Fatigue Behaviour of Aluminium Alloy

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

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Metallurgical & Materials Engineering

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CERTIFICATE

This is to certify that the thesis entitled, "FATIGUE BEHAVIOUR OF ALUMINIUM ALLOY" submitted by Sri Bhuvnesh Garg and Pankaj Kumar _ in partial fulfillments for the requirements for the award of Bachelor of Technology Degree in Metallurgical & Materials Engineering at 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:

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ACKNOWLEDGEMENT

I wish to express my deep sense of gratitude and indebtedness to Prof.S Sen. ,Department of Metallurgical And Materials Engineering, N.I.T Rourkela for introducing the present topic and for their inspiring guidance, constructive criticism and valuable suggestion throughout this project work.

I would like to express my gratitude to Prof. G.S.Agrawal (Head of the Department), Prof. K.N.Singh, Prof B.B.Verma,Prof B.C.Ray, and other teachers for there valuable suggestions and encouragements at various stages of the work. I am also thankful to all staff members of Department of Ceramic Engineering NIT Rourkela.

I am thankful to Mr.Uday, Mr.Sameer for their help in making the specimen,and conducting the tensile testing.

Last but not least, my sincere thanks to all my friends who have patiently extended all sorts of help for accomplishing this undertaking.

30th April 2007 (BHUVNESH GARG)

(PANKAJ KUMAR)

CONTENT

ABSTRACT

The present project deals with study of fatigue life of Aluminium alloy treated at two different temperatures. This temperature is above and below the recrystallisation temperature of Aluminium alloy. The specimen is commercially available Aluminium alloy which is annealed, tensile testing is done and then fatigue life of the specimen is determined. Failure of the specimen at different stress applied is determined and number of cycles to failure is noted. Fatigue has become progressively more prevalent as technology has developed a greater amount of equipment, such as automobiles, aircraft, compressors, pumps, turbines, etc., subject to repeated loading and vibration. A fatigue failure can usually be recognized from the appearance of the fracture surface, which shows a smooth region, due to the rubbing action. In our experiment we have done the annealing of aluminum alloy above and below recrystallisation temperature in the recovery range. The tensile testing of the specimen was done in INSTRON 1195. The results obtained from this test says that yield strength of the aluminum alloy was found to be more below recrystallisation temperature then that above recrystallisation temperature. The failure of the specimen here occurs at a very large number of cycles. This of the order of 10^5.this number of cycles decreases with an increase in the applied stress. As the load increases the failure of the specimen would occur at a less number of cycles. This alloy used fails at a large number of cycles. Also no endurance limit is obtained here. So for use of this alloy large number of cycles is required and also a lower yield stress. This aluminum alloy can be used for a large number of uses. Aircraft application, gas pipelines, oil tanks, pistons, etc.

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1.1 Introduction

It has been recognized since 1830 that a metal subjected to a repetitive or fluctuating stress will fail at a stress much lower than that required to cause fracture on a single application of load. Failures occurring under conditions of dynamic loading are called fatigue failures, presumably because it is generally observed that these failures occur only after a considerable period of service. Fatigue has become progressively more prevalent as technology has developed a greater amount of equipment, such as automobiles, aircraft, compressors, pumps, turbines, etc., subject to repeated loading and vibration. Today it is often stated that fatigue accounts for al least 90 percent of all service failures due to mechanical causes.

1.2 Structural Features of Fatigue Failure

A fatigue failure is particularly insidious because it occurs without any obvious warning. Fatigue results in a brittle-appearing fracture, with no gross deformation at the fracture. On a macroscopic scale the fracture surface is usually normal to the direction of the principal tensile stress. A fatigue failure can usually be recognized from the appearance of the fracture surface, which shows a smooth region, due to the rubbing action as the crack propagated through the section, and a rough region, where the member has failed in a ductile manner when the cross section was no longer able to carry the load. Frequently the progress of the fracture is indicated by a series of rings, or "beach marks", progressing inward from the point of initiation of the failure.

One can determine that a material failed by fatigue by examining the fracture sight. A fatigue fracture will have two distinct regions; One being smooth or burnished as a result of the rubbing of the bottom and top of the crack. These visual clues may be seen in figure-1

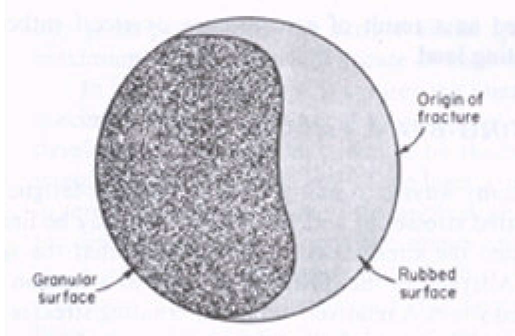

Figure-1.1

Notice that the rough surface indicates brittle failure, while the smooth surface represents crack propagation

Other features of a fatigue fracture are beach marks and striations. Beachmarks, or clamshell marks, may be seen in fatigue failures of materials that are used for a period of time, allowed to rest for an equivalent time period and the loaded again as in factory usage. Striations are thought to be steps in crack propagation, were the distance depends on the stress range. Beachmarks may contain thousands of striations. Visual Examples of Beachmarks and Striations are seen below in Fig. 1 and 2:

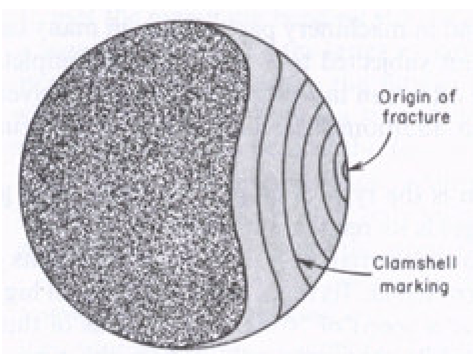

Figure 1.2

An example of beachmarks or "clamshell pattern" associated with stress cycles that vary in magnitude and time as in factory machinery

Figure 1.3

An example of the striations found in fatigue fracture. Each striation is thought to be the advancement of the crack. There may be thousands of striations in a beachmark.

1.3 Factors causing fatigue failure

Three basic factors are necessary to cause fatigue failure. These are:

- Maximum tensile stress of sufficiently high value,
- Large enough variation or fluctuation in the applied stress, and
- Sufficiently large number of cycles of the applied stress.

In addition, there are a host of other variables, such as stress concentration, corrosion, temperature, overload, metallurgical structure, residual stresses, and combined stresses, which tend to alter the conditions for fatigue. Since we have not yet gained a complete understanding of what causes fatigue in metals, it will be necessary to discuss each of these factors from an essentially empirical standpoint.

Chapter 2

LITERATURE REVIEW

2.1 Stress Cycles

At the outset it will be advantageous to define briefly the general types of fluctuating stresses which can cause fatigue. Figure 4 serves to illustrate typical fatigue stress cycles. Figure 4a illustrates a completely reversed cycle of stress of sinusoidal form. For this type of stress cycle the maximum and minimum stresses are equal. Tensile stress is considered positive, and compressive stress is negative.

Figure 4b illustrates a repeated stress cycle in which the maximum stress σ_{max} (R_{max}) and minimum stress σ_{min} (R_{min}) are not equal. In this illustration they are both tension, but a repeated stress cycle could just as well contain maximum and minimum stresses of opposite signs or both in compression.

Figure 4c illustrates a complicated stress cycle which might be encountered in a part such as an aircraft wing which is subjected to periodic unpredictable overloads due to gusts.

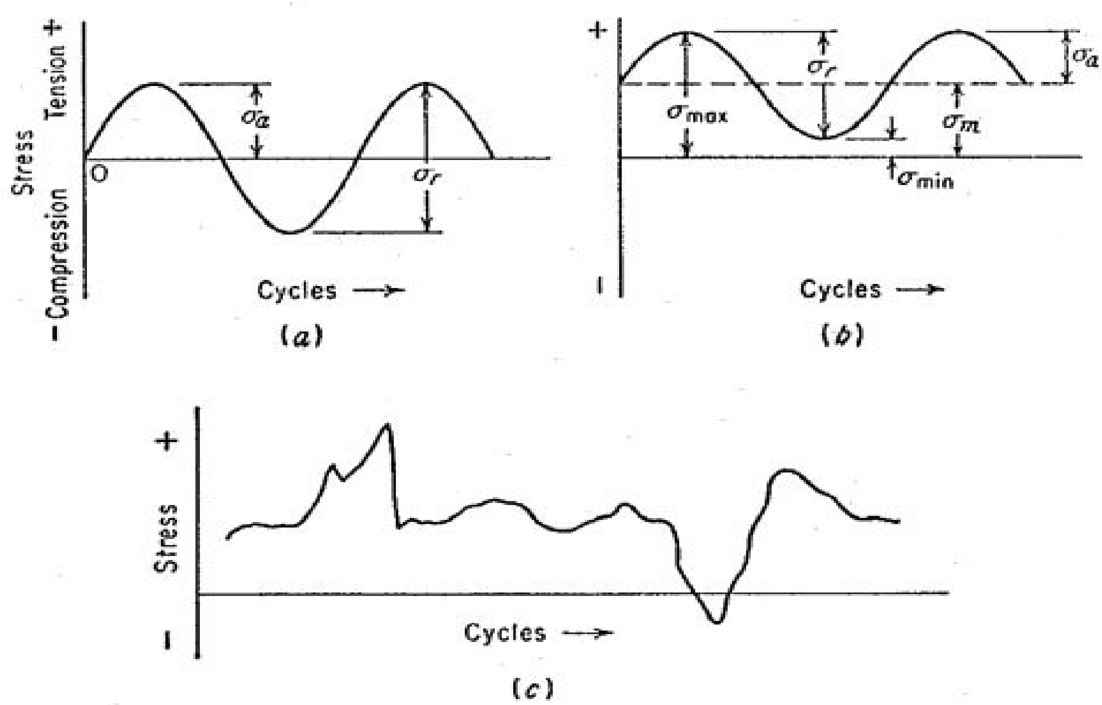

Figure2.1 Typical fatigue stress cycles. (a) Reversed stress; (b) repeated stress; (c) irregular or random stress cycle.

2.2 S-N Curve:

The basic method of presenting engineering fatigue data is by means of the S-N curve, a plot of stress S against the number of cycles to failure N. A log scale is almost always used for N. The value of stress that is plotted can be σ_a, σ_{max}, or σ_{min}. The stress values are usually nominal stresses,

The highest stress at which a run out (non-failure) is obtained is taken as the fatigue limit. For materials without a fatigue limit the test is usually terminated for practical considerations at a low stress where the life is about 10^8 or $5x10^8$ cycles. The S-N curve is usually determined with about 8 to 12 specimens.

2.2.1 Low-Cycle Fatigue

The engineering failures which occur at relatively high stress and low numbers of cycles to failure. This type of fatigue failure is called low cycle fatigue failure and must be considered in the design of nuclear pressure vessels, steam turbines, and most other types of power machinery. Low-cycle fatigue conditions frequently are created where the repeated stresses are of thermal origin. Since thermal stresses arise from the thermal expansion of the material, it is easy to see that in this case fatigue results from cyclic strain rather than from cyclic stress.

2.2.2 High Cycle Fatigue

High Cycle Fatigue (HCF) results from vibratory stress cycles at frequencies which can reach thousands of cycles per second and can be induced from various mechanical sources. It is typical in aircraft gas turbine engines and has led to the premature failure of major engine components (fans, compressors, turbines). While LCF involves bulk plasticity where stress levels are usually above the yield strength of the material, HCF is predominantly elastic, and stress levels are below the yield strength of the material.

2.3 Crack growth rate

The crack growth rate da/dN, is obtained by taking the derivative of the above crack length, a, versus cycles, N, curve. Two generally accepted numerical approaches for obtaining this derivative are the spline fitting method and the incremental polynomial method. These methods are explained in detail in many numerical methods textbooks. Values of log da/dN can then be plotted versus logΔK, for a given crack length, using the equation

$$\Delta K = K_{max} - K_{min} = f(g) \cdot \Delta\sigma \cdot \sqrt{\pi a}$$

Where ΔK is the remote stress applied to the component as shown in Fig 5.

A plot of log da/dN versus logΔK, a sigmoidal curve, is shown in Fig.5. This curve may be divided into three regions.

Region I

At low stress intensities, Region I, cracking behavior is associated with threshold, ΔK_{th}, effects, below which no observable crack growth occur. At stresses below cracks behaves as non propagating cracks. this occurs at a crack growth rate of .25 mm/cycles or less.

Region II

In this region the slope of the log da/dN versus log ΔK curve is approximately linear and lies roughly between 10-6 and 10-3 in/cycle. Many curve fits to this region have been suggested. The Paris equation, which was proposed in the early 1960s, is the most widely accepted. In this equation

$$\frac{da}{dN} = C(\Delta K)^m$$

where C and m are material constants and ΔK is the stress intensity range K_{max} - K_{min}.Values of the exponent, m, are usually between 3 and 4. These range from 2,3 to 6,7 with a sample average of m = 3,5.

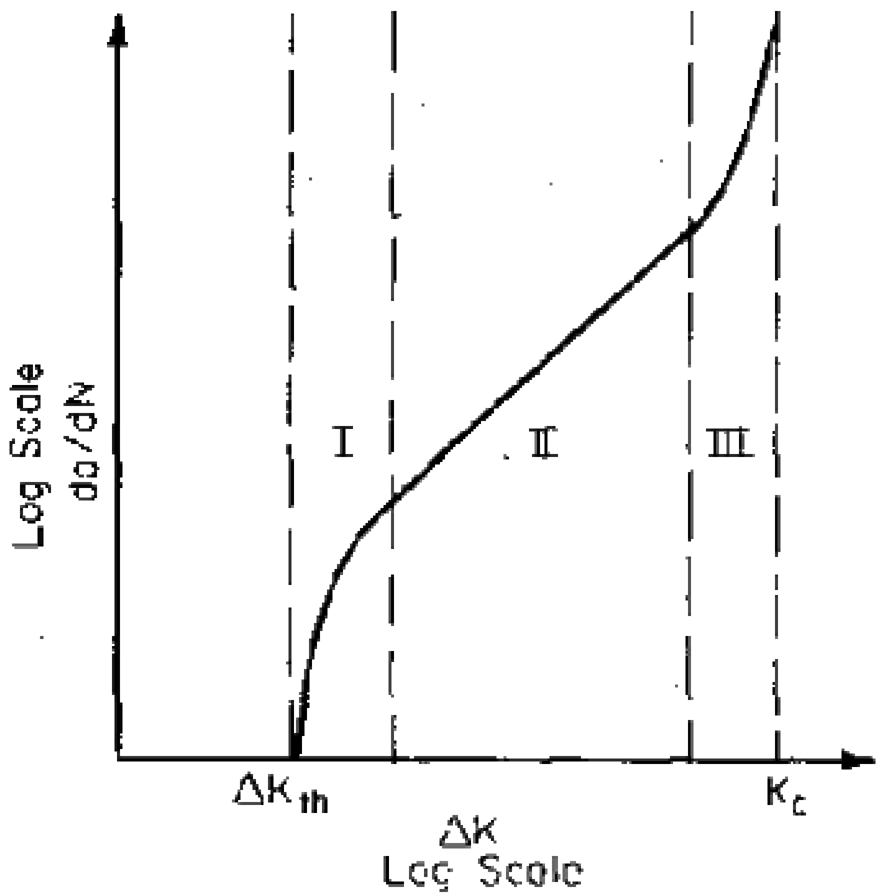

Figure 2.2 Three regions of crack growth rate curve

Region III

Finally, in the Region III, at high ΔK values, crack growth rates are extremely high and little fatigue life is involved. The values here approach to fracture toughness of the material.

2.4 Structural features of fatigue

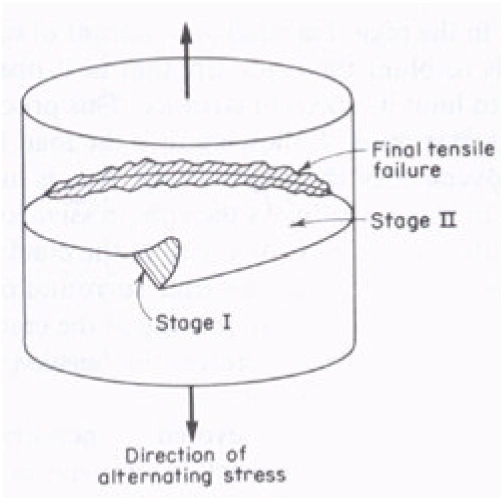

Figure-2.3

When a metal is subjected to fatigue the basic structural changes occurring can be divided into following stages.

Crack initiation-includes the early development of fatigue damage which can be remove by annealing. Fatigue crack is formed before 10 percent of the total life of the specimen has elapsed.

Slip band crack growth- involves the deeping of the initial crack on the planes of high shear stress. This is called as stage 1 crack growth. Here larger comprises of low stress, high cycle fatigue. This crack propagates along the persistent slip bands. The rate of crack propagation is very slow, on the order of nm per cycle. The fracture surface of this crack growth is featureless.

Demonstration of Crack Propagation Rate

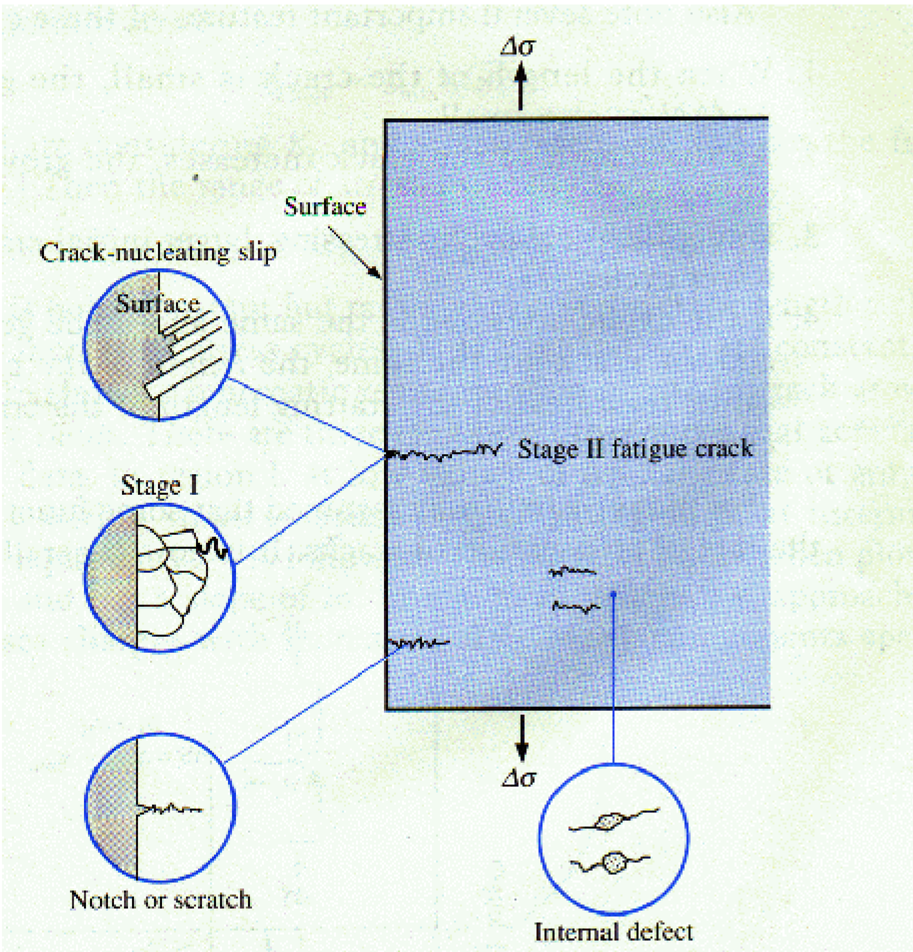

Figure-2.4

Crack growth on planes of high tensile stress- involves growth of well defined crack in direction normal to maximum tensile stress, called as stage 2 crack growths. Crack propagation rate is in order of microns per cycle. The fracture surface here shows a pattern if ripples or fatigue striations. This crack propagation occurs by plastic blunting process.

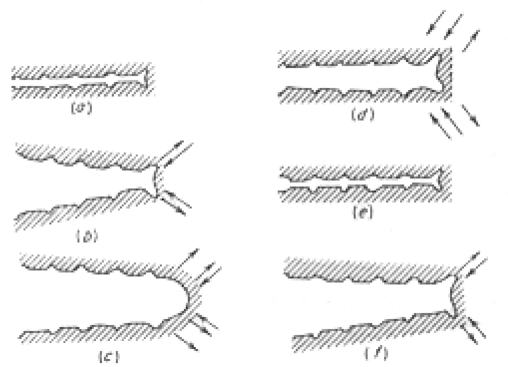

Figure-2.5. Plastic blunting process for growth of stage II fatigue crack

At the start of the loading cycle the crack tip is sharp (Fig. 8 a). As the tensile load is applied the small double notch at the crack tip concentrates the slip along planes at 45° to the plane of the crack (Fig. 8 b). As the crack widens to its maximum extension (Fig. 8 c) it grows longer by plastic shearing and at the same time its tip becomes blunter. When the load is changed lo compression the slip direction in the end zones is reversed. The crack faces are crushed together and the new crack surface created in tension is forced into the plane of the crack (Fig. 2.5).

Ultimate ductile failure occurs when the crack reaches sufficient length so that the remaining cross section cannot support the applied load.

2.5 Fatigue of aluminum alloys

Aluminum alloys or aluminum alloys are alloys of aluminum often with copper, zinc, manganese, silicon, or magnesium. They are much lighter and more corrosion resistant than plain carbon steel but not quite as corrosion resistant as pure aluminum. Bare aluminum alloy surfaces will keep their apparent shine in a dry environment, but light amounts of corrosion products rub off easily onto skin when touched. Galvanic corrosion can be rapid when aluminum alloy is placed in proximity to stainless steel in a wet environment. Aluminum alloy and stainless steel parts should not be mixed in water-containing systems or outdoor installations. When these alloys are subjected to thermal treatment failure on its surface will be there, which would lead to failure of the material.

The fatigue crack growth of metallic materials is widely considered to be affected by both ***intrinsic*** **and** ***extrinsic*** contributions to propagation resistance Extrinsic resistance to propagation is identifiable with a variety of micromechanical effects which can reduce the crack tip driving force, with crack closure (and associated compressive load transfer in the crack wake) being identified as a major influence on crack growth resistance in various material/load condition.

It has been seen that endurance limit for aluminum metal is not present and thus is taken at a number of cycles of the order 10^8.due to the presence of interstitial elements in this alloys, no fatigue limit is seen. Performance of these aluminum alloys are taken by noting its crack growth rate ((da/dN) as a function of stress intensity factor ΔK.

This property of aluminum alloys is used in various applications such as aircrafts, space shuttles, marine purpose r cars, trains; offshore structures etc.The alloy standards for aluminum are set by the society of automotive engineer's standards organization, specifically its aerospace standards subgroups.

2.5.1 Types of Aluminum alloys

Aluminum alloys can be grouped into four categories. They are

- *Wrought and cast aluminum alloys*
- *Work hardened aluminum alloys.*
- *Solution heat treated alloys*
- *Age hardened alloys*

Table 2.1. Designations for alloyed wrought and cast aluminum alloys.

None (99%+ Aluminum)	1XXX	1XXX0
Copper	2XXX	2XXX0
Manganese	3XXX	
Silicon	4XXX	4XXX0
Magnesium	5XXX	5XXX0
Magnesium + Silicon	6XXX	6XXX0
Zinc	7XXX	7XXX0
Lithium	8XXX	

2.6 Heat Treatment of Aluminium Alloy:

In our project we are studying the fatigue behavior of aluminum alloy which occurs when the alloy is subjected to heat treatment. Due to the application of temperature failure of the alloy will occur at a stress much lower then its yield stress. In this process first the specimen will be heated to its recrystallisation temperature and then annealing is done at temperature at and below this temperature. This treatment will thus lead to failure of the material. This failure resulting from heat treatment can be by any of the processes.

Various heat treatment processes that can be employed are

- Normalizing
- Tempering
- Annealing
- Quench Tempering
- Cold Working

2.6.1 Annealing of Aluminium Alloy

Due to cold working hardness tensile strength, electrical resistance increases while a decrease in the ductility is there. Also a large increase in the number of dislocation is there. The cold worked material is at higher internal energy than the undeformed metal. Although it is mechanically stable, but not thermodynamically. With increasing temperature it will become more unstable. Hence annealing is done by which the distorted cold worked lattice structure is changed back to one which is strain free by application of heat In this process heating to and holding of the specimen at a temperature and then cooling at a suitable rate is done which thus decreases the hardness, improves machinability, and other properties producing a desired microstructure.

This annealing treatment can be divided into three processes.

1. Recovery
2. Recrystallisation
3. Grain growth

During this process various structural and physical property changes occur in the specimen. The various changes occurring in aluminum alloys during this annealing for subsequent processes are given below

Recovery

This is usually defined as the restoration of the physical properties of the cold worked material without any observable change in the microstructure. Electrical conductivity increases and lattice strain decreases as measured with x-ray. The properties mostly affected are those sensitive to point defect. No effect on the strength of the material is there.

Recrystallisation

As the upper temperature of recovery range is reached minute new crystal appear in the microstructure. These have same composition and lattice structure as the original undeformed grains. These crystals appear at the most drastically deformed portion of the grains, usually the grain boundaries and slip planes. Recrystallisation depends upon time and temperature. This relationship can be expressed by a rate equation of the type:

$$1/t = ke^{-a/T}$$

Where t is time, T is the absolute temperature, e is the base of natural logarithms, and k and a are constants.

- The constant a is frequently replaced by Q/R, where R is the gas constant and Q is an energy term, similar to an activation energy. Aluminum alloys generally show good agreement with this time-temperature relationship except when secondary reactions interfere, such as the solution or precipitation of intermetallic phases at annealing

Grain growth

- Heating after recrystallisation may produce grain coarsening. This can take one of several forms. The grain size may increase by a gradual and uniform coarsening of the microstructure. This is usually identified as "normal" grain growth. The driving force for this is less then that for recrystallisation. However is strongly temperature dependent.
- It proceeds by the gradual elimination of small grains with unfavorable shapes or orientations relative to their immediate neighbors. This occurs readily in high-purity aluminum and its solid solution alloys, and can lead to relatively large,

Chapter 3

EXPERIMENTAL WORK

Experimentation steps involved

3.1 Specimen preparation

1. A specimen sheet was taken of the size 1 feet X 170 mm. It was cut into the size so as to make 2 tensile specimens and 2 fatigue specimen of size,

<u>For tensile specimen</u>

Length= 100 mm

Thickness= 6 mm

Breadth= 10 mm

Gauge length= 25 mm

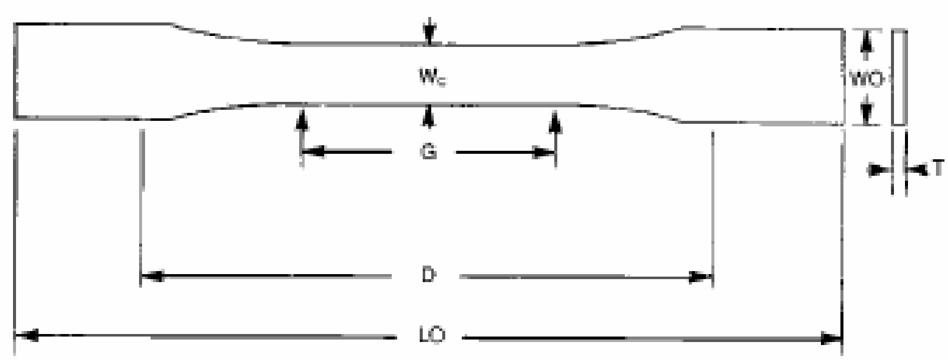

Figure-3.1

Fatigue specimen was made of the size
Length=170 mm
Breadth=52 mm
Thickness= 6 mm
Notch size= 13 mm

3.2 Finishing of specimen

Initially cutting of the specimen was done by power hacksaw. Then finishing of the sample was done by milling machine. The specimen was properly finished in the milling machine. Smoothening of the specimen was done in belt grinder.

3.3 Annealing of the sample

This specimen was then annealed in the furnace at a temperature below recrystallisation temperature of 150^0C and the other above recrystallisation temperature at 200^0C .

3.4 Tensile testing

This was done so as to get the specimen tensile strength. This test was done in INSTRON 1195.From this obtained data the fatigue test was done. Yield strength of the sample is obtained from this machine. Other related data are also obtained.

Tensile strength tester Instron 1195:

- applications: tensile, compression and bending tests in a temperature range from –196 to 1600 °C;
- type: mechanical tensile strength tester;
- max. force: 100 kN tensile, 50 kN compression;
- speed: 0.05 tot 50 mm/min;

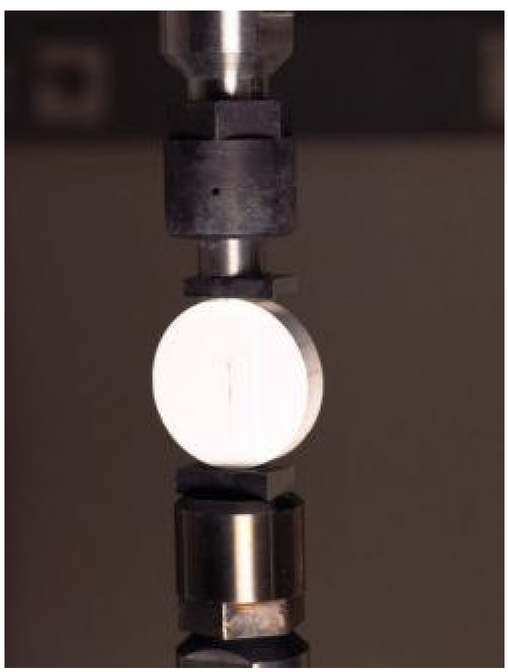

Figure-3.2

Figure-3.3 Instron 1195

3.5 Fatigue testing

After the calculation of yield stress is done, the specimen then would be treated in INSTRON 8502 .In this fatigue life of the material is known. In this machine number of cycles leading to failure of the material is known which gives the fatigue strength. This is a Electro-magnetic resonance machine capable of 50kN dynamic and 100kN static loading. Fitted with a DCPD system with PC based data acquisition. In this test the fatigue life of the specimen was determined at two different temperatures one above the recrystallisation range other below this temperature in recovery range. This recrystallisation temperature for aluminum alloy was found to be0..5 tm. Melting temperature of Aluminium found to be 667 so recrystallisation temperature was found to be 200.

Instron 8502 Servo-Hydraulic Dynamic Testing System

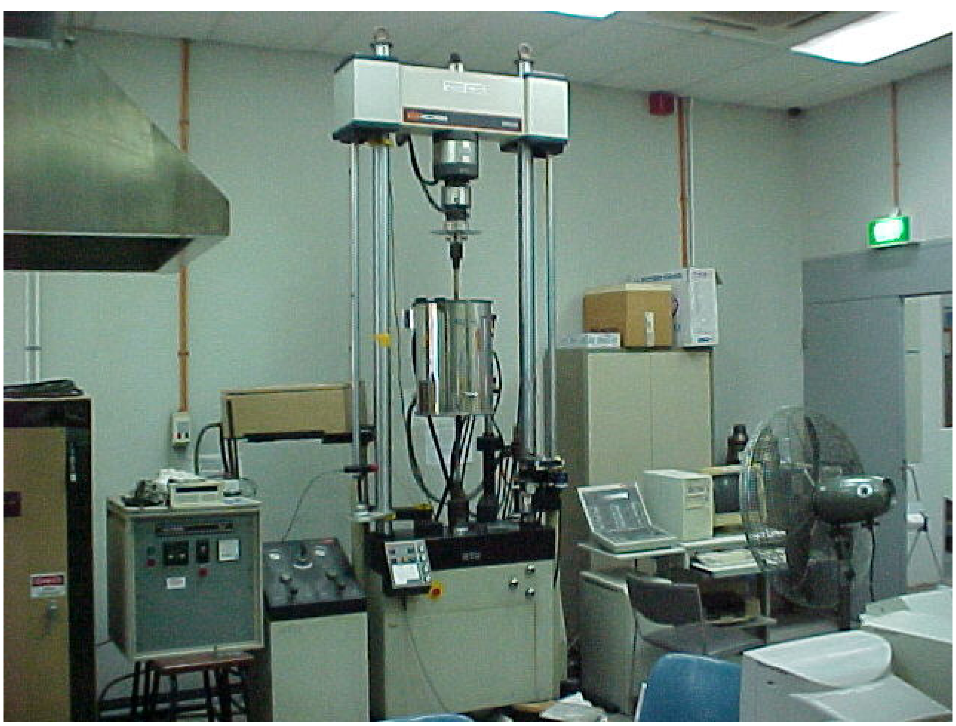

Figure-3.4 INSTRON 8502

In this machine the fatigue life of the specimen is calculated. The load applied here is 90% of the yield stress of the material.

Chapter 4

RESULTS AND DISCUSSION

4.1Introduction

The Aluminium alloy sample was first annealed at two different temperatures above and below recrystallisation temperature. The tensile testing of this specimen is done in INSTRON 1195.The tensile data obtained are tabulated in table 2

4.2 FINDINGS FROM TENSILE TESTINGS

Table-4.1

Annealed Specimen at Temperature	Above Recrystallisation 200 C	Below Recrystallisation 150 C
Youngs Modulus(MPa)	5699	1149
Stress at 0.2% Yield (MPa)	1.282	9.081
Stress at Break (MPa)	60.49	44.75
Energy to Yield Point (J)	0.5550	4.9350
Energy to Break Point (J)	49.43	52.10

4.3 Theoretical data for fatigue testing

After this test is done the fatigue test is done. This is done at a stress value of about 90% of the yield stress. The specimen taken were applied a load of about this high stress value.

Table-4.2

Maximum Load	Life	
	Below Recrystallisation Temperature	Above Recrystallisation Temperature
70 % Y S	5.3 x 10^6	5.8 x 10^6
80% YS	7 x 10^5	7.6 x 10^5
90 % YS	8.7 x 10^4	1.05 x 10^5

4.4 Discussion

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- As seen in table the difference between numbers of cycles to failure of the specimen is less at an applied stress of 70% of the yield stress. This difference in the number of cycles is near about same for 70% Y.S and 80% Y.S. But this difference increases for 90% Y.S.
- The failure of the specimen here occurs at a very large number of cycles. This of the order of 10^5.this number of cycles decreases with an increase in the applied stress. As the load increases the failure of the specimen would occur at a less number of cycles.
- As seen from theory the failure of the copper specimen at two different temperature was found to be very high then that of aluminum alloy. Greater difference in the number of cycles to failure is seen here in copper specimen. This difference in the number of cycles was found to be less in aluminum alloy. This is because of high stacking fault energy. Hence this difference in the number of cycles to failure is very less

Chapter 5

CONCLUSION

From our experiment we have seen that annealing of this aluminum alloy gives variation in the tensile data

The result from our project can be summarized as

1. Yield strength of Al alloy below Tr(Recrystallisation temperature) is more then at Tr temperature
2. No. of cycles difference is less
3. After increase in applied load during fatigue test would result in greater number of cycles to failure
4. From the literature survey, we know, in Cu difference in number of cycles is more as compared to Al because of high stacking fault energy of Al

This difference occurs due to different heat treatment condition. Use of this alloy can be in application where annealing is done at a lower temperature. This lower temperature results in greater strength of the alloy. Hence alloy treated at lower temperature is best suitable. Also for use of this aluminum alloy we have to take into consideration the number of cycles leading to failure of specimen. This alloy used fails at a large number of cycles. Also no endurance limit is obtained here. So for use of this alloy large number of cycles is required and also a lower yield stress. This aluminum alloy can be used for a large number of uses. Aircraft application, gas pipelines, oil tanks, pistons, etc. are the various uses of this specimen.

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