IMPROVING THE FATIGUE LIFE OF FASTENER HOLES BY USING COLD EXPANSION TECHNIQUE

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DECLARATION

I declare that this project report entitled *"IMPROVING THE FATIGUE LIFE OF FASTENER HOLES BY USING COLD EXPANSION TECHNIQUE"* is the result of my own work except the cited in the references.

Signature : ....
Name : TALAL MAHMOOD OTHMAN AHMED
Date : ....

SUPERVISOR'S DECLARATION

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 with Honours.

Signature : -------------------------------------

Name of Supervisor:PROF. MADYA ABD SALAM BIN MD TAHIR

Date : -------------------------------------

DEDICATION

Every time when I need them the most,
They are always by my side.
This humble work of mine I would like to dedicate to

My lovely mother,
My lovely father,

The kind, humble and knowledgeable lecturer who I was lucky to be guided by him.

My supervisor,
PROF. MADYA ABD SALAM BIN MD TAHIR

I really appreciate your time, continues help and valuable advice.

My fiancée
The girl who believes in me all the way,

And
All my friends,
For their assistance& support.

ABSTRACT

Fatigue can be defined as the behavior in which the failure takes place in a material due to repetitive applications of loads subjected to that material. Fatigue constitutes a serious concern for engineers as it happens suddenly and cannot be predicted accurately. Cracks are the leading cause of the fatigue failure which happens in many engineering structures and components. Cold expansion technique is one of the techniques that has been used in the last forty years to retard the crack initiation and propagation. As a result of using this technique, the strength of material and fatigue life are improved. In this thesis, Aluminum alloy 6061 is used as the tested material. A total of 15 specimens of dog-bone shaped with centralized holeto act as the stress concentration zone are prepared based on ASTM standards to study the fatigue life before and after applying the cold expansion technique. High carbon steel is the material that was used to produce the cold expansion tools. A set of machining process need to be done in order to prepare the specimens for both tensile and fatigue tests. Three different amount of interferences, which are 1.5% , 2.2% and 2.9%, are generated to study the impact of cold expansion process. The fatigue tests are conducted by using INSTRON 8802 universal testing machine and the test is run at 0.1 stress ratio and 10 Hzresonant frequency. The results obtained from this study are shown in tables and plotted in the form of S-N curve. The findings indicated a remarkable improvement in the fatigue life when the interference is 2.2%. In contrast, there is a decrease in the fatigue life when the interferences are 1.5% and 2.9% respectively.

ABSTRAK

Lesu boleh ditakrifkan sebagai gaya laku di mana kegagalan berlaku dalam suatu bahan disebabkan aplikasi beban berulang yang dikenakan kepada sesuatu bahan. Lesu diambil pertimbangan serius oleh jurutera disebabkan ia boleh berlaku secara mengejut dan sukar diramalkan dengan tepat. Retak adalah merupakan sebab utama kegagalan lesu dimana terjadi kepada komponen dan struktur kejuruteraan. Teknik pengembangan sejuk adalah merupakan salah satu teknik yang telah digunakan sejak lebih 40 tahun lalu untuk menghalang permulaan dan perambatan retak. Sebagai kesan penggunaan teknik ini, kekuatan bahan dan hayat lesu dapat ditingkatkan. Dalam tesis ini, aluminiumaloi 6061 digunakans ebagai bahan yang diuji. Sebanyak 15 spesimen berbentuk tulang-anjing dengan lubang ditetengahnya bertindak sebagai zon konsentrasitegasan telah disediakan berdasarkan piawaian ASTM untuk mengkaji hayat lesus ebelum dan selepas teknik pengembangansejuk dilakukan. Keluliberkarbontinggiadalahbahan yang digunakanuntukmenghasilkanalatpengembangansejuk. Beberapa proses pemesinanperludilakukanuntukmenyediakanspesimenujiantegangan dan ujianlesu. Tigatahapperselisihanbersamaan 1.5%, 2.2% dan 2.9% telahdihasilkanuntukmengkajiimpak proses pengembangansejuk. Ujianlesudijalankandenganmenggunakanmesinujianumum INSTRON 8802 pada nisbahtegasan 0.1 dan frekuensi 10Hz. Keputusan yang didapatidarikajianiniditunjukkandalambentukjadual dan juga graf S-N. Dapatankajianmenunjukkanbahawahayatlesudapatdipertingkatkandenganketarabilaperselisihanadalah 2.2%. Sebaliknya, terdapatpenguranganhayatlesubilaperselisihanadalahbersamaan 1.5% dan 2.9%.

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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
σ_{max}	Maximum stress
σ_{nom}	Nominal stress
P	Force applied
D	Diameter of test section of specimen
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
Nf	Fatigue life cycles

LIST OF ABBREVIATION

NO	**TITLE**
CE	Cold Expansion
SCF	Stress Concentration Factor
ASTM	American Society for Testing and Materials
CNC	Computer Numerical Control
ISO	International Organisation for Standardisation
Al	Aluminium
AA6061	Aluminium alloy 6061
Cr	Chromium
Cu	Copper
Fe	Iron
Mg	Magnesium
Si	Silicon
Ti	Titanium
Zn	Zinc
Mn	Manganese

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CHAPTER 1

INTRODUCTION

1.1 Background

Deformation and fracture are the two common responses of any material under an external force. The deformation can be elastic,plastic ,viscoelastic (time dependent elastic deformation) or creep (time dependent plastic deformation). With respect to fatigue which finally lead to failure by fracture, which is the dangerous response of the materials since it may occurs suddenly sometimes, typically happen after repeated cycles of loads and this is what is called “Fatigue". (William, M. 2009)

Each material has its static and dynamic behavior in the term of fatigue. To avoid the unpredictable failure and increase the aspect of safety, studies have been conducted to know the properties of materials and the best geometry design for each mechanical part or system. Therefore, the maximum cyclic stress that can be applied need to be known in order toavoid fatigue failure.

Fatigue, as defined by the technology of materials, is a progress in which damage takes place due to the repetitive applications of loads that may be lower than the yield strength of the specific material (David 2008). The progress of fatigue is very dangerous because one cycle of the load applied will not show any ill effects. Thus, the conventional stress analysis may conclude that safety is achieved while it is not. Generally, the fatigue in metals start at an internal or surface point where the stress is concentrated, and includes initially of shear flow along that point or slip planes. After a number of cycles, intrusions and extrusions are generated by this slip to create a crack as a result. This crack will propagate to reach its critical size which immediately end up with a fatigue failure to the mechanical part or system.

There are many methods created to improve the fatigue life. Most of them were made in the time when the initial ideas of design for metal aircraft structures did not take in consideration the advantages provided. In addition, the point of view of the initial ideas is used to deal with the potential increases as a protection. The processes initially were used to improve the life through that otherwise considered safe, or to demand it when premature cracks appeared. All these ideas are not valid anymore. Recently, the established life enhancement is used by the high-tech military aircraft during the manufacturing process. for example, in the McDonnell Douglas F-18 , the aircraft which uses the technique of cold expansion for the hole, ring pad coining , shot peening and the interference-fit fastener. The need for higher performance structure with lower cost now makes it more necessary than before to quantify the life improvements and make sure that they are perfect.

In 1960s, Boeing Company developed the split-sleeve hole cold expansion. This technique has been efficiently used for more than thirty years (Houghton S.J. 2010). Split sleeve cold expansion is an effective way to overcome the problems related to fatigue holes and cracks in the metallic structures. Split sleeve expansion is conducted by pulling a tapered mandrel, pre-fitted with a lubricated split sleeve through a hole in aluminum, titanium or steel. The function of the expendable split sleeve cold expansion is to make sure of the correct radial expansion of the hole, decrease the mandrel pull force and allow uniaxial processing.

1.2 Objectives:

The main objectives of this study are

- To conduct fatigue tests and determine the S-N curve of the tested specimens of aluminum alloy 6061.
- To show clearly the benefit and impact of cold expansion technique in the term of improving the fatigue life.

1.3 Scope

The scopes involving in this study are :

- To identify the suitable materials to conduct the required technical tests for the study.
- To identify the best design for the specimen based on the previous studies and the machines available in the lab of the faculty of Mechanical Engineering.
- To conduct the tensile and fatigue tests for the specimens.
- To develop the S-N Curves.
- To study the effects of the changes in geometry and also the effect of cold expansion technique on the specimens.
- To show clearly all the results produced in order to improve the fatigue life.

1.4 Problem Statement

Due to the need for higher fatigue strength of the mechanical parts especially in some systems like air turbines, aircrafts and automobiles which are subjected to repeated loading and vibration, fatigue has become a serious matter need to deal with. Most of the incidences in the structures, fatigue starts from the holes or stress concentration areas, specially the fasten ones.

In this study, the emphasis is on improving and studying the fatigue life and fatigue behavior for better understanding and enhancement on fatigue life of structures through a cold expansion technique.

CHAPTER 2

LITERATURE RIVIEW

2.1 Overview

According to (Rallis 2014), the purpose of literature review is to provide a theoretical outline and foundation for the related research study. This chapter will discuss the background of this project in a general way. In addition, this chapter will show the published previous studies related to the particular subject area. Moreover, this chapter will be a summary of the sources of this project. Literature review focuses normally on specific issues of an interest and the critical analysis of the connection among different mechanisms and any information related to this project.

2.2 Material Failure

The meaning of deformation failure is the change in the physical dimensions or shape of a component that is sufficient for its function to be lost or impaired (Dowling, N.E., 2013). Deformation failure in materials can be occurred in two basic types which are deformation and fracture. Because of the different causes to these types of failure, it is very important to identify correctly the main reason and determine the compatible analysis method in order to find the suitable solution for the problem. Basic types of deformation and fractures are shown in figure 2.1.

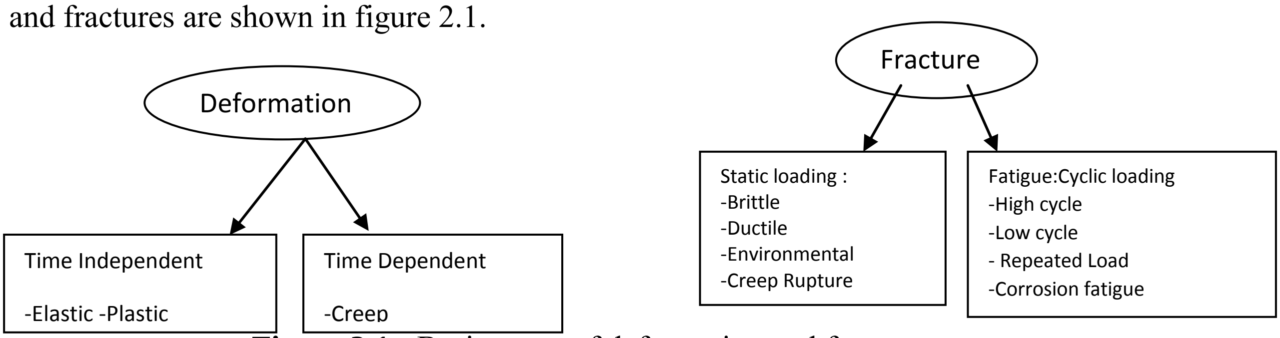

Figure 2.1 : Basic types of deformation and fractures

2.2.1 Static loading and cyclic loading

It is important to differentiate between cyclic loading and static loading. Static loading is normally related to the static fatigue especially in the brittle solids such as ceramics and glasses. Usually this kind of fatigue happened due to the moisture in these materials which cause cracks to grow. Thus, static fatigue is a corrosion response not like the fatigue in this present project which happens due to the cyclic (repeated) loading's effects in the fastener holes where stress concentration factor is located. Cyclic loading affects badly the mechanical structures and components. Over the time, the cracks start to grow and failure occurs as a result.

In general, there are two kind of cyclic loading which are constant amplitude loading and non-constant amplitude loading. (Meyers, M. ,&Chawla, K. K. 2008).

2.2.2Constant Amplitude cyclic loading

This kind of cyclic loading includes constant values of maximum and minimum stresses. It is used to find and study the behavior of the material fatigue. There are some important parameters we should know about constant amplitude cyclic loading which are (Bargiggia.U.,2008) :

- Stress Ratio, R : the ratio of the minimum stress to maximum stress in each cycle.

$$R = \frac{Smin}{Smax}$$

- Stress Range, Sr : the algebraic difference between the maximum stress and the minimum stress in each cycle.

$$Sr = Smax - Smin$$

- Stress Amplitude : the half of Stress Range.

$$Sa = \frac{Smax - Smin}{2}$$

-Mean Stress : the average of the maximum and minimum stresses in one cycle.

$$Sm = \frac{Smax + Smin}{2}$$

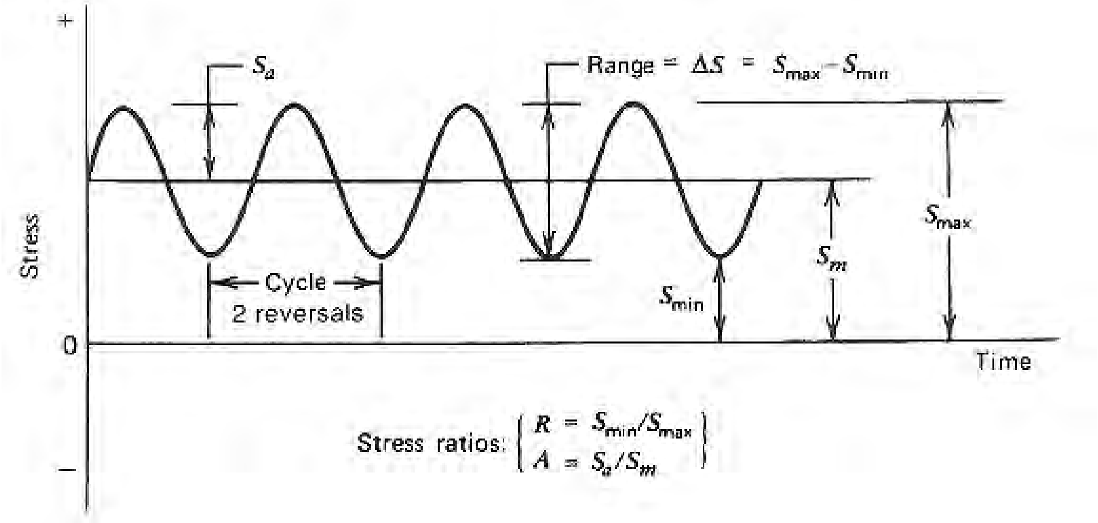

Figure 2.2: Nomenclature for constant amplitude cyclic loading(Stephens, R.I. et al., 2001)

Constant Amplitude loading involves three main types which are,

1- Tensile-to-Tensile Load. (Figure 2.3 (a))

2- Fully-Reversed Load. (Figure 2.3 (b))

3- Zero-to-Full Tensile Load. (Figure 2.3 (c))

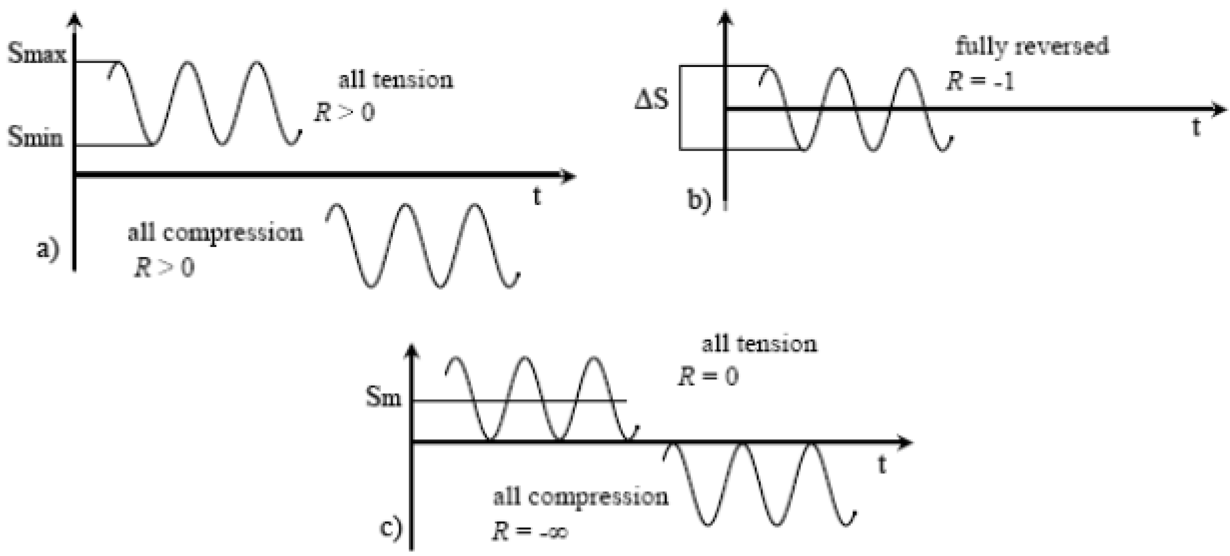

Figure 2.3: Types of constant amplitude, proportional loading. (a) 'tensile-to-tensileload', (b)'fully-reversed load', (c) zero-to-full tensile load'.

2.2.3 Non-Constant Amplitude Cyclic Loading

It is the condition when the load-ratio acts as a time dependent. The normal constant amplitude loading uses a single R to determine the mean and alternating values. In contrast, the non-constant type of cyclic loading is completely random and thus there is no analytical pattern can represent its complexity. On the other hand, the calculations of cumulative damage are used to determine the total value of fatigue damage because the fatigue loading that causes the maximum damage cannot be determined easily. Therefore, the cycle counting is converted to a number of functions to reduce the complex load-recording. After that, these functions can be calibrated with the data of constant amplitude test. Trucks loading over the bridges and wind loading over the aircraft are two common examples of non-constant amplitude cyclic loading. Figure 2.4 shows a schematic load history of this type of loading.

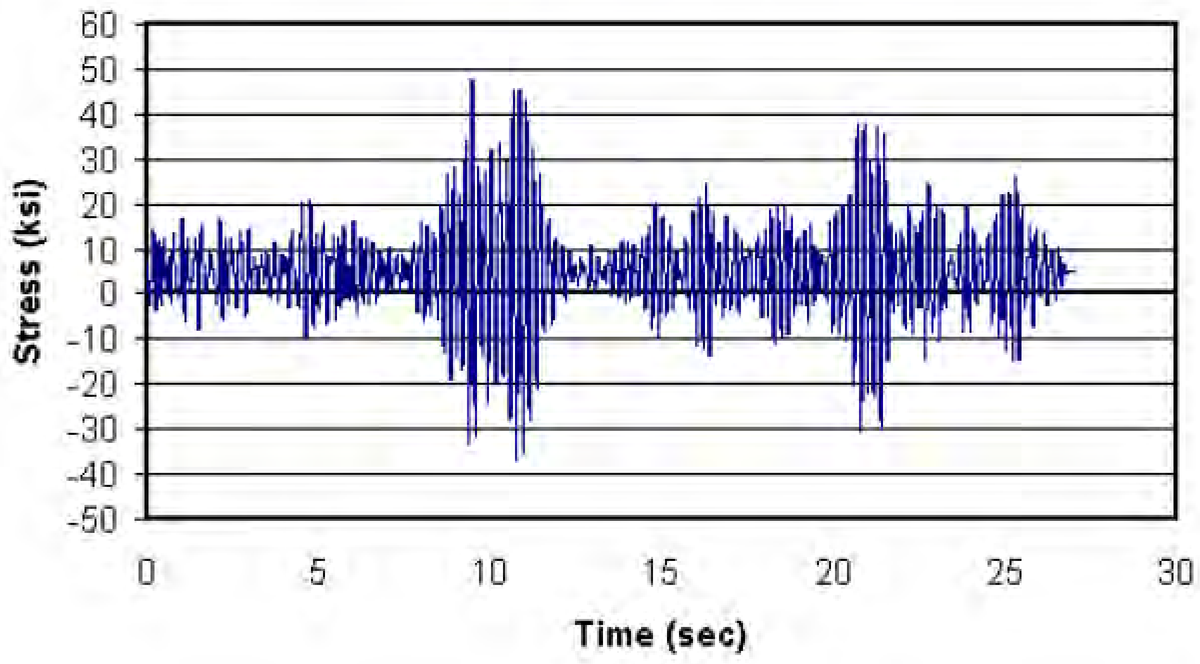

Figure 2.4: Non-Constant Amplitude Cyclic Loading.