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Effect of Shot Peening Time on fatigue and corrosion fatigue life for A27 cast carbon Steel

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Abstract

A 27 cast carbon steel, which was used in induced draft fan blades of Nasiriyah thermal electricity station was chose to actualize the aim of this paper by studying the effect of shot peening time on dry and corrosion fatigue life. .Many specimens from the metal choice for tensile and fatigue tests were equipped according to ASTM (E8/E8M-09) some of preparing specimens were subjected to shot peening by steel ball in diameter 2.25 mm for different time (10, 20, 30) minute. Hardness, residual stress, surface roughness , dry fatigue and corrosion fatigue were tested. The result showed an improvement in the tensile strength for shot peening comparing with the base metal. The tensile strength of the shot peening metal at 20 minute was higher than the tensile strength of the shot peening at 10,30 minute. Also shot peening contributed in improvement fatigue life but the best time was 20 minute and this improvement witness decay in fatigue life by corrosion fatigue test due the effect of environment in addition of cyclic loads.

Keywords: dry fatigue, corrosion fatigue, S-N curve, shot peening, A27cast carbon steel,.

1. Introduction

Fatigue is very general defect style and merits a significant care for the reason that it can cause injury on a material at a stress equal that is far less than the material's design limit. Fatigue has been impute with performance a Role in about 90% of all material fundamental defeats [1] several segments of structural equipment by the materials are regarded to obtain cyclic loading and it is chief to actualize the fatigue quality of these materials. And then, it is also very significant to the advance of the fatigue strength for asserting in contradiction of the security and the reliability of the structural apparatuses. As the fatigue flaws generally start on the materials external, it is very valuable to make strengthening of surface film for the advance of the fatigue quality of the materials [2]. Corrosion fatigue definition is fatigue in a corrosive environment. An aggressive medium can be deleterious for fatigue life of structures and machines. The preservation against corrosion is very necessarily and designers must count corrosion in service not only in view of fatigue [3].Corrosion fatigue is a mechanical degradation of a material under the two actions of corrosion and cyclic loading. Nearly all engineering structures expertise some form of alternating stress and risky to harmful environments during their service life. The environment plays a critical role in the fatigue of high strength structural materials like steel, aluminum alloys, titanium alloys, etc. [4]. The shot peening (SP) method is one of valuable conducts to improve the fatigue quality of metallic materials in several manufacturing regions [5]. Shot peening is a conservative and largely practical process for presenting a film of compressive surface remaining stress. In shot peening, the parts surface is shot with small spherical glass, ceramic or metallic shells, which produces a film of plastic deformation. A reactive compressive residual stress expanse is manufactured when the elastically deformed material under and nearby the compressed zone tries to get well its real geometric shape [6] [7]. Many researchers were study the subject such as study examined the influence of diverse shot peening time (SPT) on the rotating bending fatigue behavior of type 321 austenitic stainless steel. The life improvement factor (LIF) was rise by means of a factor reaching among 1.72 to 5.3. These entire advances were occurred up to 20 minute shot peening time. Further than this point the fatigue conduct has a propensity to reduction[8]. Another researcher investigated the influence of shot peening procedure on the fatigue conduct of ductile iron contained of austenitizing at 875 for 90 minute tracked by austempering at three diverse temperatures of 320C°, 365C° and 400C° was actualized. Rotating-bending fatigue examination was implemented on shot peening specimens using 0.4 – 0.6 mm jolts. Results pointed out that the of austempered fatigue strengths of shot peening specimens austempered at different temperature are improved in 27.3%, 33.3% and 48.4%, consecutively[9]. And another study showed the effect of shot peening procedure on corrosion fatigue of an austenitic& ferritic stainless steel. It has been observed that the shot peening has led to increase in dry fatigue limit by 7 %. The corrosion fatigue test using a hot sodium chloride as a solution, having a pH of 2 at 80°C. Shot peening had an effect on the nearby surface micro flaw progress. The compressive remaining stress field leads to some kind of flaw and then the influence which depresses the flaw advance rate[10] .

The present paper aims to study the effect of shot peening surface treatment at different time on the fatigue strength in dry environment and corrosion environment for A27 cast carbon steel.

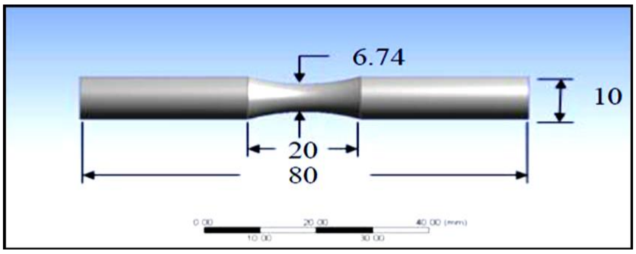


Fig.(2) Fatigue Specimen dimension [11].

2. Material and experimental work

2.1 Material

A 27 grade N-2 cast carbon steel has been used and studied as a work piece material. These specimens were supplied by Nasiriyah thermal electricity station from induced draft fan blades. The chemical analysis result of the used metal,which was performed by ARL Spectrometer device available in the State Company for inspection and engineering rehabilitation. Table (1) shows the measured and standard chemical composition with the percentage weight.

Table (1) Chemical composition of steel A27 (grade N-2)

Element wt.%	C%	Si%	Mn%	P%	S%	Cr%	Mo%	Ni%	Al%	V%	Cu%	Fe%
Standard wt.% Max.	0.35	0.80	0.60	0.035	0.035	–	–	–	–	–	–	–
Measured wt.%	0.324	0.756	0.372	0.021	0.0163	0.040	0.002	0.010	0.0629	0.001	0.016	Bal.

2.2 Experimental procedure

To achieve the aim of this study, many tests on specimens needed to be done and prepared as the following:-

2.2.1 Preparation tensile test specimens

A number of tensile test specimens for inspection are equipped from Cast carbon steel A27 by dimensions shows in Fig. (1) According to ASTM E8M by CNC Milling machine.

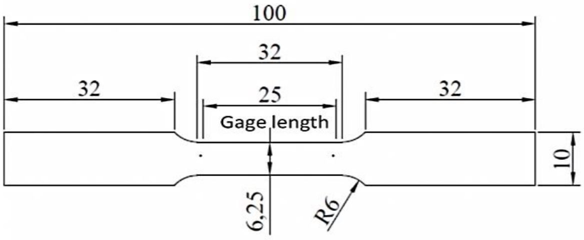


Fig.(1) Tensile Test Specimen Dimensions[11].

2.2.2 Preparation fatigue test specimens

Fatigue specimens are fabricated from Cast Carbon steel A27 based according to the ASTM (E8/E8M-09) specifications by CNC lath machine in dimension was shown in Fig.(2).

The surface of the specimen is smoothed by using silicon carbide papers for finishing.

2.3 Categorization of the tested specimens

The specimens are grouping according to treatment process as shown in Table (2)

Table (2) The Categorization of test specimens.

Symbol		Condition
A		As received
B	B1	Shot peening at 10 minutes
	B2	Shot peening at20 minutes
	B3	Shot peening at30 minutes

2.4 Shot Peening Process

Many tensile, fatigue specimens be subjected to shot peening procedure for generating serious plastic deformation on the samples external surface as of the whole sides using steel ball has diameters 2.25 mm for 10, 20 and 30 minute for each groups using an air-blast device tumbles control model (STB – OB) machine No. 03008 05 type as shown in Fig. (3). the awry nozzle angle is be removed by 10° with respect to the vertical axis. The space between the nozzle and samples location is nearby120mm, shot velocity is 40 m/ min. Average blasting pressure = 12 bar and Fig. (4) Shows the surface shape of specimens after subjecting to the shot peening.

Fig.(3) Shot peening device.

Fig.(4) the surface of specimens after shot peening at 20min.

2.5 Examination and testing

2.5.1Compressive residual stress

Computerized (Lab XRD-6000 shiatsu X-RAY diffraction meter) is Employment in measurement the strain which is the consequence from shot peeing in the crystal lattice and the measure of the strain is applied in brag law to calculate the compressive remaining stress which is gotten from device and were listed in Table (7).

2.5.2 Surface Roughness

The average measurement of the free surface roughness, which was measured at the external face zone of samples (A) and peened area for specimens (B1 , B2 , B3)from table (2) designated using the factor (Ra) which is represented the center-line average of adjacent peaks consequences are shown in Table (7).

2.5.3 Micro hardness test

The micro hardness examination is implemented on cross piece of all samples. The space among any two neighboring evaluations be located (1) mm. The digital Vickers micro hardness device of kind (Qulitest, QV-100 Japan) in the production engineering and metallurgy department. Applied micro hardness test by means of a load 200 gm. for 15 sec. The obtained results were recorded in Table (7).

2.5.4 Tensile Test

The tensile examinations were completed using testing device measuring control Software of type WDW-200E model with a capacity of 200KN.This tool was found in the laboratory of Production Engineering and Metallurgy Department, University of Technology. Examination was performed at room temperature.

2.5.5 Fatigue Test

All fatigue tests were carried out in the laboratories of electromechanical engineering department, University of Technology using PUNN rotary fatigue bending machine as shown in Fig.(5).The experiments are conducted at room temperature and at stress ratio R=-1. The quantity of the applied load (P) is calculated by Newton (N), carried out to the specimen for a recognized amount of stress (σ) measured using (N/mm2) and extracted by utilizing the relation below:

$\sigma b\ (N/mm^2) = (32 \times 135.7 \times P(N))/(\pi \times d^3)$

Where: (σb) is the applied stress (MPa), (P) load, (d) (mm) is the lower diameter of the sample.

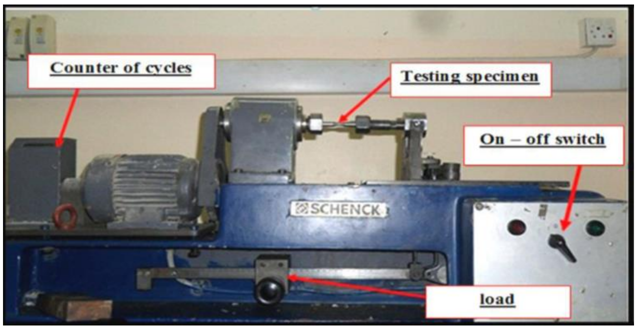


Fig. (5) PUNN Rotary fatigue bending machine

Shot peening specimens and base fatigue specimens of A27Carbon steel are exposed to dry corrosion rotating bending fatigue tests under constant stresses at room temperature with main stress R=-1.the fatigue life was defined using the Basquin method as $\sigma f = ANF^{-\alpha}$ represented the S-N curve of it.

Where: σf= fatigue limit Mpa, A= constant, NF=number of cycle which the metal failed, α= the slop between the applied stress and number of cyclic.

The metal of induced draft fan blades was exposed to corrosion fatigue caused by the fan drafts gases from furnace, where the temperature was about 120 C° and according to calculating of dew point under this temperature, the withdrawn gasses are condensed. These gasses contain the oxides of sulfur, and when it was mixed with drops of water it produced H2SO4 which attacks the blades of the fan. This acid is considered as the main factor in addition to the withdrawn gases to produce the corrosive environment. The corrosion fatigue test was performed in a mixture of corrosive solution corresponding approximately to the ingredients of the environment in which the A27 steel blade is exposed during operation. It was prepared in laboratories of the ministry of Science and Technology .This solution consists of:

- NaCl =17 gm
- Mixture of ash taken from Nasiriyah electric station that precipitate on blades of induced draft fan and produced corrosion on steel A27 metal of blades =24gm
- H_2SO_4 =5ml
- Distilled water= 500ml

This solution is put in corrosion system which is prepared for actualized the corrosion fatigue test as shown in Fig. (6).

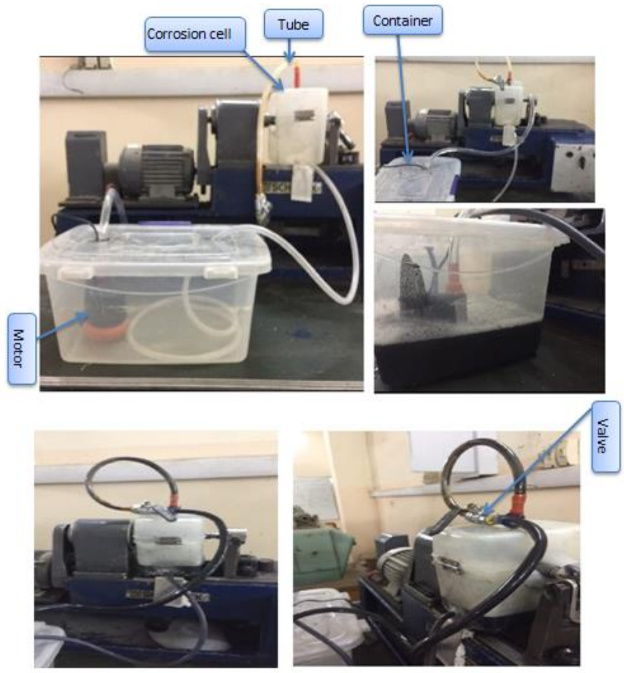


Fig.(6) Corrosion fatigue assembly

3- Results and discussions

The mean values of yield stress and ultimate stress for as received specimens were (230Mpa and 433Mpa, respectively). Depending on these values specimens from group (A) without and with corrosion environment were subjected to rotating bending fatigue at constant stress amplitude with (R= -1) stress ratio at room temperature to find the effect of corrosion on the experimental fatigue life. The experimental results are given in Table (3) The S-N curve was obtained from these results as shown in Fig. (7) the corrosion in general has the overall effect in the fatigue limit it is reduction by 37.5 % that effect on quality of a structure and the strength of the metal. In other words corrosion weakens the surface properties, decreasing its hardness and hence causing a significant reduction in strength of metals. The equation of power law regression is given by using the Basquin method and the fatigue limit at10^7 cycles are given in Table (4).

Table (3) basic S-N fatigue results for dry fatigue and corrosion fatigue.

Applied Stress (σf) (MPa)	Cycle to failure Nf average (cycle)
320	50000
300	73000
280	97000
260	120000
240	312000
220	550000
200	780000
180	1800000
170	2200000
160	No failure
Corrosion fatigue for as received specimens	
280	48000
260	65000
240	85000
220	118000
200	310000
180	510000
160	730000
140	1100000
120	2100000
100	No failure

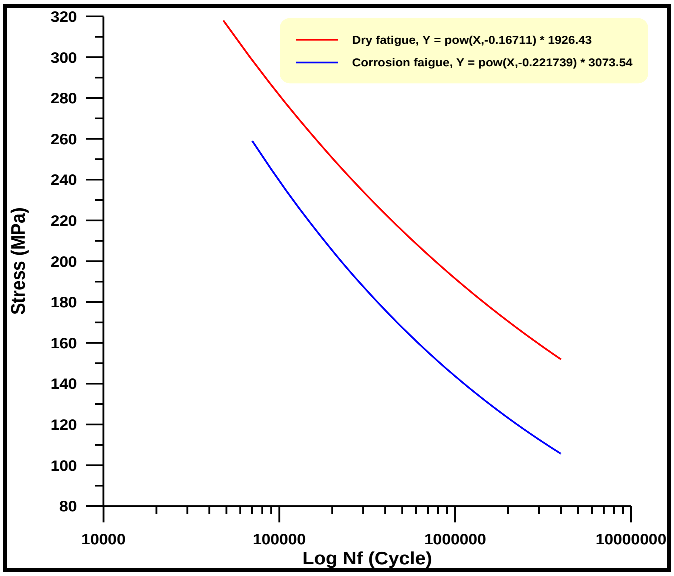


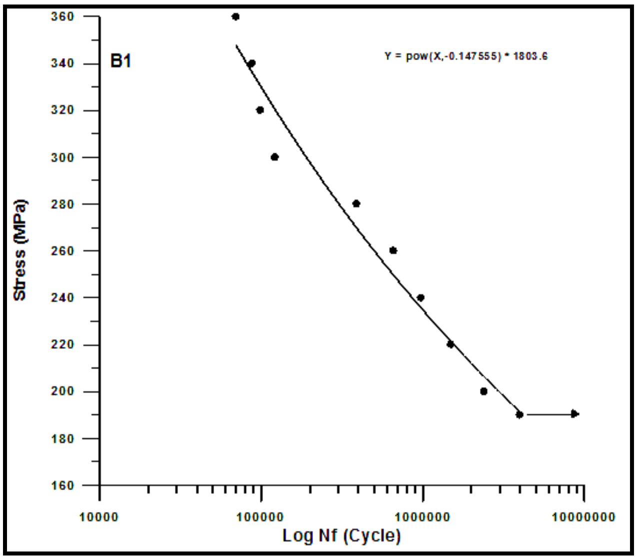
Figure (7) S-N curves for dry and corrosion fatigue conditions.

Table (4) Fatigue limit and S-N Curve Equations for dry fatigue and corrosion fatigue test.

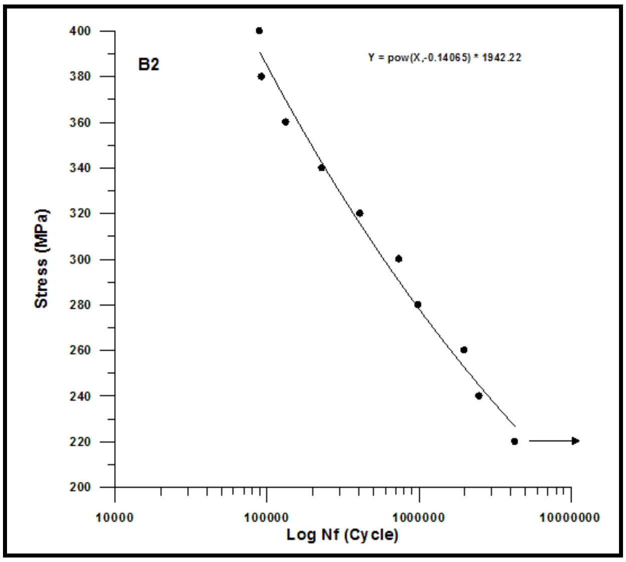
Description	Fatigue limit in Mpa	S-N curve Equation	Reduction in Fatigue limit%
Dry environment	160	$\sigma f = 1926.43Nf^{-0.16711}$	-
Corrosion environment	100	$\sigma f = 3073.54Nf^{-0.221739}$	37.5

The amounts of yield stress, ultimate stress for specimens subjected to shot peening for(10,20,30) minutes were (250 Mpa , 449 Mpa, respectively) for B_1 specimen ,((258 Mpa , 470 Mpa, respectively) for B_2 specimen and (249Mpa, 448Mpa, respectively) for B_3 specimen , dependent on these values samples from group (B_1, B_2, B_3) were subjected to rotating bending fatigue tests. Fig.(8) represented the S-N curves. The experimental results for dry fatigue test exhibited that the best time of shot peening was at 20 minute, which gave an improvement in fatigue limit about 18.7% at 10 minute, 37.5% at 20 minute, 6.25% at 30minute as compared to fatigue limit for untreated specimens.

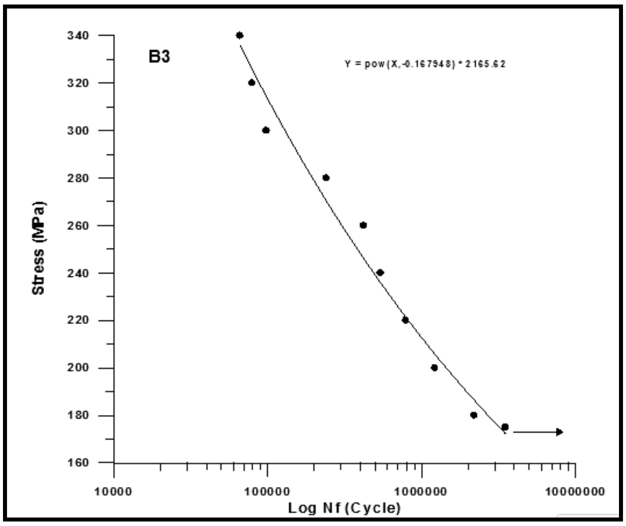
(a)



(b)



(c)



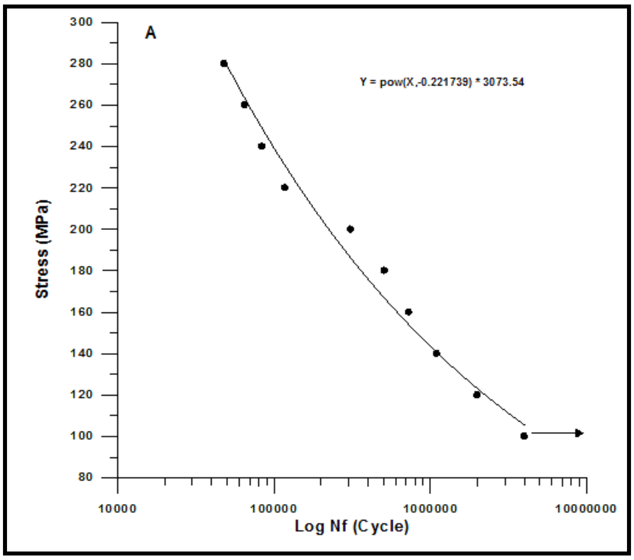
(d)

Fig.(8) The S-N curve with dry fatigue,(a) specimens A,(b) specimens B1,(c) specimens B2, (d) specimens B3.

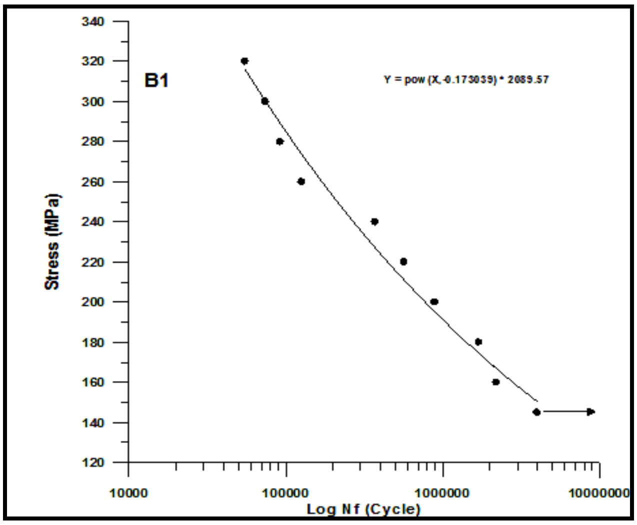
Table (5) Fatigue limit and S-N Curve Equations at Diverse Shot peening Time (SPT).

Specimens symbol	Fatigue limit at $(10)^7$cycle in Mpa	S-N curve Equation
A	160	$\sigma f = 1926.43Nf^{-0.16711}$
B1	190	$\sigma f = 1803.6Nf^{-0.147555}$
B2	220	$\sigma f = 1942.22Nf^{-0.14065}$
B3	170	$\sigma f = 2165.62Nf^{-0.167943}$

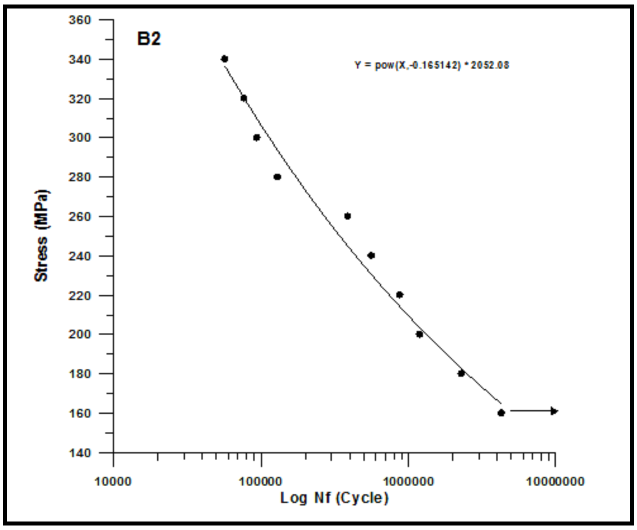
Specimens (B_1, B_2, B_3) exposed to corrosion fatigue at constant stresses .Fig. (9) represented the S-N curves. The experimental results for corrosion fatigue exhibited that the best time of shot peening was at 20 minute.



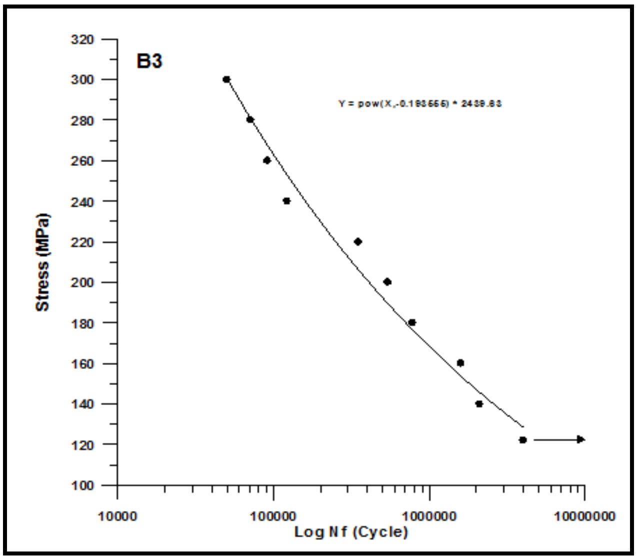
(a)



(b)



(c)



(d)

Fig.(9) The S-N curve with corrosion fatigue ,(a) specimens A, (b) specimens B1, (c) specimens B2, (d) specimens B3.

Table (6) corrosion Fatigue limit and S-N Curve Equations at Diverse Shot peening Time (SPT).

Specimen symbol	Corrosion Fatigue limit a $(10)^7$cycle in Mpa	S-N curve Equation
A	100	$\sigma f = 3073.54 Nf^{-0.221739}$
B1	140	$\sigma f = 2035.57 Nf^{-0.173035}$
B2	160	$\sigma f = 2052.03.57 Nf^{-0.165142}$
B3	120	$\sigma f = 2439.21 Nf^{-0.182666}$

Table (7) shows The testing results of compressive residual stress, surface roughness and micro hardness. from S-N Curve for specimens (A,B1,B2,B3)for dry fatigue test were observed an improvement in the fatigue resistance for specimens (B1,B2 ,B3) .The increases in fatigue limit comparing with Basic metal which is representing the symbol (A) through improved the tensile strength by shot peening which contributed in producing compressive residual stress layer and increase when increasing shot time this layer made the delay in fatigue crake from initiated .compressive residual stresses is the greatest extensively used surface engineering methods in ameliorative the fatigue limit and fatigue life. The contained plastic flow at the surface , resultant in the shot peening method , reasons work hardening of the surface , common roughening of the surface a long with generation of the compressive residual stresses [6][7] . All of these factors can be expected to influence on together the fatigue limit and fatigue life. The variation of fatigue limit with shot peening time can be seen in Fig. (10) , compressive residual stresses increase when shot time increase [12] due to shot peening form high density of dislocation and lead to refinement of grain in upset surface layer after shot which improve fatigue properties in addition to plastic deformation . Shot peening compressive residual stresses and the large amount was at time 20 min which was represented specimen (B2) then it was decreased as the time increased to 30 minute , that shows in specimen (B3) due to the stress in this time reach to fullness and hardens was decreased due to shot peening generating high temperature and low cooling rate . It is recognized that the relations between corrosion and fatigue can dramatically quicken the crack length and propagate the cracks in a fast way and offer fatigue lives shorter than the lives tested in air only [9] the conduct of the S-N curves designate that the fatigue life of corroded samples reduced analogy with that of parent metal due to the controlling factor is the applying load. From the result of Table (4) corrosion in common has the general influence on the surface property of a structure, and if not noticed it could growth to condition that removes the weakness of the material, in other words corrosion weakens the surface and reducing its hardness and hence causing an important decrease in strength of materials, this result agreed well with the conclusion mentioned in reference [13].

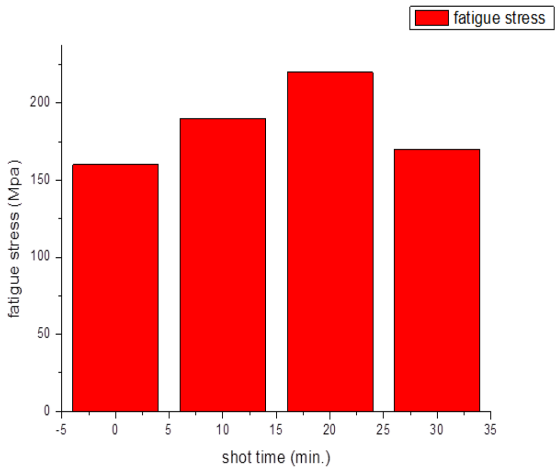


Fig. (10) The influence of shot peening time on the fatigue limit.

Table (7) The testing results of compressive residual stress, surface roughness and Macro hardness

Specimens symbol	Compressive Residual stress Mpa	Surface roughness µm	Micro hardeness Hv (Kg/mm2)
A	-18	0.06	185
B_1	-273.2	1.99	193
B_2	-287	2.31	206
B_3	-265	2.43	190

2.6 Conclusions

1- Fatigue limit of specimens at corrosive environment of (100 Mpa) is greatly decreased compared with fatigue limit of specimens at dry conditions (160 Mpa).

2- The reduction in fatigue limit is 37.5% by corrosive solution in corrosion fatigue test for metal used in this work.

3-Shot peening time of 20 minute in dry and corrosion fatigue give the best results of fatigue limit compared with the base metal it was 220 Mpa by dry medium and 160 Mpa by corrosion medium .

4-After shot peening at 20 minute, the improvement in fatigue limit gradually decreases until it reaches 170 Mpa in dry conditions and 120 in the corrosion environment .

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