VIKAS PIPRANI
10504017

FATIGUE LIFE ESTIMATION OF PRE-CORRODED ALUMINIUM ALLOY SPECIMEN

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

In

Metallurgical and Materials Engineering

By

VIKAS PIPRANI

&

PRACHI SAMAL

Under the Guidance of

Prof. B.B.VERMA

&

Prof. P.K.RAY

Department of Metallurgical and Materials Engineering

National Institute of Technology, Rourkela.

National Institute of Technology

CERTIFICATE

This is to certify that the thesis entitled, "FATIGUE LIFE ESTIMATION OF PRE-CORRODED ALUMINIUM ALLOY SPECIMEN" submitted by VIKAS PIPRANI in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Metallurgical and Materials Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date:

Prof. B.B.VERMA

Dept. of Metallurgical and Materials Engg.

National Institute of Technology

Rourkela-769008

ACKNOWLEDGEMENT

We record our sincere gratitude to Prof. B.B.Verma, Dept. of Metallurgical and Materials Engineering & Prof.P.K.Ray, Dept. of Mechanical Engineering for assigning us the project "Fatigue life estimation of pre-corroded aluminium alloy specimen". It is not possible to acknowledge sufficiently his important contributionof talent and time given unselfishly in proceeding with this work. His constant voice of advice and constructive criticism has been our source of inspiration.

We wish to record our gratitude to our project coordinators Prof. A.K. Panda and Prof. M. Kumar for helping us at each and every step in bringing out this report.

We are also thankful to Prof. U.K. Mohanty, Dept. of Metallurgical and Materials Engineering for permitting us to access the SEM. We would also like to thank Mr. S.Hembrom and Mr. Rajesh Pattnaik of Metallurgical and Materials Engineering Dept. for helping us throughout our project work.

Vikas Piprani 10504017

Prachi Samal 10504010

B.Tech

Metallurgical and Materials Engineering

Abstract

The effect of time and mode of corrosion in fatigue life of pre-corroded 7020-aluminum alloy has been determined and compared with that of uncorroded specimens. It is known that fatigue properties of any material depend on the homogeneity of the material mostly the surface uniformity .Any irregularity present may cause fatigue crack initiation at a stress comparably lower than that shown by the S-N curve and thus the pre-corroded specimens' S-N curve shows some deviation from the actual curve due to the presence of corrosion pits.

As the fatigue failure process exploits the weakest links (discontinuities) within the test material, which act as nucleation sites for crack origins, the fatigue properties of uncorroded and pre-corroded 7020-aluminum alloy in aqueous solution of NaCl (3.5% NaCl , 8.2 pH) along with forced corrosion at different sweep rates have been studied and compared in this project. The properties being the S-N curve, fatigue life, endurance limit, fatigue crack growth mechanism, SEM fractograph and probable crack initiation cause and spot.

Round specimen generally used in classical fatigue tests for life estimation have been used in this experiment. S-N curve is plotted by using Moore's rotating cantilever beam type fatigue testing machine. The tests are conducted in uncorroded specimen and in pre-corroded specimen and then results are compared. Also the mechanism and spot of crack initiation is predicted by using fractographs under SEM.

CONTENTS

1.INTRODUCTION

Alumimium is remarkable for its ability to resist corrosion(due to the phenomenon of passivation). Aluminium and its alloys are being used successfully in a wide range of applications, from packaging to aerospace industries due to their light weight. Due to their good mechanical properties and low densities, these alloys have an edge over other conventional structural materials. They are also used as light weight earth movers. Aluminium alloys continue to be the dominating structural materials for aircraft. In most of the aircraft, the air-frame consists of about 80% aluminium by weight (Zehnder 1996). Now-a-days, the cost reduction for aircraft has become an important criterion in many airlines and the selection of material is done on the basis of life cycle approach. The composites are very competitive materials for aircraft structural applications. However, they are generally considered to have higher initial cost, require more manual labour in their production and are more expensive to maintain. Ref[1]

Damage by corrosion fatigue is probably the main structural damage factor that will affect the performance and the life of an airplane . However the severity of the degradation of an aircraft component by corrosion fatigue depends on its location in the airplane structure. Wings are subjected to ground (G.A.C.) cycles due to the landing and takeoff and to fatigue cycles during the flight, due to atmospheric perturbations and to plane maneuvers. On the contrary of the fuselage, the combination of a flight and a ground cycle corresponds to one single fatigue cycle. Tensile stresses are induced in the fuselage by the pressurization of the cabin. These stresses are relieved by depressurization during landing. An alteration of pressurization and depressurization constitutes one fatigue cycle. Ref [2]

When corrosion takes place at the same time as fatigue, a synergistic effect is developed between the two degradation processes. Damage is enhanced. Corrosion fatigue is a serious issue for airplanes that are exposed to marine and/or polluted air. This environment is particularly detrimental to the corrosion fatigue performance of airplanes since chloride compounds induce the breakdown of the passive film which covers aluminum alloys and which protects them from the atmosphere.

Aluminum-zinc alloys use in aircraft components was not introduced until 1940s, after a long research in the mechanical stability of these alloys at a wide range of temperatures and pressures conditions. Aluminum-zinc alloys are attracting much attention because of their favorable strength-to-weight ratio and corrosion resistance compared to conventional stainless steels. Relatively little work has been done on corrosion of 7XXX aluminum-zinc alloys. Alloying elements such as zinc, copper, magnesium, and silicon added to aluminum improve mechanical properties but frequently reduce localized corrosion resistance, in particular, pitting and exfoliation corrosion. Stronger localized attack on alloys in comparison with aluminum has been ascribed to alloy surface microstructural heterogeneity. Precipitates presence, inclusions and intermetallic particles provoke discontinuities during the layer growth and promote galvanic couples formation with the alloy matrix. Ternary and quaternary Al-based particles frequently found in these alloys exhibit different electrochemical characteristics compared to the surrounding microstructure. Mg-containing particles tend to be anodic, while Cu, Fe and Mn-containing ones tend to be cathodic in relation to the matrix. In both cases, localized dissolution processes are promoted. Since 7XXX aluminum alloys use to have good mechanical performance as aeronautical materials, it is essential to improve localized corrosion processes understanding. Ref [3]

Metal Fatigue: A phenomenon which results in the sudden fracture of a component after a period of cyclic loading in the elastic regime. Failure is the end result of a process involving the initiation and growth of a crack, usually at the site of a stress concentration on the surface. Occasionally, a crack may initiate at a fault just below the surface. Eventually the cross sectional area is so reduced that the component ruptures under a normal service load, but one at a level which has been satisfactorily withstood on many previous occasions before the crack propagated. The final fracture may occur in a ductile or brittle mode depending on the characteristics of the material. Fatigue fractures have a characteristic appearance which reflects the initiation site and the progressive development of the crack front, culminating in an area of final overload fracture.

- Initiation site(s).
- Progressive of crack front characterize by beach marks.
- Culminating in an area of final fracture.

Fig. la illustrates fatigue failure in a circular shaft. The initiation site is shown and the shell-like markings, often referred to as beach markings because of their resemblance to the ridges left in the sand by retreating waves, are caused by arrests in the crack front as it propagates through the section. The hatched region on the opposite side to the initiation site is the final region of ductile fracture. Sometimes there may be more than one initiation point and two or more cracks propagate. This produces features as in Fig. 1b with the final area of ductile fracture being a band across the middle. This type of fracture is typical of double bending where a component is cyclically strained in one plane or where a second fatigue crack initiates at the opposite side to a developing crack in a component subject to reverse bending. Some stress-induced fatigue failures may show multiple initiation sites from which separate cracks spread towards a common meeting point within the section.

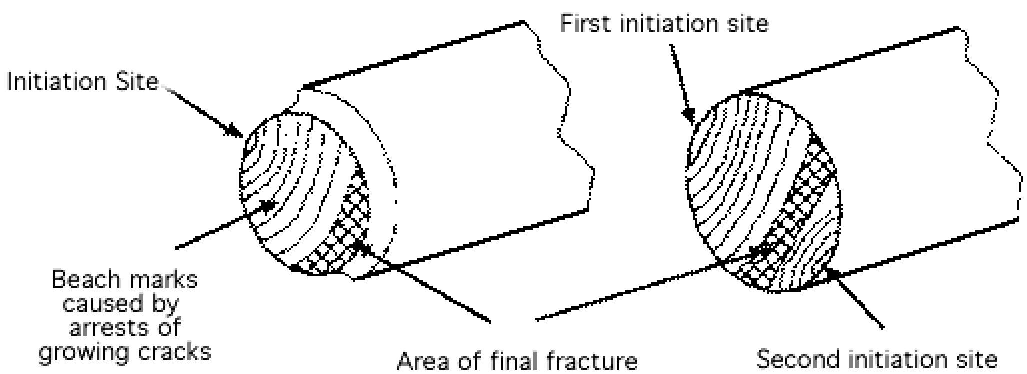


Fig 1

1.1 Heat Treatment

The term “heat treating” for aluminum alloys is frequently restricted to the Specific operations employed to increase strength and hardness of the precipitation-hardenable wrought and cast alloys. These usually are referred to as the “heat-treatable” alloys to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling.

The commercial heat-treatable alloys are, with few exceptions, based on ternary or quaternary systems with respect to the solutes involved in developing strength by precipitation. Commercial alloys whose strength and hardness can be significantly increased by heat treatment include 2xxx, 6xxx, and 7xxx series wrought alloys and 2xx.0, 3xx.0 and 7xx.0 series casting alloys.

Heat treatment to increase strength of aluminum alloys is a three-step process:

- Solution heat treatment: dissolution of soluble phases
- Quenching: development of supersaturation
- Age hardening: precipitation of solute atoms either at room temperature (natural aging) or elevated temperature (artificial aging or precipitation heat treatment).

1.1 a.Solution Heat Treatment

The objective of solution heat treatment is to take into solid solution the maximum practical amounts of the soluble hardening elements in the alloy. The process consists of soaking the alloy at a temperature sufficiently high and for a time long enough to achieve a nearly homogeneous solid solution. It is desirable that the solution heat treatment is carried out as close as possible to the liquidus temperature in order to obtain maximum solution of the constituents. Accurate furnace temperature and special temperature variation must be controlled to within a range of ±5°C for most alloys. Overheating must be avoided i.e. exceeding initial eutectic melting temperatures. Often the early stages of over heating are not apparent but will result in a deterioration of mechanical properties.

1.1 b.Quenching

Quenching is in many ways the most critical step in the sequence of heat-treating operations. The objective of quenching is to preserve the solid solution formed at the solution heat-treating temperature, by rapidly cooling to some lower temperature, usually near room temperature. In most instances, to avoid those types of precipitation that are detrimental to mechanical properties or to corrosion resistance, the solid solution formed during solution heat treatment must be quenched rapidly enough (and without interruption) to produce supersaturated solution at room temperature - the optimum condition for precipitation hardening. The resistance to stress-corrosion cracking of certain copper-free aluminum-zinc-magnesium alloys, however, is improved by slow quenching. Most frequently, parts are quenched by immersion in cold water, or in continuous heat treating of sheet, plate, or extrusions in primary fabricating mills, by progressive flooding or high-velocity spraying with cold water.

1.1 c.Age Hardening

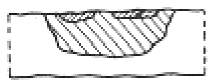
After solution treatment and quenching hardening is achieved either at room temperature (natural aging) or with a precipitation heat treatment (artificial aging). In some alloys, sufficient precipitation occurs in a few days at room temperature to yield stable products with properties that are adequate for many applications. These alloys sometimes are precipitation heat treated to provide increased strength and hardness in wrought or cast products. Other alloys with slow precipitations reactions at room temperature are always precipitation heat treated before being used.

The artificial ageing or precipitation heat treatments are low temperature long time processes. Temperatures range from 115-200°C and times from 5-48 hours. As with solution treatment accurate temperature control and spatial variation temperatures are critical to the process and generally temperatures should be held to a range of ±7°C.

1.2 Pitting Corrosion

Localized corrosion (pitting corrosion)

The basis metal is eaten away and perforated in places in the manner of holes, the rest of the surface being affected only slightly or not at all.



Wide pitting corrosion

The corrosion causes localized scarring.

The pitting is the most common form of corrosive attack in aluminum alloys. The corrosion is caused by the potential difference between the anodic area inside the pit – which often contains acidic, hydrolyzed salts – and the surrounding cathodic area. Pitting is first noticeable as a white or gray powder deposit, similar to dust, that blotches the surface. When the superficial deposit is cleaned away, tiny pits or holes can be seen in the surface. These pits may appear either as relatively shallow indentations or as deeper cavities of small diameters.

Pitting may occur in any metal, but it is particularly characteristic of aluminum and aluminum alloys. Pitting (localized) corrosion leading to fatigue crack initiation and crack growth is considered to be one of the most significant damage mechanisms in aging structures. Even low-levels of pitting corrosion on aluminum structures resulting from saltwater spray and/or salt fog is the precursor to corrosion fatigue degradation.

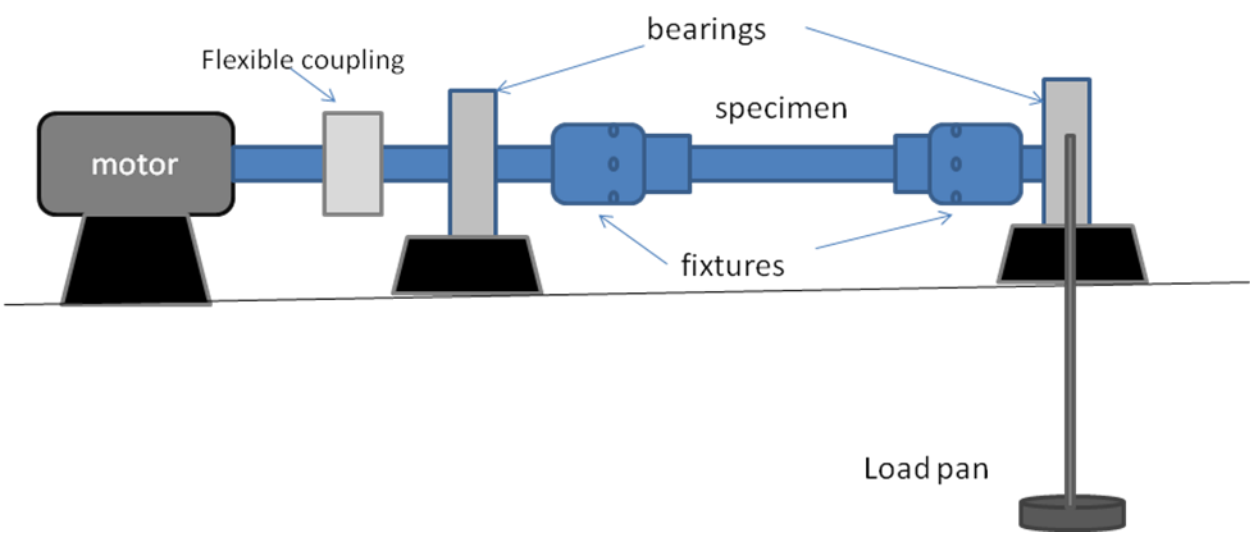
1.3 Fatigue testing machine (Moore test):

- Theory of Operation: works on rotating beam principle. The specimen function as a cantilever beam point loaded at the end point .

- Load Frame Features: loaded by weight pan below the table.

- Specimen Loading: when rotated one half revolution, the stresses in the fibers originally below the neutral axis are reversed from tension to compression and vice versa. Upon completing the revolution, the stresses are again reversed so that during one revolution the test specimen passes through a complete cycle of flexural stress (tension and compression).

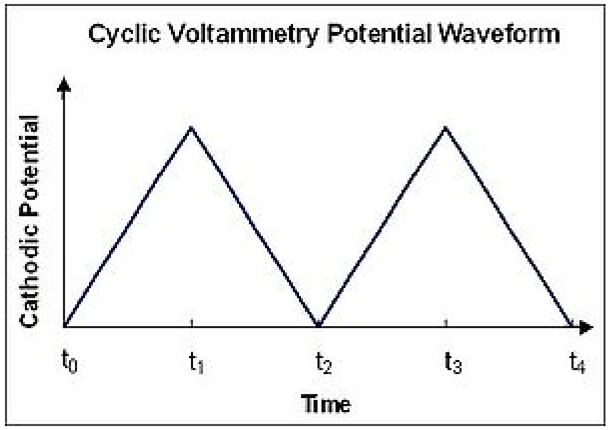
- Digital Display: measures number of cycles.



1.4 Cyclic voltammetry

Cyclic voltammetry or CV is a type of potentiodynamic electrochemical measurement. The method uses a reference electrode, working electrode, and counter electrode which in combination are sometimes referred to as a three-electrode setup. Electrolyte is usually added to the test solution to ensure sufficient conductivity. The combination of the solvent, electrolyte and specific working electrode material determines the range of the potential.

In cyclic voltammetry, the electrode potential ramps linearly versus time as shown. This ramping is known as the experiment's scan rate (V/s). The potential is measured between the reference electrode and the working electrode and the current is measured between the working electrode and the counter electrode. This data is then plotted as current (*i*) vs. potential (*E*). As the waveform shows, the forward scan produces a current peak for any analytes that can be reduced (or oxidized depending on the initial scan direction) through the range of the potential scanned. The current will increase as the potential reaches the reduction potential of the analyte, but then falls off as the concentration of the analyte is depleted close to the electrode surface. If the redox couple is reversible then when the applied potential is reversed, it will reach the potential that will reoxidize the product formed in the first reduction reaction, and produce a current of reverse polarity from the forward scan. This oxidation peak will usually have a similar shape to the reduction peak. As a result, information about the redox potential and electrochemical reaction rates of the compounds are obtained.



2. LITERATURE REVEW:

D.L. DuQuesnay et.al(International Journal of Fatigue 25 (2003) 371–377) examined 7075-T6511 Aluminium alloy provided in the form of extruded channel sections. The fatigue coupons were machined with the loading axis parallel to the longitudinal direction of the extrusion and extrusion thickness was 6.5mm. It showed that artificially produced pitting corrosion gives a severe reduction in the fatigue life of laboratory specimens when subjected to transport aircraft spectrum loading in laboratory air. A simple two-dimensional crack growth calculation using AFGROW software successfully predicted the fatigue lives of the pitted specimens using the depth and average width of the corrosion pits as the starting crack size for the analysis. Thus it showed that there is good potential for this technique to be applied to predict remaining life of corrosion damaged airframe structures.

Al.Th. Kermanidis et.al(Journal of Theoretical and Applied Fracture Mechanics 43 (2005) 121–132)prepared 2024 T351 Aluminium alloy in bare, sheet form of 1.6 mm nominal thickness. Machining of the specimens was made according to the specifications ASTM E 466-82 for the fatigue, ASTM E 647-93 for the fatigue crack growth and ASTM E 561-94 for the fracture toughness specimens. The effect of 36 h exposure to exfoliation corrosion solution of bare 2024 T351 aluminum specimens on the fatigue life of the specimens showed that the corrosion attack results in a significant drop of the materials fatigue life . Metallographic corrosion characterization of specimens exposed to exfoliation corrosion solution for 24 h showed that the presence of corrosion pitting and intergranular corrosion facilitates essentially the onset of fatigue cracks and, hence, reduces the fatigue life of the corroded specimens appreciably.

K.Genel (Scripta Materialia 57 (2007) 297–300)showed the effect of pitting corrosion produced by prior immersion in 3.5% NaCl solution on the fatigue behavior of 7075-T6 aluminum alloys.It was concluded from the results that pit population, pit density as well as pit depth increase with increasing pre-corrosion time. Pits, once formed, act as stress concentration sites and can also facilitate fatigue crack initiation when the stress intensity factor reaches the threshold value or promotes crack growth. Depending on the pit severity, the degradation in fatigue strength can be as much as approximately 60%.

K. van der Walde et.al(International Journal of Fatigue 27 (2005) 1509–1518) performed quantitative fractography on forty 2024-T3 sheet aluminum fatigue specimens. It was found that over half of the specimens analyzed had two or more crack-nucleating pits. The number of nucleating pits per specimen was found to be positively correlated with stress level and an interactive effect with corrosion exposure duration was observed. From the fatigue modeling efforts it is concluded that increased accuracy can be achieved by incorporating multiple crack effects, particularly at higher stress levels where consistently unconservative life predictions can be avoided.

W. Guo et.al(International Journal of Fatigue 25 (2003) 733–741) used three dimensional finite element (FE) models with 20-node singular elements arranged around the crack tip to calculate the SIFs(stress intensity factors) of elliptical surface cracks in round bars with different notches and theoretical stress concentration coefficients. From the numerical results, it was obtained that the 3D FE model with singular 20-node elements arranged around the crack border is effective to yield reliable SIFs for surface cracks at notches in round bars. It showed that the SIFs are strongly influenced by the theoretical stress concentration coefficient *K*t, especially near the notch root. An empirical expression for the SIFs as a function of crack geometry and *K*t was obtained by fitting the numerical results which can be used conveniently in life prediction of notched bars with various notch geometry and stress concentration coefficients at least within the range of parameters studied in this work.

R.M. Chlistovsky et.al(International Journal of Fatigue xxx (2007) xxx–xxx) in their study subjected axial fatigue specimens of 7075-T651 aluminium alloy to a loading spectrum that consisted of a fully reversed periodic overload of near-yield magnitude followed by 200 smaller cycles at high R ratio.The specimens were fatigue tested while they were fully immersed in an aerated and recirculated 3.5 wt% NaCl simulated seawater solution. A damage analysis showed that the presence of the corrosive environment accelerated the damage accumulation rate to greater extent than that observed in air, particularly at low stress ranges. This resulted in a reduction in the fatigue strength of the material when it was simultaneously subjected to overloads and a corrosive environment. It is believed that the reduced fatigue life was due primarily to corrosion pit formation and a combination of anodic dissolution at the crack tip and hydrogen embrittlement.

Kimberli Jones et.al(Corrosion Science 47 (2005) 2185–2198)conducted pit-to-crack transition experiments on 1.600 mm and 4.064 mm 7075-T6 aluminum alloy. Specimens were corroded using a 15:1 ratio of 3.5% NaCl solution and H2O2 to fatigue loading.

Corrosion pits were identified as crack origins in all corroded specimens in the study, while large pit surface areas contributed to crack development in a low number of cycles. The combined effects of pit depth, pit surface area, and proximity to other pits were found to substantially reduce fatigue life.

R.A. Siddiqui et.al(Materials and Design xxx (2007) xxx–xxx)showed experimentally the effect of seawater corrosion, aging time, and aging temperature on the fatigue resistance property of 6063 aluminum alloy. The 6063 aluminum alloy that was used for the study was heat treated and soaked in seawater for different intervals of time between 2 and 30 weeks. It was found that the maximum fatigue resistance property in the 6063 aluminum alloy was observed when aged between 7 and 9 h and heat treated at temperatures between 160 °C and 200 °C. Generally at constant load, the results indicated that the number of cycles to fail the 6063 aluminum alloy decreased with increasing the soaking time in seawater. Moreover, fracture surfaces were considered and studied under a scanning electron microscope (SEM). The results showed that the brittle fracture pattern tended to occur with the increase in aging time and temperature. The fatigue striations were observed very clearly at low and peak aging temperature.

3. EXPERIMENTAL:

The material available was in the form of rolled 25 mm thickness 7020 aluminum alloy sheet, generally used in ground transportation system generally Armoured vehicles, military bridges, motor cycle and bicycle frames and also used in aircrafts and ship structure.

The 7020 aluminium alloys have various mechanical properties with pre-determined values such as follows:

Tensile Strength	352.14 MPa
Yield Strength	314.70 MPa
Young’s Modulus	70000 MPa
Elongation in 40mm	21.45 %

Its composition is given in table 1.

Table 1.composition of 7020 Al alloy

Element	Cu	Mg	Mn	Fe	Si	Zn	Al
Wt.%	0.05	1.20	0.43	0.37	0.22	4.60	balance

The plate(sheet) is cut into pieces according to the dimension of the standard fatigue test specimen on Moore fatigue testing machine. The detailed drawing of specimen is shown in figure1.Prior to fabricating to its required dimensions the cut pieces were solution treated at a temperature of 520°C for 3 hours and water quenched. This was followed by step-aging done at 110°C and 150°C for 10 hours and 20 hours respectively followed by air cooling. The time for solution treatment and aging was determined by optimization technique so as to obtain good hardness. This heat treatment cycle is generally known as T7 type. This is done to improve the machinability of material so as to obtain desired surface finish of material and confirmation to dimensions. The specimens were notched to improve the stress concentration so as to cause failure at specific point. Some of the fabricated samples were corroded using NaCl solution (3.5% by weight, pH 8.2) at room temperature by dipping the samples in it for 100 hours. Some others were corroded by same solution but by forcing potential through a potentiostat by dipping the specimens in the solution. The process employed is known as Cyclic Voltametry (CV). The rate of corrosion in this method was changed by altering the sweep rate.

Specimens corroded by both the above stated methods are subjected to fatigue testing at various loads through a Moore's (Rotating Beam) Fatigue testing machine. The number of cycles to failure for each specimen were recorded and compared. The fractured surface was further observed in microscope and in SEM to get an idea about fracture behavior of material (fractographic analysis).

The rest of the samples which were corroded by both methods but were not subjected to loading were cut near the notches and observed under hot stage microscope to determine number of corrosion pits formed per unit length and area and pit depth . This is further useful in calculation of stress intensity factor (SIF) which is further useful in life estimation of specimens. The SEM analysis of the same were also carried out inorder to get the same set of parameters.

Through all this life estimation of samples pre-corroded under various conditions were estimated and the fracture surface was analysed and compared for the same.

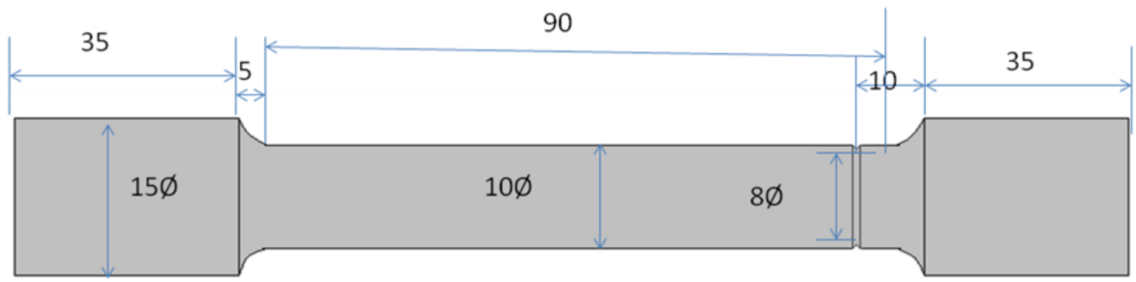


Figure 1

4. RESULTS AND DISCUSSION:

4.1 Heat Treatment Optimization

The solution treatment was carried out in muffle furnace for different time periods followed by water quenching. After this the samples were grinded and polished with emery paper so as to obtain a smooth even surface. Further cloth polishing was done with aluminium chloride solution. The polished surface thus obtained was tested for Vickers Hardness Number (VHN) under a load of 5kgf.

Sl.no	Time in furnace	Length of diagonal 1 in mm	Length of diagonal 2 in mm	Average length in (mm)	VHN
1.	2 hours	0.334	0.332	0.333	84
		0.331	0.332	0.3315	
2.	2.5hours	0.323	0.322	0.3225	89
		0.324	0.325	0.3245	
3.	3hours	0.300	0.298	0.299	104
		0.296	0.297	0.2965	

From the above table it is clear that solution treatment for 3 hours yields the maximum hardness and hence preferred.

After the solution treatment time is optimized now the aging time is varied to obtain maximum hardness of the specimen after grinding and polishing. The samples after aging are subjected to air cooling which is further followed by polishing and subsequent testing for VHN in which diagonals of indentation are measured to measure the hardness.

Sl.no	Aging treatment	Length of diagonal 1 in mm	Length of diagonal 2 in mm	Average length in mm	VHN
1.	110°C- 10 hours 150°C- 18 hours	0.271	0.272	0.2715	126
		0.272	0.273	0.2725	125
		0.270	0.271	0.2705	127
2.	110°C- 8 hours 150°C- 20 hours	0.287	0.286	0.2865	113
		0.288	0.286	0.287	114
		0.289	0.288	0.2885	111
3.	110°C- 10 hours 150°C- 20 hours	0.263	0.265	0.264	133
		0.263	0.264	0.2635	133
		0.263	0.263	0.263	134

From the above table it can be observed that aging done at 110°C for 10 hours followed by at 150°C for 20 hours yields maximum hardness. Hence this aging cycle is selected prior to fabrication.

Hence for project investigation purpose the alloy material in consideration was solution treated at 520°C followed by quenching and subsequently 2 stage artificial aging was carried out at 110°C and 150°C for 10 hours and 20 hours respectively followed by air cooling.

4.2 Stress Calculation

Diameter of specimen at notch, d = 8.0mm

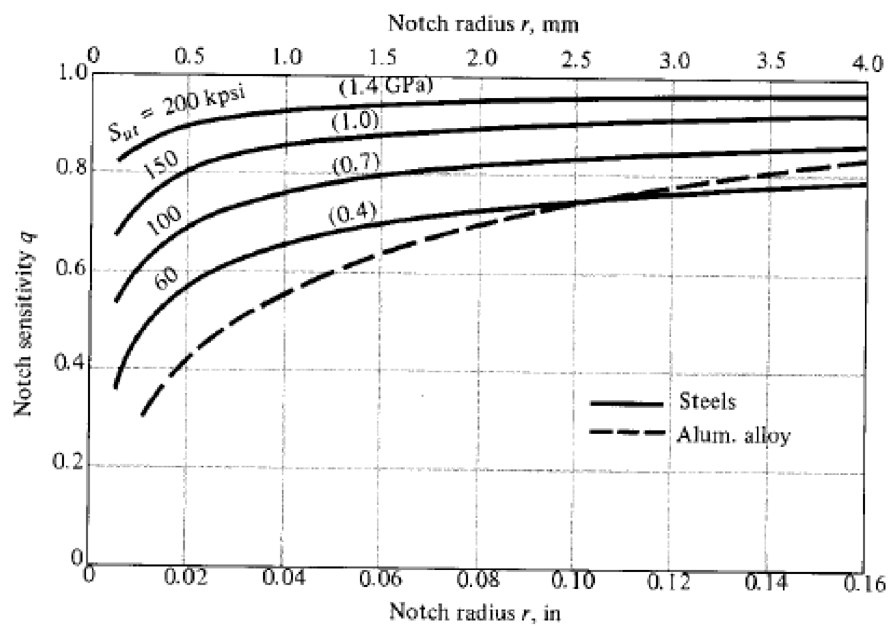
Diameter of specimen, D = 10mm

Radius of notch tip, r = 0.5mm

Implies, r/d =0.0625   D/d= 1.25

Notch sensitivity factor for aluminium alloy, q=0.4

Notch Sensitivity Factors
(Bending Example)

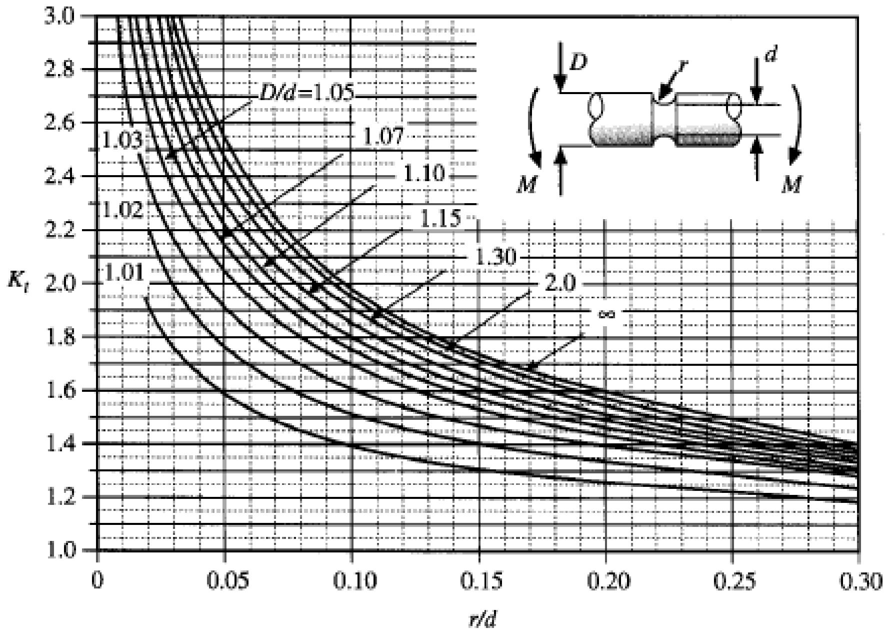


Shigley, Fig. 5-16

K_t from chart=2.2

Geometric Stress Concentration Factors

(Bending Example)



Spotts, Fig. 2-12, Peterson

K_t is the theoretical stress concentration factor

$K_f = 1 + q\,(K_t - 1)$

$= 1.48$

K_f is fatigue stress concentration factor

$$Actual\ stress, \sigma = Kf\frac{My}{I}$$

Where I- Moment of inertia

M_y is the bending moment at the notch

By substituting the required values we get a simplified relation of load applied and stress obtained as:

$\sigma = 30.91 \times W$,   where W= load applied

The table below shows the stress obtained from various load applied:

Load Applied (kg)	Resulting Bending Stress (MPa)
3	90.54
4	120.72
5	150.9
6	181.08
7	211.26
8	247.28
9	278.2

4.3 Corrosion

After fabrication of samples some of the specimens are corroded by dipping them in NaCl solution (3.5% by weight, pH 8.2) for 100 hours at ambient tempearture. Few others are corroded with the help of potentiostat using cyclic voltametry method. While the rest are left uncorroded.

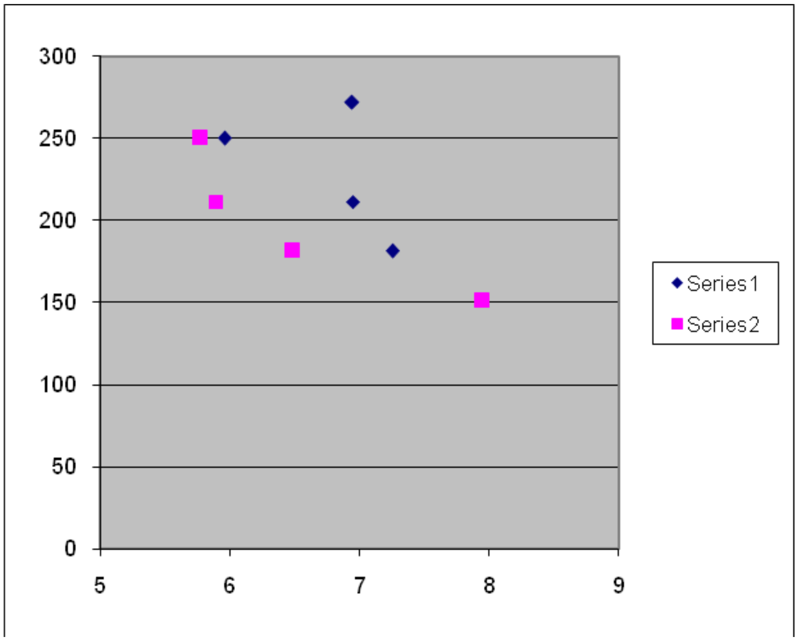
4.4 Life Estimation by Moore's Fatigue Testing Machine

The samples obtained by above corrosion methods and uncorroded ones are tested under various load (stress) conditions by Moore's (Rotating Beam) Fatigue testing machine and number of cycles to failure (N) for each of them is determined. The diatance of the notch from point of application of load was kept constant.

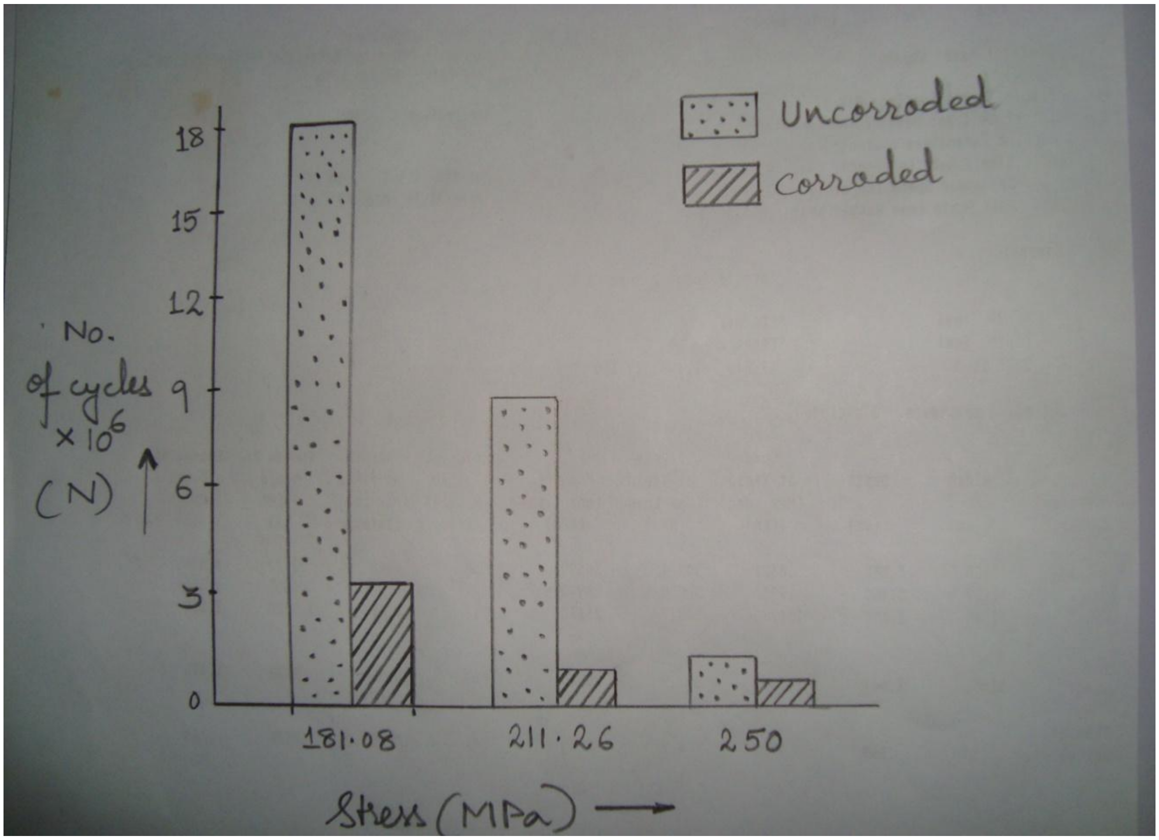
Sl.no	Load in kg	Bending Stress in MPa	Mode of Corrosion	No. of cycles to failure (N)
1.	4	120.72	Uncorroded Dipped for 100 hours CV method	Did not break upto $1.5x10^7$ --- ---
2.	5	150.9	Uncorroded Dipped for 100 hours CV method	$0.6x10^6$ $0.9x10^7$ ---
3.	6	181.08	Uncorroded Dipped for 100 hours CV method	$1.8x10^7$ $0.31x10^7$ $2.7x10^7$
4.	7	211.26	Uncorroded Dipped for 100 hours CV method	$8.9x10^6$ $0.78x10^6$ ---
5.	8	247.28	Uncorroded Dipped for 100 hours CV method	$0.92x10^6$ $0.6x10^6$ ---
6.	9	271.62	Uncorroded Dipped for 100 hours CV method	$0.88x10^6$ --- ---

--- indicates test not performed

The graph below shows a plot of stress in MPa on y-axis and number of cycles to failure (N) on x-axis. Series 1 indicates uncorroded samples and series 2 indicates samples corroded by dipping specimens in saline solution for 100 hours.

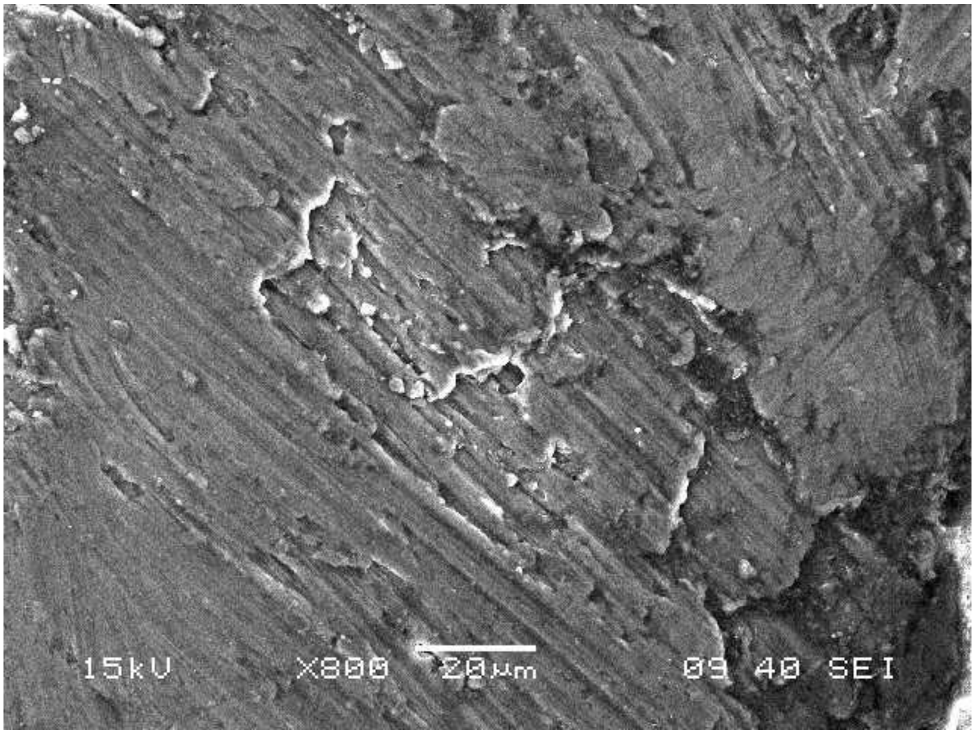


From the graph it is clear that fatigue life of corroded samples is much lower than that of uncorroded samples. However due to unforeseen circumstances the testing of specimens corroded by CV method could not be completed. Also as the stress increased the number of cycles to failure for a given set of conditions was considerably lowered.

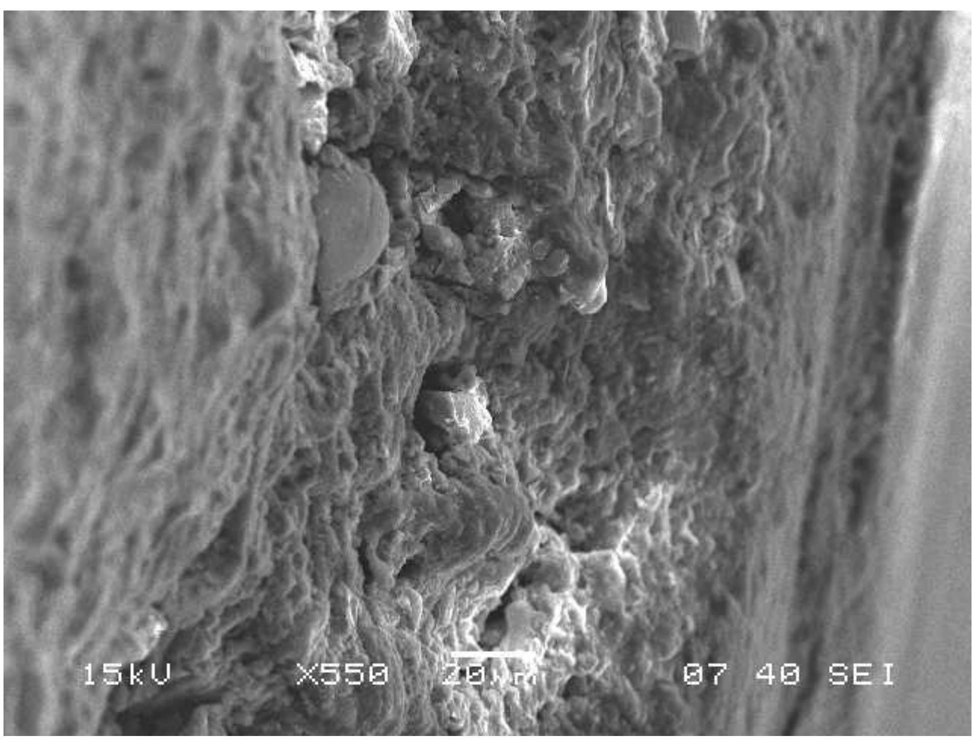


4.5 **Fractographic Analysis**

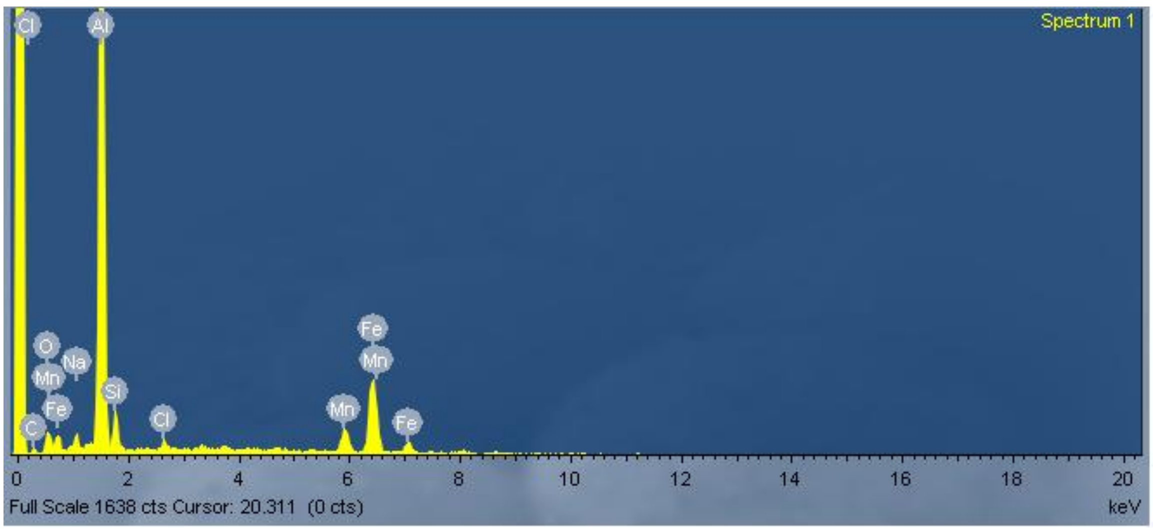
The fractured and the corroded surfaces were observed through SEM so study the effect of pit sizes on failure and to determine the point of initiation of crack which ultimately lead to failure.



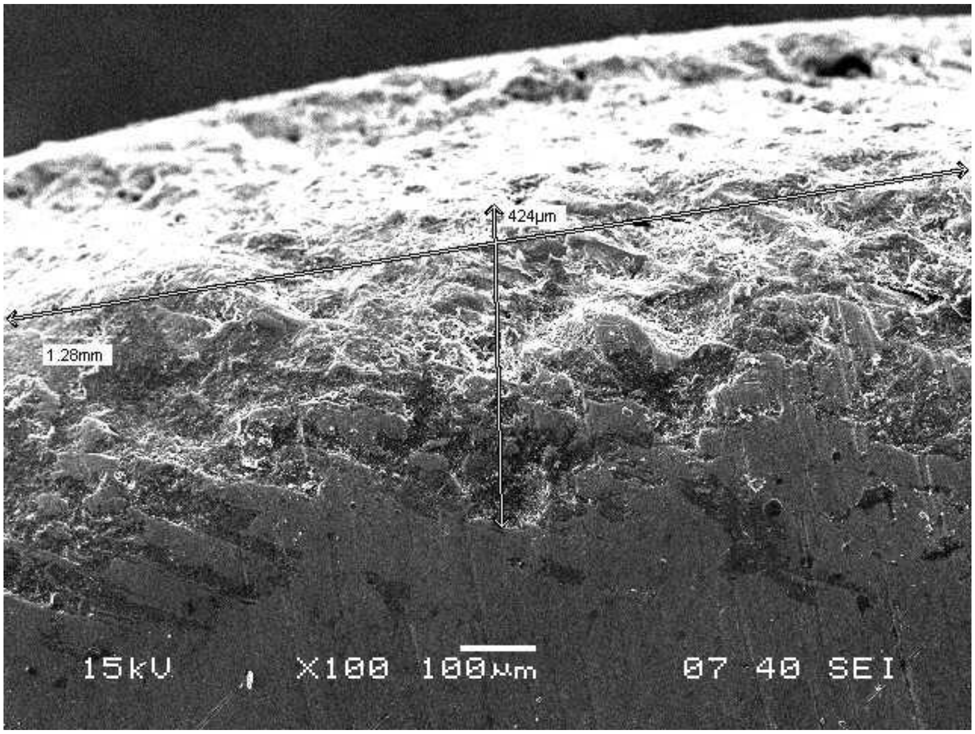
The above figure shows the fractograph of a corroded specimen. Here scratches are observed on the surface which may be produced during the rubbing action of specimen pieces after breakage. Hence no fractographic evidence is observed.



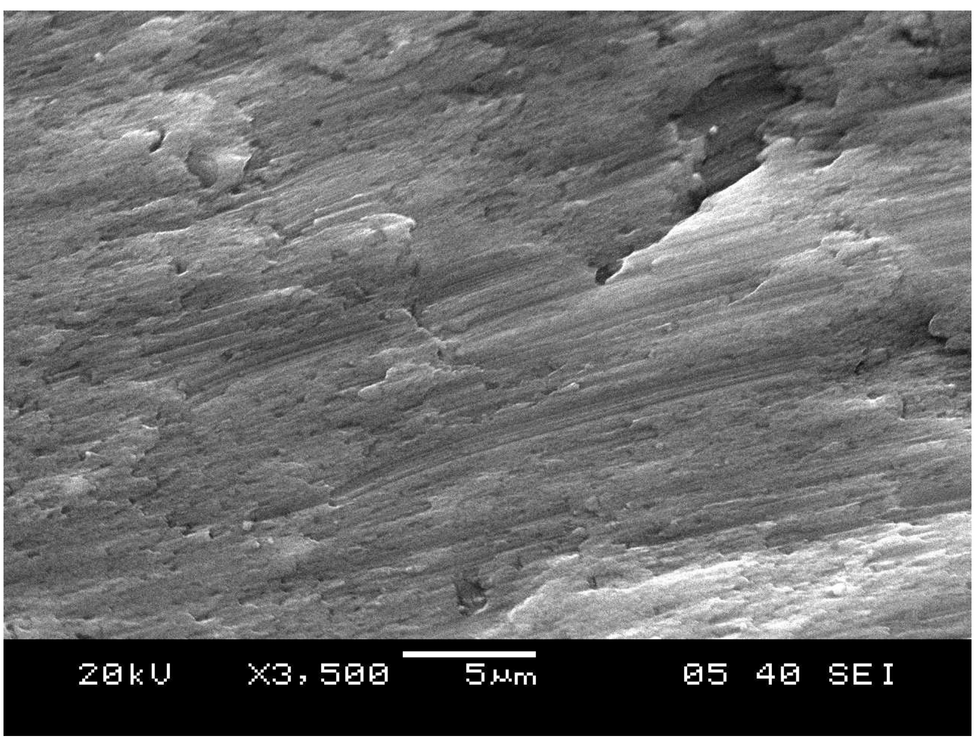
The previous figure shows edge of a notched specimen which has been corroded. Here volcano mouth type features are observed which indicates galvanic corrosion. Composition analysis of this corroded specimen showed the following result:



Here the chloride ions are present due to deposition on surface of Al. Fe,Si,C,Mn exists as impurities which further indicate galvanic corrosion. Rest may be impurities or corrosion products.



The above figure shows the length and width of the specimen subjected to corrosion. The corrosion pit appears to be elliptical in shape. The length of minor axis of the ellipse itself may be considered as depth of corrosion pit.



The previous figure roughly indicates the area of crack initiation. The distance to which this area extends is about 220µm.This is the required distance to calculate the Stress Intensity Factor.

4.6 Microscopy:

Here the corroded samples were observed under low magnification to observe the corrosion pits. The samples were corroded by CV method by applying different sweep rates of 2.4mV/s and 4.8mV/s.

The specimen corroded with sweep rate of 2.4mV/s showed about 10 pits/mm and 26pits/mm^2 having a maximum size of about 0.2mm. The specimen corroded with sweep rate of 4.8mV/s showed about 22pits/mm^2 having a maximum size of 0.1mm.

5. CONCLUSION:

1. The number of cycles to failure for a corroded sample is lower than that of an uncorroded sample.
2. The number of cycles to failure for specimen corroded by dipping is greater than that of those corroded by forced corrosion method.
3. No clear fractographic evidence was obtained in SEM analysis as the fractured surface might have been damaged due to the rubbing action.
4. Compositional analysis showed certain impurities which might have formed as a result of galvanic corrosion.
5. Volcano mouth type features on the surface indicates galvanic corrosion which has occurred.
6. The number of pits per unit area for specimen corroded by a lower sweep rate is greater than that of specimen corroded with higher sweep rate. This is due to more defined corrosion taking place in the former.
7. At higher values of stresses the effect of corrosion is much reduced than that at lower stress values.
8. The number of pits formed by open circuit corrosion are less in number and shallower than that formed by forced corrosion.

Future work:

1. Study the effect of temperature on pit size.
2. Corrosion effect on crack growth.
3. Testing under corrosive environment.
4. Determination of Stress Intensity Factor through pit depth.
5. Life estimation by corrosion at different temperatures.

6. REFERENCES:

[1]Study of fatigue behaviour of 7475 aluminium alloy,B B VERMA, J D ATKINSON and M KUMAR.

[2] Corrosion fatigue performance of alloy 6013-T6,Jean Mark P.Genkin, Massachusetts institute of technology,1994.

[3] LOCALIZED CORROSION OF 7XXX-T7 ALUMINUM ALLOYS IN CHLORIDE MEDIA, Wilson de Jesus, Marinalda Claudete Pereira,Roberto Zenhei,Technical Contribution to the xxst International Congress of the ABM, January 24-27th 2007, Rio de Janeiro – RJ – Brazil.

[4] Materials World, Vol. 12, No. 3, pp. 37-38, March 2004.

[5] Bard, Allen J.; Larry R. Faulkner (2000-12-18). Electrochemical Methods: Fundamentals and Applications (2 ed.). Wiley. *ISBN 0471043729*.

[6] Fatigue crack growth from corrosion damage in 7075-T6511 aluminium alloy under aircraft loading D.L. DuQuesnay ∗ , P.R. Underhill, H.J. Britt,2003.

[7] Fatigue and damage tolerance behaviour of corroded 2024 T351 aircraft aluminum alloy, Al.Th. Kermanidis, P.V. Petroyiannis, Sp.G. Pantelakis,2005.

[8] The effect of pitting on the bending fatigue performance of high-strength aluminum alloy K. Genel* , Mechanical Engineering Department, Sakarya University, Adapazari 54187, Turkey, April 2007.

[9] Multiple fatigue crack growth in pre-corroded 2024-T3 aluminum, K. van der Waldea, J.R. Brockenbroughb, B.A. Craigc, B.M. Hillberrya, August 2005.

[10] Stress intensity factors for elliptical surface cracks in round bars with different stress concentration coefficient ,W. Guo , H. Shen, H. Li, January 2003.

[11] Corrosion-fatigue behaviour of 7075-T651 aluminum alloy subjected to periodic

overloads R.M. Chlistovsky, P.J. Heffernan *, D.L. DuQuesnay, January 2007.

[12] Pit-to-crack transition in pre-corroded 7075-T6 aluminum alloy under cyclic loading Kimberli Jones *, David W. Hoeppner, December 2004.

[13] Effect of aging time and aging temperature on fatigue and fracture behavior of 6063 aluminum alloy under seawater influence R.A. Siddiqui, S.A. Abdul-Wahab *, T. Pervez, December 2006.

[14] JOURNAL OF AIRCRAFT,Vol. 41, No. 2, March–April 2004 Corrosion Fatigue in 7075-T6 Aluminum: Life Prediction Issues for Carrier-Based Operations Basir Shafiq and Vinod S. Agarwala.

[15] Surface cracks in notched round bars under cyclic tension and bending, Andrea Carpinteri*, Roberto Brighenti, Sabrina Vantadori, 2006.

[16] Fatigue Testing and Life Prediction for Notched Specimens of 2024 and 7010 Alloys Subjected to Aeronautical Spectra, Claude Bleuzen, 1 Madeleine Chaudonneret, 2 Lawrence Farcy, 3 Jean-Francois Flavenot, 3 and Naraganasuvami Ranganathan.

[17] Low-cycle fatigue in rotating cantilever under bending. III: Experimental investigations on notched specimens ,A.M. Eleichea,*, M.M. Megahedb, N.M. Abdullah, July 2005.

[18] Damage tolerance approach for probabilistic piitting corrosion fatigue life prediction, Pan Shi and Sankaran Mahadevan, October 2000.

[19] Corrosion Fatigue Behaviour of 7050 aluminium alloys in different tempers, Chih-Kuang Lin and Sheng-Tseng Yang.

[20] Comparative Study of Corrosion–Fatigue in Aircraft Materials**,** Q. Y. Wang, R. M. Pidaparti, and M. J. Palakal, AIAA JOURNAL Vol. 39, No. 2, February 2001.

[21] The effect of exfoliation corrosion on the fracture and fatigue behaviour of 7178-T6 Aluminium , J.P. Chubb, T.A. Morad, B.S. Hockenhull and J.W. Bristow , March 1994.

[22] (Engineering Fracture Mechanics 76 (2009) 134–148) Fatigue life predictions using fracture mechanics methods,T. Ghidini a,*,1, C. Dalle Donne.

[23] Spectrum Fatigue Life Assessment of Notched Specimens Using a Fracture Mechanics Based Approach, Michael Vormwald, l Paul Heuler, 2 and Christian Krae,1994.

[24] Effects of Notches and Saltwater Corrosion on the Flexural Fatigue Behavior of High-Strength Structural Alloys, R. C. Schwab and E. J. Czyryca.

[25] Fatigue Life Predictions for a Notched Shaft in Combined Bending and Torsion, Steven M. Tipton and Drew V. Nelson.

[26] Solidification, solution treatment and age hardening of a Mg–1.6 wt.% Ca–3.2 wt.% Zn alloy G. Levi *, S. Avraham, A. Zilberov, M. Bamberger, November 2005.

[27] SOLUTION TREATMENT OF ALUMINUM ALLOYS IN THE AERODYNAMIC HEATING FURNACES , Alexey Sverdlin, Arnold Ness.

[28] Corrosion fatigue crack initiation of Al–Zn–Mg–Mn alloy in 0.5 M Na2SO4 solution Su-Il Pyun *, Seung-Jin Orr, Soo-Woo Nam, May 1997.

[29] Deflections and Strains in Cracked Shafts Due to Rotating Loads: A Numerical and Experimental Analysis Nicol`o Bachschmid and Ezio Tanzi .

[30] EFFECT OF ANODIC POLARIZATION ON STRESS CORROSION CRACKING OF SOME ALUMINUM ALLOYS, M. Czechowski.