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## Effect of Shot Peening and Solidification on Fatigue Properties of Epoxy Base Composite Material

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# Effect of Shot Peening and Solidification on Fatigue Properties of Epoxy Base Composite Material

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**Abstract.** This work evaluated experimentally the fatigue stress behavior of two types of composite material (SIR-epoxy resin with woven E-glass fiber as reinforcement and SIR-epoxy resin with random E-glass fiber as reinforcement) subjected to shot peening (2, 4 and 6 min) through three different times of solidification of samples (two, four and six days). The results show that, for woven reinforced composite, the great improvement in fatigue stress was obtained at both two and six days of solidification with (2, 4 and 6) min of shot peening times (SPTs) in which the percentage of the maximum enhancement was 59.38% in fatigue stress (at two days of solidification and 6 min shot peening time). For random reinforced composite the great improvement of fatigue stress was obtained at two and six days of solidification with (2, 4 and 6) min of shot peening times (SPTs) in which the percentage of the maximum enhancement was 33.78% (at two days solidification and 6 min shot peening). After four days of solidification, increasing shot peening time will decrease the fatigue stress for both types of composite materials (woven reinforcement and random reinforcement) and the maximum decreases in fatigue stresses at 6 min of shot peening was -43.06% and -28.9% for woven composite and random composite respectively. The tensile test and the fatigue test were done after full solidification of all the patterns.

**Keywords:** Fatigue, Composite Material, Shot Peening.

## 1. Introduction

Composite materials become a common engineering materials and are designed and manufactured for several applications involve sporting goods, consumer goods, aerospace parts, automotive components, oil industry and in the marine industry. Between all materials, composite material has the ability to replace widely use of steel and aluminum, and many times with better behavior. Today, it appears that composites are the materials of choice for many engineering applications. Therefore, many of the researchers investigated the best way to enhance the composites' mechanical properties. One of these procedures is shot peening which it's a method used to create a compressive residual stresses to gain surface enhancement for metals, alloys and composites, some researchers evaluated the influence of this method on composite materials with a metallic resin, but investigating the influence of shot peening on polymer matrix composite materials still very few and scanty. Therefore this work generally concentrates on this spot. [1] (1990), investigated the influence of shot peening on the fatigue life of MMC of aluminum (6061, 2024) composites which are reinforced with silicon carbide whisker (SiCw) or silicon carbide particle (SiCp) by the volume fraction ( $V_f$ ) of 20% generated by squeeze casting and powder metallurgy, respectively. The shot peening time (SPT) was (15 sec), shot ball's diameter (105-250 $\mu$ m), and coverage of (300%). The results obtained showed that the shot peening enhances the fatigue stress of SiCp/ 2024. The fatigue stress of SiCw/6061 wasn't affected by shot peening. [2] (1991), evaluated the influence of shot peening process on the residual



stress and surface roughness of metal matrix composites which formed from (2024 Aluminum alloys) reinforced with 15% volume fraction of silicon carbide (SiC) whiskers and particulates. The incremental drilling method was used for residual stress determination. The results showed that the shot peening behavior of MMC is similar to the unreinforced materials; Ra and Rt roughness, the level of compressive residual stresses and the depth of the pre-stressed layer change with the shot peening variables. H. J. C. Voorwald and A. L. M. Carvalho, [3] (2007), investigated the shot peening effect on the fatigue stress of aluminum 7050-T7451 alloy chromium electroplated. The shot peening treatment was applied in order to create residual stresses using two types of shots, with and without hard chromium electroplated layer. The fatigue stress with number of cycles to failure curves (S–N curves) were gained in axial and bending fatigue tests and compare them with the 7050-T7451 aluminum alloy. An increase in the axial fatigue strength of 50% and 25% of glass shots and ceramic shots, respectively, was observed. However, in bending fatigue, the performance was practically equivalent for the two processes. [4] (2009), studied the shot peening influence on the fatigue behavior of cast magnesium A8. Shot peening was found to offer a considerable enhancement in the fatigue stress, with an increase in the fatigue stress of up to five times reliant on the applied stress, and a 30% increase in the fatigue life of the material. Ruaa H. Abdel-Rahim [5] (2012), studied the physical and mechanical properties and erosion wear of traditional and hybrid polyester matrix composites. Traditional and hybrid composites were made by Hand lay-up molding and studied. The composite materials constituents were a matrix from unsaturated polyester resin, reinforcement from 3% and 6% volume fractions of carbon fibers and 3% of  $\text{Al}_2\text{O}_3$ , 3% of Al, Cement and local Gypsum as filler particles. As a result, the tensile strength for unsaturated polyester (UP) reinforced with 3 % Aluminum particle was 38.846 MPa. Salah F. Abd-El Jabbar et. al., [6] (2013) evaluated the shot peening's influence on the fatigue-creep behavior on Al 7075-T651. The result obtained shows that the combination of shot peening and fatigue-creep interaction could be used successfully so as to increase fatigue stress for several sampels subjected to cumulative fatigue damage. It was also found that when shot peening time increased, the surface roughness increased. The average Vickers microhardness measured on the surface of unpeened Al 7075-T651 was about 280 HV. The magnitude of hardness was increased with increasing SPT by 38 % of the based hardness to 387 HV at 15 min of shot pening. [7] (2014) evaluated the shot peening's effect on the fatigue stress of two composite materials: unsaturated polyester with E-glass and unsaturated polyester with aluminum powder. The experimental result showed that shot peening improve the endurance limit for the first material (the percentage of maximum enhancement was 25% at 6 min of shot peening, while for the second material there was decrease in the fatigue life and the percentage of maximum reduction was 29%. S. [8] (2017), studied the enhancement in fatigue stress on high strength aluminum alloy, steel and welded connection by shot peening treatment. The results show considerable variations in the surface layer of metals, aluminum alloy produced a fatigue stress enhancement of 15–250%, steel plain members produced a fatigue stress enhancement of 6-200%, and welded connections produced a fatigue stress enhancement of 50-75% and considerable enhancement in mechanical properties like hardness, corrosion, roughness reduction, tensile strength, scuffing and wear.

In this work, the effect of shot peening on fatigue stress of two types of composite material was studied, also the effect of solidification was studied.

## 2. Experimental Work

### 2.1. Preparation of Specimens:

In this work, two types of E-glass fiber reinforcement were prepared with SIR-epoxy resin, which are woven E-glass reinforcement (density=600 kg/m<sup>3</sup>, thickness= 0.25mm) and random E-glass reinforcement (density= 450 kg/m<sup>3</sup>, thickness= 0.25mm) [9]. The preparations of specimens were done as follow;

1. Preparing a 30\*30\*0.3 cm glass mold shown in figure 1. The inner wall of the mold was covered by thin layer of oil to prevent any cohesion between the epoxy resin matrix and the glass mold.

2. The SIR-Epoxy resin was mixed with the hardener (Methyl Ethyl Keton Peroxide, MEKP) by a percentage of 2% [7].
3. Cutting the fiber layer (sheet) to 30\*30 cm the two types of E-glass fiber (woven reinforcement and random reinforcement).
4. The composite plate was produced by placing the fiber sheets one above the other in the glass mold (5 layers) with the resin mixed well and poured it on the fiber layers in the glass mold (hand lay-up)
5. Repeating this process with a constant volume fraction of 41%.
6. After putting the sample in the mold and closed it to prevent any interaction between the mixture and the environment. The sample stays in the mold for 24 hours at room temperature.
7. Samples are extracted from the mold (see figure 2). Cutting the plate into the proper dimensions for the tensile and the fatigue tests using a CNC machine, figure 3 shows the plate after cutting the tensile test specimen and the fatigue test specimen
8. Cut the specimens for the tensile test according to standers of ASTM-D638-I [10], figures (4, 5) show the tensile test specimen for woven type and random type respectively.
9. Cut the fatigue test specimens according to machine specification manual [11], see figure 6.

### 2.2. Shot Peening Machine:

The machine used in this work is the wheel type that shown in figure 7, ball hardness for practically all steel (ferrous) parts can be (45-50 HRC), ball diameter is 2.25mm, ball linear velocity is 40m/min.

### 2.3. Tensile Test:

The machine for this test is micro-computer controled electronic universal testing machine WDW-100 (figure 8). Tensile tests have been done before and after the shot peening and for all the times [12].

### 2.4. Fatigue Test:

The fatigue stress testing machine that have been applied in this work was HI-TECH alternative bending fatigue (HSM20) as shown in figure 9 [12]. Subjecting the specimens to deflection vertical to the specimens' axis at the free side of the specimens, and the other side was fixed, generating bending stresses as a cantilever beam which it can be set straight from the equation below[11];

$$\sigma = \frac{1.5 E t \delta}{L^2} \quad (1)$$

Where;  $\sigma$ : endurance limit, E: young modulus (GPa), t: specimens' thickness (3cm)  $\delta$ :the free end side's deflection of the specimen measures by dial gauge (mm), L: specimens' effective length (50mm).

### 2.5. Solidification:

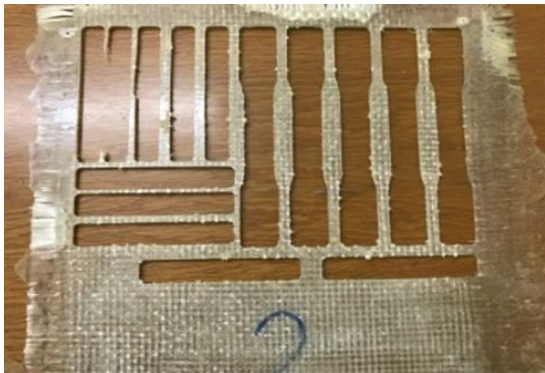
It has been kown that the composite plate take six days for full solidification by testing the hardness of the composite material (shore D test), using Digital Hardness Tester for polymer and composite material (Quail test HPE) (see figure 10) after one day from the casting process, and day by day the hardness of the material increase until it's become stationary (no remarkable change in reading between the sixth and the seventh days). Therefor the solidification period (six days) will be divided in this order (two, four and six days).



**Figure 1.** Glass Mold



**Figure 2.** Composite Plate



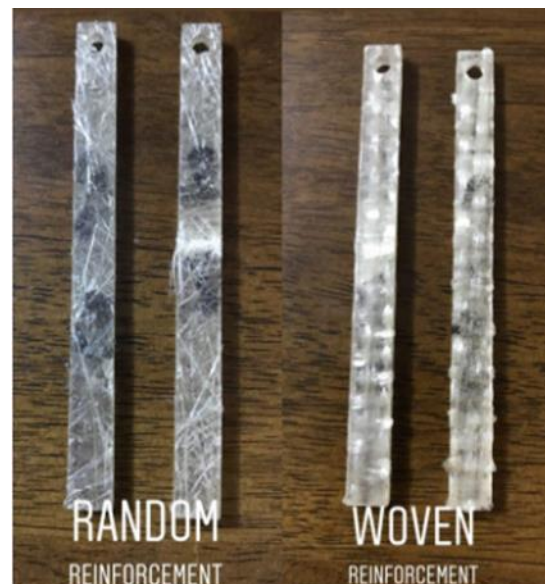
**Figure 3.** Cutting Using CNC Cutting Machine (woven)



**Figure 4.** Tensile Test Specimens (Woven)

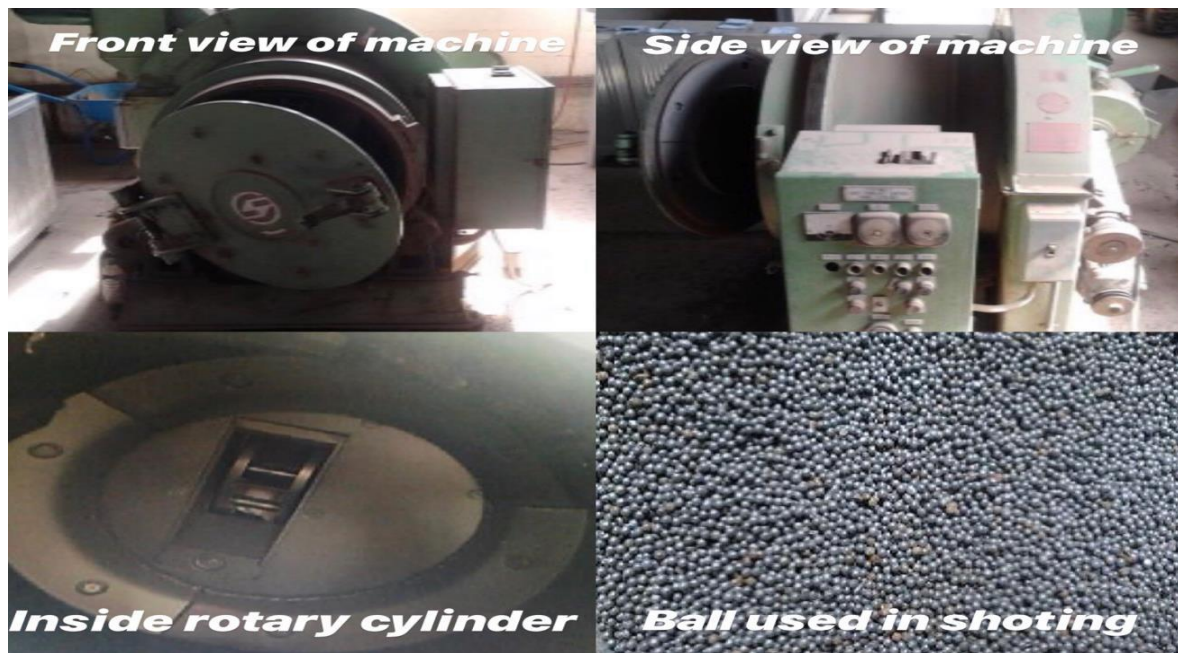
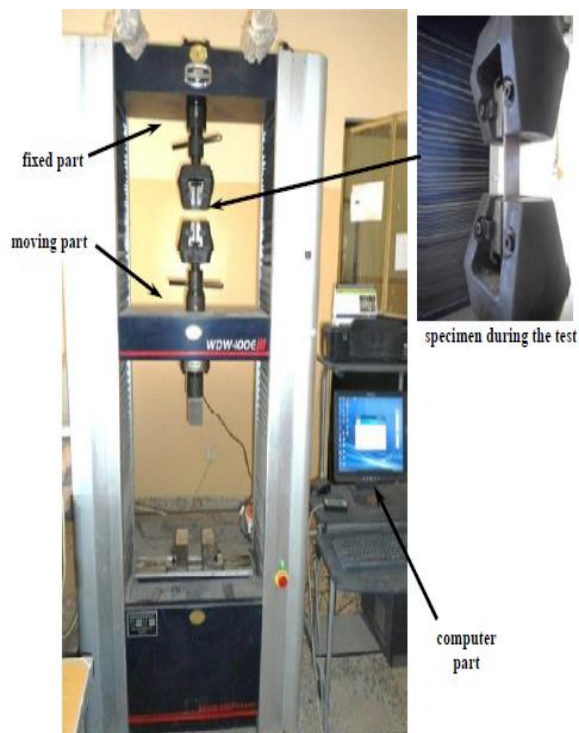
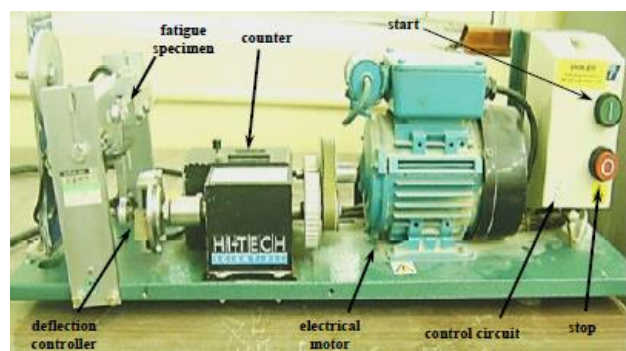


**Figure 5.** Tensile Test Specimens (Random)



**Figure 6.** Fatigue Test Specimens



**Figure 7.** Shot Peening Machine**Figure 8.** tensile test machine**Figure 9.** Fatigue Testing Machine



**Figure 10.** Hardness Tester

### 3. Results and Discussion

#### 3.1. Tensile Test Results

The tensile test properties for the same composite material were changed due to the shot peening process and the solidification time. Tables (1, 2) show the mechanical properties for epoxy resin reinforced by woven E-glass fiber (table 1), and random E-glass fiber (table 2). The result in the two tables below (for the two types of composite material) for 2 and 6 days of solidification shows that if increase the shot peening time (SPT) (2, 4 and 6 min) the mechanical properties increase, but if the shot peening time (SPT) become more than 6 min (8 min) that will make extreme decrease in the mechanical properties, and the maximum improve in the mechanical properties was 31.53% at 2 days solidification and 6 min of shot peening for the woven reinforcement composite material, and 24.68 % for the random reinforcement composite material (at 6 days solidification and 6 min shot peening). While at 4 days of solidification the mechanical properties decrease with increasing the shot peening time (SPT) (weaken) with maximum decrease of about 42% for woven E-glass reinforcement composite (at 8 min of shot peening) and about 50.34% for random E-glass reinforcement composite (at 8 min). The tensile test was done after full solidification of all the patterns.

**Table 1.** Mechanical Properties for Epoxy Resin Reinforced by Woven E-Glass Fiber for Different Shot Peening Times (SPTs) at Three Different Days of Solidification (2, 4 and 6 days).

SPT (min)	Mechanical Properties	Solidification Time (day)		
		Two	Four	Six
0	$\sigma_{ult}$ (MPa)	-	-	130
	E (MPa)	-	-	1211
2	$\sigma_{ult}$ (MPa)	148	128	150

4	<b>E (MPa)</b>	1447	1004	1433
	<b><math>\sigma_{ult}</math>(MPa)</b>	165	125	162
6	<b>E (MPa)</b>	1500	996	1485
	<b><math>\sigma_{ult}</math>(MPa)</b>	171	120	169
8	<b>E (MPa)</b>	1578	886	1568
	<b><math>\sigma_{ult}</math>(MPa)</b>	70	75	80
	<b>E (MPa)</b>	780	820	880

**Table 2.** Mechanical Properties for Epoxy Resin Reinforced by Random E-Glass Fiber for Different Shot Peening Times (SPTs) at Three Different Days of Solidification (2, 4 and 6 days).

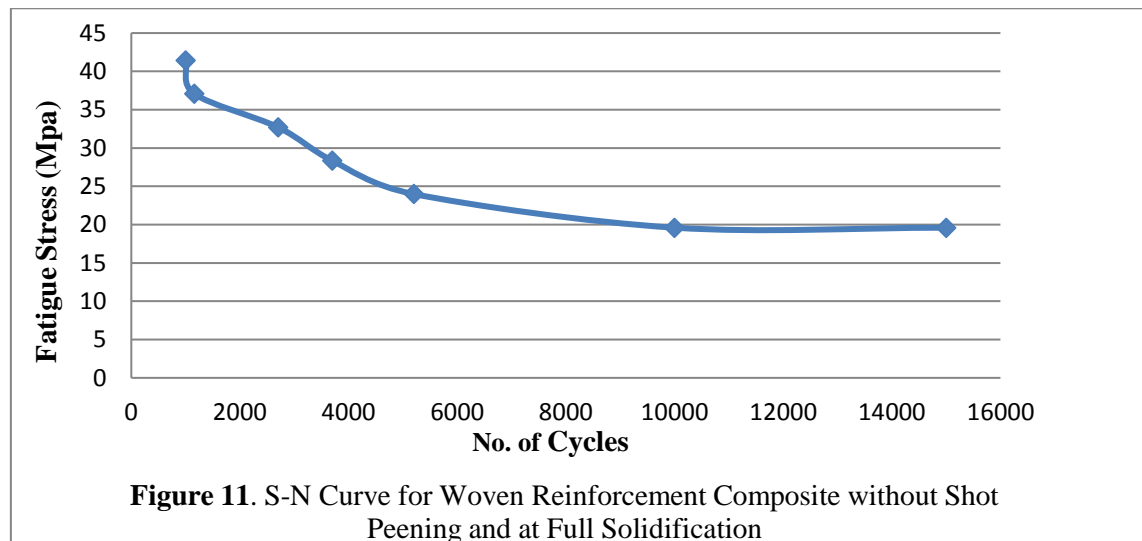
SPT (min)	Mechanical Properties	Solidification Time (day)		
		Two	Four	Six
0	<b><math>\sigma_{ult}</math>(MPa)</b>	-	-	86
	<b>E (MPa)</b>	-	-	973
2	<b><math>\sigma_{ult}</math>(MPa)</b>	92	80	94
	<b>E (MPa)</b>	1045	875	1042
4	<b><math>\sigma_{ult}</math>(MPa)</b>	97	74	99
	<b>E (MPa)</b>	1087	862	1074
SPT (min)	Mechanical Properties	Solidification Time (day)		
		Two	Four	Six
6	<b><math>\sigma_{ult}</math>(MPa)</b>	104	69	107
	<b>E (MPa)</b>	1102	849	1096
8	<b><math>\sigma_{ult}</math>(MPa)</b>	35	42	46
	<b>E (MPa)</b>	420	485	533

### 3.2. Fatigue Test Result

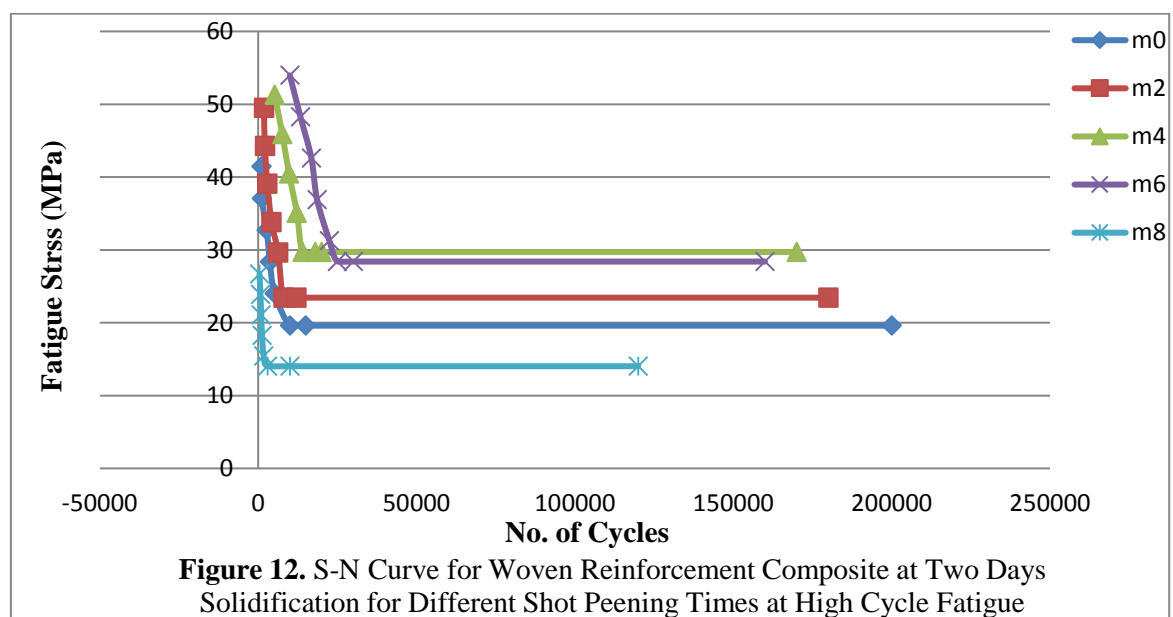
The fatigue test were done before and after shot peening and it's behavior is explained as fatigue stress with number of cycles to failure curves (S–N curves), as shown in figures (8,9,10,11 and 12) for the woven reinforcement composite and figures (13,14 and 15) for random reinforcement composite. The fatigue stress has a bit similar behavior like the mechanical properties, which it increase in 2 and 6

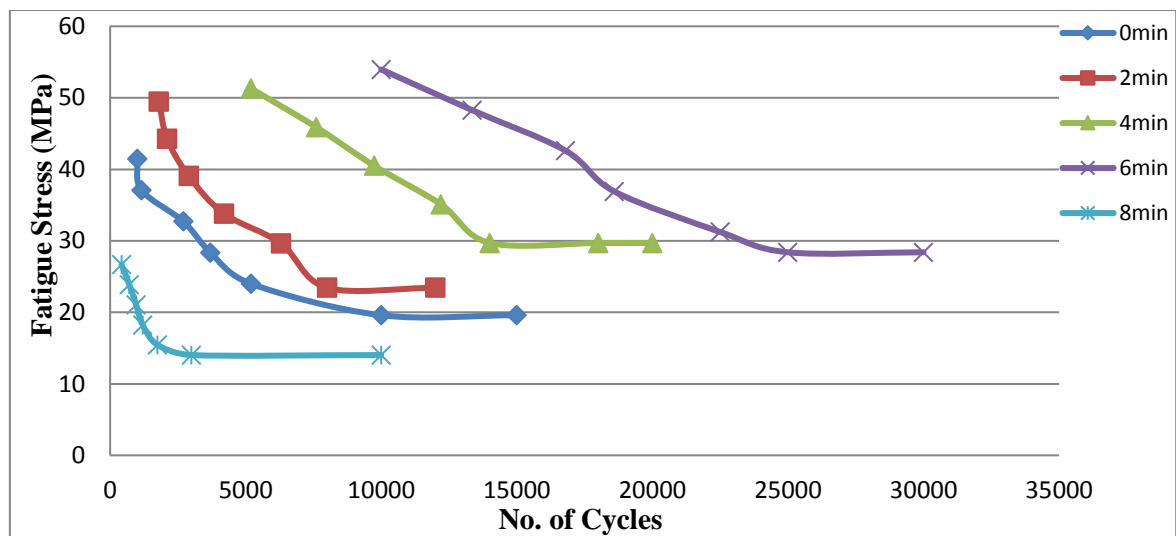


days of solidification and decrease in 4 days of solidification (for both types of composite; woven and random reinforcement). The fatigue test was done after full solidification of all the patterns.



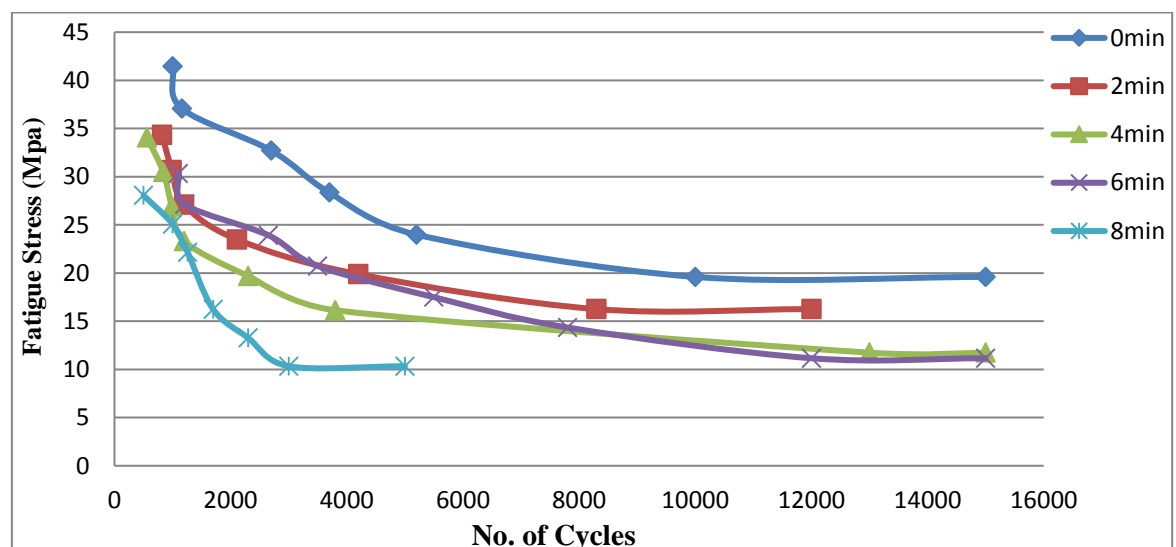
The difference between the two figures (12 and 13) is; figure 12 shows the S-N curves when we reach number of cycles equal to 200,000 cycles (High Cycle Fatigue HCF) and at this point the change in curves will not be remarkable for the eye, figure 13 shows the S-N curves at Low Cycle Fatigue (LCF), therefor Low Cycle Fatigue is used for composite materials. Figure 13 shows that increasing the shot peening time (SPT) will increase the fatigue stress of the composite material and the maximum increase was 30.21% (at 6 min of shot peening) and the reason for that is the shot peening process minimized the inter-particle distances of the composite plate, also the residual compressive stresses delivers at the surface of the composite plate, but the fatigue stress will decrease when the shot peening time become more than 6 min (8min).





**Figure 13.** S-N Curve for Woven Reinforcement Composite at Two Days Solidification for Different Shot Peening Times at Low Cycle Fatigue

Figure 14 shows the effect of shot peening at four days of solidification for woven reinforcement composite material. Increasing the shot peening time will decrease the fatigue stress and the maximum decrease in its value was 32.31% (at 8 min shot peening), that because the shot peening changed and ruined the molecular arrangement of the composite plate particles and this issue affect more than the effect of the residual stresses.



**Figure 14.** S-N Curve for Woven Reinforcement Composite at Four Days Solidification for Different Shot Peening times

Figure 15 shows the effect of shot peening at six days of solidification for woven reinforcement composite as S-N curve. This S-N curve shows that increasing the shot peening time will increase the fatigue stress because of the residual stresses that delivered at the surface of the composite plate and the maximum increase in fatigue stress was 29.41%. Increasing the shot peening time more than 6 min (8min) will weak the composite plate and that explained in the behave of its endurance limit.

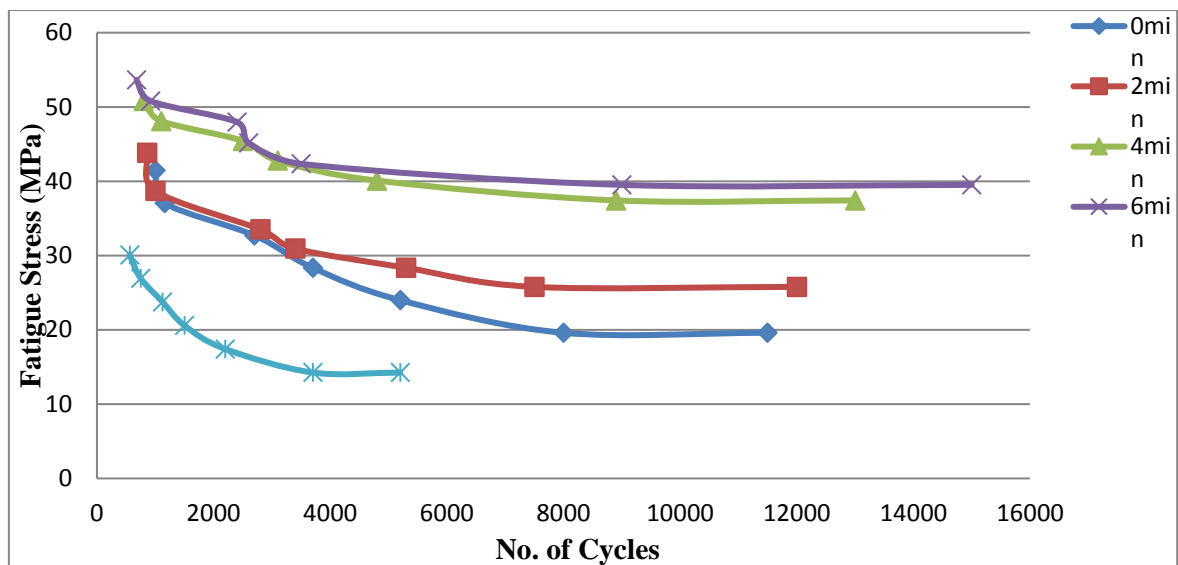


Figure 15. S-N Curve for Woven Reinforcement Composite at Six Days Solidification for Different Shot Peening Times

Figures 16,17,18 and 19 for random reinforcement composite and it has similar behavior like the first composite material (woven reinforcement type). On figure 17 (2 days solidification) the fatigue stress increase with increasing the shot peening time and the maximum increase in the fatigue stress was 11.65% (at 6 min of shot peening), but if the shot peening time become more than 6 min (8min) the fatigue stress decrease. On figure 18 (4 days solidification) the maximum decrease in fatigue stress was 50.16% (at 8 min of shot peening).

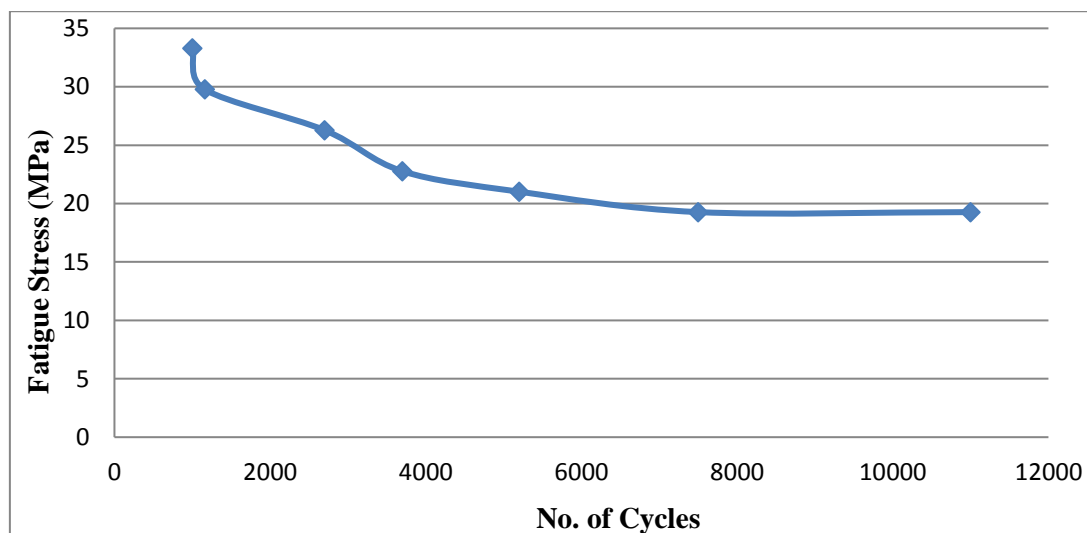
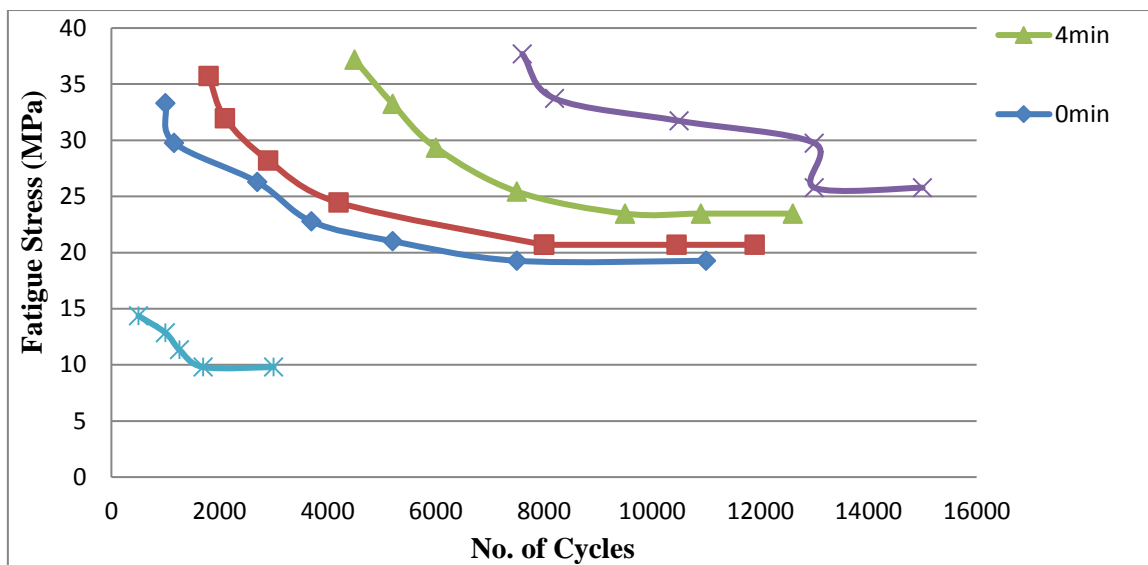
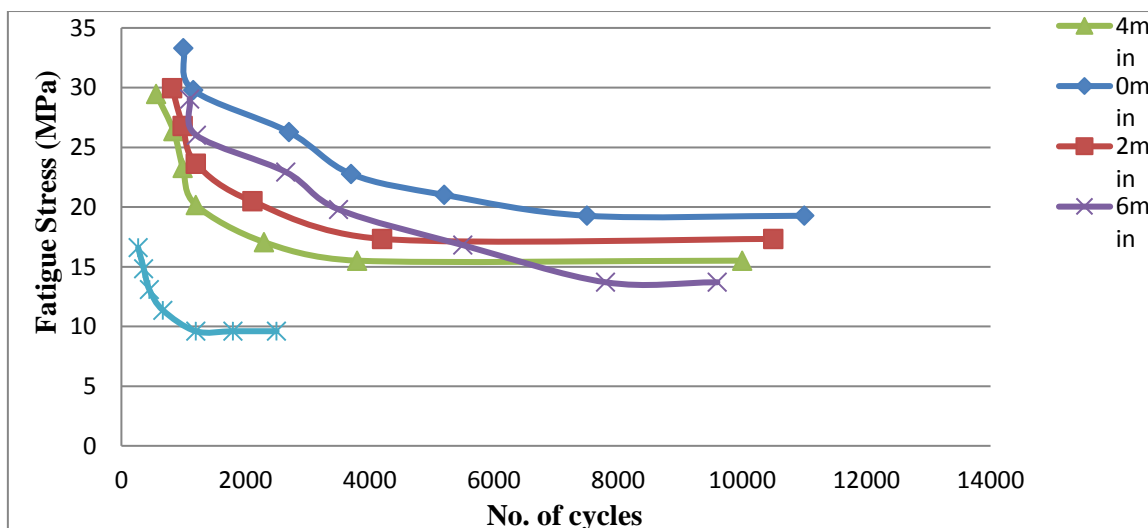


Figure 16. S-N Curve for Random Reinforcement Composite without Shot Peening and at Full Solidification

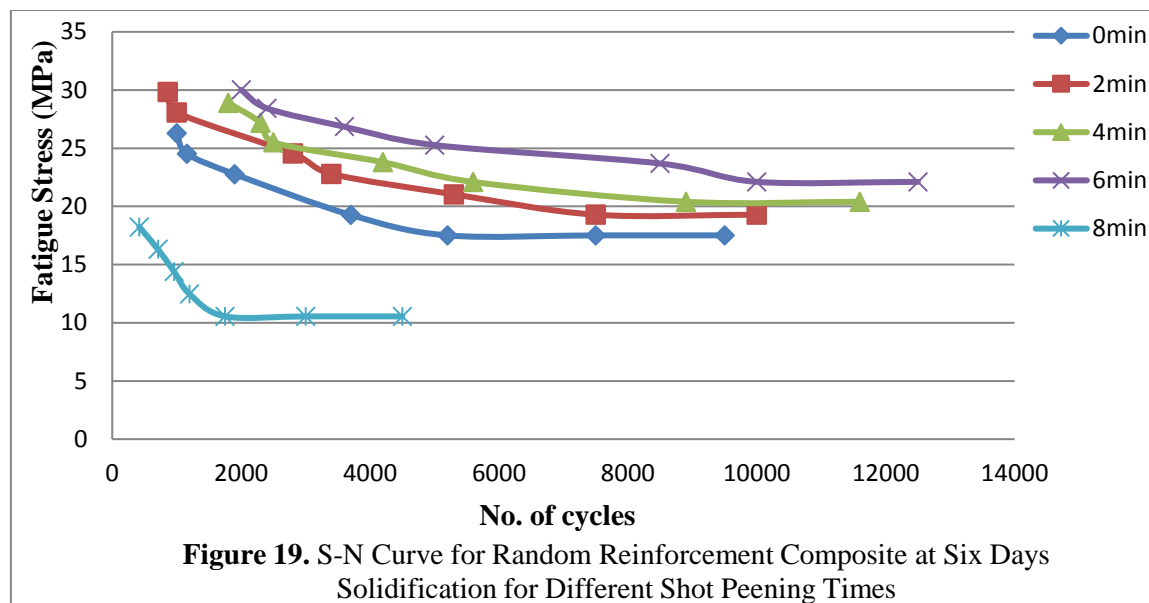


**Figure 17.** S-N Curve for Random Reinforcement Composite at Two Days Solidification for Different Shot Peening Times



**Figure 18.** S-N Curve for Random Reinforcement Composite at Four Days Solidification for Different Shot Peening Times

On the 6 days solidification (figure 19) the maximum increase was 14.19% (at 6 min shot peening) and if we increase the shot peening time more than 6 min (8min) the fatigue stress decrease .



#### 4. Conclusions:

The main conclusions are:

1. Increasing the shot peening time with two or six days of solidification will increase the mechanical properties and the fatigue stress for woven reinforcement composite (from 130 MPa ultimate stress without shot peening to 171 MPa and 169 MPa with shot peening at two and six days of solidification respectively), also for random reinforcement composite (from 86 MPa ultimate stress without shot peening to 104 MPa and 107 MPa with shot peening at two and six days of solidification respectively).
2. Increasing the shot peening time more than 6min will cause a huge decrease in the mechanical properties (ultimate stress and Young's modulus) and in the fatigue stress for two and six days of solidification.
3. For the woven reinforced composite, the maximum improvement in the fatigue stress was 59.38% (two days of solidification, 6 min shot peening). For random reinforced composite the maximum improvement in the fatigue stress was 33.78% (two days of solidification, 6 min shot peening).
4. Increasing shot peening on samples with four days of solidification will decrease the mechanical properties and the fatigue stress. The maximum decreases in fatigue stresses at 6 min of shot peening was -43.06% and -28.9% for woven composite and random composite respectively.

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