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Interaction of Corrosion-Cumulative Fatigue and Shot Peening of 1100-H12 Aluminum Alloy

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Abstract

Corrosion-fatigue occurs by the combined actions of cyclic loading and corrosive environment. The effect of shot peening on cumulative corrosion-fatigue life of 1100-H12 Al alloy was investigated. Before fatigue testing, specimens were submerged in 3.5%NaCl solution for 71 days. Constant fatigue tests were performed with and without corrosive environment. Cumulative corrosion-fatigue tests were also carried out in order to determine the fatigue life before and after shot peening. The constant fatigue life was significantly reduced due to corrosive environment and the endurance fatigue limit was reduced by 13% compared with dry fatigue. In case of shot peening the cumulative , corrosion -fatigue life was increased by a factor of about (2) compared with cumulative corrosion-fatigue life without shot peening.It was found that the CFLIF%(Cumulative Fatigue Life Improvement Factor) was about (2-6) due to shot peening surface treatment .

Keywords: *Corrosion -fatigue , shot peening , 1100-H12 Al alloy, cumulative fatigue damage.*

1. Introduction

If the metals are exposed to the concurred actions of repeated stress and corrosive environment, then its fatigue behavior will become quite different from that in air ,it means that there is a significant decrease in fatigue strength and fatigue life[1].In case of light metals the presence of corrosion is known to reduce their strength significantly ,thus it does great harm to engineering structural integrity of frames ,especially those working in marine environment [2]. The combined action of corrosion and repeated stresses defined by corrosion fatigue .The effect of corrosive actions on a metal surface may cause a general roughening to the surface and lead to the generation of crevices and pits at different points on the surface which result in a greater loss in fatigue strength of the metal when it subjected to fluctuating stresses at the same time, than when each factor acts separately. Corrosion fatigue is considered as the reason of a wide variety of failures in service, including, for example, marine propeller shafts, boiler and superheater tubes, turbine and pump components, and pipes carrying corrosive liquids,...etc. [3].

One of the most important remedies for corrosion fatigue is shot peening .Shot peening is a process in which a round metallic shot is thrown on the metal surface at a relatively high velocity(10-40m/sec) and it also known as acold-working method . Each shot makes a small dent in the metal surface . A plastic flow of the surface grains is generated by the shot impact. There is a several parameters that affect on this process such as (the kinetic energy , impinging angle of the shot impact , the physical properties of the surface (hardness , toughness),...etc).

Fatigue failure, (which cause about 90% of the mechanical catastrophic failures in metal parts and structures) largely start at surface cracks that grow under tensile stresses ;thus shot peening generally results in considerably greater fatigue strength because the residual compressive stresses caused by shot peening will counteract the applied tensile stresses on the metal surface[4].

Menan and Hénaff [5]investigated the interactions between mechanical, environmental and microstructural parameters during corrosion fatigue crack growth of 2024 Al alloy using 3.5% NaCl solution .it was found that the corrosion crack growth rate is higher in NaCl solution than in air or distilled water. Alalkawi et al.[6] examined constant and cumulative fatigue test under the effect of shot peening treatment for two aluminum alloys 2024 and 5052 .It was concluded for 2024 Al alloy that as the shot peening time increases the cumulative fatigue life is improved but above 10 min. The fatigue life is reduced .While shot peening reduced the fatigue life of 5052 Al alloy. Gao.Y.K. [7] studied the fatigue behavior of 7050-T7451aluminum alloy for machined ,laser and shot peened specimens . Results indicated that laser and shot peening improve the fatigue life and strength compared to the unpeened results. Dong et al. [8] predicted the effect of prior corrosion on the crack propagation of aluminum alloy based on scanning electron microscope (SEM).Results indicated that corrosion pits increases the crack growth rate which can be empirically expressed by the term of ($k\sigma_{\max}^{n}a$). Ford. F.P.[9] studied the corrosion fatigue crack propagation rates for aluminum-7% magnesium. It is suggested that the cracking mechanism is slip dissolution and the rate determining steps increase the crack growth. Laurino et al.[10] studied the fatigue behavior of 6101 Al alloy under corrosive media and it was found that corrosion -fatigue interactions reduced the fatigue life of the 6101 Al alloy. The main goal of this work is to report experimental evidence about the constant fatigue and fatigue damage accumulation behavior of 1100-H12Aluminum alloy under corrosion fatigue and studying the effect of shot peening process on the mechanical behavior of the mentioned alloy.

2. Experimental Procedures

Aluminum of the 1100-H12 class is used in the current work and it is primarily used in applications where electrical conductivity , formability , ductility , and the resistance to stress corrosion are more important than strength. Chemical analysis of the metal used was tested at (State Company for Inspection and Engineering Rehabilitation(SIER) in Iraq).The results, which are compared to the American Society for Testing and Materials (ASTM B209) [11], are summarized in Table (1) below while the mechanical properties are listed in Table (2) .

Table 1,
Chemical composition of 1100 Al alloy in wt%.

Alloying element%	Si	Fe	Cu	Mn	Mg	Zn	Other elements*	Al
ASTM B209 [11]	0.95		0.05 - 0.2	0.05	0.05	0.1	0.15	Rem
Measured	0.112	0.447	0.3	0.017	0.004	0.015	0.0126	Rem

*Other elements include (Cr ,Ni, Ti ,Pb, Co)when tested experimentally they found to be in the following percentages (0.003, 0.002, 0.006 ,0.0006, 0.001) respectively.

Table 2,
Mechanical properties of 1100 Al alloy.

Property	Ultimate Tensile strength MPa	Yield Strength Mpa	Elongation % In 100 mm	Modulus of Elasticity Gpa
ASTM B209[11]	min.= 96.5	min.=75.8	min.=6	70
Measured	107	82	7	71

3. Testing Procedures

3.1. Tensile Testing

The experimental mechanical properties listed in table (2) above were measured using (WDW-200E) tensile test apparatus with a capacity of 200KN. The tensile specimen was taken according to American Society for Testing and Materials (ASTM B209) .shape and dimensions of the tensile specimen is illustrated in Figure (1) .

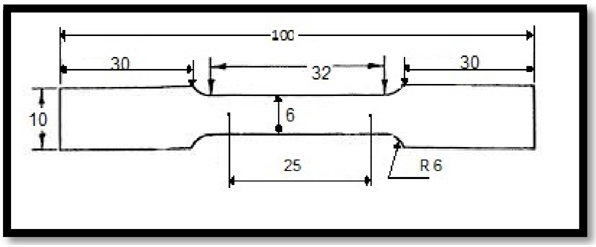

Fig.1. Tensile test specimen according to ASTMB209.

3.2. Fatigue Testing

The AVERY Fatigue Testing Machine Type-*7305* was used to apply reverse loads with or without an initial static load as shown in figure (2).

The fatigue test is a cyclic bending loading procedure with R=-1. The purpose of the test is to generate *S-N* data (stress vs. number of cycles) for metal used.

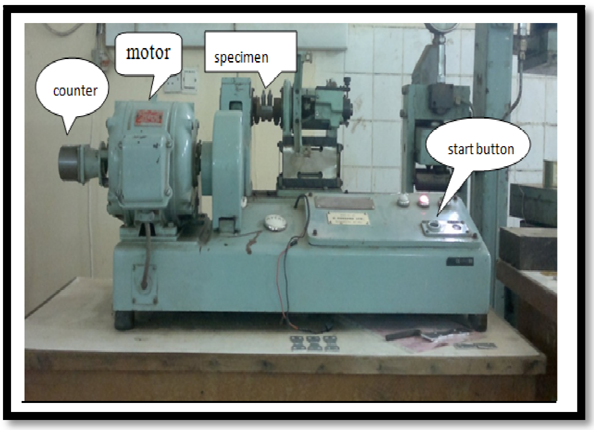

Fig. 2. Fatigue testing machine.

Shape and dimensions of Fatigue test specimen is shown in Figure (3) below:

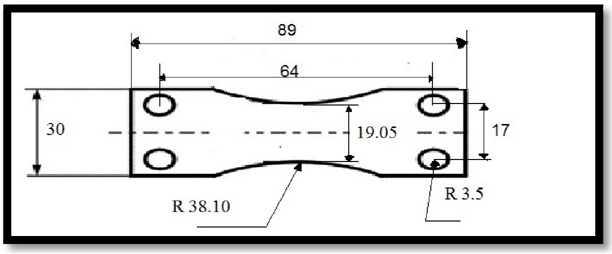

Fig. 3. Shape and dimensions of fatigue specimen (all dimensions in mm) according to ASTM D3479/D3479M–96 standard

3.3. Corrosion Test

The specimens before fatigue testing were immersed in a 3.5%NaCl solution for (71)days especially those serving in marine environment (sea water)[12].

3.4. Shot Peening Procedure

The specimens were shot peening treated from all sides using tumbleset control panel apparatus Model STB-OB Machine No. 03008 with the following properties:

Average ball size = 0.6 mm .
Ball material = cast steel .
Rockwell hardness = (48 - 50)HRC .
Pressure = 12 bars.
Velocity = 40 m/sec .

Shot peening is carried out on fatigue specimens at different time intervals which are (10 , 20, 30) minutes. The shot peening apparatus is shown in Figure (4) below:

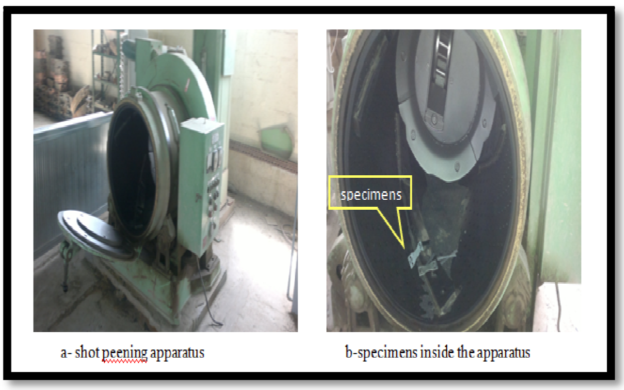

Fig. 4. Shot peening apparatus.

4. Experimental Results and Discussion

4.1. Fatigue Results

Fatigue analysis are normally based on the results obtained from constant amplitude continuous cycling tests. Thus , the first step of work was to establish the base - line data for 12 specimens (dry fatigue) and 12 specimens for(corrosion- fatigue) which were immersed in 3.5% NaCl solution for 71 days .The results are tabulated in Table (3) as shown below:

Table 3,
Fatigue results.

Specimens No.	Theta ($\theta°$)	Applied stress Mpa	N_f Cycles	N_f, Average
Dry condition				
1,2,3	12°	441	19000 , 14000, 16500	16500
4,5,6	10°	393	21000, 27000, 24000	24000
7,8,9	6°	195	276000 , 211000 ,245000	244000
10,11,12	4°	137	2713000, 2870000 ,2960000 (unfailed specimens)	2847667
71 days corrosion condition				
13,14 ,15	12°	441	13000 , 14000 , 18000	15000
16,17 , 18	10°	393	23000 , 24000 ,22000	23000
19,20 ,21	6°	195	252000 , 209000 , 233000	231333
22, 23, 24	4°	137	684280 , 688740 , 693200	688740

From the Table (3) above ,it is clear that there is no effect of corrosion on fatigue life at LCF(Low Cycle Fatigue) .The reason of this finding is due to dominate parameter of the applied load .While the corrosion is not significantly influence on the fatigue life[13]. The following figure (see ,fig.5), indicate that the fatigue life of pre-corroded specimens decreased compared with that of as-received specimens.

Also the fatigue strength is reduced by a factor of 13% compared with dry fatigue strength . An approximately 60% decrease in fatigue strength of 7075-T6 A l-alloy was found by Genel[14] using the same conditions of the present work.

The conventional ,constant stress amplitude S-N curves for the above conditions are shown in the following Figure (see, Fig. 5) :

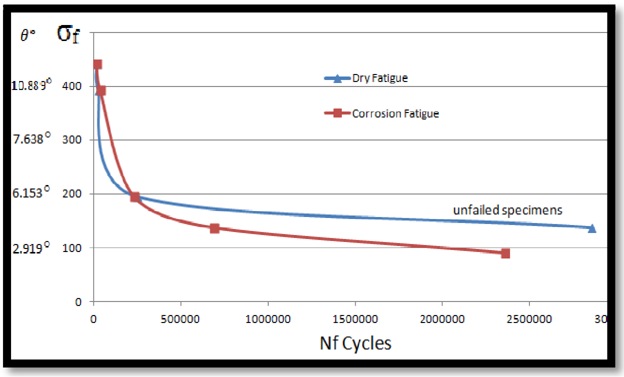

Fig. 5. Conventional ,constant stress amplitude S-N curves for dry and corrosion fatigue conditions.

The S-N curves has been used by several workers to evaluate the cumulative fatigue damage .The Endurance limit at 10^7 cycles and reduction factor for dry and corrosion fatigue conditions are shown in Table (4). P.S.Pao et al.[13]tested 7075-T351 Aluminum alloy under fatigue loading using the 3.5%NaCl solution as a medium. They found that the threshold stress levels are significantly reduced due to the presence of corrosion pits.

The presence of a corrosive environment during fatigue loading eliminates the fatigue limit for the metal used [15].

Table 4,
Endurance limit at 10^7 cycles and reduction factor.

Condition	Equations	Endurance limit at 10^7 cycles	Reduction Factor
Dry fatigue	$\sigma_f = 3982.5\ N_f^{-0.232}$	62 Mpa	
Corrosion fatigue	$\sigma_f = 12931\ N_f^{-0.338}$	55 MPa	13%

4.2. Cumulative Fatigue Damage Results

Most engineering components in service are subject to a complex , non-constant ,state of stress .Each cycle or group of cycles at a particular amplitude induces damage to the component : the addition of all this damage is called Cumulative Damage (CD) .In laboratories ,CD is usually examined by testing specimens with a definite number of cycles at one stress level ,and then to continue the test at other stress levels till failure [16] Cumulative fatigue results for 71 days corrosion are listed in Table (5) below:

Table 5,
Cumulative fatigue results for 71 days corrosion.

Specimen No.	Loading sequence (MPa)	N_f Cycles	N_f av.
25 , 26 , 27 , 28	L -H (195- 441)	22000, 25000 28000,31000	26500
29 , 30 , 31 , 32	H-L (441-195)	45000 , 36000 , 29000 , 29000	34750

Table (6) illustrate the cumulative corrosion-fatigue with the interaction of shot peening at different times of peening.

Table 6,
Interaction of 71 days cumulative corrosion fatigue with shot peening for different times.

Specimens No.	Loading Sequence (MPa)	Nf	N_f Average
		Shot peening time -10 min	
33 , 34 , 35	L-H (195 - 441)	50000 58000 58000	54000
36 , 37 ,38	H-L (441 - 195)	43000 41600 48000	44200
		Shot peening time -20 min	
39 , 40 , 41	L-H (195 - 441)	50000 , 50000, 50000	50000
42 , 43 , 44	H-L (441 -195)	47000 , 46000 , 46500	46500
		Shot peening time -30min	
45 , 46 , 47	L-H (195 - 441)	38000 , 48000 , 43000	43000
48 , 49 , 50	H-L (441 -195)	54000 , 55000 , 54500	54500

4.3. Cumulative Fatigue Life Improvement Factor(CFLIF%)

The percentage of cumulative fatigue life improvement factor can be calculated by the following equation (eq.1) [17] :

$$\text{CFLIF\%} = \left(\frac{\log Nf\,(corr.+sp) - \log Nf(corr.)}{\log Nf\,(corr.+sp)}\right) \times 100 \quad \ldots(1)$$

where :

N_f (corr.+sp) =No. of cycles to failure at the interaction of corrosion fatigue with shot peening (sp) for two stress levels.

Nf(corr.) =No. of cycles to failure at corrosion environment for two stress levels .

Table (7) shows the CFLIF% results.

Table7
Results of CFLIF% under the interaction of corrosion fatigue with shot peening

Shot Peening Time	10 min.	20 min.	30 min.
L-H (MPa)	195 - 441	195 - 441	195 - 441
H-L (MPa)	441- 195	441- 195	441- 195
	6.53	5.85	4.53
CFLIF%	2.26	2.72	4.138

It can be noticed that the CFLIF% is positive and this means that SP treatments improved the cumulative corrosion-fatigue life of 1100 Al alloy.In general shot peening had a noticeable effect on cumulative fatigue life ,see table(7).The process of shot peening affect on crack growth life by increasing the time to failure by a factor of (2 - 4) for the lower applied stresses or by a factor of (1.2 - 2.7) for the higher stress levels [18].

In the present work ,shot peening improved the corrosion-cumulative fatigue life by a factor of approximately (2).

Seong et al. [12] studied the effect of shot peening on the fatigue life of 7075-T6 using 3.5% NaCl solution for one week to one year under room temperature .They concluded that the shot peening has superior effectiveness to increase the corrosion-fatigue life and improved the fatigue limit by 24% compared with corrosion fatigue limit .

5. Conclusions

From the current work on the interaction of cumulative corrosion-fatigue and shot peening process of 1100 Al alloy, the following remarks can be derived :

1. Constant fatigue life was significantly reduced under corrosive environment and the fatigue strength was reduced by a factor of 13%.
2. CFLIF% was found to be from (2 - 6).
3. Shot peening improved the cumulative corrosion-fatigue life by a factor of about (2).
4. Shot peening is a useful method for components working under corrosive environment.

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تداخل تأثير الكلال التراكمي التآكلي مع القذف بالكريات لسبيكة المنيوم 1100-H12

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الخلاصة

يحدث الكلال التاكلي بوساطة تأثير مركب بين الحمل الدوري والوسط التآكلي .تمت دراسة تأثير التصليد بالقذف بالكريات على عمر تراكم الكلال التآكلي لسبيكة الالمنيوم(1100-H12). تم غمر العينات بمحلول يحتوي على نسبة %٣.٥ NaCl لمدة (٧١) يوم قبل اجراء فحوصات الكلال.تم اجراء فحوصات الكلال ثابتة السعة مع و بدون الوسط التاكلي . كذلك تم اجراء فحوصات تراكم الكلال التاكلي لغرض ايجاد اعمار العينات قبل وبعد عملية القذف بالكريات . اعمار الكلال عند فحوصات السعة الثابتة قلّت بشكل واضح نتيجة للوسط التاكلي وان حد الكلال قلَ بنسبة ١٣% مقارنة مع الكلال الجاف . وجد ان في حالة القذف بالكريات فان عمر تراكم الكلال التاكلي قلَ بعامل (٢) مقارنة مع عمر تراكم الكلال بدون عملية القذف . تم التوصل الى ان عامل تحسن عمر الكلال التراكمي بوصفه نسبة مئوية (CFLIF%) تراوح ما بين (٦-٢) نتيجة لمعاملة السطح بالقذف بالكريات .