aluminum powder composites required in numerical analysis are imported from the experimental tests results, while for E-glass fiber composites (orthotropic) the material properties required in numerical analysis are imported depending on Ref. [9].The resultant fatigue life was obtained for each specimen as shown in Figure (5-c). The obtained fatigue lives were compared with the experimental results as shown in Figure (12) and Figure (13).



(a)



(c)

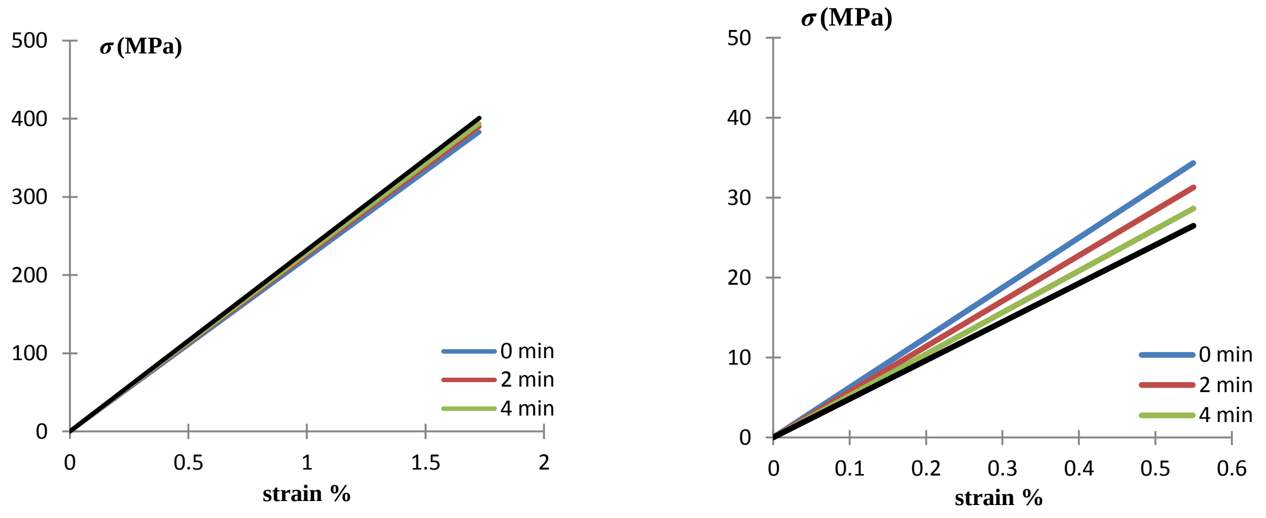
Fig. 5. The model specimen (a) Mesh (b) Applying load (c) Fatigue life.

4. Results and Discussion

4.1. Tensile Test Results

From the tensile test, the ultimate tensile strength and modulus of elasticity for each types of composite materials were obtained. The tensile test properties were changed due to the submission the polymer matrix composites to the shot peening process. The mechanical properties of the studied composite materials were orthotropic for unidirectional fiber glass reinforced polyester and isotropic for aluminum powder reinforced polyester. Figure (6-a) shows the stress-strain diagram for polyester resin reinforced by E-glass fiber with volume fraction of 33% and Figure (6-b) shows the stress-strain diagram for polyester resin reinforced by aluminum powder with volume fraction of 2.5 %. This figure clarify the effect of treatment by shot peening process on the mechanical properties, where a direct comparison was performed between the shot peened and the unpeened specimens. The tensile test results (ultimate tensile strength and modulus of elasticity) are listed in Table 1.

For fiber glass composites (as shown in Figure (7) and Figure (8)), the mechanical properties improved gradually where the maximum improvement was about 5 % at (SPT = 6 min) with respect to the unpeened specimens (SPT = 0 min).Figure (9) reveals a reduction in mechanical properties for 2.5% aluminum powder composites where the maximum reduction did not reaches 23% at (SPT = 6 min) with respect to the unpeened specimens (SPT = 0min).

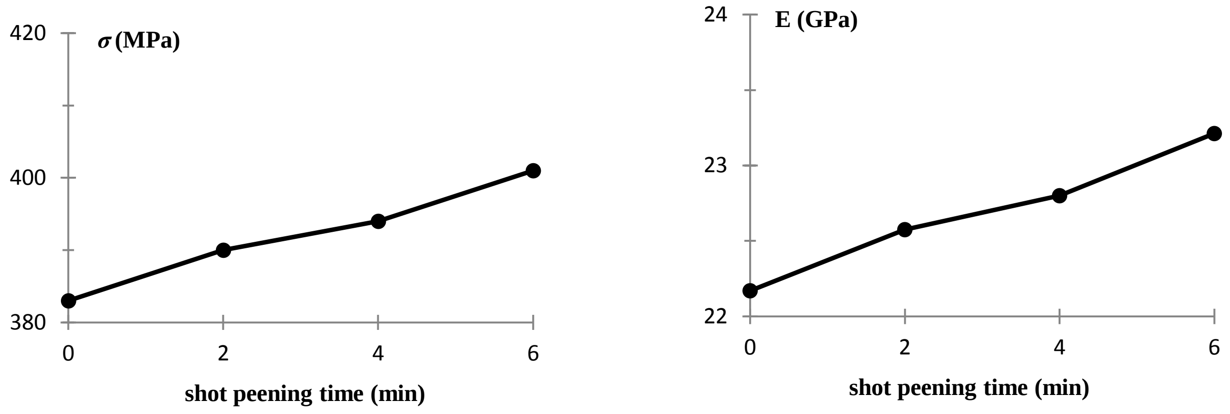


(a) **(b)**

Fig. 6. Stress-strain diagram for polyester and (a) 33 % volume fraction fiber glass composites, and (b) 2.5 % volume fraction Aluminum powder composites.

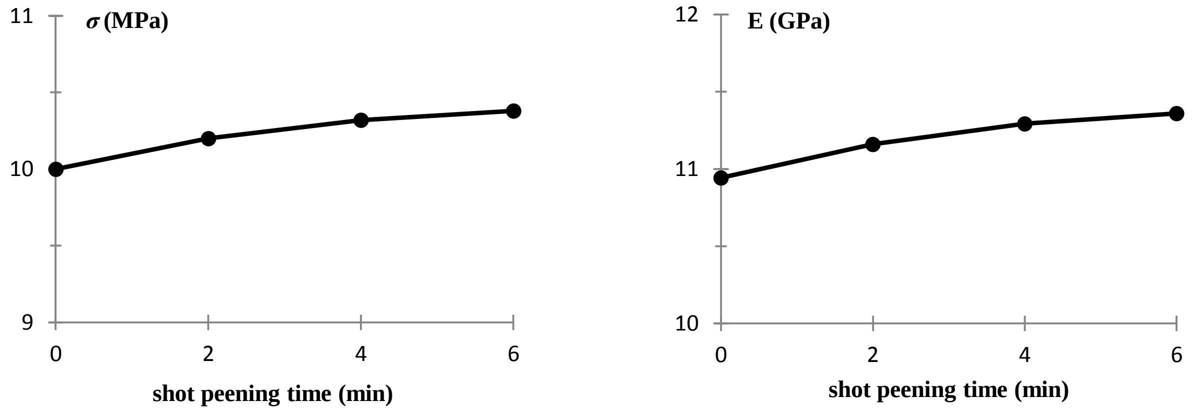
Table 1,
Mechanical properties before and after shot peening.

SPT	**Mechanical properties**	**Fiber glass composites**		**Aluminum powder composites**
		Longitudinal	**Transversal**	
0 min	σ ult (MPa)	383	10	34.35
	E (GPa)	22.17	10.943	6.249
2 min	σ ult (MPa)	390	10.2	31.28
	E (GPa)	22.575	11.16	5.687
4 min	σ ult (MPa)	394	10.32	28.66
	E (GPa)	22.8	11.293	5.211
6 min	σ ult (MPa)	401	10.38	26.5
	E (GPa)	23.212	11.36	4.82



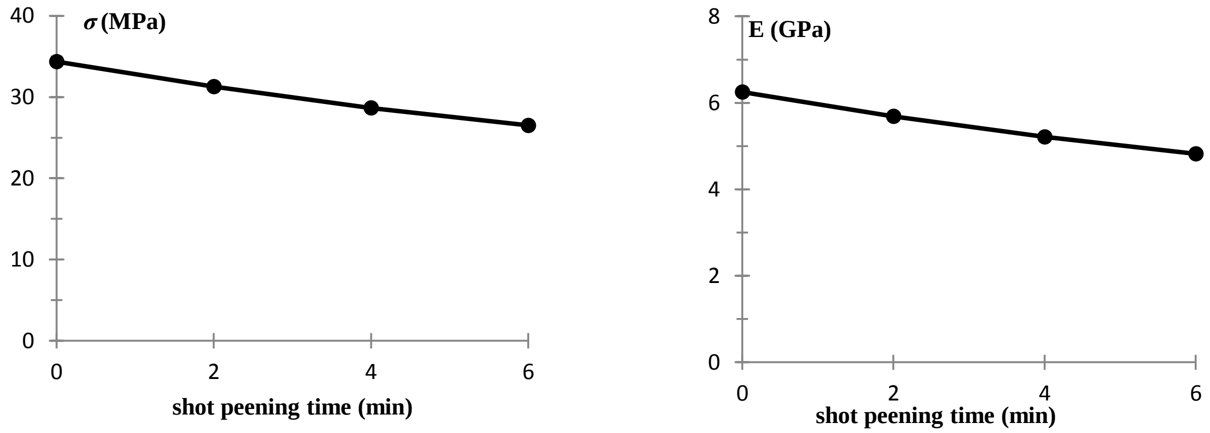
(a) **(b)**

Fig. 7. Variation of mechanical properties at different SPT forlongitudinal fiber glass composites (a) Ultimate tensile strength (b) Young's modulus.



(a) **(b)**

Fig. 8. Variation of mechanical properties at different SPT transverses fiber glass composites (a) Ultimate tensile strength (b) Young's modulus.



(a) **(b)**

Fig. 9. Variation of mechanical properties at different SPT for Aluminum powder composites (a) Ultimate tensile strength (b) Young's modulus.

4.2. Fatigue Test Results

The fatigue behavior before and after shot peening is illustrated as *S*-*N* curves, as shown in Figure (10-a)for fiber glass composites and Figure(10-b) for aluminum powder composites. These curves give an indication about the variations in fatigue life. From these data, the fatigue life estimation equations were determined using the power law regression;

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

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.

The value of endurance limit is not clearly obvious on the *S*-*N* curve; therefore, the endurance limit can be calculated by using the fatigue life estimation equation at 10^6 cycles. The fatigue life estimation equations are listed in Table 2 and the endurance limitsare listed in Table 3.

For the fiber glass composites (polyester with E-glass of 33% volume fraction), it can be seen from Figure(10-a) that the shot peening treatment showed an increasing in the fatigue life in all cases as compared to the unpeened*S*-*N* curve across the whole range of stress amplitudes, as well as an increasing in the endurance limit. The best improvement in fatigue life (endurance limit) was at 6 min shot peening time with a percentage of25% as compared with the unpeened case.

For aluminum powder composites(polyester with aluminum of 2.5 % volume fraction),it can be seen from Figure (10-b) thatthe shot peening treatment showed a decreasing in endurance limit in all cases as compared with the unpeened *S*-*N* curve across the whole range of stress amplitudes, as well as a decreasing in the endurance limit. The maximum reduction in fatigue life (endurance limit) was at 6 min shot peening time with a percentage of29 % as compared with the unpeened case.

Figure (11-a) shows an increasing in the endurance limit for the fiber glass composites as the shot peening time increasing, where the endurance limit increased from 184.12MPaat (SPT = 0 min) until reaches 230.245MPa at (SPT = 6 min). Besides that, Figure (11-b) can give an indication about the reduction in endurance limitfor the aluminum powder composites as the shot peening time increasing, where the endurance limit decreased from 12.7MPaat (SPT = 0 min) until reaches 9.03MPa at (SPT = 6 min).

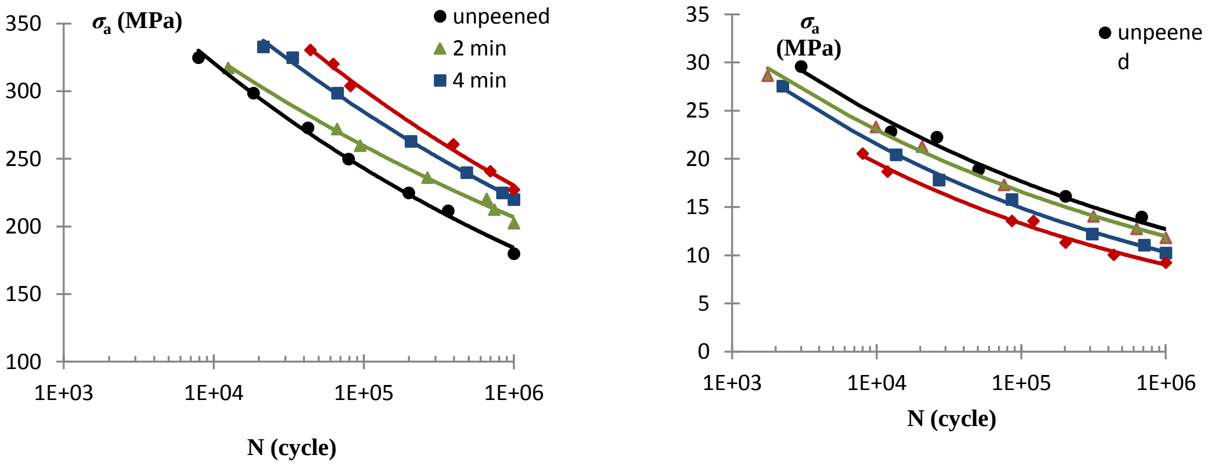
The increment in mechanical and fatigue properties offiber glass composites with the shot peening due to the generating compressive residual stresses at the surface layer of the specimen. The reduction in properties of aluminum powder composites due to formation of cracks at the surface of the specimens and generating tensile residual stresses at the surface layer.

It is observed that the fiber glass composites have fatigue strength more than ten times for aluminum powder composites. Generally, the properties of fiber glass composites have a high value as compared with aluminum powder composites. Fibers are the main load carrying material in composites, and as the number of load carrying elements increases in a material, its strength increases. Fiber glass composites give higher results due to the fibers that can withstand more loads when compared to the powder.

The numerical behavior of fatigue life for all cases can be expressed in Figure(12) and Figure (13). From these figures, the *S*-*N* curves equations can be concluded as in eq. (2), which are also listed in Table 2. The numerical endurance limit can be obtained from the *S*-*N* curve equation at 10^6 cycle and given in Table 3. In this table, the percentage error of endurance limit between the experimental work and numerical analysis is also listed, which is also calculated by the following equation;

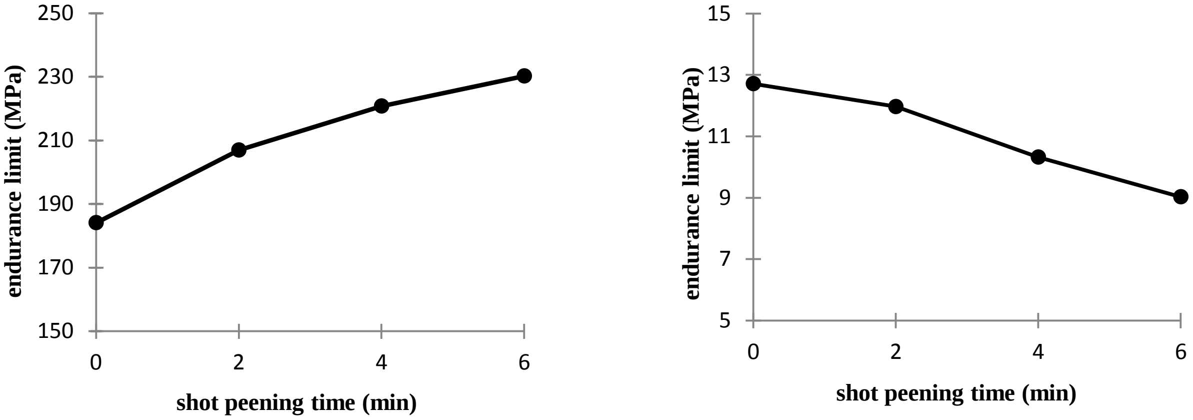
$$Error = \frac{\sigma_{e\,(exp)} - \sigma_{e\,(num)}}{\sigma_{e\,(exp)}} \times 100\ \% \qquad \ldots(3)$$

It is clear from the comparison figures that the experimental *S*-*N* curves are agreed with the numerical *S*-*N* curves.



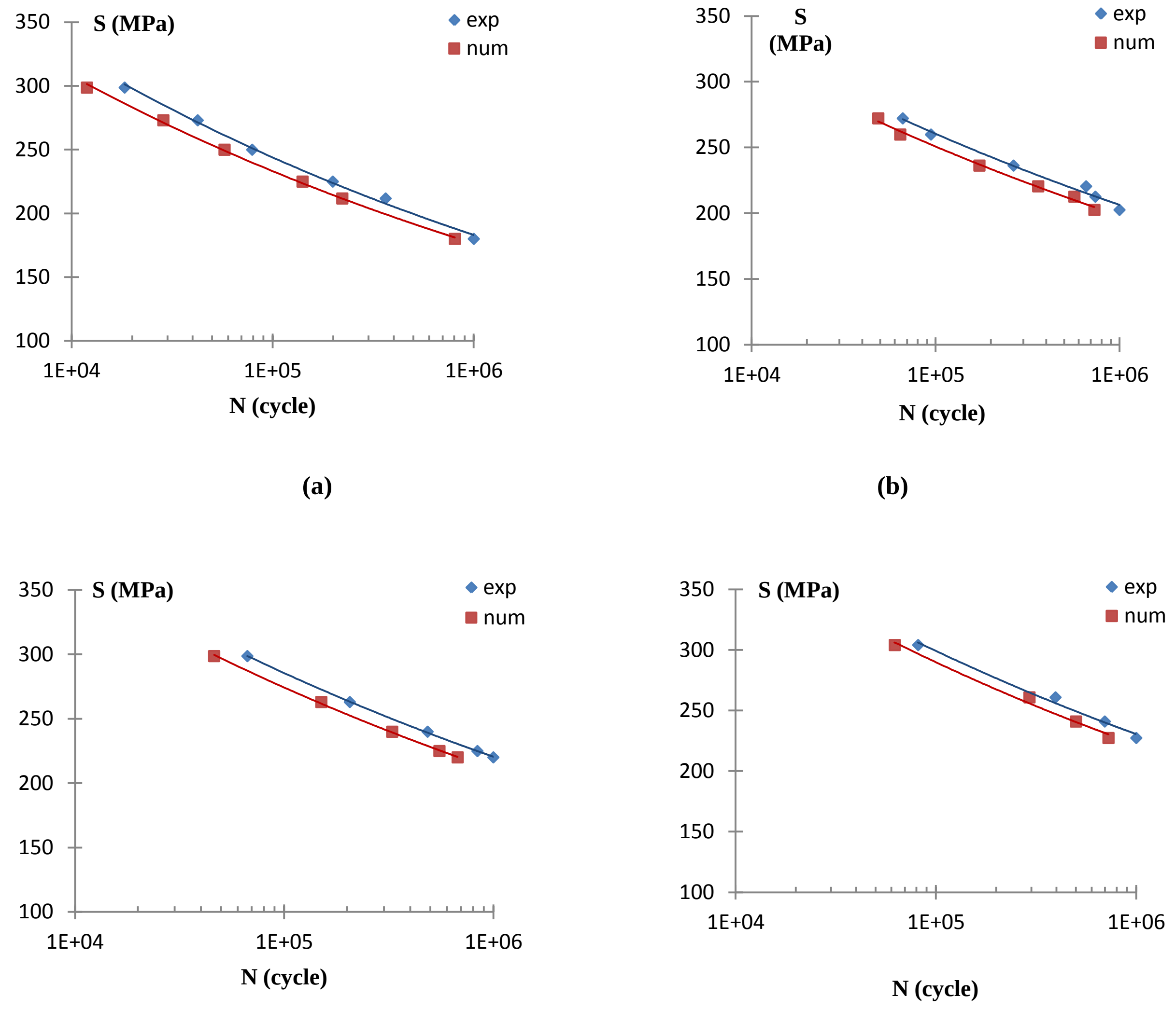
(a) (b)

Fig. 10. Semi-log S-N curves for polyester and (a) 33 % volume fraction fiber glass composites, and (b) 2.5 % volume fraction Aluminum composites.



(a) (b)

Fig. 11. Relationship between endurance limit and SPT for (a) 33 % volume fraction fiber glass composites, and (b) 2.5 % volume fraction Aluminum composites.



(a)

(b)

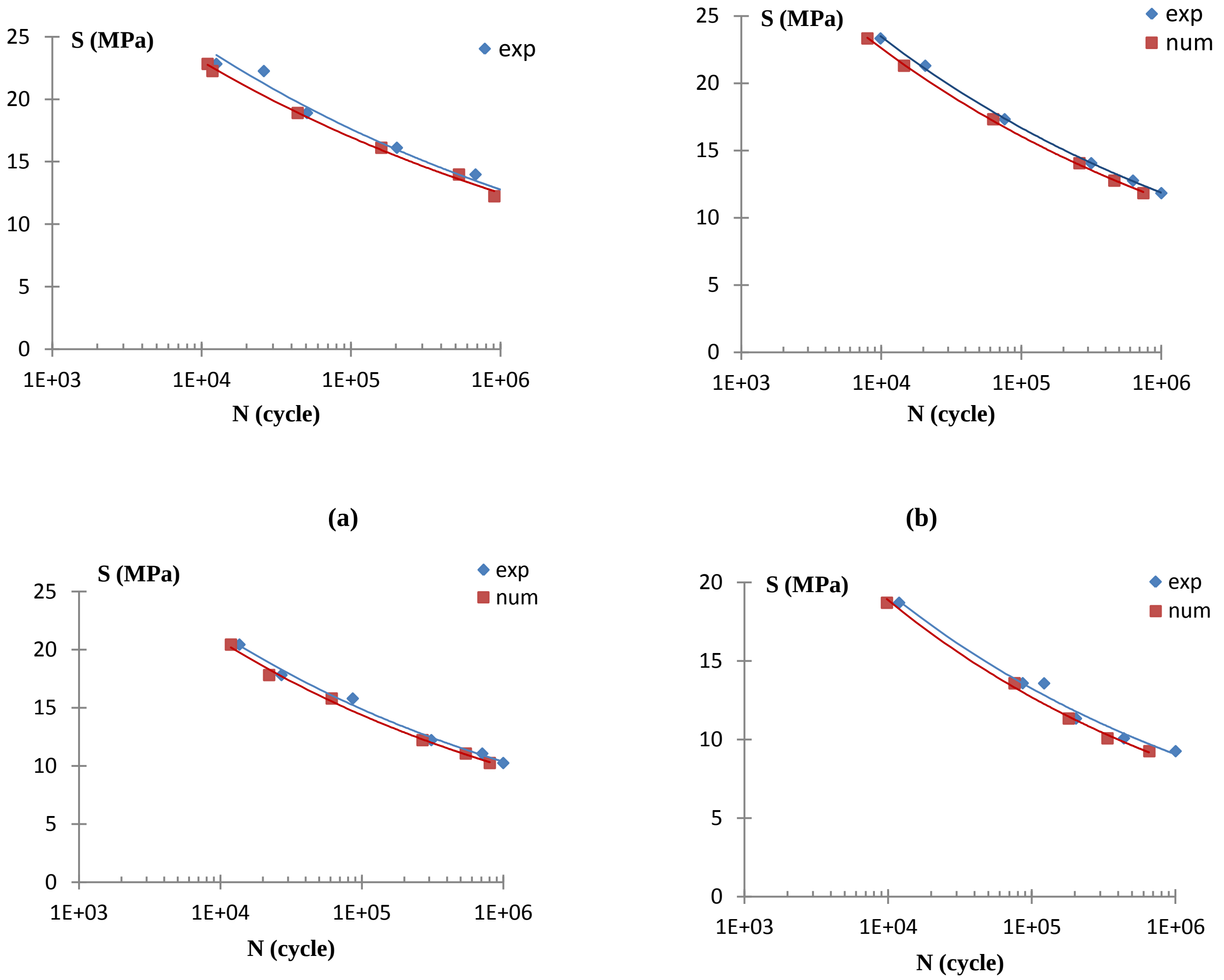
(c)

(d)

Fig. 12. Semi-log S-N curves comparison between experimental and numerical data for fiber glass composites at SPT of (a) 0 min (b) 2 min (c) 4 min (d) 6 min.

Table 2,
Experimental and numerical equations of S-N curves for all cases.

Material type	SPT (min)	Experimental *S-N* equation	Numerical *S-N* equation
Polyester + 2.5 % Al	0	$\sigma = 91.676\ N^{-0.143}$	$\sigma = 78.4\ N^{-0.133}$
	2	$\sigma = 84.874N^{-0.1418}$	$\sigma = 88.777N^{-0.1485}$
	4	$\sigma = 93.6282N^{-0.1596}$	$\sigma =89.972\ N^{-0.1593}$
	6	$\sigma = 92.1\ N^{-0.1681}$	$\sigma = 92.32N^{-0.1724}$
Polyester + 33 % Fiber glass	0	$\sigma = 972.972\ N^{-0.1205}$	$\sigma = 939.12\ N^{-0.121}$
	2	$\sigma = 808.112N^{-0.0986}$	$\sigma = 812.123\ N^{-0.1021}$
	4	$\sigma = 1012.015N^{-0.1102}$	$\sigma = 1026.445\ N^{-0.1147}$
	6	$\sigma = 1146.543\ N^{-0.1162}$	$\sigma = 1099.956\ N^{-0.1158}$



(a) (b)

(c) (d)

Fig. 13. Semi-log S-N curves comparison between experimental and numerical data for Aluminum powder composites at SPT of (a) 0 min (b) 2 min (c) 4 min (d) 6 min.

Table 3,
Experimental and numerical endurance limit for all cases.

Material type	**SPT (min)**	**Experimental endurance limit (MPa)**	**Numerical endurance limit (MPa)**	**Error % by eq.(3)**
Polyester + 2.5 % Al	0	12.7133	12.483	1.81
	2	11.9667	11.41	4.65
	4	10.323	9.9611	3.5
	6	9.03	8.529	5.55
Polyester + 33 % Fiber glass	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

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 (SPT = 6 min) to a value of about 230.245MPa compared with 184.12MPa for the unpeened case (SPT = 0 min).
2. Increasing the shot peening time decreases the endurance limit of aluminum powder composites with maximum decreasing of about 29 % at (SPT = 6 min) to a value of about9.03MPa compared with 12.7133MPa for the unpeened case (SPT = 0 min).
3. The mechanical properties of 33% E-glass fiber composites increased with increasing shot peening time by a percentage of about 5 %and the mechanical properties of 2.5 % Aluminum powder composites decreased with increasing shot peening time by a percentage of about 10 %.
4. The E-glass fiber composites give material with orthotropic properties.While, the aluminum powder composites give material with isotropic properties.
5. The properties of powder composites depend mainly on the resin material properties which can be affected by the additive powder as compared with long fiber reinforcements.
6. 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 5.55 % for endurance limit for all cases.

6. References

[1] J. Lu, B. Miège and J. F. Flavenot, "Study on the Effect of Shot Peening on the Residual Stress in Al-SiC Composite" , France, pp. 169-178,1989.

[2] S. Tohriyama, M. Kumano and S. Hisamatsu, "Influence of Peening on Fatigue Life of SiC Reinforced Aluminum " Material Development Depatment, Isuzu Motors Limited, Japan, pp. 307-316, 1990.

[3] Hill S., Gregson P. J. and O'Hara P., "Effect of Shot Peening on Fatigue Performance of Advanced Aluminum Alloys and Aluminum Based Metal Matrix Composites" Engineering Materials, University of Southampton, UK, Metal Improvement Company, pp. 371-376 1992.

[4] Weizhi Luan, Chuanhai Jiang, Vincent Ji and Haowei Wang, "Effect of Shot Peening on Surface Mechanical Properties of TiB2Al Composite" Journal Material Science 44, pp. 2454-2458 2009.

[5] American Society for Testing and Materials (ASTM) D 5687/D 5687 M-95 "Standard Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation" Annual book of ASTM standards, 1995.

[6] American Society for Testing and Materials (ASTM) D 3039/D 3039 M " Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials" Annual book of ASTM standards, 2000.

[7] American Society for Testing and Materials (ASTM) D 638 " Standard Test Method for Tensile Properties of Plastics" Annual book of ASTM standards, 2001.

[8] N. P. Roberts and Nigel R. Hart, "Alternating Bending Fatigue Machine (HSM20), Instruction Manual" , Hi-Tech Ltd. UK., 2001.

[9] Muhannad Z. Khelifa andHayder M. Al-Shukri "Fatigue Study Of E-Glass Fiber ReinforcedPolyester CompositeUnder Fully Reversed Loading And Spectrum Loading" Eng.& Technology Journal,Vol. 26, No.10, 2008.

مقارنة سلوك عمر الكلال لمادتين مركبتين مختلفتين تحت تأثير أزمنة مختلفة للسفع بالكرات

أحمد نايف ابراهيم الخزرجي* مهدي نعمان مسلم**
**، ** قسم هندسة المكائن والمعدات/ الجامعة التكنولوجية*
*البريد الالكتروني: Dr_ahmed53@yahoo.com
**البريد الالكتروني: Mahdi.numaan@yahoo.com

الخلاصة

تم في هذا البحث دراسة تأثر سلوك عمر الكلال لمادتين مركبتين خاضعتين لأزمنة مختلفة من السفع بالكرات (٢ و ٤ و ٦ دقائق). المادة المركبة الاولى حُضرت من مادة البولي أستر غير المشبع مع مدعمات من الليف الزجاجي بكسر حجمي ٣٣ %. بينما كانت المادة الاخرى محضرة من البولي أستر غير المشبع مع مسحوق الالمنيوم بكسر حجمي ٢,٥ %. أظهرت النتائج العملية بأن التحسن في حد الكلال قد حصل للمادة الاولى عند أزمنة سفع بالكرات (٢ و ٤ و ٦ دقائق) حيث كانت أقصى نسبة مئوية للتحسن ٢٥ % عند زمن سفع بالكرات قدره ٦ دقائق. بينما قلّ حد التحمل للمادة الثانية عند أزمنة السفع بالكرات (٢ و٤ و ٦ دقائق) حيث كان أقصى نقصان بنسبة مئوية ٢٩ % عند زمن سفع بالكرات قدره ٦ دقائق. وتمت برهنة النتائج العملية باستخدام برنامج (ANSYS.14 workbench) وبمقبولية جيدة بين العملي والتحليل النظري.