FATIGUE LIFE PREDICTION ON HEAT TREATED LOW CARBON STEEL AND ALUMINIUM

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ABSTRACT

This research is to find the fatigue life prediction on low carbon steel and aluminum. The objective of this project is to find the fatigue life of the different material which is low carbon steel and aluminum. The second objective is to find out the effect of heat treatment to the fatigue life of the material. The annealing and quenching heat treatment is investigated in this research. The optical microscope and the fatigue test machine was use in assisting for completing the research. The low carbon steel properties has the higher strength compare to aluminum due to the higher fatigue life. The changing of the microstructure due to heat treatment has changing the strength and surface fracture of the material based on type of heat treatment. The annealing process have reduce the strength of the material but the quenching process has increase the strength of both material.

ABSTRAK

Kajian ini adalah untuk mencari jangka hayat lesu pada keluli karbon rendah dan aluminium. Objektif projek ini adalah untuk mencari hayat lesu bahan yang berlainan iaitu keluli karbon rendah dan aluminium. Objektif kedua adalah untuk mengetahui kesan rawatan haba kepada ramalan jangka hayat lesu bahan. Penyepuhlindapan dan rawatan haba pelindapkejutan disiasat dalam kajian ini. Mikroskop optik dan mesin ujian lesu adalah digunakan dalam membantu untuk melengkapkan kajian. Ciri-ciri keluli rendah karbon mempunyai kekuatan yang lebih tinggi berbanding dengan aluminium kerana jangak hayat lesu yang lebih tinggi. Perubahan mikrostruktur kerana rawatan haba telah mengubah kekuatan dan keretakan permukaan bahan berdasarkan jenis rawatan haba. Proses penyepuhlindapan telah mengurangkan kekuatan bahan tetapi proses pelindapkejutan telah meningkatkan kekuatan kedua-dua bahan.

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LIST OF SYMBOLS

V_f	Feed rate
f	Feed
^oC	Degree Celsius
Fe	Iron
C	Carbon
Cr	Chromium
Si	Silicon
Mn	Manganese
S	Sulfur
Al	Aluminum
Cu	Copper
Mg	Magnesium
$\frac{da}{dN}$	Fatigue growth rate per cycle
K^m	The stress intensity factor
σ_e	Limit failure
μ	Micro

LIST OF ABBREVIATIONS

Pa	Pascal
RPM	Revolution per minutes
S-N	Stress-Strain

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Steel is one of the most important material in our world. People mostly use steel everywhere including in the construction, automotive industry or even in the daily equipment manufacturing. Steel is a simply known as a material that consists of iron and varying amounts of carbon. Iron is the major component in steel while carbon was their excess between 0.2% to 2.14% depend on the grade. There 5 major classifications of steel which is carbon steel, alloy steel, high-strength low-alloy steel, stainless steel and tool steel (William et al,2005).

Different type of steel can be differentiate by the different in composition of the carbon on the steel. The composition of carbon can be known by looking at the microstructure of the steel. Carbon steel is defined as a steel that consist of various of carbon, produce everything from machines to bedsprings to bobby pins (William et al,2005). Carbon steel have 3 different types ; low carbon steel, medium carbon steel and high carbon steel.

Low carbon steel has a composition of an iron alloy that contains less than 0.25% carbon. Low carbon steel is very reactive and will readily revert back to iron oxide (rust) in the presence of water, oxygen and ions (Satish Kumar et al, 2003).

There are material which are non steel that widely use in the engineering field. The non steel material is important is producing a part that need high ductility and low strength. One of the example of non steel material is aluminum. Aluminum has an ability of being extruded into complex shapes to exact tolerances. Aluminum also has been successfully formed into literally thousands of unique profiles, each one able to meet a number of specific structural and aesthetic requirements. It is this capability to provide simple elegant solutions to extremely complex design problems that has led to aluminum's enduring appeal.

There are method to change the material property without changing the shape. The method is called a heat treatment method. There are 3 most common method used in heat treatment which is annealing, quenching in water and also quenching in water. The heat treatment is use in changing the microstructure of the material from ductile to brittle phase. Heat treatment uses phase transformation during heating and cooling to change a microstructure in a solid state.

There are some test that can be done to know the strength of the material by using fatigue test method. By undergo the fatigue test, the cycle of where the material will be fail can be known. To know the actual fatigue life of the material is mostly impossible. The engineer has developed a method can be use to predict the fatigue life of the material. The method is called a fatigue test.

1.2 PROBLEM STATEMENT

Low carbon steel is the most common type of steel used for a general purpose. It is the cheapest steel among the other steel but has lack of hardenability due to composition of carbon which is only 0.3%. The manufacturer try to find a way in manipulating this cheapest carbon steel to increase the application by using the same material to reduce their operation cost. Low carbon steel can be used to manufacture a wide range of manufactured goods like home appliances and ship sides to low carbon steel wire and tin plates.

Aluminum alloys with a wide range of properties are used in engineering structures. Aluminum alloys are used widely in aircraft due to their high strength-to-weight ratio but pure aluminum metal is much too soft for such uses, and it does not have higher tensile strength that is needed for airplanes and helicopters.

Each material has an unpredictable fatigue which they can fail at any time. The failure of the material is a dangerous when its relating to the human life for example the blade fan of the airplane. The fail of the fan blade will make the plane fail to operate normally and can cause an accident.

1.3 OBJECTIVE

1. To study the fatigue life predictions of a different material. Two types of specimen is taken which is low carbon steel and also aluminum.
2. To investigate the effect of heat treatment on the fatigue life of low carbon steel and aluminum alloy.

1.4 SCOPE OF PROJECT

The project is focusing on the fatigue life prediction of low carbon steel and aluminum. The scope of this project is including :

a) The preparation of the raw material by using the band saw machine
b) The machining specimen for the required shape using the Lathe machine
c) The material undergo the heat treatment which is annealing and quenching
d) The microstructure of the material is analyze using optical microscope
f) The fatigue test is undergo to find the fatigue life prediction of different material
g) The surface fracture of the failed fatigue material is analyze

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION OF STEEL

Steel is a family of materials that is derived from ores that are rich in iron, abundant in the Earth's crust and which are easily reduced by hot carbon to yield iron. Steels are very versatile. They can be formed into desired shapes by plastic deformation produced by processes such as rolling and forging (Lesliw,2007). They also can be treated to give them a wide range of mechanical properties which enable them to be used for an enormous number of applications. Indeed, steel is wide use in our everyday life including construction, automotive industry and many manufacturing industry.

There are various type of steel in the industry. Every type of the steel has their unique properties. The different type of steel is use in a different type of application. The application is divided into categories which is light use, medium use and heavy use.

The steel can be divided into two main group which is plain carbon steel and alloy steel. The Table 2.1 show the commonly encountered classes of iron and steel. It show the typical user for different steel and the source strength of steel.

Table 2.1 : Class of steel

Class	Distinguish feature	Typical user	Source of strength
Cast iron	More than 2 % of C and 1 to 3% of Si	Pipes, valve, gear, engine block	Ferrite-pearlite structure as effected by free graphite
Plain-carbon steel	Principle alloying element is carbon up to 1%	Structural and machining part	Ferrite-pearlite structure if low carbon; quenching and tempering if medium to high carbon
Low-alloy steel	Metallic element total up to 5%	High strength structural and machine part	Grain refinement, precipitation, and solid solution if low carbon; otherwise quenching and tempering
Stainless steel	At least 10% of Cr, do not rust	Corrosion resistant, piping and nuts and bolt	Quenching and tempering if < 15% Cr and low Ni; cold work or precipitation
Tool steel	Heat treatable to high hardness and wear resistance	Cutters, drill bit	Quenching and tempering

Source : Dowling,1999

The table has classified the different between the type of steel. The steel can be differentiate by the chemical composition in the material. Every type of material has their different mechanical properties for a different purpose.

2.2 ALUMINUM IN ENGINEERING FIELD

Aluminum is the most abundant metallic element, and the third constituent of the earth's crust. Aluminum occurs many in the environment, in salts and oxides forms. Because of its physical and chemical properties, aluminum metal and compounds have a wide variety of uses: building, transportation, food packaging, beverage cans, cooking utensils, food additives, medicines, surgery materials, cosmetics, water purification (Gourier-Frery et al, 2004).

Aluminum is a very light weight material yet has a high strength. In the investigation on aluminum automotive engineering in German show that aluminum cover nearly the whole range of semi-finished product and casting as show in Figure 2.1 (Jirang et al, 2009).

Vehicle design for environment has been considered by automotive manufacturing and research. Based on the weight reduction concept, some of basic idea should be considered such as designing key structural component for prime alloy with a maximum property to mass ratio, minimizing the number of material or alloy in one part and choosing standard alloying element (Jirang et al, 2009).

2.3 MICROSTRUCTURE OF STEEL

Steel is the common building material use in the construction industry. It primary purpose is to form a skeleton for a building or structure. Steel was made from an iron with addition of carbon in it. Because the influence of carbon on mechanical properties of iron is much more than other alloying elements. The atomic diameter of carbon is less that interstice between iron and atoms and carbon goes into solid solution of iron. As carbon dissolves in the interstices, it distorts the original crystal lattice iron (Satish Kumar et al, 2003).

The distortion of the crystal lattice have effect the external applied strain to the crystal lattice and blocking it. This result the mechanical strength is increase. When the adding much more of carbon will result in more distortion of the crystal lattice and increasing in its mechanical strength. Unfortunately, the increasing of mechanical strength has effect the other important property of the iron which called ductility.

Ductility is define as an ability of the iron to undergo large plastic deformation (Roylance, 2001).

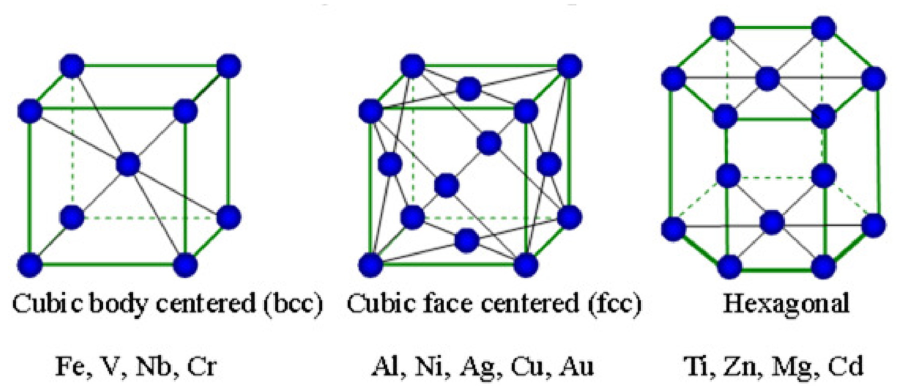

Figure 2.1 : Crystal lattice structure

Source : Dimitri,2012

The addition of carbon is not the only way to increase the mechanical strength, there are another way even without adding another composition of carbon. This process is called heat treatment process. This process is undergo with heat the iron to certain temperature and been cool down by annealing or quenching. The iron-carbon equilibrium diagram is a plot of transformation of iron with respect to carbon content and temperature. This diagram is also called iron-iron carbon phase diagram shown in Figure 2.2 (Satish Kumar et al, 2003).

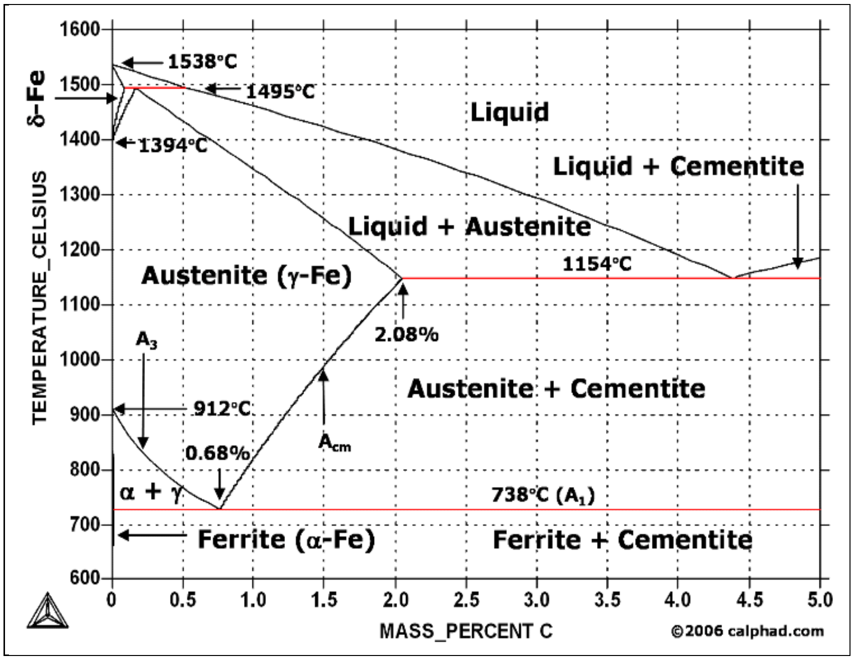

Figure 2.2 : Iron carbon phase diagram by mass

Source : http://www.calphad.com/iron-carbon.html

1) Ferrite (α): Virtually pure iron with body centered cubic crystal structure (bcc). It is stable at all temperatures up to 900C. The carbon solubility in ferrite depends upon the temperature; the maximum being 0.02% at 723^{o}C.

2) Cementite: Iron carbide (Fe3C), a compound iron and carbon containing 6.67% carbon by weight.

3) Pearlite: A fine mixture of ferrite and cementite arranged in lamellar form. It is stable at all temperatures below 723^{o}C.

4) Austenite (γ): Austenite is a face centred cubic structure (fcc). It is stable at temperatures above 723^{o}C depending upon carbon content. It can dissolve up to 2% carbon.

2.4 HEAT TREATMENT

Heat treatment is a process to changing the mechanical properties of the material without changing the shape. Heat treatment of carbon steel component is done to take the advantages of crystalline defect and their effect and thus obtain a certain desirable properties or condition. The differences in mechanical properties of a given steel are the result of different microstructures formed during cooling.

According to I.F Machado, the microstructure of AISI 1020 steel in the as-receive condition is show in Figure 2.3 below. In this steel, pearlite was observe in the microstructure and its volumetric fraction of about 40% volume was related to the mass carbon percentage in the steel (Machado,2006).

Figure 2.3 : Microstructure as-receive of AISI 1020

Source : Machado,2006

The result of Vickers microhardness (20 N) of the sample of AISI 1020 in the as-receive condition, heat-treated at 750 ^{o}C for 150 min and the at 750 degree C for 150 min by applying 27 V were display in the Table 2.2

Table 2.2 : Vickers microhardness of AISI 1020

Condition	Time(min)	V	A	HV 2
1020 AS	0	0	0	191.7 ± 1.5
1020 HTQ	150	0	0	254.3 ± 10.0
1020 HTQ 58	150	27	5.8	447.0 ± 21.2

2.5 HARDENING OF MATERIAL

Hardening is only possible via heat treatment on medium to high carbon steels, the metals are heated to certain temperatures depending on their carbon content (780°C to 850°C) then cooled quickly usually by quenching the metals in water or oil, the reason the metals are heated to these temperatures called their 'austenitic crystal phase' is because the crystal structures of the metals can then start to alter, forming bonds to create cementite as the carbon diffuses which is a very hard and brittle material.

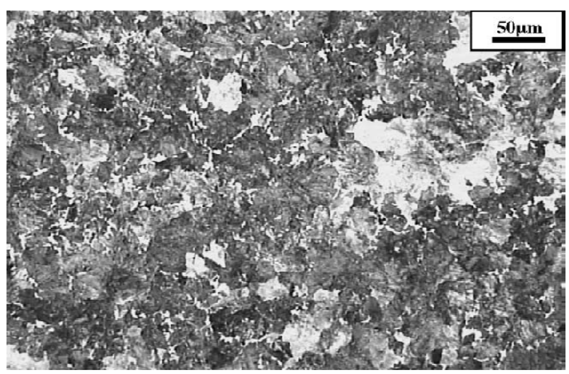

Figure 2.4 : Microstructure of the AISI 1020 steel heat treated

Source : Machado,2006

2.6 INTRODUCTION OF FATIGUE LIFE

The engineering material scope is mostly concentrated on the failure of component and static loading in an overload situation. In this real world, failure always occurs at stresses much lower that material ultimate strength. This phenomena of component which is failing at relatively low strength become quite a surprise for some engineers in the early time of engineering material component design. More worst for this problem is the material did not give anything sign of fatigue or tiredness. The fatigue term which has been justified for this aspect of metal behavior at a repeated cycle is a bit misleading as the material would not regain its strength after resting, but will actually remember the previous stress cycle.

2.7 FATIGUE BACKGROUND AND HISTORY

One of the first people trying to figure out the fatigue problem was a railway engineer in Germany, August Wholer. Wholer use full scale railway axles and some other test and drew up a stress versus stress cycle to failure curve, S-N curve. Wholer most important curve is shown in the Figure 2.5 and also found that the steel exhibit something called endurance limit, which will result in no damage below this stress value (Wholer, 1997).

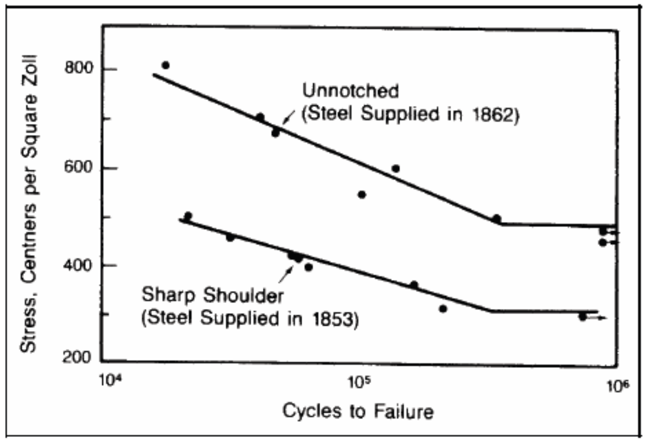

Figure 2.5 : S-N diagram by Wholer

Source : Wholer,1997

2.8 FATIGUE TEST

A perusal of the broken parts in almost any scrap yard will reveal that the majority of failures occur at stresses below the yield strength. This is a result of the phenomenon called fatigue which has been estimated to be responsible for up to 90% of the in-service part failures which occur in industry.

If a bar of steel is repeatedly loaded and unloaded at about 85% of its yield strength, it will ultimately fail in fatigue if it is loaded through enough cycles. Also, even though steel usually elongates approximately 30% in a typical tensile test, almost no elongation is evident in the appearance of fatigue fractures. Basic fatigue testing involves the preparation of carefully polished test specimens (surface flaws are stress concentrators) which are cycled to failure at various values of constant amplitude alternating stress levels (Berman, 2007).

The data are transfer into an alternating Stress, S, verses Number of cycles to failure, N, curve which is generally referred to as a material's S-N curve. As one would expect, the curves clearly show that a low number of cycles are needed to cause fatigue failures at high stress levels while low stress levels can result in sudden, unexpected failures after a large number of cycles

2.9 S-N CURVE

Before the fatigue process microstructure understanding was developed, engineers had developed empirical means of quantifying the fatigue process and design against it. After that, the most important concept is the S-N curve, for example the one shown in Figure 2.6 in which the constant cyclic stress amplitude, S is applied to a specimen and the number of loading cycle, N until the specimen fails was obtain. Many of cycle needed, even millions of cycle might be required to cause failure at lower loading levels.

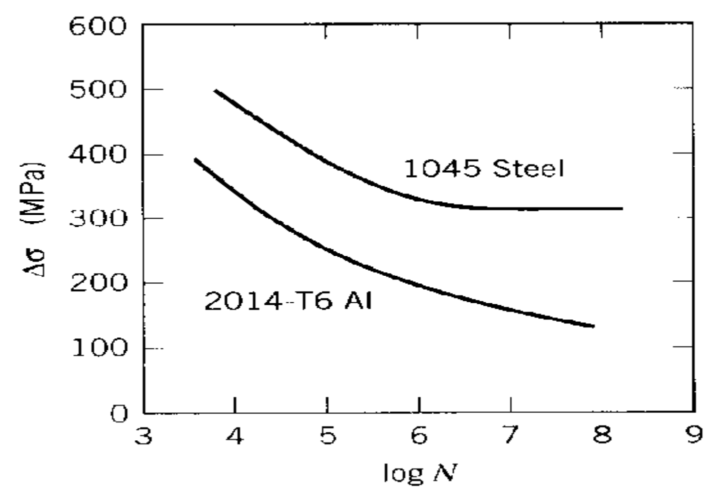

Figure 2.6 : Curve for aluminum and low carbon steel

Source : Jirang et al. 2009

In some of other material, notably ferrous allow, the S-N curve was flattens out eventually, so that below certain limit σ_e failure does not occur no matter how long the