FATIGUE STRENGTH AND BEHAVIOUR OF NOTCHED STEEL SPECIMENS

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"I hereby declare that I have read this thesis 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 (Structure and Materials)"

Signature: ……………………….

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DECLARATION

"I hereby declare that the work in this report sufficient in terms of scope and quality for the award of the degree of
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Signature: ……………………….
Supervisor: ……………………….
Date: ……………………….

Dedicated specially for

my beloved family

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ABSTRACT

Fatigue is refers to the behaviour of materials under the action of repeated stresses or strain as distinguished from their behaviour under monotonic or static stresses or strains. Fatigue is the leading causes of failure in mechanical components and structures since they have been manmade structures or components. Fatigue has become progressively more prevalent as industries have developed various types of equipments that subjected to repeated loading and vibration. Fatigue failure is particularly insidious because it happened without any obvious warning. In this thesis, the material used is AISI 1020. A total of 24 specimens are prepared according to the specified design in ASTM standard for unnotched and notched specimens to compare their fatigue strength and behaviours. Certain machining process need to be done in order to prepare the specimen to the required dimension for the test specimens. The stress concentration factors applied to the notched specimen is defined and U-notch is chosen in this study. The fatigue test is conducted by using the INSTRON 8802 servohydraulic machine with its software and the test is run at low stress ratio (R = 0.1) and high stress ratio (R = 0.5). The data obtained from this study are plotted in the S-N curves and FDM of the materials. Based on the overall results, the fatigue strength for the unnotched specimens is higher than the notched specimens for both low and high stress ratio. Besides, the specimens conducted at high stress ratio also have higher fatigue strength and fatigue life. However, there are differences between the experimental and theoretical fatigue limits for the test specimens due to few factors which include effect of stress concentration, surface condition, stress parameters and etc. Finally, the faceted fracture surface is analysed as well as its relationship with the stress ratio and three different stages of crack propagation.

ABSTRAK

Kelesuan merujuk kepada sifat sesuatu bahan apabila ditindak dengan daya tegasan atau terikan yang berulang di mana sifat bahan ini berbeza apabila ditindak dengan daya tegasan atau terikan yang monotonik atau statik. Kelesuan adalah penyebab utama kepada kegagalan dalam komponen mekanikal dan struktur yang dibina atau dicipta oleh manusia. Kelesuan menjadi semakin meluas selari dengan teknologi di mana ia sering berlaku dalam komponen-komponen yang dikenakan beban atau getaran secara berulang-ulang. Kegagalan yang disebabkan oleh kelesuan adalah amat berbahaya kerana ia berlaku tanpa sebarang amaran. Dalam tesis ini, bahan yang digunakan adalah AISI 1020. Sejumlah 24 batang spesimen akan digunakan dalam kajian ini disediakan mengikut piawai dalam ASTM untuk membandingkan kekuatan kelesuan dan perilakunya. Beberapa proses perlu digunakan untuk menyediakan spesimen ujikaji dalam dimensi yang diperlukan. Faktor konsentrasi daya tegasan yang diterapkan dalam spesimen ditakrifkan dan U-lekuk dipilih dalam kajian ini. Ujian kelesuan ini dilakukan dengan mesin INSTRON 8802 dengan perisiannya dan ujian ini dijalankan pada nisbah daya tegasan rendah (R = 0.1) dan daya tegasan tinggi (R = 0.5). Data yang diperoleh dalam kajian ini diplot dalam graf S-N dan FDM. Berdasarkan keputusan secara keseluruhan, kekuatan kelesuan untuk spesimen tidak berlekuk adalah lebih tinggi untuk kedua-dua nisbah daya tegasan rendah dan tinggi. Selain itu, spesimen yang dijalankan pada nisbah daya tegasan tinggi juga memiliki kekuatan kelesuan yang lebih tinggi. Namun, terdapat perbezaan antara batas-batas kelesuan eksperimental dan teori spesimen ujikaji kerana beberapa faktor termasuk pengaruh konsentrasi daya tegasan, keaadaan permukaan, daya tegangan dan sebagainya. Akhirnya, permukaan patah spesimen turut dianalisis.

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LIST OF SYMBOLS

NO	TITLE
S	Stress
N	Number of cycles to failure
S_m	Mean stress
S_r	Stress range
S_a	Stress amplitude
S_{max}	Maximum stress
S_{min}	Minimum stress
R	Stress ratio/ Radius of fillet
A	Alternating stress ratio
K_t	Stress concentration factor
σ_{max}	Maximum stress
σ_{nom}	Nominal stress
P	Force applied
D	Diameter of test section of specimen
h	Depth of notch
r	Radius of notch
k_s	Surface factor
G	Gage length
A	Length of reduced section
P_y	Yield load
P_{ult}	Ultimate tensile load
σ_y	Yield strength
σ_{ult}	Ultimate tensile strength
σ_{min}	Minimum stress

P_{max}	Maximum load
P_{min}	Minimum load
P_{mean}	Mean load
P_{amp}	Load amplitude
σ_f	Fatigue limit

LIST OF ABBREVIATION

NO	**TITLE**
FDM	Fatigue Damage Map
SCF	Stress Concentration Factor
FEM	Finite Element Method
ASTM	American Society for Testing and Materials
AISI	American Iron and Steel Institute
CNC	Computer Numerical Control
ISO	International Organisation for Standardisation
JIS	Japanese Industrial Standard
C	Carbon
Mn	Manganese
P	Phosphorus
S	Sulphur

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CHAPTER 1

INTRODUCTION

1.1 Background

Mechanical failures have caused many injuries and financial losses. However, relative to the large number of successfully designed mechanical components and structures, mechanical failures are minimal.

Many different mechanical failure modes exist in all fields of engineering. These failures can occur in simple, complex, inexpensive or expensive components or structures. Stephen et al. (2001) stated that failure due to fatigue is multidisciplinary and is the most common cause of mechanical failure. Fatigue is a leading cause of failure in mechanical components and structures that are subjected to fluctuating stresses and strains which is below the yield stress. It may results in cracks or fracture after sufficient number of fluctuations. Fatigue on metal means that the metal will fail at much lower stress or formally known as repetitive loads and the metal will fail at much lower stress which the part can withstand under the application of a single static stress. Failure is the end result of a process involving the initiation and growth of crack, usually at the site of a stress concentration on the surface.

Fatigue failure is a result from the repeated applications of stress below the tensile strength of the material. The failure process consists of initiation of one or more cracks, the propagation of a dominant crack and final separation. Fatigue cracks usually initiate at the surface. Thus, the conditions of the surface and the environment are important factors influencing fatigue behaviours. Three basic factors are necessary to cause fatigue failure such as maximum stress, large enough variation or fluctuation in the applied stress and sufficiently large number of cycles of the applied stress. In addition, there are host of the other variables such as stress concentration, corrosion, temperature, overload, metallurgical structure, residual stresses and combined stresses which tend to alter the condition for fatigue.

Fatigue test can be thought of as simply applying cyclic loading to test specimen to understand how it will perform under similar condition in actual world or practice. The load application can either be repeated application of a fixed load or simulation of in-service loads. The material is subjected to repeated load cycles or fatigue in actual use. Engineers are faced with predicting fatigue life which is defined as the total number of cycles to failure under specified loading conditions. The closer the simulated analysis and testing are to the real product and its usage, the greater confidence in the engineering results.

Laboratory tests are essential in understanding fatigue behaviour and current studies with fracture mechanics test specimens are beginning to provide satisfactory design criteria. In 19^{th} century, Wohler was the first to carry out extensive fatigue test programs on the test specimens rather than actual components and to use both rotating bending and axial loading test. Then, the plots of stress amplitude versus the log of number of cycles to failure or known as S-N curves are introduced.

Besides, the presence of a notch or hole will reduce the fatigue resistance but not as simply as a direct function of the notch stress concentration factor, the size of notch or hole is also need to be considered. It is important especially after the two crashes of de Havilland Comet passenger jets based on the study from the McEvily (2002). It was concluded that the crash had been due to failure of the pressure cabin at the forward Automatic Direction Finder window in the roof. The failure was a result of metal fatigue caused by the repeated pressurisation and depressurisation of the aircraft cabin. Moreover, the supports around the windows were punch riveted, not bonded as the original specifications for the aircraft and the defect cracks created by imperfect nature of punch riveting caused the start of fatigue cracks around rivet. In addition, it was discovered that sharp cornered cut outs at the windows had higher stresses. Therefore, all future aircraft would feature windows with rounded corners to eliminating stress concentration. From the investigation, the sharp corners near the window opening acted as initiation sites for cracks. Since then, fatigue has been found at the root of failure of many mechanical components and stress concentration areas are important in determining the fatigue strength.

1.2 Objectives

The overall aims of this study are:

1) To determine and develop S-N curve and FDM (Fatigue Damage Map) of the test materials.
2) To generate useful information and data for the design of engineering components or structures based on the ‘stress-based’ concept or approach.

1.3 Scope

Based on the objectives mentioned above, the study is narrowed down to be more specific, in order to give a clearer view on the critical points. The scopes including in this study are:

1) To identify the suitable steel materials as available in store Faculty of Mechanical Engineering.
2) Design the test specimens for notched and unnotched conditions. Method of fatigue test, type and size of notches to be proposed based on the literature review.
3) To define the stress concentration factors (SCFs) applied to notched specimens either analytically or numerically (FEM).
4) To conduct fatigue tests to study the effects of stress ratios R, notch geometry and size.

5) Develop S-N curve and FDM of the test material.
6) Examine the faceted fracture surface (fractographic analysis) and establish its relationship with the effect of R- ratio and three different stages of the crack propagation.

1.4 Problem Statement

When a material is subjected to repeated loading and unloading, fracture is occurred. Microscopic cracks will begin to form at the surface if the loads are above a certain threshold and eventually a crack will reach a critical size and the structure will suddenly fracture. The shape of the structure will significantly affect the fatigue life. Sharp corners, grooves, key-holes or notches will lead to stress concentration where fatigue cracks can initiate. Therefore, stress concentration areas play important factors in determining the fatigue strength of the structure. Round holes and smooth transitions or fillets are important to increase or improve the fatigue strength of the structure as well as to eliminating the stress concentration of the part. Failure to control the geometries which included the notches and variation in cross section throughout a part will result in more severe damage of the object. Thus, the study of the fatigue strength and behaviour of notched steel specimens is important in this case.

CHAPTER 2

LITERATURE REVIEW

2.1 Cyclic loading

Mechanical components or structures are subjected to repeated load cycles. Most laboratory fatigue testing is done either with axial loading or in bending. Thus, it produced only tensile and compressive stresses. The stress usually is cycled either between a maximum and a minimum tensile stress or between a maximum tensile and a maximum compressive stress. There are two types of cyclic loading which are constant amplitude loading and variable amplitude loading.

2.1.1 Constant Amplitude Loading

Some practical applications and also many fatigue tests on materials, the cycling between maximum and minimum stress levels are usually maintained constant. Constant amplitude loading is used to obtain material fatigue behaviour for use in fatigue design. Nomenclature to describe test parameters involved in cyclic stress testing includes mean stress, S_m; stress range, S_r; stress amplitude, S_a; maximum stress, S_{max}; minimum stress, S_{min}; stress ratio, R and alternating stress ratio, A. All the nomenclature is shown in Figure 2.1.

The mean stress, S_m is the algebraic average of the maximum and minimum stresses in one cycle.

$$S_m = \left(\frac{S_{max} + S_{min}}{2}\right)$$

The range of stress, S_r is the algebraic difference between the maximum and minimum stresses in one cycle.

$$S_r = S_{max} - S_{min}$$

The stress amplitude, S_a is one half the range of stress.

$$S_a = \frac{S_r}{2} = \left(\frac{S_{max} - S_{min}}{2}\right)$$

The maximum stress, S_{max} is the total of the means and stress amplitude in one cycle.

$$S_{max} = S_m + S_a$$

The minimum stress, S_{min} is the difference between the mean stress amplitude in one cycle.

$$S_{max} = S_m - S_a$$

The stress ratio, R is the ratio of the minimum stress to the maximum stress.

$$R = \frac{S_{min}}{S_{max}}$$

The alternating stress ratio, A is the ratio of the stress amplitude to the means stress.

$$A = \frac{S_a}{S_m}$$