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The Effects of Anodizing Process on the Corrosion rate and Fatigue Life of Aluminum Alloy 7075-T73

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K E Y W O R D S

Anodizing, Mechanical properties, Aluminum Alloy 7075-T73, Fatigue Life.

A B S T R A C T

This research aims to study the effect of using the anodizing process on the corrosion rate, 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. 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 AA7075-T73 were obtained before and after the anodizing process. All the results were listed in detailed tables and figures for comparison purpose. Generally, these results showed a decrease in corrosion rate by (155.06%) in comparison with untreated, an increase in hardness by (21.54%) and a slight decrease in fatigue life by (7.7%) due to anodizing for a time of 20 min at the stress level of (σa = 491.10 MPa). It was concluded that this technique could be applied on other aluminum alloys in order to know the magnitude of change in the mechanical characteristics and their fatigue life.

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1. Introduction

Aluminum is widely used in various industrial fields, such as different parts of transportation, aerospace and aviation systems. Nevertheless, aluminum alloys possess less corrosion resistance and lower strength. Accordingly, this necessitates the improvement of corrosion characteristics of such alloys by the anodization technique or passivation [1]. This method is too competent and influential to improve the performance of Al alloys and their resistance to corrosion, tensile and wear properties. Structure of the anodized aluminum comprises two layers: a thin inner layer and a thick outer porous layer. The outer layer might be the shortcomings that reduces the resistance of anodized aluminum to corrosion, such as pitting corrosion due to the generation of electrochemical activities between the grain boundaries the inter metallic compounds [2].

High tensile strength and superior fatigue resistance are important criteria in the selection of materials for aircraft undercarriage components. In fact, these structures are exposing to cyclic loads in the landing procedure. 7xxx series of aluminum alloys are the best selections for making joints in these fields [3,4]. It has proved that corrosive environment conditions and friction forces imposed to the aircraft undercarriage lead to a reduction in its operating life. Therefore, in the existence of these deteriorating phenomena, using surface modifying and coating processes are essential to prevent any corrosion and wear in this field [5].

Majority of surface failures of metallic parts which caused by fatigue that occurs due to cyclic loading or alternating stress with amplitude would not cause failure when only subjected once. Different mechanical parts may fail by fatigue, like blades of turbines, aircrafts and automobiles components, ships and marine parts, structures of bridges, etc. Usually, fatigue requires applying cyclic loading, tensile stresses and plastic deformation, and the failure will not take place when one of these parameters has missed. Material failure beyond certain cycles exhibits that specific permanent variation should take place in each cycle. Plastic deformation should induce in each cycle although it may be very small. Normally, fatigue occurs in three stages, where the first stage is the crack nucleation via the nonhomogeneous plastic deformation small magnitudes at the microscopic level, and the 2nd stage being a slow growth of such cracks via cyclic burden. In the third stage, an abrupt fracture eventually takes place when the cracks approach a critical size [6]. Fatigue corrosion results in a reduction in the fatigue strength because of the corrosion effects, and fatigue cracking by corrosion differs from stress corrosion cracking and hydrogen induced cracking, in which the kind of the subjected stresses is cyclic instead of static. Crack of fatigue is often characterized by “beach marks” or striation patterns, which are perpendicular to the direction of crack propagation. The required stress for the initiation and propagation of crack can reduce in the corrosive environments [7].

Hao et al. [8] investigated the effect of fixed voltage process and fixed density of current process on the anodic coating growth for Al anodized in the solution of H_2SO_4 with respect to the theoretical model and equation. The growth rate changes of the anodic coatings with the main parameters were explicitly characterized in number of equations. Theoretically, it was shown that the fixed density of current process possesses several benefits than the conventional fixed voltage process. Thus, the current density process was vigorously recommended for anodizing of Al in the electrolyte of H_2SO_4. Camargo and Voorwald [9] studied the anodization effect on the fatigue strength of 7050-T7451 aluminum alloy, and evaluated the effect on the anodic films fatigue life, where these films had grown on the Al alloy (7050-T7451) via hard anodizing, chromic acid anodizing, and H2SO4 anodizing. The effect on rotating and reverse bending fatigue strength of the anodic films grown on this aluminum degraded the stress life fatigue performance of the base alloy. Shahzad et al. [10] studied the effect of anodizing process upon the fatigue life of (7050-T7451) Al alloy via conducting the axial fatigue tests with a ratio of ‘R’ = 0.1. Degreasing and pickling used prior to before the anodizing on the fatigue life were investigated. Formation of pits was of the initial consideration in terms of the accelerated initiation of fatigue and the formation of the consecutive anodic coating. The outputs showed that the process of pickling is harmful since it reduces greatly the fatigue life, and for most anodized samples, the cracks of fatigue yet initiate at the pits with less cracks that initiated from the anodic coating. Chaussumier et al. [11] investigated the fatigue life of anodized 7050 aluminum alloy specimens, and observed that the fatigue failure was desirable via the existence of multiple cracks. From the results of experiments, the predictive model of fatigue life was established, involving the consideration of multi-site crack, the coalescence among the neighboring cracks, the stage of the short crack growth and the stage of the long crack spread. The predictive model data were compared with the data of the experimental fatigue results determined for the anodized (7050-T7451) samples. The results of the predictions and experimental results were in good agreement. Zalnezhad et al. [12] studied the influences of the hard anodizing variables upon the surface hardness of the aerospace Al alloy (AL7075-T6) utilizing fuzzy logic method for the use of fretting fatigue. It was found that the hardness of the samples coated by the hard anodizing rose until (360 HV), whereas the hardness of the uncoated samples was (170 HV). Results showed that the hard anodizing enhanced the fretting fatigue life of the Al alloy (AL7075-T6) by 44 % in the low-cycle fatigue. Liu et al. [13] investigated the effect of green trivalent Cr coating upon the anodized film surface. The resistance of corrosion of the anodized films beyond the passivation was assessed using an electrochemical impedance spectroscopy and a potentio-dynamic polarization. Depending on the curves of the polarization, the potentials of corrosion of the passivation and the sealing-anodized film were found more positive than the anodized film. Nevertheless, the potentials of corrosion of the combined passivation and the sealing operation were more negative than the separated operation. In addition, the Scanning Electron Microscopy results revealed that the size of pore clearly reduced beyond the passivation and sealing process. Hajihashemi et al. [14] investigate the influence of common surface operations in aviation industries on the fatigue behavior of the most applicable aerospace alloys (including Al 7075-T6 alloys). Therefore, three different anodizing processes in sulphuric acid, chromic acid solutions, and hard anodizing were applied to aluminum alloys, and their fatigue behaviors were evaluated by drawing stress-life curves. The results obtained from the stress-life curves of aluminum alloys showed that the presence of anodized coating resulted in the reduction of its fatigue life. Presence of tension stresses arising from the anodized coatings is the main reason for this decrement in fatigue strength. Therefore, by referring to the above investigations, there is a little research work concerning the anodizing treatment by sulfuric acid considering the fatigue life of AL 7075-T73. Thus, the objectives of this research are to study the formation of anodic oxide film for such type of alloy (AL 7075-T73) by means of sulfuric acid anodizing treatment at constant time an current density in order to investigate influence of the anodizing on the rate of corrosion, growth of film thickness, mechanical properties of the anodize alloy and fatigue life before and after the anodizing process.

The paper should be organized into logical parts or sections. Subsections are not numbered. Any subsection is given a brief heading. The contents include the introduction that should define clearly the nature of the problem, and the references should be made to previously published papers. Theoretical, experimental, results, discussions and conclusions form the main sections of the paper. Theoretical section extends the analytical background of the article and develops a new formulation of the problem. Calculations are achieved here using the developed equations and the modifications should be pointed out. Depending on the suggested research methods, the experimental investigation is achieved, using the testing instruments or design and manufacturing a test rig. Materials and methods are detailed here. In the results and discussions section, the significance of the obtained results should be pointed out and the citations and the discussions of the literatures should be avoided in this section. Sometimes results and discussions are combined in one section.

2. 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 x122cm x 0.313cm). 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 Figure 1. Where, the gauge length is (60 mm), shoulder length (75 mm), (R = 75 mm) for plane sheet specimen, and the overall length is 165 mm. These tests were carried out in the State Company for Inspection and Engineering Rehabilitation (SIER) in Baghdad and Central Organization for Standardization and Quality Control COSQC in Baghdad in accordance with the Iraqis Specification Quality (ISQ) 1473/1989. The tensile tests included the mechanical and physical properties, and the results are shown as in Table 2.

A reverse bending fatigue machine type AVERY DENISON-7306, as shown in Figure 2, was used to conduct the fatigue test. These tests were performed a ratio of stress (R= -1), and the rate of cycling was (1420 rpm) (frequency = 23.6 Hz). All tests were carried out in the laboratory atmosphere. The fatigue machine has a cycle counter, which registers the cycle’s number in thousands.

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	2.24
Component	% Cr	% Zn	% Ti	% other	% Al

Standard	0.18-0.28	٥.١-٦.١	≤0.2	≤0.15	Reminder
Used	0.265	5.18	0.03	0.098	Reminder

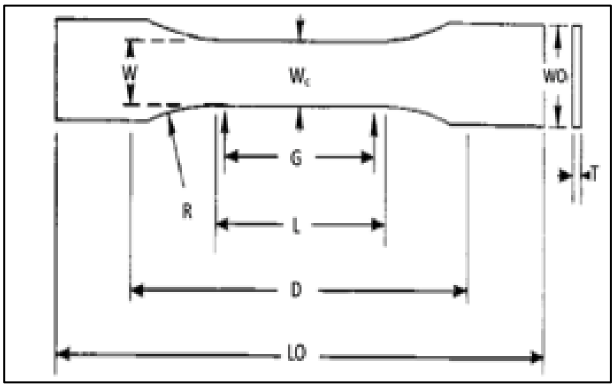

Figure 1: Standard Tensile Test Specimen with (T=3, LO=165, W=W$_C$=12.5, WO=20, D=75, L=65, G=60 and R = 75 all dimensions in mm) for plane specimen [ASTMD-638-I]

Table 2: The mechanical and Physical properties of (AL7075-T73) Al alloy as received from the COSQC in Baghdad-Iraq

The Property	Magnitude
Rockwell hardness (B)	90
Maximum tensile strength	502 (MPa)
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)

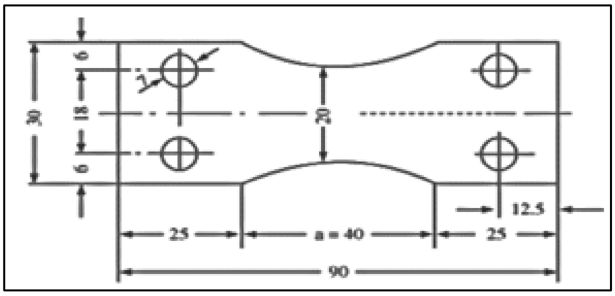

Figure 2: Standard Fatigue Test Specimen having (3 mm) thickness [Avery]

The strip of Al was joined to the positive end to be the anode, whereas the strip of the stainless steel was linked to the negative end to be the cathode. A photograph for the complete assembly of the anodizing apparatus is depicted in Figure 3

If the whole of experiment needs were setup, the power supply was then switched on so that a fixed current was obtained. The specimen was merged in the solution, whilst the power supply was 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, if the power supply was on, the voltage would increase in a gradual way and the density of current maintained at the fixed value for the remaining time of the experiment. Until the wanted ending time, the power supply was then switched off, and the anode was taken away from the cell of anodizing sooner to prevent dissolution of the anodic film.

The specimen was washed by the running water preceded by the distilled water for cleaning the surface from the remained solution, and then it was dried by the furnace at (50°C) for (30 min) and kept inside a dissector for (30 min). After the stage of anodizing (H_2SO_4 treatment) was finished in accordance with the required state, the specimen was dipped in hot distilled water that placed in a flask and held for (10 min) at (97-99°C) for sealing the porous anodic film. All specimens were later dried by the furnace at (50°C) for (30 min) and kept in the dissector for around (30 min).

The polarization was conducted in a beaker of one litter comprising of reference, counter, and working electrodes. The working electrode was (1x1) cm made from (7075-T73) Al alloy, and the other side and the thickness of specimen was coated by the epoxy to avoid the exposure to the solution, fixed via Al jigs made to fix the specimens, and it was shielded by a shrinkage tube for providing a bad contact and holding it steady in the cell.

The reference electrode was a standard calomel electrode (SCE) kind (Tacussel kind C4) bridged by a Laggin-Haber probe. While, the counter electrode was platinum kind (Tacussel Pt-F05/30) set straightly in the opposite direction to the working electrode. The distance between the Laggin-Haber capillary and the surface of the electrode surface was about the optimum value of (1 mm) for minimizing the error of the experimen owing to the (IR) drop. A thermometer was utilized to keep the temperature of the solution within ($\pm$ 1^{o}C).

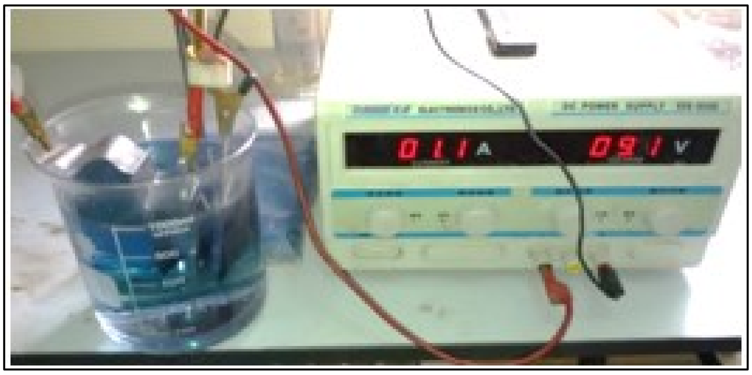

Figure 3: Photograph of the complete assembly of the anodizing apparatus

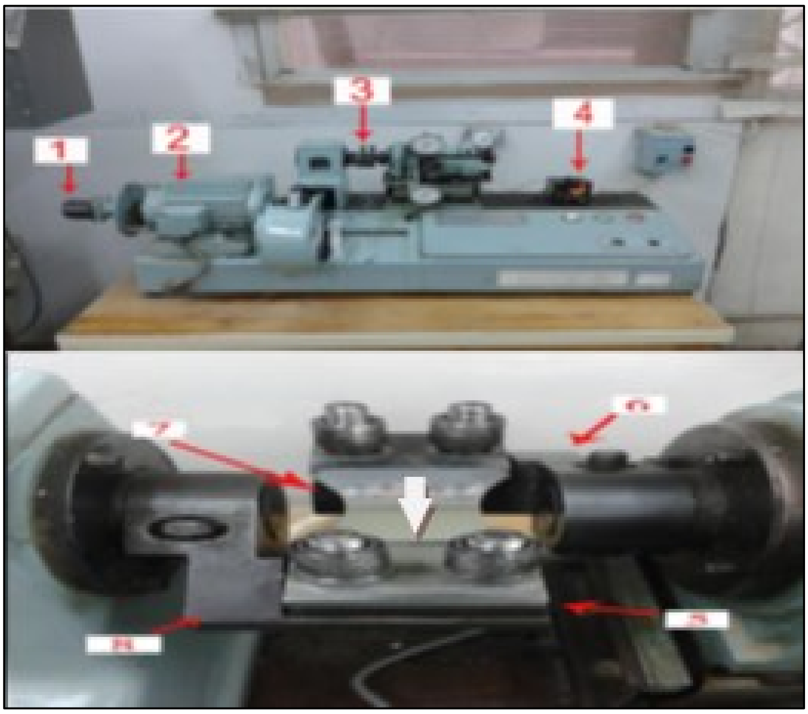

Figure 4: Fatigue testing machine

1. Mechanical counter 2. Motor 3. Specimen fixture 4. Digital counter5. Clamp 6. Fixed grip 7. The specimen 8. Movable gripIn this research, Rockwell B hardness tester was used.

3. Results and Discussion

Beyond the anodizing process, the mechanical properties of the treated specimens at the anodizing time 20 min were found as given in Table 3 together with the as-received specimen for comparison purpose.

I. Corrosion Rates

According to the corrosion test results, it was found that the corrosion rate decreased after anodizing, as depicted in Table 3. This indicates that the major value of corrosion rate (652 mpy) was for 20 min anodizing time, and this is lower than the corrosion rate (1663 mpy) for the untreated specimen, with percentage reduction of (155.06%). This is ascribed to that the anodized film reduced the corrosion rate for the aluminium 7075-T73 owing to the passive layer (Al_2O_3) on surface since such layer covers the surface and avoids the aggressive attacking of the solution for the surface of alloy in comparison with untreated specimen.

II. Hardness

It can be seen that the hardness generally increased after anodizing. The hardness value is (110 HB) for 20 min, so the hardness improvement is (21.54 %) in comparison with the hardness (90.5 HB) of the untreated specimen Table 3. This increase is owing to the anodized film formation on the surface of specimen.

III. Surface roughness

It was noticed that the roughness largely increased after anodizing. The surface roughness value was (0.358 µm) for 20 min time. Thus, the roughness increment is (377.34 %) with respect to that for untreated specimen (0.075 µm), as shown in Table 3, since through the anodizing, a new phase produced, i.e. Al_2O_3.

IV. Thickness of anodizing layer

It was found that the thickness increased after anodizing. The thickness value was (19.3 µm) for anodizing of 20 min time, Table 3. This is due to more chemical deposition of the anodized layer with time, resulting in higher anodic film thickness.

V. Ultimate and yield tensile strengths

The result showed that both the ultimate and tensile strength decreased very slightly after anodizing. Figure 5(a) depicts the effect of anodizing time 20 min on the Stress-Strain curve of the untreated specimen. It is seen from these figures that the ultimate strength decrease was (1.86 %) at 20 min anodizing time and (7.11%) for yielding strength, Table 3.

VI. Fatigue strength

All the results of the high fatigue cycle tests for as-received and anodized specimens treated at time 20 min are listed in Tables 4 and 5. It can be noted that the fatigue strength lives very slightly decreased when compared with the values for the as-received specimen, but the fatigue strength lives increased with the reduction of amplitude stress value as shown in Tables 6. The percentage of the fatigue life decrease is also given in Table 6. All the results were used to plot the S/N curve for the untreated and treated specimens at 20 min anodizing times, as shown in Figure 5(b), the anodized specimen for 20 min experienced lower fatigue lives when compared with the untreated specimen. The reason of decrement of fatigue life is thought to be due to the existence of pores in the anodize layer and that may decrease the layer toughness and create early layer cracking. Thus, the local non uniform zone was sufficiently brittle for simply nucleating a primary crack. Basquin equation (σa= (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 5, the following equation was obtained: (σa =89.79(425E+03)-0.052) with (σa=65.54 MPa), after the anodizing for 20 min time.

Table 3: Mechanical Properties and Corrosion rate Experimental Results of AL-Alloy 7075-T73 for as-received and anodized specimens at time 20 min

AL-Alloy 7075-T73			
Properties	Time of Anodizing 20 min	As-received without Treatment	Percentage of increase or degrease
Hardness, Rockwell (HB)	110	90.5	21.54
Surface roughness (µm)	0.358	0.075	377.34
Thickness of anodizing layer (µm)	19.3	0	
Corrosion rate (mpy)	652	1663	-155.06
Ultimate Tensile Strength (σ_{ut}) MPa	526	536	-1.86
Tensile Yield Strength (σ_{yt}) MPa	418	450	-7.11
Fatigue Strength (σ_f) MPa	76	74.6	1.87

Table 4: Fatigue Life Data of the AL-Alloy 7075-T73 Calculated As- received Without Treatments

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σf) (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 (σa) (MPa)		$\sigma_a = \sigma_f N_f^{-0.063}$			

Table 5: Fatigue Life Data of the AL-Alloy 7075-T73 Calculated after Anodizing (t=20 min)

Eccentric Pos. angle θ (deg.)	Failure Stress Applied (σf) (MPa)	Number of Cycles * 10^3			$N_{f(average)}$ Cycles
		N_{f1}	N_{f2}	N_{f3}	
2	44.89	212 5	212 5	212 5	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 (σa) (MPa)		$\sigma_a = \sigma_f N_f^{-0.063}$			

Table 6: Fatigue Life Data and Percentage of Decreasing after anodizing time 20 min

Amplitude Stress σa (MPa)	**Number of Cycles * 10^3**		**Percentage of Decreasing %**
	As-received	Anodizing (t=20 min)	
30.1	2450	2125	22.21
65.69	536	425	26.12
146.3	201	130	54.61
224	56.2	51	10.19
277.3	28.4	27.5	3.28
365.4	16.5	16.1	2.48
491.1	9.7	9	7.7

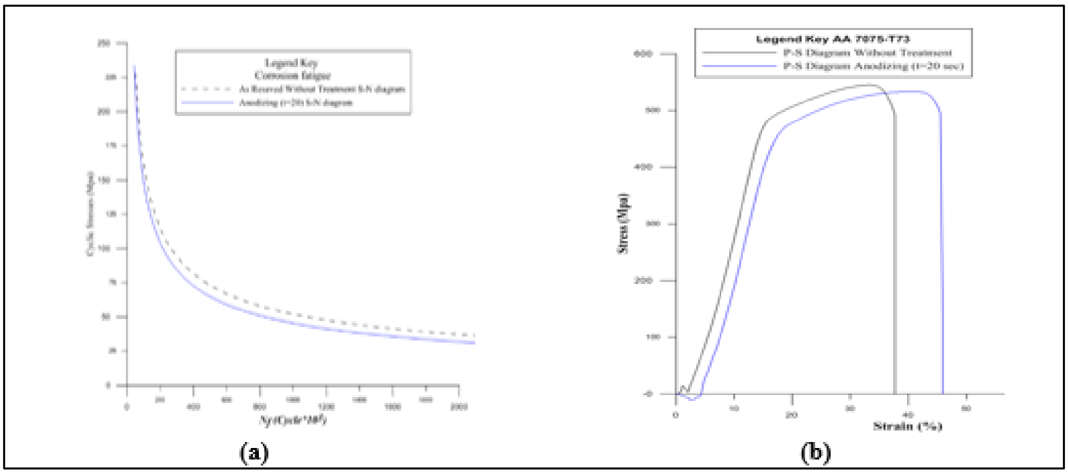

Figure 5: (a) The effect of Anodizing time on Stress-Strain diagrams of AA 7075-T73 (b) The S-N Diagram of AA 7075-T73 with and without Anodizing at time 20 mi

3. Conclusions

1. The corrosion rate was reduced in the anodized Al alloy in comparison with the untreated specimen (using sulfuric acid as electrolyte), the percentage of reduction was (155.06%.(
2. A little effect of anodizing was found on the mechanical properties according to the time of anodizing for the alloy used. The ultimate strength decrease was (1.86 %) at 20 min anodizing time and (7.11%) for yielding strength.
3. A higher effect of anodizing was noticed on the value of hardness, surface roughness, thickness of anodizing layer. The hardness improvement was (21.54 %), the roughness increment is (377.34.(%
4. Fatigue life of AA 7075-T73 was slightly decreased after anodizing for 20 min time as compared with the untreated alloy. The percentage of the fatigue life decrease was 7.7% at amplitude stress equal to 491.1 .
5. The influence of thickness of the anodized layer wasn’t obvious at the higher amplitudes of stress, but the clear effect of the anodized layer thickness was apparent at the lower amplitudes of stress.

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