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Prior Aggressive Corrosion and Fatigue of AA6063-T6 under Shot Peening Application

Mazin Mahmood Yahya[1, *], Abdulwahab.M. Al-Mushehdany[2], Hussain Jasim M. Alalkawi[3]
[1,2,3]Aeronautical Techniques Engineering Department, Bilad Alrafidain University College, Iraq

Abstract

The mechanical and constant fatigue behavior of AA6063-T6 exposed to aggressive 3.5 wt.% NaCl solution corrosion has been investigated. The selected alloy used in this work is typically employed in structured components like aircraft spars. Some tensile and fatigue specimens were hardened using shot peening (SP) treatment for 10 mins, shot peening time. The experimental results revealed that the (UTS) and (YS) were reduced by 10.88% and 9% respectively due to corrosion while ductility increased from 12.5% to 14%. SP treatment improved the above reduction percentage to 8.17% for (UTS) and 7.53% for (YS). Corrosion-fatigue had a significant impact on fatigue life as well as strength at lower stress levels, but had no influence at higher stress levels. The endurance fatigue limit (EFL) reduced to 62.64 MPa and raised to 64 MPa due to corrosion when using (SP) treatment.

Keywords: AA6063-T6, 3.5%NaClcorrosion, mechanical properties, constant fatigue loading, shot peening (SP)

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1. Introduction

Shot peening (SP) has beneficial applications in improving the tensile and corrosion-fatigue properties. (SP) generates compressive residual stresses (CRS). There are many examples relevant peened parts such as fuselage skin, landing gear, wing ribs etc. In addition, several references have employed (SP) and determined that (SP) has a significant positive influence on mechanical and fatigue properties regarding different aluminum alloy grades [1]. The AA1100 aluminum alloy was subjected to a compression extrusion load using two ACRHS and UCRHS extrusion Dies. The extruded metal from these dies and the received metal were subjected to tensile and fatigue tests, in the absence of corrosion and when there was corrosion for a period of 90 days in a salt solution of 0.35% Nacl. The results of the tests showed that the corrosion reduces the fatigue strength at 10^7 cycles from 40 to 33.65 Mpa for the samples as received and from 49.47 to 46.73 Mpa for the ACRHS samples and from 49.5 to 45.89 MPa for the UCRHS samples. The results showed that the best mechanical and fatigue properties under the influence of corrosion were the samples extruded through the UCRHS die [2].

The mechanical and buckling properties of AA2024 at elevated temperatures have been studied. Thermal tensile rig of 400ºC capacity was used to obtain the properties of the alloy. While a thermal rotating buckling machine was used for buckling tests, the use of high temperatures led to a decrease the buckling and mechanical property. The use of Euler theory gave higher results for the properties buckling, but by using safety factor, the results were closer to reality [3].

Over the past years, the use of AA7075 alloy has increased due to its improved mechanical and fatigue properties. The use of Nano composites needs deeper studies to know the mechanical and fatigue properties. The current study uses stirs casting route of AA7075 with Nano particles of AL_2O_3 (35nm size). The mechanical and fatigue tests of Nano composite and matrix were done at room temperature. Low and high cycle fatigue were subjected to base metal and composites. To evaluate the behavior of Nano composite samples SEM was applied. The use of Al2o3 Nano improved the mechanical and fatigue properties comparing with the matrix. The improvement in properties is due to the grain reinforcement and to the distribution of Al2o3 in the matrix [4].

* Corresponding author:dr.mazin@bauc14.edu.iq

The current research used 10 min (SPT) as optimum peening parameter following the work of Ref. [5].The impacts of several surface treatments on performance of fatigue crack growth that is related to the friction stir welded 2195 Al alloy have been explored. The goal has been to increase welded joint fatigue life and decrease fatigue crack growth rates. At stress ratio (R) of 0.10 and 0.70, the crack growth rates have been characterized and assessed under various peening conditions. The surface and through-thickness residual stress distributions for various regions of a weld were examined and shown. Following laser peening, tensile residual stresses created throughout welding were shown to become considerably compressive. The influence of compressive stress was thought to be accountable for the welds' increased resistance to fatigue crack growth. When put to comparison with peening and native welded specimens, the results show that laser peening reduces fatigue crack growth rates significantly. This slower rate of fatigue crack growth has been equivalenting to unwedded base material [6].

SP's effect on the fatigue characteristics regarding 0Cr13Ni8Mo2Al steel was investigated. Experiments have been used for determining the alterations in surface topography, surface roughness, and the residual compressive stress field. Shot peening increases fatigue characteristics, and fatigue crack sources are moved to area beneath hardened layer, according to the results. Due to its sensitivity to surface roughness, low Almena intensities must be utilized in the case SP 0Cr13Ni8Mo2Al steel [7].

SP can be defined as a mechanical surface treatment that improves fatigue characteristic of the metallic components. The research object for fatigue analyses prior to and following SP was a T-welded structure that has been manufactured from Q345D steel through CO2 gas shielded arc welding, which represents a typical joint that is utilized in River-Sea-Going Ships (RSGS). Metallographic phase, micro-hardness, roughness, residual stress, and surface topography regarding near weld toe region have been characterized with a goal of examining SP influence on the fatigue life and determining the reason for the optimal SP parameter of the T-welded joint specimens [8].

The contributions regarding the high densities of dislocation, residual compressive stresses, and surface roughness caused by SP to the enhancement of Al 2024 fatigue life are evaluated individually. For both peak-aged (T6) and aged (T3) conditions, stress amplitudes to several fatigue cycles (S-N) curves and micro crack propagation (da/dN-ΔK curves) have been specified. Fatigue tests are used to analyze fatigue behavior regarding electro polished (which is reference condition), shot peened, shot peened and stress relieved, shot peened and polished, and shot peened, stress relieved, and polished. [9].

2. Experimental work

2.1 Tensile and Fatigue Specimen

The medium strength aluminum AA6063-T6 is largely utilized in structural components. Table (1) lists the mechanical and chemical properties regarding such alloy

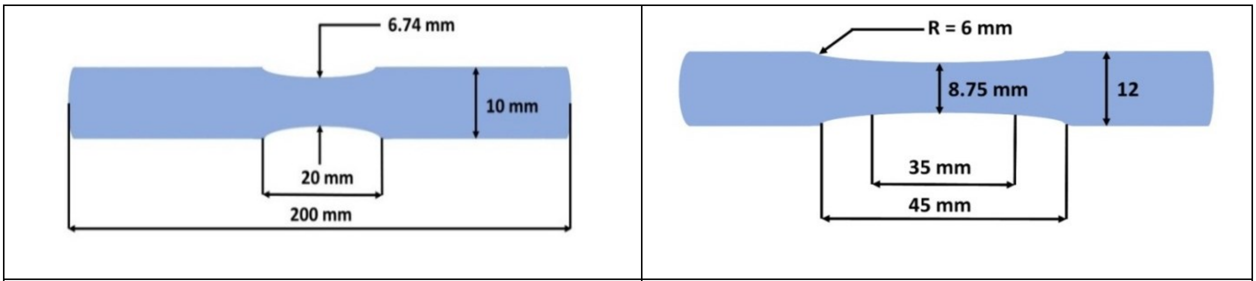
Table (1) AA6063-T6 chemical analysis

Chemical analysis									
Standard	**Si**	**Mg**	**Fe**	**Cr**	**Cn**	**Zn**	**Mn**	**Ti**	**others**
Ref. [10]	0.2	0.45	0.35	0.1	0.1	0.1	0.1	0.1	0.1
Experimental	0.22	0.44	0.32	0.08	0.09	0.1	0.09	0.075	0.09

Table (2) AA6063-T6 mechanical properties

Standard	UTS (MPa)	YS (MPa)	E (Gpa)	Ductility
Ref. [10]	241	214	71	12
Experimental	248	220	70	12.5

All specimens (fatigue and tensile samples) have been polished parallel to loading axis using finer sandpaper grades ranging from 200 to 1200 and finished with emery cloth. Figure 1 shows dimensions and geometry of the fatigue and tensile specimens.



(a) Tensile specimen **(b) Fatigue specimen**

Fig. 1 Tensile and fatigue specimens

Fig. 2 The tensile test sample is produced as a circular form according to the ASTM

The tensile tests have been carried out using WDW-50 type tensile test while the fatigue tests at constant amplitudes have been achieved with the use of rotating bending fatigue test type. These test machine an illustrated in figures (2) and (3).

Rotating bending fatigue test type is utilized for executing all fatigue experimentals, constant amplitude and variable loading, as illustrated in figure (3).

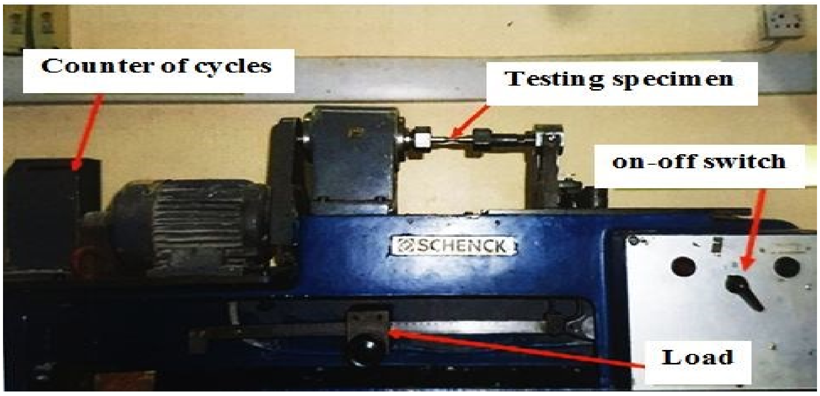


Fig. 3 Rotating bending fatigue test machine**.**

2.2 Corrosion Test

The corrosion test was done using reservoir containing two liters regarding simulated seawater solution that is made from a 3.5we%NaCl solution with initial PH of 7 [11].

The tensile and fatigue specimens have been immersed in 3.5wt% NaCl solution for 100days and then tested under tensile or fatigue loading. The container for corrosion can be seen in figure (4).

Fig. 4 Corrosion container for 3.5wt%, NaCl solution

3. Results and Discussion

3.1 Tensile Test Properties

This section includes the experimental results obtained in three cases i.e., dry (D), dry and shot peening (D+SP), corrosion (C) and shot peening with corrosion (SP+C). The above interaction of the AA6063-T6 is a major issue in the practice life assessment of aircrafts. Corrosion can dramatically reduce the mechanical properties. Table (2) gives the tensile results of four cases. The results in table (2) can be plotted in figure (5) which show the effect of corrosion (C) and SP. However, the results of table (2) are plotted in figure (5)

Table (2) Results of tensile tests and average of three readings.

Mechanical Characteristics	UTS (MPa)	E (GPa)	YS (MPa)	Ductility
Standard [10]	241	71	214	12
Experimental (D)	248	70	220	12.5
(D+SP)	269	70.5	236	11
(C)	221	70	200	14
(SP+C)	239	70.5	218	12.8

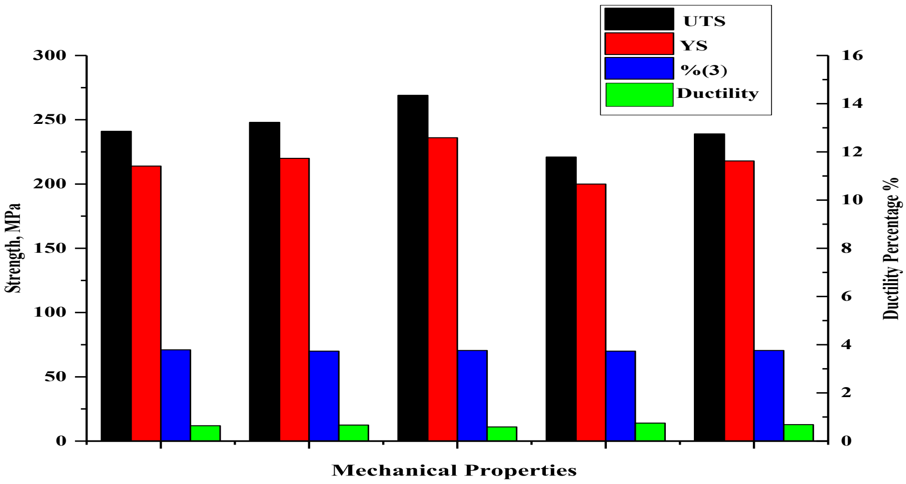


Fig. 5: Mechanical properties variation with corrosion (C) and shot peening (SP)

It is clear that, table (2) and figure (5), corrosion reduces the mechanical properties due to the disability of samples surface (maximum stress location) to withstand the applied load. The amount of reduction percentage in (UTS) and (YS) were reduced to be 10.88% and 9% respectively while ductility was increased from 12.5% to 14%.

But shot peening (SP) process improved (reduced the above reduction percentage), the tensile properties (UTS) by 8.17% for dry samples and 7.53% for corrosion case. Also, the (YS) improves by 6.77% for dry and 8.25% for corrosion samples. This finding agreed well with the results concluded by [12].

It is well known that corroded samples produce accreted crack initiation and propagation leads to reduces the fatigue life and strength. The corrosion resistance of aluminum alloys depends on both metallurgical and environmental factors [13].

3.2 S-N curve results

Four groups of testing were prepared to test under fatigue of constant amplitude with room temperature as well as stress ratio of (R=-1). Table (3) illustrates the fatigue tests for 36 samples, 9 samples for each condition of testing and 3 specimens for each stress level. The average of three readings for each stress level was adopted. The results can be tabulated in table (3).

Table 3: Constant fatigue results under for condition of testing for AA6063-T6

Specimen number			Test condition	Applied stress σ_f (MPa)	Number of cycles to failure N_f (cycles)			Average N_f (cycles)
1	2	3	D	0.8(UTS)=198.4	21600	24000	28800	24800
4	5	6		0.7(UTS)=173.6	52000	60800	48000	53600
7	8	9		0.6(UTS)=148.8	114000	120000	106000	113333
10	11	12	(SP+D)	0.8(UTS)=198.4	28000	36800	40000	34933
13	14	15		0.7(UTS)=173.6	72000	66800	56000	64933
16	17	18		0.6(UTS)=148.8	138000	126000	152000	138666
19	20	21	(C)	0.8(UTS)=198.4	14000	18200	11000	14400
22	23	24		0.7(UTS)=173.6	32000	41800	46000	39933
25	26	27		0.6(UTS)=148.8	91000	88000	102000	93666
28	29	30	(SP+C)	0.8(UTS)=198.4	18000	22800	20000	20266
31	32	33		0.7(UTS)=173.6	35000	50800	52800	46200
34	35	36		0.6(UTS)=148.8	107000	111000	121000	113000

3.3 Corrosion-fatigue in constant S-N curve:

The experimental fatigue life of AA6063-T6 under lab-air or dry (D), shot peeping and dry (SP+D), corrosion (C) and shot peeping-corrosion (SP+C) are experimentally listed in table (3). The reduction in lifetime due to corrosion is majorly a result of small fatigue cracks resulting from pitting. At lower stresses the corrosion has enough time to generate the small cracks but at high stresses there is no enough time to initiate the cracks [14].

Kimberi and David [15] tested AA2024-T3 with prior aggressive corrosion using 15:1 ratio of 3.5% sodium chloride. The experimental results indicated that pitting corrosion resulted the pit-to-crack transition which reduced the fatigue life and strength. For example, at stress level $\sigma_f = 250$ MPa (high stress) and $\sigma_f = 120$ MPA (low stress), the fatigue life has been decreased via a factor of 2.237 and about 5 for high and low stress levels respectively. It is noticed that at low stress levels corrosion has a greater impact on fatigue life because the corrosion pits have enough time to form the short cracks. This finding is in good agreement with the finding of Lin C-K and Yang S-T [16].

3.4 Plotted results

The experimental results of constants fatigue test of AA6063-T6 are plotted in figure (6)

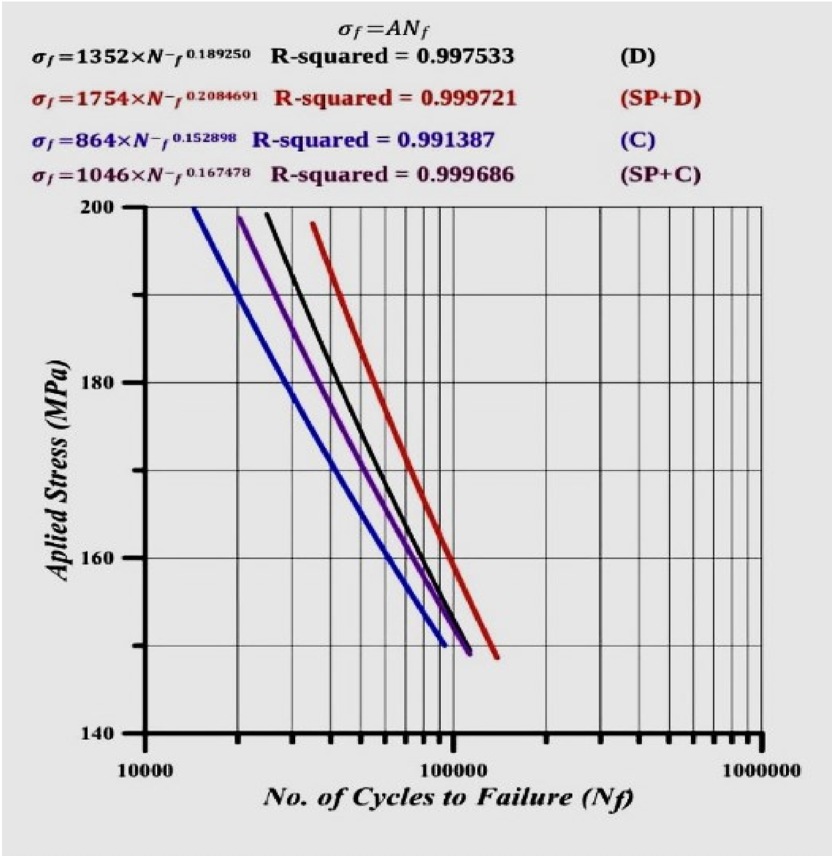


Fig. 6 Constant S-N curves at four conditions of testing

3.5 Fatigue strength

Table (4) illustrates the fatigue strength of AA6063-T6 at various conditions of testing at 10^7cycles. Here fatigue strength denoted as endurance fatigue limit (EFL). Also, the Basquin equations for describing the behavior of S-N curves are also tabulated.

Table (4) fatigue strength of AA6063-T6 at various conditions of testing.

Test condition	(EFL) at 10^7cycles. (MPa)	S-N curve equation	R^2
(D)	64	$\sigma_f= 1352N_f^{-.18925}$	0.9975
(D+SP)	65.64	$\sigma_{f f}=1828 N_f^{-.2084}$	0.9947
(C)	62.64	$\sigma_{f f}=864 N_f^{-.1628}$	0.9913
(SP+C)	64	$\sigma_{f f}=1046 N_f^{-.1733}$	0.9996

The value of (EFL) stress increases with (SP), for (D) case shot peening (SP) improves the (EFL) by 2.5%, while for case (C), the improvement percentage is reported to be 2.12%. It is clear that the (SP) process improves corrosion resistance of AA6063-T6 because of compressive residual stresses that are generated during (SP). Kharia et al [17] examined the impacts of (SP) on corrosion of AA6061-T6 in aqueous solution. They concluded that (SP) improved the corrosion resistance due to increase, the layer surface hardening resulted in compressive residual stresses lead in reducing corrosion rate.

Shmoos R.M.[18] has found that (SP) remarkably enhanced the fatigue life and strength for AA6061-T6 oil corrosion experimentally.

For comparison, the experimental results have been plotted for stress ratio (R=-1) and in-air (D), shoot peening and in air (SP+D), corrosion (C) and shot peening and corrosion (SP+C). The variation of (EFL) depending on the type of test is shown in figure (7).

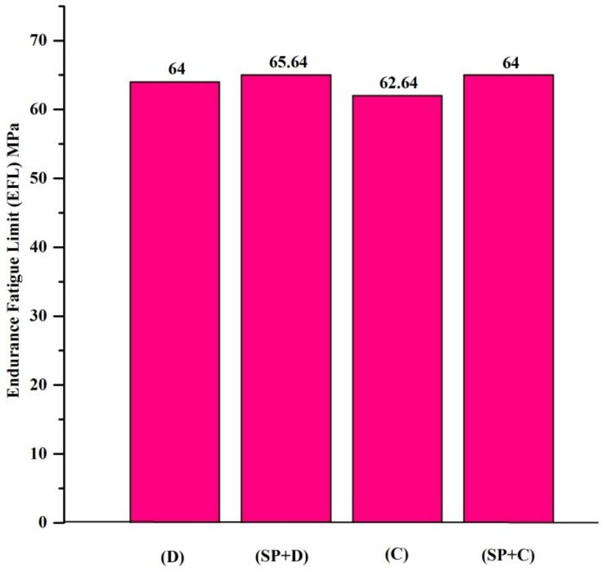


Fig. 7 Ductility values under different test types

Conclusions

The influences of corrosion on mechanical and fatigue properties of AA6063-T6 have been reported. The material was subjected to a 3.5wt% NaCl simulated seawater solution. Many remarks could be derived can be remarked from the experimental results and discussion presented:

1. The mechanical properties of AA6063-T6 were decreased considerably through the application of corrosion in 3.5 wt.% NaCl when put to comparison with the lab-air (D) without corrosion. The (UTS) and (YS) were reduced by 10.88% and 9% respectively due to corrosion while ductility increased from 12.5% to 14%.
2. SP treatment reduced the above reduction percentage for (UTS) and (YS) to 8.17% and 7.53% because of the generating compressive residual stress at surface and below it.
3. Corrosion-fatigue had a large impact on the fatigue life of the AA6063-T6 at lower stresses while they have little effect at high stresses.

The fatigue strength (EFL) reduced under corrosion from 64 MPa to 62.64 MPa but (SP) raised it to 64 MPa.

Conflict of interest

A conflict of interest statement must be placed at the manuscript as below: "The authors declare that there are no conflicts of interest regarding the publication of this manuscript".

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