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Effect of Shot Penning with Surface Anodic Coating on the Mechanical Strength and Fatigue Life of Aluminum Alloy 7075-T73

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ABSTRACT
BACKGROUND: Shot peening is a cold working process originally implemented to increase fatigue strength. Anodizing is an electrolytic process for producing very much thicker oxide coating than the natural oxide (atmospheric oxide) whose improved physical and chemical properties have greatly increased the field of application of aluminum. **OBJECTIVE** The objective of this research is to study the effect of using the shot penning with anodizing process on the mechanical properties as well as the fatigue life for aluminum alloy (7075-T73), which is one of the most commonly used aluminum alloy in production of aircrafts, vehicles and ships structures. **RESULTS** The shot penning times were (16, 26, and 36) min and the anodizing process was employed through using sulfuric acid for time (20) min in a salty atmosphere. The mechanical properties and fatigue life of the aluminum alloy (7075-T73) were obtained before and after the shot penning with anodizing process. All the results were listed in detailed tables and figures for comparison purpose. **CONCLUSION** Generally, these result showed an increase in hardness by (45.85%) in comparison with untreated and increase in fatigue life due to the shot penning with anodizing by (108.00%) in case of a time of 26 min at the stress level of (σ_a =65.69 MPa).

INTRODUCTION

In industry, aluminum is extensively used in many applications, like aviation systems and aerospace, various components of locomotive, etc. However, Al alloys have good resistance to corrosion and lower strength (Polmear, 1989). Therefore, it is necessary to enhance the corrosion properties of these alloys by the anodization technique or passivation. This technique is too efficient and influential to improve the performance of Al alloys together with the resistance to corrosion, wear and tensile strength. The anodized Al structure contains two layers: an outer thick porous layer and an inner thin layer. The latter might be the defects that lowers the anodized Al resistance to corrosion, like pitting corrosion owing to the formation of electrochemical activities between the inter metallic's and grain boundaries (Aluminum Anodizing Council, 2003).

Shot peening is a cold working process originally implemented to increase fatigue strength. A stream of shot is used to bombard a metal's surface, inducing compressive stresses and relieving tensile stresses within the material. The depth of the shot peening effect is typically about 0.13 to 0.25 mm below the surface. The altering of residual stresses on the metal's surface results in a higher fatigue resistant material and a higher resistance to corrosion fatigue and stress corrosion cracking (Kent, 1967).

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Corrosion fatigue is a decrease in fatigue strength due to the effects of corrosion. Corrosion fatigue cracking differs from stress corrosion cracking (SCC) and hydrogen induced cracking in that the applied stresses are cyclic rather than static. Fatigue cracking is often characterized by “beach marks” or striation patterns which are perpendicular to the crack propagation direction. Both the stress required for crack initiation and propagation can be lower in corrosive environments (Craig *et al*., 2006).

Zupanc and Grum (2010) used the aluminum alloy type 7075-T651 as flat fatigue specimens. This study aimed to investigate the effect of surface hardening by shot peening on the fatigue properties of a high –strength aluminum. The authors described the effects of shot peening treatment by presenting analyses of residual stresses, surface roughness, microstructure changes and material bending fatigue resistance. The fatigue limit of the shot peened specimens increased to 218 MPa at 10^7 cycles. The increased resistance to plastic deformation and the residual stress profiles provided a corresponding fatigue crack closure. Gao (2012) determined the fatigue strength for High Cycle Fatigue (H.C.F) of 7050–T7451 aluminum alloy for machined, shot-peened (SP) and laser-shot peened (LSP) specimens. Moreover, fatigue lives were compared under the same load conditions. The results showed that a deeper compressive residual stress layer and better surface finish in laser peening induced; therefore, they improved the fatigue properties more effectively. Analysis and fracto-graphic examination depicted that the fatigue cracks initiated in the subsurface layer beneath the compressive residual stress field for SP and LSP specimens, whereas the fatigue cracks formed at the surface for as machined ones. Luong and Hill (2011) studied the high cycle fatigue performance of AL 7050-T7451, investigated for untreated as machined, LSP and SP conditions. Both treatments significantly increased the fatigue performance. At a moderate level of stress, the peened specimens outlasted as machined specimens, by a factor of 7.9 for LSP and 2.9 for SP. At higher stress, the life improvements were lower, by a factor of 3.3 for LSP and 2.1 for SP. At a 100,000-cycle lifetime, the fatigue strength of SP specimens was 30% higher than as machined, and the fatigue strength of LSP specimens was 41% higher than that for the as-machined specimens. Jabur (2012) investigated the effects of shot peening on the fatigue life of 7075-T6 aluminum alloy. The shot peening process was done at several times of (0, 15, 25, 35, 45 and 55 min.). The analysis revealed that the benefits of shot peening in terms of fatigue life are dependent on the shot peening time. As shot peening time increased from zero to 15 min, the fatigue life increased. The factor of fatigue life improvement at an amplitude stress of $0.6\sigma_u$ (360 MPa) was limited up to 15 min. SPT and equals to 3.185. After shot peening time of 25 min, the fatigue life reduced with time, and the factor of fatigue life reduction is appeared. Castillo (2014) studied the effects of SP, LSP and ultrasonic impact treatment (UIT) as a severe plastic deformation process on the fatigue behavior of 2024-T3, 7075-T6 and 6061-T6 aluminum alloys. Crack propagation experiments showed the retardation for both of the UIT examined. Retardation caused by material properties and residual stress changes enhances fatigue life, observed in the endurance test after skimming. Gujba and Medraj (2014) compared the Shot Peening and Ultrasonic Impact Peening with the Laser Peening process and its impact on materials properties. Shoot peening techniques give less residual compressive stresses than LSP. For the surface roughness for AL 7075-T6, it was found that Ra in (µm) for SP is (5.70) and for LSP equals (1.30). The author showed that the rate of fatigue crack growth in stir welded AL 2024-T3 joint increased by SP as compared to the LSP specimen. The fatigue crack growth was comparable with the unwelded alloy. The retardation in the rate of fatigue crack growth was for different notch configurations such as fastener hole, multiple crack stop holes and single-edge notches.

According to the previous studies, since no work found for the shot peening with anodizing process by sulfuric acid regarding the fatigue life of AL 7075-T73. Therefore, the objectives of this work are first to investigate the shot peening at different times with formation of anodic oxide film for aluminum alloys (7075-T73) by means of sulfuric acid anodizing process with constant current density and time, and then to study the effect of shot peening with anodizing on the mechanical properties, fatigue live and film thickness growth before and after shot peening with anodizing.

Experimental Work:

The material employed in this study is 7075-T73 aluminum alloy. It was received from source (ALCOA) in the form of sheet (244 cm x122 cm x 0.313 cm). A CNC milling machine was used to manufacture the test specimens in the Center of Training and Workshops at University of Technology.

The chemical composition tests were conducted at the Central Organization for Standardization and Quality Control in Baghdad according to the Iraqis Specification Quality (ISQ) 1473/1989. The results of these tests are given in Table 1 together with the standard alloy for comparison and verification purposes.

In this study, a standard (ASTMD-638-I) tensile test specimen was used with the dimensions shown as in Fig.1. Where, the gauge length is (60 mm), shoulder length (75 mm), (R = 40 mm) for plane sheet specimen, and the overall length is (165 mm). The tensile tests included the mechanical and physical properties, and the results are shown in Table 2.

Shot peening was accomplished by machine of Sintokogio LTD, model STB-OB. The shot peening machine used for this purpose is located in the Institute of Technology in Baghdad, which is illustrated in Fig 2. In this machine, the motor rotates an impeller which bombards the shots towards the specimens at 1435 r.p.m motor rotational speed with one jet of shots at an average speed of 40 m/s. The material of the shooting balls is a low carbon steel with average diameter of 1.2 mm. The peening machine consists of a rotary cylinder with inside diameter of 590 mm and depth of 740 mm, in which the specimens are placed. The shot peening times used in this work are (16,26,36) min.

A reverse bending fatigue machine type AVERY DENISON-7306, as shown in Fig.4, was used to carry out the fatigue testing. The tests were undertaken in stress control with a stress ratio R= -1, and the cycling rate is 1420 rpm (f=23.6 Hz). All the tests were performed in the laboratory environment using standard fatigue specimen shown in Fig.4. The machine is provided with a cycle counter. This cycle counter records the number of cycles in multiples of thousands.

The aluminum strip was connected to the positive terminal where it becomes (anode), while the stainless steel strip was connected to the negative terminal to be (cathode). Fig.5 shows a photograph for the whole assembly of the anodizing apparatus.

When all the requirements of experiment were set up, the power supply was switched on so that a constant current was obtained. The specimen was immersed in the solution, while the power supply was switched on. Anodizing method provides a protection for the specimens from dissolution; also, care was taken during the loading of specimens in order to prevent the short circuit, i.e., burning the surface.

Before the power supply switched on, the current density must be fixed at the desired value, and when power supply switched on, the voltage increased gradually and the current density maintained at the fixed value for the remaining time of the experiment.

At the end of the desired time, the power supply was switched off, and the anode was removed from the anodizing cell immediately to prevent the dissolution of anodic film.

The specimen was rinsed with running water followed by distilled water to remove the excess solution on it and then dried in a drying furnace at 50^0 C for 30 minutes and stayed in a dissector for about 30 min.

When the anodizing process (sulfuric acid process) stage was completed according to the predesigned condition, the specimen was dipped in a flask filled with hot distilled water and kept for 10 minutes at 97-99^0 C in order to seal the porous anodic film. Then, the specimens were dried in a drying furnace at 50^0 C for 30 minutes and stayed in a dissector for about 30 min.

RESULTS AND DISCUSSION

After shot peening with anodizing treatment, the results obtained for the mechanical properties of treated specimens is shown in Table (3) together with as-received specimen for comparison purpose.

(a) Hardness:

It can be seen that hardness generally increased after shot peening with anodizing. The hardness value is (132.0 HB) for 26 min, so the hardness improvement is (45.85 %) in comparison with the hardness (90.5 HB) of the untreated specimen Table (3). This increase is due to the formation of the anodized film on the specimen surface and shot peening. This increase in hardness is in agreement with Refs. (Al-Fattal *et al*., 2106a; Al-Fattal *et al*., 2106b; Shaymaa A A, 200; Talib, M N, 2000).

(b) Corrosion rates:

The corrosion rate was found decreasing after shot peening with anodizing, as shown in Table (3). This means that the value was for 26 min anodizing time (413 mpy), lower than that for untreated specimen (1663 mpy). So, the percentage of reduction was (285.84%). This is attributed to that the anodized film reduces the corrosion rate for the aluminum alloy (7075-T73) due the passive layer added on the surface Al_2O_3. This layer coats the surface and prevents the aggressive solution attacking the alloy surface as compared with the untreated specimen. This increase in corrosion rate is in agreement with Ref. (Metalast Tech Center, 2004).

(c) Surface roughness:

It was noticed that the surface roughness largely increased after shot peening with anodizing. The surface roughness value was (3.716 µm) for 26 min time. Thus, the roughness increment is (4854.67 %) with respect to that for untreated specimen (0.075 µm), as shown in Table (3), because during the anodizing, a new phase is formed, Al_2O_3 and due to shot peening. This increase in roughness is in agreement with Ref. (Talib M N, 2000).

(d) Thickness of anodizing layer:

It was found that the thickness increased after anodizing. The thickness value was (20.5 µm) for anodizing of 26 min time, Table (3). This is due to more chemical deposition of the anodized layer with time, resulting in higher anodic film thickness. This increase in thickness was found in agreement with Refs. (Al-Fattal *et al*., 2106a; Al-Fattal *et al*., 2106b).

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(e) Ultimate and yield tensile strengths:

The result showed that both the ultimate and tensile strength increased after shot peening with anodizing. Figure (6) depicts the effect of shot peening with anodizing time 26 min on the Stress-Strain curve of the untreated specimen. It is seen from these figures that the ultimate strength increase was (6.0 %) at 20 min anodizing time and (6.0 %) for yielding strength, Table (3). This increase in yield and ultimate strengths is in agreement with Refs. (Al-Fattal *et al*., 2106a; Al-Fattal *et al*., 2106b).

(f) Fatigue strength:

All the results of the high fatigue cycle tests for as-received, anodized and shot peening with anodizing specimens treated at time 20 min are listed in Tables (4) to Tables (8). It can be noted that the fatigue strength lives increased when compared with the values for the as-received specimen. The percentage of the fatigue life increase is also given in Table (9). All the results were used to plot the S/N curve for the untreated and treated specimens at 26 min anodizing times, as shown in figure (7), the shot peening with anodized specimen for 26 min experienced higher fatigue lives when compared with the untreated specimen. The reason of increment of fatigue life is due to the increasing in the surface compressive residual stress. Basquin equation ($\sigma a = \sigma f(Nf)^{-b}$) was used for calculating fatigue life of as-received and treated specimens. Table (4) depicts the relevant equation for as-received alloy without treatment. For example, for the second specimen in Table 8, the following equation was obtained: ($\sigma_a = 196.6(977E+03)^{-0.124}$) with ($\sigma a = 35.549\ MPa$), after the shot peening with anodizing for 26 min time. This increase in fatigue strengths and fatigue live was found in agreement with Ref.(Al-Fattal *et al*., 2106a).

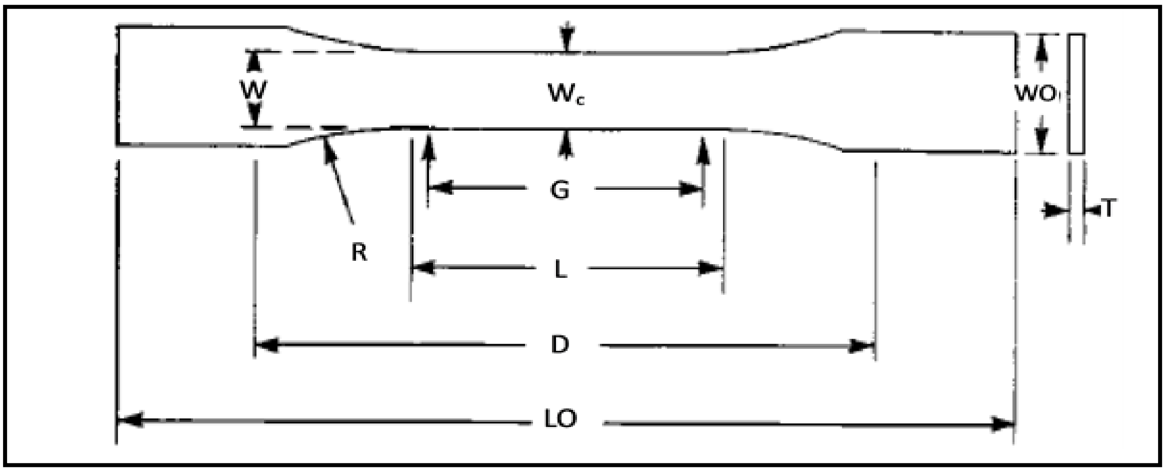


Fig. 1: Standard Tensile Test Specimen with (T=3, LO=165, W=W_C=12.5, WO=20, D=75, L=65, G=60 and R = 75 (all dimensions in mm) for plane specimen [ASTMD-638-I]

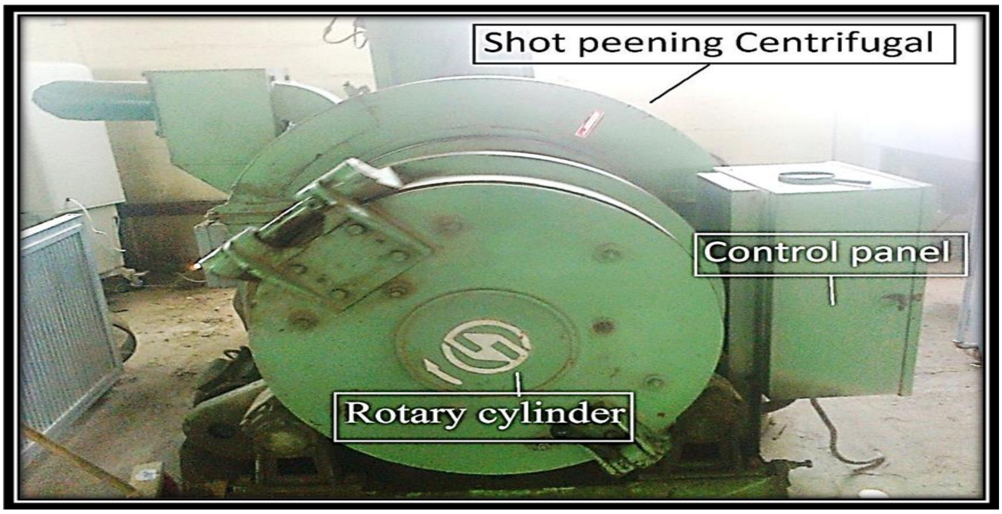


Fig. 2: The shot peening machine model STB-OB

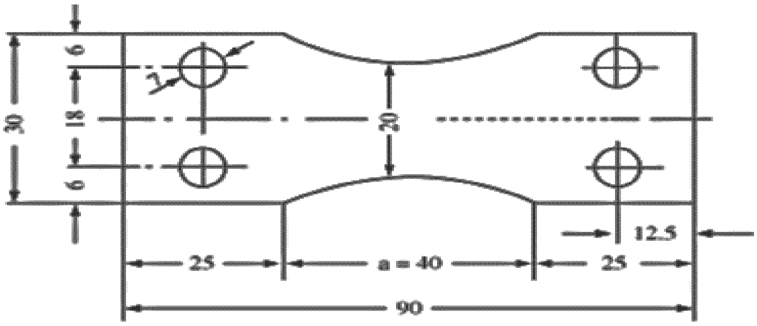
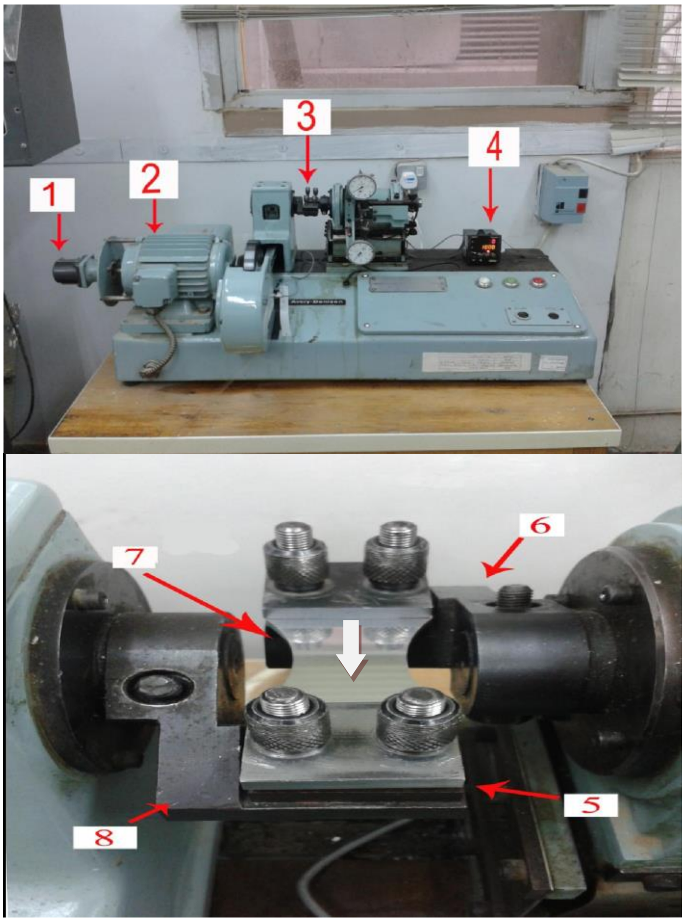


Fig. 3: Standard Fatigue Test Specimen with thickness of 3mm [Avery]



1. Mechanical counter 2. Motor 3. Specimen fixture 4. Digital counter
5. Clamp 6. Fixed grip 7. The specimen 8. Movable grip

Fig. 4: Fatigue testing machine

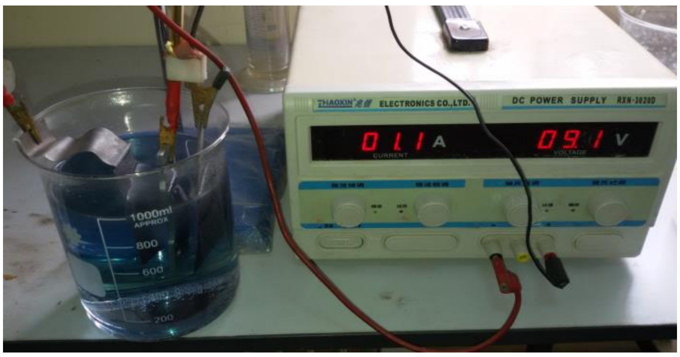


Fig. 5: Photograph of the complete assembly of the anodizing apparatus

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Table 1: Chemical Compositions of the Used AL-Alloys 7075-T73 Together with the Standard Alloy

Component	% Si	% Fe	% Cu	% Mn	% Mg
Standard	≤0.4	≤0.5	1.2-2.0	≤ 0.3	2.1-2.9
Used	0.28	0.26	1.51	0.21	2.42
Component	% Cr	% Zn	% Ti	% other	% Al
Standard	0.18-0.28	5.1-6.1	≤ 0.2	≤ 0.15	Reminder
Used	0.265	5.18	0.03	0.098	Reminder

Table 2: Mechanical Properties of AL-Alloys 7075-T73 as Taken from the Central Organization for Standardization and Quality Control / Iraq-Baghdad (COSQC)

Mechanical Properties	Value
Hardness , Rockwell B	90
Ultimate Tensile Strength	502 MPa
Tensile Yield Strength	406 MPa
Elongation at Break	16.%
Modulus of Elasticity	74 GPa
Poisson's Ratio	0.33
Fatigue Strength	156 MPa
Shear Modulus of Elasticity	27.15 GPa
Shear Strength	325 MPa
Specific Heat Capacity	0.875 J/g-°C
Thermal Conductivity	130 W/m-K

Table 3: Mechanical Properties of AL-Alloy 7075-T73 for As- received and Shot Penning with Anodizing Specimens at Time 26 and 20 min, Respectively

Properties	Shot Penning with anodizing	As-received without Treatment	Best Enhancement %
Hardness, Rockwell B	132	90.5	45.85
Surface roughness (μm)	3.716	0.075	4854.67
Thickness of anodizing layer (μm)	20.5	0	
Corrosion rate (mpy)	31	1663	285.84
Ultimate Tensile Strength (σ_{ut}) MPa	568.16	536	6
Tensile Yield Strength (σ_{yt}) MPa	477	450	6
Modulus of Elasticity (E) GPa	76.092	74.6	2
Fatigue Strength (σ_f) MPa	203.875	166.2	22.66

Table 4: Fatigue Life Data of the AA 7075-T73 Used As-received without Treatment

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σ_f) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
2	45.78	2750	2750	2750	2750
4	91.57	550	539	561	550
6	192.4	343	270	330	224.3
8	284.2	71	72	67	70
10	339.5	46	41	51	46
12	431.8	17.7	18.8	17.5	18
14	561.7	9.7	10	10.3	10
16	711.4	6	6.5	7	6.5
Amplitude Stress (σ_a) (MPa)		$\sigma_a = \sigma_f N_f^{-0.063}$			

Table 5: Fatigue Life Data of the AA 7075-T73 Calculated after Anodizing for t=20 min.

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σ_f) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
2	44.89	2125	2125	2125	2125
4	89.79	434	413	428	425
6	188.7	133	122	135	130
8	278.7	56	58	66	60
10	332.9	26.5	29	27	27.5
12	423.4	16	15.8	16.4	16.1
14	550.8	9	9.5	9	9
16	697.6	4.5	5.5	5	5
Amplitude Stress (σ_a) (MPa)		$\sigma_a = \sigma_f N_f^{-0.052}$			

Table 6: Fatigue Life Data of the AA 7075-T73 Used after SP (t= 16) with Anodizing

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σ_f) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
4	93.57	3995	3995	3995	3995
6	196.6	913	909	914	912
8	290.4	235	231	239	235
10	346.9	84	84	87	85
12	441.2	30	28	32	30
14	573.9	15.5	14.5	15	15
16	726.9	8	9	8.5	8.5
Amplitude Stress (σ_a) (MPa)		$\sigma_a = \sigma_f N_f^{-0.12}$			

Table 7: Fatigue Life Data of the AA 7075-T73 Used after SP (t= 26) with Anodizing

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σ_f) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
4	93.57	4833	4833	4833	4833
6	196.6	976	972	983	977
8	290.4	265	269	276	270
10	346.9	100	99	95	98
12	441.2	48	49	53	50
14	573.9	19	17	21	19
16	726.9	9.5	10	10.5	10
Amplitude Stress (σ_a) (MPa)		$\sigma_a = \sigma_f N_f^{-0.124}$			

Table 8: Fatigue Life Data of the AA 7075-T73 Used after SP (t= 36) with Anodizing

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σ_f) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
4	93.57	4278	4278	4278	4278
6	196.6	958	966	973	965.7
8	290.4	241	247	250	246
10	346.9	86	89	90	88.33
12	441.2	37.5	39	34.5	37
14	573.9	16	16.5	18	16.83
16	726.9	8.8	8.5	9	8.767
Amplitude Stress (σ_a) (MPa)		$\sigma_a = \sigma_f N_f^{-0.122}$			

Table 9: Fatigue Life Data and Percentage of Increasing after Shot Peening with Anodizing Time 26 and 20 min, Respectively.

Amplitude Stress σ_a (MPa)	Number of Cycles * 10^3			Percentage of Increasing %	
	As-received (a)	Anodizing (t=20 min) (b)	SP with anodizing (t=20 min) (c)	(c-a)/a	(c-b)/b
30.1	2450	2125	4359	77.85	105.13
65.69	536	425	884	64.92	108.00
146.3	201	130	264	31.34	103.07
224	56.2	51	80.4	43.06	57.64
277.3	28.4	27.5	47.3	66.55	72.00
365.4	16.5	16.1	21	27.27	30.43
491.1	9.7	9	12.7	30.93	41.11

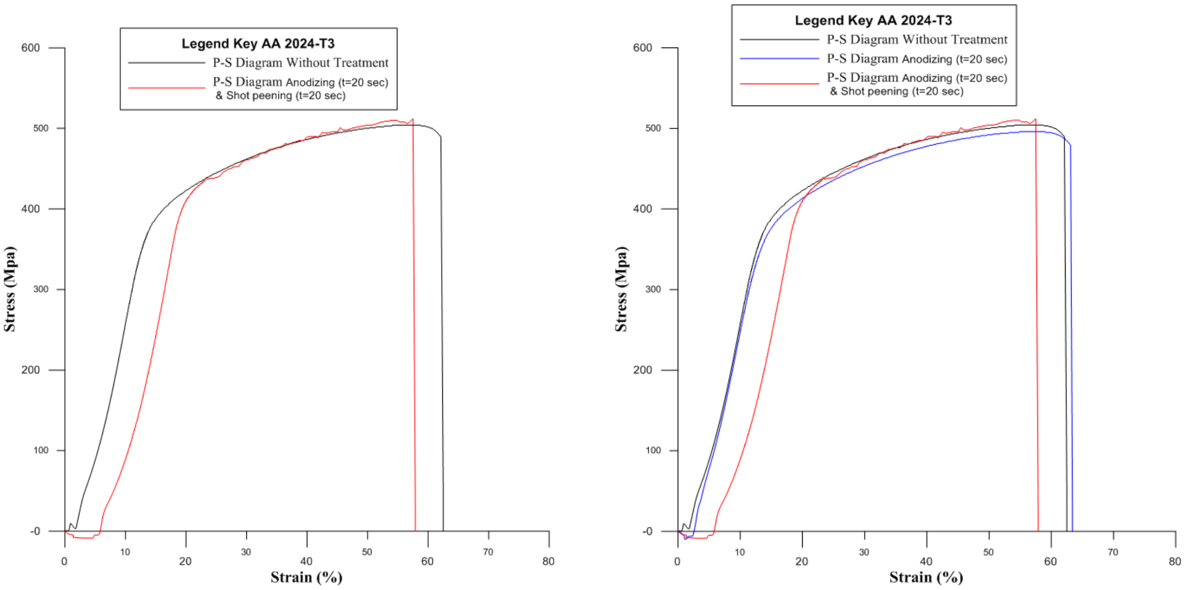

Fig. 6: (a) The effect of Shot peening with anodizing on the Stress-Strain diagram of untreated AA 2024-T3 **(b)**The effect of Shot peening with anodizing and anodizing on the Stress-Strain diagram of untreated AA 2024-T3

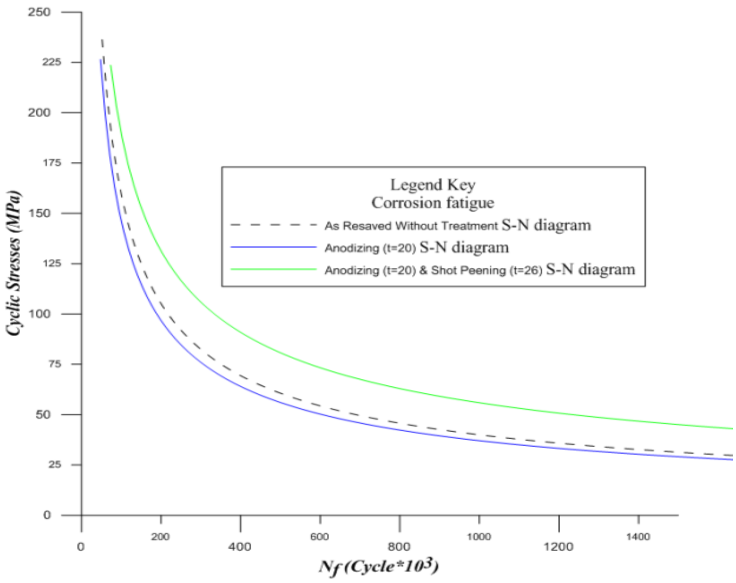

Fig. 7: The improvement in S-N Diagrams of AA 7075-T73 for Shot penned with anodized.

Conclusions:

The effect of shot peening with Anodizing on the mechanical properties (Ultimate Tensile Strength, Tensile Yield Strength and Fatigue Strength) was higher than Anodizing only. The hardness also increased by 45.85%, higher than the untreated specimens.

Shot peening with Anodizing had a major effect on the corrosion rate, the corrosion rate for Aluminum Alloy 7075-T73 in the shot peening with Anodizing was lower than untreated specimen, and the percentage of reduction was 285.84% (using sulfuric acid as electrolyte).

Shot peening with Anodizing had a major effect on the thickness of anodizing layer, the thickness of anodizing layer greatly increased with the anodizing time, increase. The surface roughness for the case of Shot peening with Anodizing had a major effect, and the percentage of increase was 4854.67%.

The increments in fatigue life for the case of Shot peening with Anodizing were greater than other cases. For the S-N curve, the effect of Shot Peening (SP) and anodizing took place with major enhancement as could be seen in the figure above with a comparison between the anodizing and untreated ones. The best increment in

N_f was 47.81% higher than Shot Peening only, an increment in N_f of 108 % higher than Anodizing only, an increment in N_f of 77.85% higher than as- received one and an increment in N_f of 66.56% higher than in air one.

Contributions:

1- Having more knowledge about the influence of anodizing process, either done separately or combined with another process, on the mechanical and fatigue behavior of the used aluminum alloys.
2- Knowing the benefit of using the shot peening technique after the anodizing process for improving the mechanical and fatigue properties of the utilized aluminum alloys in this research.

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