FATIGUE LIFE PROPERTIES OF ALLOY STEEL AT DIFFERENT STRESS RATIO

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JUNE 2016

DECLARATION

I declare that this project report entitled "Fatigue Life Properties of Alloy Steel at Different Stress Ratio" is the result of my own work except as cited in the references

Signature : …………………………………

Name : …………………………………

Date : …………………………………

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid).

Signature : …………………………………

Name of Supervisor : …………………………………

Date : ....………………………

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ABSTRAK

Fatigue failures adalah salah satu masalah yang biasa berlaku ke atas komponen mekanikal yang bergerak dan merupakan punca utama dalam kerosakan mekanikal. Kerosakan mekanikal selalunya mengambil masa kerana *fatigue cycles* adalah proses terkumpul dari penerimaan bebanan yang berbeza. Oleh itu, kerosakan mekanikal hanya dapat dikenal pasti apabila kerosakan mekanikal telah berada di dalam kondisi yang teruk dan berada pada tahap keretakan (*cracking*) yang terakhir. Sehubungan dengan itu, kajian ini bertujuan untuk mengkaji aspek *fatigue life* ke atas keluli aloi yang tertentu. Tiga objektif utama kajian ini adalah mengenalpasti jenis keluli aloi didalam pembuatan automotif *steering knuckle*, menyiasat ciri-ciri *fatigue life* keluli aloi tersebut mengunakan ujian *constant amplitude loading* dan membandingkan aspek *fatigue life* ke atas keluli aloi tersebut melalui tegasan nisbah yang berbeza. Tiga ujian yang bebeza di lakukan iaitu ujian SEM dalam menentukan komposisi bahan kimia keluli aloi tersebut. Hasil dari ujian SEM menunjukkan keluli aloi yang diambil daripada *steering knuckle* terdiri daripada karbon (c) 7.95%, silikon (Si) 2.26% and besi (Fe) 89.80% dari gred ASTM A536 65-45-12 besi *ductile*. Seterusnya, keluli aloi yang mempunyai komposisi yang sama dipesan daripada pembekal untuk tujuan ujian *tensile* dan *fatigue*. Hasil ujian *tensile* menunjukkan kekuatan utama besi *ductile* tersebut adalah 470.7 MPa dan kekuatan *yield* adalah 300.3 MPa. Keputusan ini adalah bertepatan dalam gred serdehana 65-4512 besi *ductile* yang ditemui didalam ujian SEM terdahulu. Ujian *fatigue* yang dilakukan berdasarkan tegasan nisbah R=-1, R=0 dan R=0.5. Hasil kajian menunjukkan R=-1 menghasilkan masa pemecahan yang paling rendah kerana tegasan amplitud adalah sama kepada amplitud maksimum dengan min 0. R=0 menunjukkan tegasan minimum 0 manakala R=0.5 menunjukkan amplitud dan min tegasan terendah.

ABSTRACT

Fatigue failures are common problem that will affect any moving mechanical items and it is the main cause of mechanical service failures. Due to the nature that fatigue cycles are accumulative and it receives different loading, the problem on the mechanical items will not be identified till the last minute. Usually by the time detection is made, the failure occurred is already at the last stage of cracking. So it is pertinent to conduct a study on fatigue life behavior. In this study, a fatigue life behavior test was conducted on a specific type of alloy steel. The three main aims of the study were to first identify the type of alloy steel used in automobile steering knuckle which was used as the case study in this study; to investigate the fatigue life properties under constant amplitude loading of the selected alloy steel; to compare the fatigue life behavior under different stress ratio of the selected alloy steel. Three different tests were conducted in order to answer the three objectives. The alloy steel taken from the steering knuckle underwent a SEM test in order to identify the chemical composition and determine the type of the alloy steel. The same sample was ordered from the supplier and tensile test and fatigue test were conducted using the universal testing machine. The SEM test revealed that the alloy steel consists of carbon (c) 7.95% silicon (Si) 2.26% and iron (Fe) 89.80% of ASTM A536 grade 65-45-12 ductile iron. The findings from tensile test show that the ultimate strength of the iron was 470.7 MPa and the yield strength was 300.3 MPa and it is within the average grade of 65-4512 ductile iron of the SEM results. The fatigue tests which were done based on R=-1, R=0 and R=0.5 revealed that R=-1 had the lowest cracking timing as the stress amplitude is equal to the maximum amplitude and the mean is equal to 0, R=0 had minimum stress of 0 while R=0.5 recorded the lowest amplitude and mean stress.

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S_a	=	Average Stress
S_m	=	Mean Stress
S_{max}	=	Maximum Stress
S_{min}	=	Minimum Stress
ΔS	=	Stress range
R	=	Stress ratio
A	=	Alternating stress ratio
F	=	Tensile force
A_0	=	Initial cross sectional area
e	=	Nominal strain
L_0	=	Initial gage length
ΔL	=	Change in gage length
Σ	=	True stress
e	=	True strain
σ_m	=	Mean or steady stress
σ_a	=	Alternating variable stress
$\Delta\sigma$	=	Stress range
σ	=	Engineering stress
ε	=	Engineering strain
P	=	External axial tensile load
A_o	=	Original cross-sectional area of the specimen
L_o	=	Original length of the specimen
L_f	=	Final length of the specimen

CHAPTER 1

INTRODUCTION

1.1 Background

Fatigue failure is a typical problem that usually affects any moving part or component. Some of the common examples that are subjected to fatigue failures are moving automobiles, aircraft wings and fuselages, ships at sea, nuclear reactors, jet engines, and land-based turbines. Fatigue failures have always been linked to almost 90% of all mechanical service failures. Fatigue failures happen whenever the application of fluctuating stresses that are much lower than the stress required that cause failure during a single application of stress. In the early 1800s, fatigue was initially recognized as a problem by investigators in Europe when they observed that bridge and railroad components were cracking when subjected to repeated loading. As the century progressed and there were more usage of metals with the increasing use of machines, more and more failures of components subjected to repeated loads were recorded. Today, structural fatigue is an important issue as the number of high-strength materials and higher performance materials are increasing and it demands a serious attention (ASM International, 2008).

Fatigue cracks usually start at external surface even though it can also occur on internal surfaces. Internal surfaces cracks occur when the metal contains defects such as voids and cracked second-phase particles. Fatigue crack nucleation and growth occurs in three stages. Stage I is the stage where crack starts to appear at a notch or other surface discontinuity. Crack initiation will still occur despite the lack of surface defect as persistent slip bands (PSBs) will still form on the surface. Once the length of the crack allows the stress field at the tip to become dominant, the overall crack plane changes and becomes perpendicular to the principal stress and this leads to Stage II of the crack nucleation and growth. Stage II occurs when the crack in stage I changes direction and propagates in a direction normal to the applied stress. In stage II, the growth becomes more apparent as a continual process of crack sharpening and blunting occur. Stage III is the ultimate failure in which the fatigue crack becomes long enough and it leads to the cross section could not support the applied load to the surface.

Alloy steel is any type of steel to which one or more elements besides carbon have been intentionally added, to produce a desired physical property or characteristic. Common elements that are added to make alloy steel are molybdenum, manganese, nickel, silicon, boron, chromium, and vanadium. Alloy steel is often subdivided into two groups: high alloy steels and low alloy steels. Low alloy steel has a carbon content of below 0.25 % and the most common alloying materials are aluminum, cobalt, copper, titanium, tungsten, tin and zirconium. Low alloy steel is used to achieve better hardenability and is increased corrosion resistance in certain environment. Commonly, low alloy steel is difficult to weld. Lowering the carbon content to 0.10% along with other alloying materials will increase the strength of the material (Rashid, 2011). If the carbon level in a low alloy steel is in the medium to high range, it can be difficult to weld. If the carbon content is lowered to a range of 0.1% to 0.3%, and some of the alloying elements are reduced, the steel can achieve a greater weld ability and formability while maintaining the strength that steel is known for. Such metals are classified as high strength, low alloy steels.

High alloy steel is a type of steel in which there are alloying elements more than 8% by weight of total other than carbon and iron is classified as high alloy steel. High alloy steel consists of at least two chemical elements and the properties of this type of steel depend on the percentage of chemical element present in it. If the percentage is high then its properties are depend on that chemical element with high percentage. High alloy steel is highly corrosion resistant with high reliability, and is used extensively in petrochemical, pharmaceutical, and nuclear power plants, heat exchangers, centrifugal separators, driers, pipelines, couplings, valves, bolts, salt manufacturing, exhaust gas desulfurizers, and semiconductor cleaning equipment (Rashid, 2011).

In a vehicle, the suspension system uses several types of links, arms and joints to let the wheels move freely. For this study, the focus of investigating the fatigue failure is on the steering knuckle of a car. Typically the steering knuckle helps to steer, brake and support the automobile and also allowing the front wheel to pivot and attach rotating components to suspension components beside distribute load from the road to the body. The steering knuckle assembly which is part of the suspension system might come in two separate parts attached together or it might come in one complete part. The steering knuckle is one of the major and important components in a car and it connects the brake, suspension, wheel hub and steering system to the chassis (Bhokare, Kakandikar &Kulkarni, 2014)

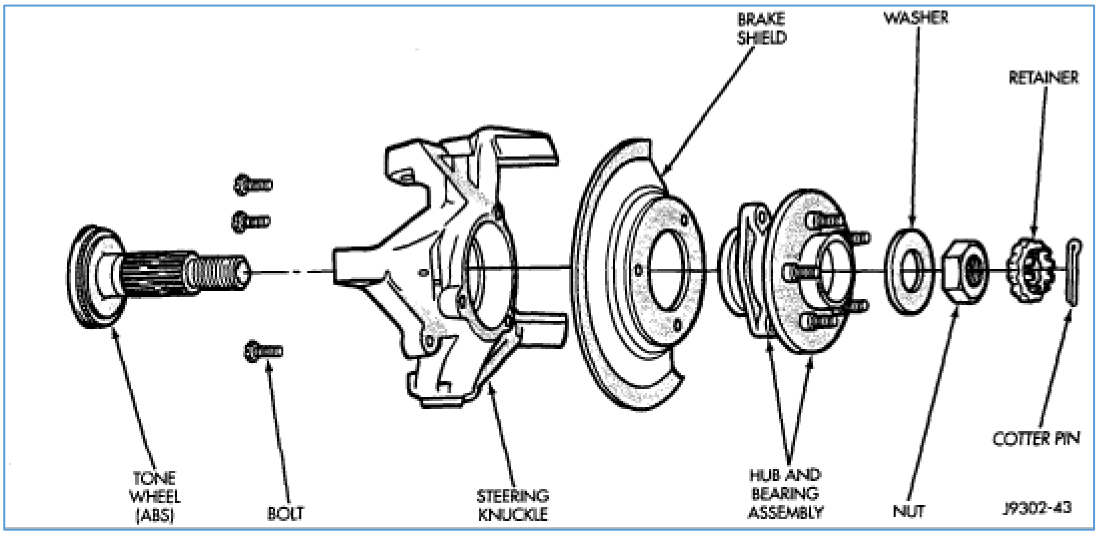

Figure 1.1: Steering knuckle assembly

(Sources: Bhokare, Kakandikar & Kulkarni, 2014)

In the automotive industry, a wide range of materials such as steel, cast iron and aluminum are being used to build the steering knuckle. As the steering knuckle is always subjected to various loads, it has the tendency to develop fatigue and get damaged. The knuckle is not repairable and it needs to be replaced once damage is detected on it. The damage in steering knuckle is done by several reasons like due to more axial load on steering knuckle or due to less suspension between the tire and the axial hub where the steering knuckle is attached (Patel & Bajaj, 2015). This study is looking at the safety and strength features of the knuckle and studying the fatigue life properties of the steering knuckle. A full understanding on the steering knuckle safety features will result in high durability and long life of the knuckle itself.

1.2 Problem Statement

Normally almost 90% of all machine and structural failures are caused by some form of fatigue and they are commonly subjected to variations of stress. Fatigue failures always begin at the surface of the material and this is because the mostly highly-stresses fibers are located at the surface (bending fatigue) and the intergranular flaws which precipitate tension failure are more frequently found at the surface. It is also important to highlight that fatigue cycles are accumulative. Certain time certain part of the machine has gone thru a test for cracks, but it might pass thru the test as fatigue of the machine has not been able to be identified. This will give reassurance to the owner or user of the machine that it can be used for a longer time. The problem will occur when over the time when suddenly cracks are finally detected and by that time it causes more problems to the machine. As it is essential to avoid premature fractures and this type of cracks, it is important to do a study on fatigue life of a specific type of metal. Alloy steel is among a type of steel that cannot avoid from being subjected to structural failures and fatigue life is known to be influenced by the stress ratio.

1.3 Objective

The objectives of this project are as follows:

1. To determine the type of alloy steel used for automobile steering knuckle as a case study.
2. To study the fatigue life properties of this material under constant amplitude loading.
3. To compare the fatigue life behavior under different stress ratio.

1.4 SCOPE OF PROJECT

The scopes of this project are:

1. The type of alloy steel used in this study is only obtained from automobile steering knuckle as the case study.
2. Fatigue tests and stress ratio used in this study are based on constant amplitude load only.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will briefly look at fatigue life, alloy steel and also the literature review on past studies.

2.2 Fatigue Life

2.2.1 Mechanism

Fatigue mechanism study started in the 19th century and the earlier theorist found out that metal will fail at a stress lower than the static loading when subjected to dynamic loading. One of the theorists and pioneer in the understanding of the mechanism of fatigue Wood (1995), proposed on specific mechanism in producing slip-band extrusion and intrusions. Figure 2.0 shows a slip mechanism that he interpreted through microscopic observation of slip produced by fatigue and he believed that this mechanism will accommodate larger total strain hardening. This mechanism for initiation of a fatigue crack is in agreement with the fact that fatigue cracks start at surfaces and that cracks have been found to initiate at slip-band intrusions and extrusions.

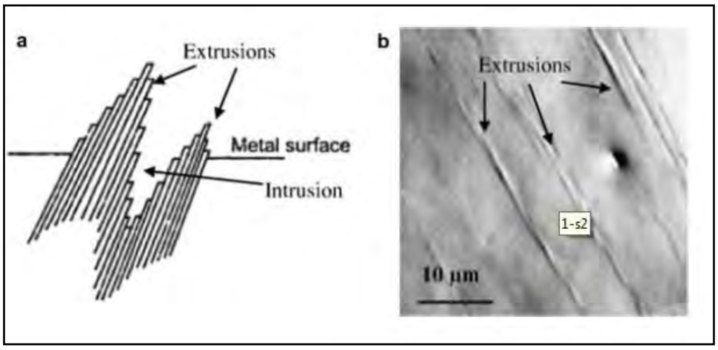

Figure 2.1: Slip Mechanism

(Source: Wood, 1995)

Figure 2.1 shows the example of Stage I crack nucleation growth and Stage II long crack propagation. It shows the fatigue damage process in which the crack nucleation starts at the highest stress concentration site in the persistent slip band.

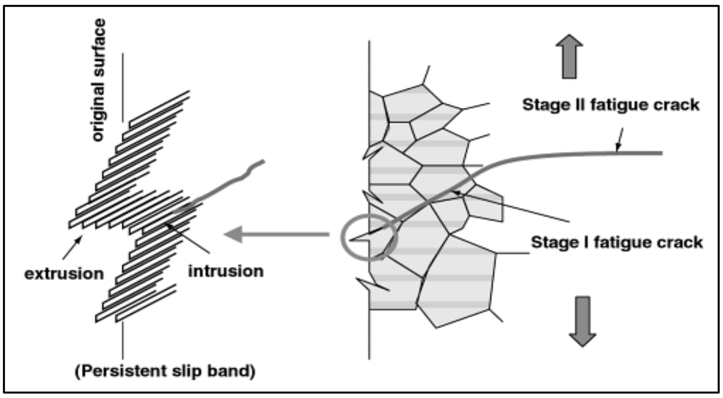

Figure 2.2: Stage I Crack Nucleation Growth and Stage II Long Crack Propagation

(Source: Wood, 1995)

The fatigue life is the number of cycles to failure at a specified stress level compared to fatigue strength which is the stress below which failure does not happen. High cycle fatigue involves a large number of cycles ($N>10^5$ cycles). The number of cycles to failure increases as the applied stress level is decreased and commonly the fatigue strength increases as the static tensile strength increases. There is a direct correlation between tensile strength and fatigue strength in which the higher-tensile-strength steels have the higher the fatigue strength limits. It is important to take note that steel not only has a higher fatigue strength than aluminum, but it also has an endurance limit. Below a certain stress level, the steel alloy will never fail due to cyclic loading alone. If the cyclic loading is accompanied by plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Low-cycle fatigue will occur if the cycle number up to the initiation of a visible crack or until final fracture is below 10^4 or 5.10^4 cycles. Figure 2.2 shows the modern type of fatigue test frame.