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Corrosion Fatigue Strength under the Effect of Shot Peening Treatment of 6063-T6 Al-alloy

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ABSTRACT

Evaluation of 20 min. shot peening surface treatment on fatigue strength of 6063-T6 Al allay is presented under 3.5% NaCl solution from one day, one week and one month under room temperature and stress ratio R= -1. The results show that the shot peening has strong effect on the fatigue strength at 10^7 cycles for corroded specimens. In case of shot peening ,only 17.5% loss in fatigue strength even after submerging for one week compared with 60% of the fatigue strength was reduced in case of un shotted specimen . But for one month pre – corroded specimens, the fatigue strength was reduced by 64% in corrosion environment while shot peening improved the above reduction to be about 44%.

Introduction

Shot peening is a cold working process in which the surface of a part is bombarded with small spherical media called shots. Every shot striking the material acts a tiny peening hammer, importing to the surface a small indentation or dimple. Shot peening has develop an even layer of metal that it is a state of residual compressive stress.

Oskouei and Ibrahim have reported that the values of the compressive stresses are at least as high as 50% of the ultimate strength of the material. The fatigue limits of specimens containing an artificial small hole were increased by shot peening and stress shot peening (SSP) was more effective in improving fatigue limit (Oskouei and Ibrahim, 2011).

The fatigue limit of spring steel specimens containing a surface defect increased 22%-51% for shot peened and 72%-100% increased for stress shot peened (Biallas and Maier, 2007).

Moreover, it is known that shot peening is one of the most common surface treatment to improve the fatigue strength of the metallic products. Furthermore shot peening can work harden and change the dislocation density just near the surface layer .Although shot peening treatment increase the surface roughness of the samples and seems to deteriorate the fatigue strength by increasing the density of crack nucleation sites , but the beneficial effects of compressive residual stresses and work hardened layer are superior (Wangand Fan, 2006; Kand et al., 2010; Engelhardt and Macdonald, 2010).

This study aims to investigate the effect of prior shot peening process on the corrosion fatigue behavior of 6063-T6 aluminum alloy.

Corrosion Fatigue

Fatigue caused under corrosive environment is termed as corrosion fatigue. It is the degradation of a material under combined action of cyclic loading and corrosion. It is known that fatigue failure constitutes for the maximum percentage of mechanical failures and thus parts exposed to harmful environments experience significant reduction in service life. Corrosion fatigue affects many metals and alloys like iron, titanium, aluminum and their alloys. And though high strength materials are developed with high threshold limits and can be used at higher stress levels, the primary concern lies in the tendency of these materials to resist corrosion. (Gilbert, 1956).

The presence of a corrosive environment during fatigue loading eliminates this stress advantage, and the fatigue limit becomes almost insensitive to the strength level of the alloys. (Kitegava and Devereux, 1972).

The existence of corrosion is known to significantly reduce the strength and hardness of metals, especially of light metals, thus it does great harm to engineering structural integrity of frames, especially those serving in marine environment. Therefore, the accurate evaluation and prediction of fatigue performance for the aircraft structural components are common and importance issues (Oskouei and Ibrahim, 2011). With ever increasing demands for higher efficiency and typical light weight, both aerospace and aircraft industries call for a maximum exploitation of potentials of materials, thus, purely empirical models that rely on large safety factors are of limited uses. Up to now, most researchers have reached a consensus that models that are closely related to the microstructure behavior provide a more reliable basis of fatigue life prediction based on adequate amount of fatigue testing data (Biallas and Maier, 2007; Wangand Fan, 2006; Kand et al., 2010; Engelhardt and Macdonald, 2010; Jones ,2008). To clarify the micro mechanism of corrosion and fatigue damage, there have been increasing interests in fatigue tests with high-resolution microscopic techniques. In situ fatigue studies conducted in a scanning electron microscope (SEM) has been realized as SEM with the servo-hydraulic loading system.

Studies have demonstrated that in situ fatigue test with SEM is an effective way to investigate material behavior in nano scale in many aspects, for example, the development of plastic slip feature (Wang et al., 2008; Biallas et al., 2005; Tao et al., 2010), crack initiation and propagation behavior Wang et al., 2004; Wang et al., 2006; Gilbert, 1956 ; Kitegava and Devereux,

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1972), especially with the existence of natural or corrosion flaw (Pao et al., 2000; Burns, 2010; Wang et al., 2003; Jones and Hoeppner, 2009; Sankaran et al., 2001).

Corrosion, in its various forms such as pit and exfoliation, must be taken into account in assessing the fatigue performance of structure due to the damage introduced by the surrounding circumstances.

Lots of studies have been done on inspecting the combination behavior of fatigue and corrosion recently (Jones and Hoeppner, 2009; Sankaran et al., 2001; Gruenberg et al., 2004; Sangshik et al., 2009; Genel, 2007; Birbilis et al., 2006). In addition, the mechanism of corrosion on fatigue crack propagation may be a chemical reaction causing by anodic dissolution and hydrogen embrittlement so called as corrosion-blunting-fracture model for corrosion fatigue crack propagation (Mhaede, 2011).

Initiation and the early stage of fatigue crack propagation on the free specimen surface with different prior corrosion damage were experimentally investigated by SEM. Real time images of small crack behavior have been clearly captured in micro scale. Results indicate that the pre-corrosion state has a significance effect on the fatigue cracking behavior of 6151-T6 alloy. In addition, the early stage of fatigue crack propagation behavior is similar to that of previous literature (Wangand Fan, 2006; Wang et al., 2008; Wang et al., 2004; Wang et al., 2006; Kitegava and Devereux, 1972; Wagner, 1999; Habibiet al., 2012; Zupanc and Grum, 2010), especially in the fatigue model such as crack-like discontinuities inherent in the aluminum alloys with the existence of 'rough flaw'.

Experimental work

The investigation was carried out on 6063-T6 Al. alloy. Fatigue specimens were corroded prior to Fatigue tests. Generally metal components need longer time in the natural environment conditions. Therefore, the corrosion- fatigue tests performed within few days.

Chemical composition

Chemical composition of 6063-T6 Al. alloy was done at the specialized institute using x-rays method. The results, which are compared to the American standards, are tabulated in table (1).

Table 1. Experimental and standard chemical composition of 6063-T6 Al-alloy, wt%

Material	%Si	%Fe	%Cu	%Mn	%Mg	%Zn	%Cr	%Al
6063-T6 experimental	0.477	0.247	0.021	0.019	0.743	0.055	-	Rem.
6063-T6 standard	0.2-0.6	0.35	0.1	0.1	0.45-0.9	0.1	0.1	Rem.

Mechanical properties

Tensile tests were carried out at RT (room temperature, 30°C). The tensile tests have done using (Instron 225 testing machine) that has a maximum capacity of 150KN and the mechanical properties of the alloy used can be illustrated in table (2).

Table 2. Mechanical properties of 6063-T6 Al alloy

Property	σ_u(MPa)	σ_y(MPa)	E(GPa)	Ductility %	Hardness (HB)
Experimental	250	215	68	16.1	75
Standard RT	240	215	69	12	73

Fatigue testing machine

Rotating bending fatigue tests were conducted at RT under stress ratio R=-1. This machine was used for fatigue tests. The test rig has a property of automatic cut-off when specimen fails. Figure (1) shows the fatigue testing machine. (AVERY Type 7305).

Figure 1. the fatigue testing machine.

Figure (2) shows the shape and dimensions of fatigue specimen slandered 50103. The manufactured specimens were classified into three groups as given in table (3).

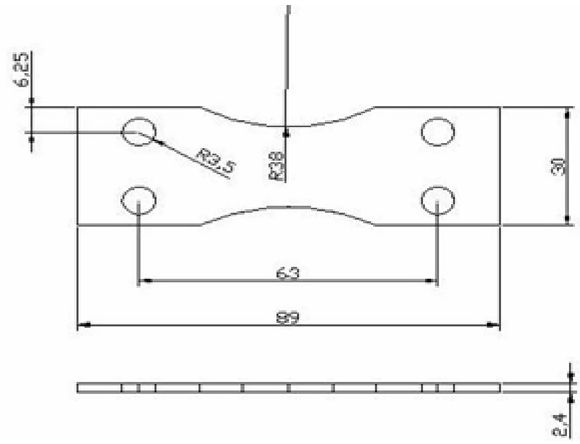


Figure 2. The shape and dimensions of fatigue specimen (all dimensions in mm)

Table 3. The plan of the experimental work

Experimental work	No. of specimens
S-N curve fatigue tests As machined	12 specimens
S-N curve fatigue corrosion	36 specimens
S-N curve fatigue prior SP (shot peening) at (20 min.) (Fatigue + corrosion)	36 specimens

Shot peening

The specimens were shot peened- treated from all sides at the Institute of Technology of Alsaklawaya using tumbleset control speed panal model STB-OB machine No. 0300805.

Cast steel – shot with hardness of 48 – 50 HV and a nominal diameter of 1mm was chosen. A constant specimen distance from the nozzle of around 100mm was maintained. Surface coverage was set to 100% with an average blasting pressure of 12 bar was achieved.

Corrosion test

The specimens before fatigue tests were placed in 3.5% NaCl solution chamber in accordance with ASTM B117 for 24 hours (one day), 168 hours (7 days) and 720 hours (one month). (Zupanc and Grum, 2010).

Experimental results and discussion

S-N curve data for 6063-T6 Al-alloy without shot peening (As machined) is illustrated in table (4)

The fatigue S-N curve of the Aluminum alloy under RT (room temperature) can be analyzed based on Basquin equation form as follows:

$$\sigma_f = 1017\, N_f^{-0.1497} \quad ------1$$

where σ_f is the applied stress at failure

N_f is the number of cycles at failure due to the applied stress σ_f

Using least square fitting curve method to obtain the experimental constants A and α, the constants are 1017 & -0.1497 respectively. The fatigue behavior can be seen in figure (3).

Table 4. S-N curve fatigue test results at room temperature (RT)

Specimen No.	Applied stress σ_f(MPa)	N_f (cycles)	Average N_f (cycles)
1,2,3	300	6020, 8125,7 900	7348
4,5,6	220	21800, 19600, 22100	21167
7,8,9	160	88100, 91600, 72800	84167
10,11,12	135	$1.5*10^6$, $1.12*10^6$, $1.09*10^6$	$1.24*10^6$

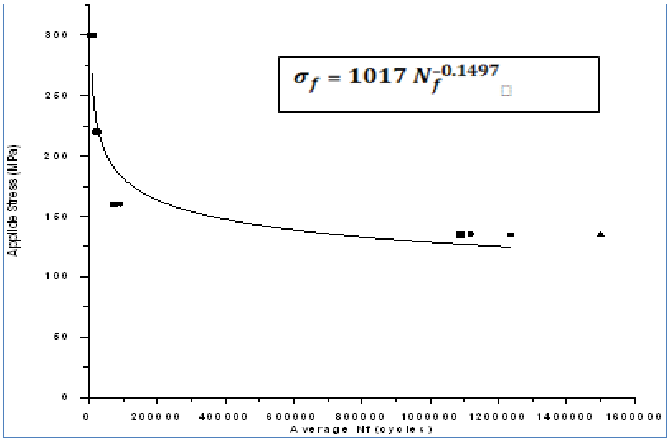


Figure 3. Shows the S-N curve behavior for the above data which gives the fatigue strength at 10^7 cycle is (91) MPa.

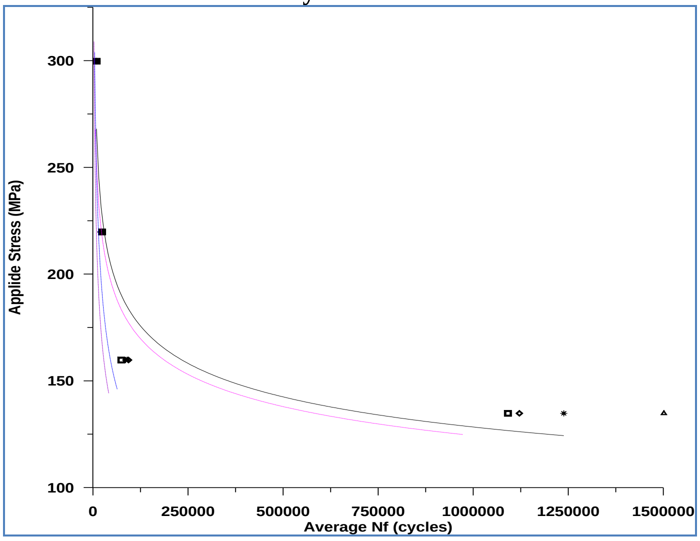
The S-N curve data of the above alloy at the same stresses but under corrosion condition is given in table (5), for different pre-corrosion times.

Before fatigue testing, specimens were submerged in 3.5% NaCl solution for one day, one week and one month under room temperature.

Table 5. Basic S-N curve data fatigue- corrosion at different pre-corrosion times

Specimen No. One day	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
13, 14, 15	5100, 6800, 5900	300	5933
16, 17, 18	17800, 15600, 12800	220	15400
19, 20, 21	72600, 80800, 66800	160	73460
22, 23, 24	$0.9*10^5$, $0.95*10^5$, $1.07*10^6$	135	$1.05*10^6$
Specimen No. One week	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
25, 26, 27	5000, 4200, 4000	300	4400
28, 29, 30	15200, 16000, 15100	220	15433
31, 32, 33	52600, 61500, 63200	160	59100
34, 35, 36	$0.71*10^5$, $0.62*10^5$, $0.58*10^5$	135	$0.64*10^5$
Specimen No. One month	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
37, 38, 39	3000, 2800, 1900	300	2567
40, 41, 42	10200, 12500, 9600	220	10767
43, 44, 45	33600, 29600, 35500	160	32900
46, 47, 48	$3*10^4$, $4.2*10^4$, $5.2*10^4$	135	$4.13*10^4$

Figure 6. Shows S-N curves, for specimens pre-corroded for one day to one month



The fatigue strength decreased considerably as the exposure time for pre- corrosion increased as shown in table (6).

Table 6. fatigue strength at 10^7 cycles with different time of corrosion.

conditions	Corrosion time	S-N curve equation	fatigue strength (MPa) at 10^7 cycle
Dry fatigue	Zero	$\sigma_f = 1017\ N_f^{-0.1497}$	91
corrosion fatigue	One day	$\sigma_f = 982\ N_f^{-0.1496}$	88
corrosion fatigue	One week	$\sigma_f = 3035\ N_f^{-0.2743}$	36.5
corrosion fatigue	One month	$\sigma_f = 2660 N_f^{-0.274}$	32

Table (7) gives the data for S-N curves under shot peening treatment for 20 min. and pre corroded for one day, one week and one month.

Table 7. S-N curves data of shot peened specimens, the effect of pre corrosion

Specimen No. One day	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
49, 50, 51	8020, 11500, 9600	300	9707
52, 53, 54	30700, 32600, 43900	220	35733
55, 56, 57	115800, 116000, 66800	160	99533
58, 59, 60	$1.62*10^6$, $1.7*10^6$, $1.72*10^6$	135	$1.68*10^6$
Specimen No. One week	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
61, 62, 63	7200, 8000, 8200	300	7800
64, 65, 66	17200, 18100, 19000	220	18100
67, 68, 69	66000, 80000, 71000	160	72333
70, 71, 72	10^5, $0.8*10^5$, $0.6*10^5$	135	$0.8*10^5$
Specimen No. One month	N_f (cycles)	Applied stress σ_f(MPa)	Average N_f (cycles)
73, 74, 75	6000, 6200, 7000	300	6400
76, 77, 78	13000, 15200, 16000	220	14733
79, 80, 81	42000, 40800, 43200	160	42000
82, 83, 84	$6*10^4$, $7.2*10^4$, $8*10^4$	135	$0.7*10^5$

The fatigue strength of 6063-T6 Al-alloy can be illustrated in table (8). This table shows the improvement of fatigue strength at 10^7 cycles compared with table (6)

Table 8. Fatigue strength at different corrosion times with 20 min prior shot peening

conditions	Corrosion time with SP 20 min	S-N curve equation	fatigue strength (MPa) at 10^7 cycle
Dry fatigue	Zero Without SP	$\sigma_f = 1017\ N_f^{-0.1497}$	91
corrosion fatigue	One day	$\sigma_f = 1079\ N_f^{-0.15}$	96.2
corrosion fatigue	One week	$\sigma_f = 7800\ N_f^{-0.288}$	75
corrosion fatigue	One month	$\sigma_f = 6450\ N_f^{-0.3}$	51

The overall behavior of the present alloy under different times of corrosion with prior shot peening at 20 min. is presented in figure (7).

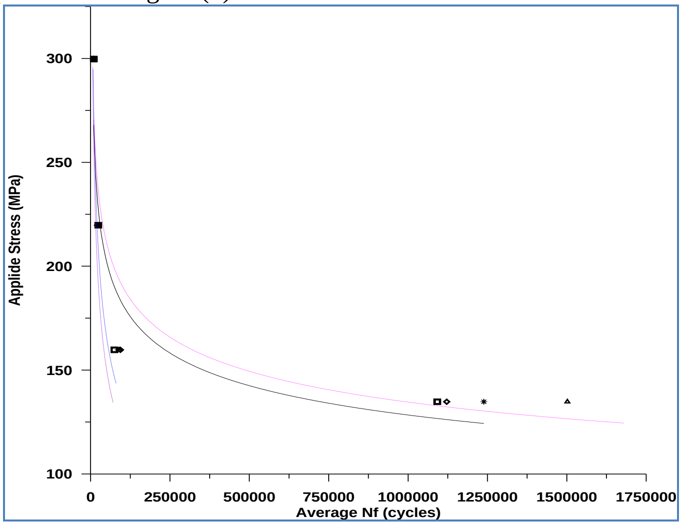


Figure 7. S-N curves behavior under 20min. SP and different times of corrosion.

Discussion

Corrosion may significantly reduce the fatigue strength of most metallic materials. The strong reduction of fatigue strength depends on the corrosion time testing. Shot peening may improve the corrosion fatigue resistance, but the degree of improvement depends on the material – environment combination. (Speldel, 1981).

Table (9) illustrates the fatigue strength for different conditions of corrosions.

Table 9. Fatigue strength under different conditions of corrosion

$\sigma_{E.L}$ MPa Fatigue	$\sigma_{E.L}$ MPa Corrosion fatigue			$\sigma_{E.L}$ MPa SP prior to Corrosion fatigue		
Dry	One day	One week	One month	One day	One week	One month
91	88	36.5	32	96.2	75	51

Surface hardness of dry specimens is 75 HB (table 2) while that of the shot peened specimens is 87HB (average value) showing about 16% increase. This value of increase in hardness due shot peening is caused by the plastic deformation of the shot causing work hardening in the surface of metal. Cheang observed 17% increases in surface hardness due to shot peening for Al. 7075-T6 (Cheong et al, 2005).

Fig.(6) and table (6) show the fatigue strength at 10^7 cycles for dry specimens (unshotted) and pre corroded for one day , one week and one month respectively . These results show that the fatigue strength slightly deceased for one day corroded (3.3% reduction in fatigue strength) , while decreased considerably as the exposure time for pre-corrosion increased (one week and one month) . The fatigue strength of one week was 63.5 MPa and 32 MPa for one month. A reduction of 60 % in fatigue strength of one week and about 65% for one month respectively. The same findings were observed by cheong and kim (Cheong and kim, 2003) for 7075-T6 Al-alloy .

Table (8) shows an improvement in fatigue strength due to 20 min. Shot peening – for one day pre-corrosion the fatigue strength is improved by about 6% while at one week and one month , reduction in fatigue strength was observed to be 17.6% and 44% respectively . This presents that shot peened specimens have better behavior under corrosion than dry specimens (unshotted). It is considered that the shot peening treatment induced residual compressive stresses generating protective layer resulting in an increase of the resistance to corrosion fatigue crack initiation (Lifka and sprowls,1970).

Conclusion:

- Shot-peened of 6063-T6 Al-alloy specimens have better resistance to 3.5% NaCl solution corrosion fatigue behavior which many be considered to be applicable afterwards to actual structures under corrosion.
- Fatigue strength of un-shotted specimens were greatly reduced under corrosion times (one week and one month).
- Shot peening treatment improved the fatigue strength by more than 100% for one week corrosion while about 60% for one month.

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