EFFECT OF NITRIDING ON FATIGUE LIFE OF THE CYLINDER BLOCK FOR TWO-STROKE ENGINE

NOR AZINEE BINTI SAID

Report submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS ◆

JUDUL: EFFECT OF NITRIDING ON FATIGUE LIFE OF THE CYLINDER BLOCK FOR TWO-STROKE ENGINE

SESI PENGAJIAN: 2008/2009

Saya **NOR AZINEE BINTI SAID (860509-29-5084)**
(HURUF BESAR)

mengaku membenarkan tesis (Sarjana Muda / ~~Sarjana / Doktor Falsafah~~)* ini disimpan di perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Tesis ini adalah hakmilik Universiti Malaysia Pahang (UMP).
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (√)

[ ]	**SULIT**	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)
[ ]	**TERHAD**	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi / badan di mana penyelidikan dijalankan)
[√]	**TIDAK TERHAD**	

Disahkan oleh:

________________________ ________________________

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:

C9, Kampung Kelubi
16600 Pulai Chondong
Kelanatan.

DR. MD. MUSTAFIZUR RAHMAN
(Nama Penyelia)

Tarikh: **30 OCTOBER 2008**

Tarikh: **30 OCTOBER 2008**

CATATAN: ◆ Potong yang tidak berkenaan
** Jika tesis ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu dikelaskan sebagai SULIT atau TERHAD.
Tesis dimaksudkan sebagai tesis bagi Ijazah Doktor Falsafah dan Sarjana secara Penyelidikan, atau disertasi bagi pengajian secara kerja kursus dan penyelidikan, atau Laporan Projek Sarjana Muda (PSM).

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the report written by Nor Azinee Binti Said entitled "Effect of Nitriding on Fatigue Life of the Cylinder Block for a Two-stroke Engine".We have examined the final copy of this project and that in our opinion; it is fully adequate, in terms of scope and quality for the awarding the degree. We herewith recommend that it be accepted in fulfillment of the requirements for the degree in the Mechanical Engineering.

Committee members of Final Examination:

Name	Signature
1. Mr Mohd Ruzaimi Bin Mat Rejab	
2. Mr Mohd Shahrir Bin Mohd Sani	
3. Mr Lee Giok Chui	

Approved for Co-ordinator of Faculty of Mechanical Engineering

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Engineering in Mechanical Engineering.

Name of Supervisor: Dr. Md. Mustafizur Rahman

Position: Senior Lecturer

Date:

STUDENT'S DECLARATION

I hereby declare that the work in this report is my own except for quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concutently submitted in candidate of any other degree.

Name: Nor Azinee Binti Said
ID Number: MA 05054
Date:

ACKNOWLEDGEMENTS

In the name of Allah, the Most Benevolet, the Most Merciful. First of all I wish to record immeasurable gratitude and thankfulness to the One and The Almighty Creator, the Lord and Sustainer of the universe, and the Mankind in particular. It is only hod mercy and help that this work could be completed and it is keenly desired that this little effort be accepted by Him to be some service to the cause of humanity.

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Md. Mustafizur Rahman for his germinal ideas, invaluable guidance, continueous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a doctorale program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to graduate program to these concluding moments. I also sincerely thanks for the time spent proofreading and correcting my many mistakes.

My sincere thanks go to all my members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to member group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I can not find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

Aluminum alloys are one of the most capable material selections for automobiles parts and electrical component to reduce their weight and to increase their specific strength. This project report describes the role of nitriding process on fatigue life of the cylinder block for a two-stroke internal combustion engine. The objectives of this project are to predict the fatigue life of cylinder block using stress-life, to identify the critical location, toinvestigate the effect nitriding process and to optimize cylinder block's material. The structural model of cylinder block was developed using the computer aided design software. The finite element modeling and analysis were performed utilizing finite element analysis code. The set of aluminum alloys is consider in this study. The three-dimension solid model was imported to the MSC.PATRAN software and employed to generate meshes and define material properties for finite element modeling. The finite element analysis was performed using MSC.NATRAN code. The finite element model of component was analyzed using the linear elastic approach. The fatigue life analysis was carried out using MSC. FATIGUE software. Fatigue stress-life approach was used and sensitivity analysis on fatigue life is discussed. Stresses obtained previously are employed as input for the fatigue life. From the result, it was shown that the Goodman mean stress correction method is predicted more conservative (minimum life) results. It was found to differ considerably the compressive and tensile mean stresses to give noticeable advantages and fond to be design criteria. Based on the finite result, it is observed that the nitrided treatment produces longest life for all loading conditions. Therefore, the nitriding process is one of the promising surface treatments for aluminum alloy part to increase the fatigue life of the linear engine cylinder block.

ABSTRAK

Aloi aluminium merupakan bahan yang paling berkeupayaan dalam bidang pembuatan perkakas-perkakas elektrik dan dalam pembuatan bahan-bahan automotif yang bertujuan untuk mengurangkan berat bahan dan juga untuk meningkatkan daya kekuatan khususnye. Projek ini membentangkan penyelidikan menggunakan unsur terhingga berasaskan pengkomputeran tentang peranan rawatan permukaan terhadap hayat lesu dengan mengunakan rawatan nitrat bagi blok selinder terhadap komponen enjin linear omboh dua-lejang dalam enjin pembakaran. Objektif projek ini dijalankan ialah untuk meramalkan penilaian kebolehtahanan, untuk mengenalpasti komponen enjin linear omboh yang selamat, untuk menyiasat kesan rawatan nitrat dan untuk pengoptimuman bahan bagi silinder blok. Permodelan struktur pejal tiga-dimensi bagi enjin omboh dibangunkan dengan perisian lukisan bantuan komputer.Pengesahan model unsur dan analisis unsur dibangunkan untuk pengesahan keputusan kod model unsur. Set aloi aluminium digunaan dalam projek ini. Model pejal tiga- dimensi dimasukkan ke perisian MSC.PATRAN bagi menjana jejaring dan ditentukan sifat bagi permodelan unsur terhingga. Analisis unsur terhingga dijalankan dengan kod MSC.NASTRAN. Model unsur terhingga bagi komponen dianalisis menggunakan pendekatan elastik linear. Hayat lesu analisis diteruskan dengan menggunakkan perisian MSC. FATIGUE. Pendekatan tegasan hayat lesu digunakan dan kepekaan hayat lesu analisis dibincang. Tegasan yang diperolehi sebelumnya digunakan sebagai masukan dalam pengiraan hayat lesu. Keputusan didapati bahawa analisis menggunakan kaedah pembetul tegasan min Goodman meramalkan hayat konsevertif. Ia menunjukan perbezaan berdasarkan tegangan dan pemendekan tegasan min memberi kebaikan kepada reka bentuk kriteria. Berdasarkan keputusan yang diperolehi menunjukkan rawatan nitrat memberikan hayat lebih panjang untuk semua keadaan bebanan. Oleh itu, proses penitridan memberi rawatan permukaan yang baik bagi komponen aloi aluminium menambah hayat enjin silinder blok.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

N_i	Number of fatigue life
S_i	Load cycle with amplitude
D	Cumulative damage
n_i	Number of load cycles at this amplitude
S_r	Constant stress range
S_a	Constant stress amplitude
N_f	Fatigue life
S_m	Mean stress
R	Stress ratio
A	Amplitude ratio
σ_a	Stress amplitude
σ'_f	Fatigue coefficient,
b	fatigue strength exponent
S_e	Altering stress
σ_m	Mean stress
S_u	Ultimate tensile strength
σ_f	True tracture strength
S_f	Fatigue strength
n	Strain hardening exponent
K	Strength Coefficient
$K1C$	Fracture toughness
S_y	Yield Strength

LIST OF ABBREVIATIONS

AA	Aluminum Alloy
A-A	ASTM air to air typical fighter loading
Al	Aluminium
ASTM	American Society for Testing and Materials
CAD	Computer-Aided Drafting
CAE	Computer-Aided Engineering
DS	Double Strap
FEM	Finite Element Modeling
FE	Finite Element
IC	Internal Combustion
MBD	Multibody Dynamics
SAE	Society of Automotive Engineers
MPC	Multi-Point Constraints
AISI	Steel

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The most of the failure observed in the real structure and mechanical component are due to the fatigue. In the design of the real system subjected to the environment loadings, both the fatigue strength and dynamic properties of the external loads are important. Fatigues are the progressive and localize material damage that occurs when material is subjected to cyclic loading. Fatigue is an important parameter to be considered in the behavior of components subjected to constant and variable amplitude loading (Torres and Voorwald, 2002). In this study variable amplitude are consider due to the service load histories. Realistic representation of service load is a key ingredient of successes fatigue analysis. Therefore, it is important to accurate measure the applied load on existing component or structure or to predict loads on a component or structure does not yet exist. (Koster and Field, 1973) suggested that the main mechanical property adversely affected by machining is high cycle fatigue strength, the actual endurance limit being dependent on the particular process used and the severity of operation. While it is known that fatigue life is heavily influenced by residual stresses, the metallurgical condition of the materials and the presence of notch-like surface irregularities induced by machining play a key role (Novovic et al., 2004).

Cylinder block is the most critical component of engine in automotive industry. The cylinder block or engine block is a machined casting (or sometimes an assembly of modules) containing cylindrically bored holes for the pistons of a multi-cylinder reciprocating internal combustion engine, or for a similarly constructed device such as a pump. The engine cylinder block or "block" is cast in one piece. Usually, this is the largest and most intricate single piece of metal in the automobile. Even when the cylinders, cylinder heads, or cylinder sleeves are separate pieces, the crankcase is still the largest single part in the engine. The cylinder block serves as the main structural component of the engine and houses what's commonly referred to as the "the bottom end" (crankshaft, rods, pistons). Cylinder block structures are very commonly subjected to fatigue loading (Rahman et al., 2006a).

Aluminum (Al) and its alloy have benefit over non metallic materials: aluminum alloys have a high melting point, a good workability and also have a good thermal conductivity. Aluminum alloys are one of the most capable material selections for automobiles parts and electrical component to reduce their weight and to increase their specific strength (Rahman et al., 2007a). Aluminum alloys is suitable material due to safety, environmental and performance benefit.

Nitriding is now widely used in manufacturing for surface hardening of ferrous and non-ferrous materials. Nitriding, one of the most widely used thermo-chemical methods, produces a high compressive residual stresses on the surface of components. Nitriding is a process for hardening the surface by diffusing nitrogen into the surface. All machining, stress relieving, as well as hardening and tempering are normally carried out before nitriding. Nitriding steels offer many advantages: a much higher surface hardness is obtainable when compared with case-hardening steels; they are extremely resistant to abrasion and have high fatigue strength.

1.2 PROBLEM STATEMENT

Cylinder block is the critical component in the internal combustion engine. The cylinder block failure is due to the fatigue. Due to the market pressure for improvements in productivity, reliability, ductility, wear resistance and profitability of mechanical system, manufacturers replacing increasing demands on available materials (Rahman et al., 2006). Surface treatment likes nitriding is used to improve fatigue performance and increased the life. This simplification allows designers to use linear elastic stress results obtained from multibody dynamic FE (finite element) simulations for fatigue life analysis. To optimize component material, aluminum alloys is the suitable material due to light and less weight. Nowadays, the most capable material selection for automobiles parts and manufacturing is aluminum alloys because it light and less weight.

1.3 OBJECTIVES OF THE PROJECT

This project is focus on the finite element based on the fatigue analysis of the cylinder block for a two-stroke internal combustion engine using positive mean loadings.

The overall objectives of this project were:

(i) To predict the fatigue life of the cylinder block using stress-life method and to identify the critical locations
(ii) To investigate the effect of nitriding treatment
(iii) To optimize cylinder block's material

1.4 SCOPE OF STUDY

This project concentrates on the stress-life approach under variable amplitude loading. The scopes of study are as follows:

(i) Structural modeling
(ii) Finite element modeling (FEM)
(iii) Fatigue analysis
(iv) Surface treatment analysis
(v) Optimization of material

1.5 OVERVIEW OF THE REPORT

Chapter 1 gives the brief the content and background of the project. The problem statement, scope of study and objectives are also discussed in this chapter.

Chapter 2 discusses about the fatigue life prediction method, fatigue life prediction in variable amplitude loading and surface treatment process.

Chapter 3 presents the development of methodology, finite element modeling and analysis, fatigue life prediction technique and linear elastic analysis.

Chapter 4 discusses the result and discussion of the project. The discussion aims is to determine the predicted facts and correlate them with the current international researches on the field of the fatigue mean stress effects.

Chapter 5 presents the conclusions of the project. Suggestions and recommendations for the future work are put forward I this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the surface treatment, fatigue life method and variable amplitude loading. The review is organized chronologically so as to offer approaching to how research hard works have laid the base for subsequent studies, including the present research effort. The review is fairly detailed so that the present research effort can be properly modified to add to the present body of literature as well as to justify the scope and direction of present research effort.

2.2 FATIGUE LIFE PREDICTION METHOD

Fatigue analysis can be used to determine how long the component can maintain in a given service condition. In general, fatigue life refers to the ability of a component to function in the presence of defect for a given loading. In practice, the predominant failure mode is fatigue and hence, the term fatigue life analysis was used to describe the analysis of the fatigue performance. In engineering design, the criteria for the fatigue life of a component can very depending of the functional requirements of material characteristic. The fatigue properties are determined from the constant amplitude loading test. However, the real structural seldom experience constant amplitude loading. Therefore, an irregular loading history must be reduced to a series of constant amplitude events each with its corresponding mean and amplitude for comparison with sample laboratory specimen testing data.

Rahman et al. (2007b) were studied about finite element based durability assessment in a two- stroke free piston linear engine component using variable amplitude loading. The study discussed the finite element analysis to predict the fatigue life and identify the critical locations of the component. The effect of mean stress on the fatigue life also investigated. The linear static finite element analysis was performed using MSC. NASTRAN finite element software. The result was capable of showing the contour plots of the fatigue life histogram and damage histogram at the most critical location.

Conle and Mousseau (1991) used vehicle simulation and the finite element result to generate the fatigue life contours for the chassis component using automotive proving ground load history result combine with the computational techniques. They concluded that the combination of the dynamics modeling, finite element analysis is the practical techniques for the fatigue design of the automotive component.

Srikantan et al. (2000) discussed vehicle durability and fatigue analysis using data from proving ground testing. The authors discuss the differences between yield strength based durability analysis and fatigue analysis. Fatigue analysis reduces the design cycle and produces a more optimally design structure. The authors concentrated on the design of the truck body structure and the service duty that accompany them. The loads from proving ground test of similar vehicle. The simulation used to calculate fatigue life is MSC.FATIGUE, while the stresses are determined using MSC.NASTRAN. When the fatigue life design criteria are met a prototype is then built and tested. If the design criteria are not met the prototype is modified. The results from a correlation study showed the analytical strains from FE analysis and proving ground test correlated very well.

Nadot and Denier (2003) have been studied fatigue phenomena for nodular cast iron automotive suspension arms. They find out that the major parameter influencing fatigue failure of casting components are casting defects. The high cycle fatigue behavior is controllers mainly by surface defects and oxides while the low cycle fatigue is governed by multiple cracks initiated independently from casting defects.

Kim et al. (2002) also studied a method for simulating vehicles dynamic loads, but they add durability assessment. For their multibody dynamics analysis (MDA) they use DADS and a flexible body model. The model was for a transit bus. For the dynamic stresses analysis MSC.NASTRAN was used. The fatigue life was then calculated using a local strain approach. From the fatigue life, it was found that the majority of the fatigue damaged occurred over a frequency range that depend on terrain traveled (service or accelerated test course). This showed that the actual service environment could be simulated instead of using an accelerated testing environment.

2.3 VARIABLE AMPLITUDE LOADING

When components are subjected to variable amplitude service loads, additional uncertainties arise, whether the loading in laboratory tests related to the loads that could be expected to appear. Traditionally this problem is solved by using the simplifying assumption of damage accumulation, and constant amplitude tests in laboratory are transformed to variable amplitude severity by the Palmgren-Miner rule which says that a

$$D = \sum_{i=1}^{m} \frac{n_i}{N_i} \tag{2.1}$$

load cycle with amplitude S_i adds to the cumulative damage D, a quantity ($1/N_i$). Here, N_i denotes the fatigue life under constant amplitude S_i loading with amplitude and ni is the number of load cycles at this amplitude. The lack of validity of this accumulation rule has been demonstrated in many applications and in consequence its usage will introduce uncertainties which must be compensated for by safety factors, see for instance (Berger et al., 2002).

One possible way to diminish the deviations from the damage accumulation rule is to perform the laboratory experiments closer to the service behavior with respect to the loads. A method for establishing a Wohler curve based on variable amplitude loads has recently been developed and is presented in a parallel paper (Johannesson et al., 2003).The use of this method should be customized to each specific application by performing laboratory tests with load spectra covering different service requirements. One idea is that service measurements are used to establish a few reference load spectra for use in laboratory tests. Based on the resulting variable amplitude Wohler curve, fatigue life can be predicted for load spectra similar to the reference types.

Svensson et al. (2004) were conducted the fatigue life prediction based on variable amplitude tests-specific applications. Three engineering components have been tested with both constant amplitude loading and with different load spectra and the results are analyzed by means of a new evaluation method. The method relies on the Palmgren-Miner hypothesis, but offers the opportunity to approve the hypothesis validity by narrowing the domain of its application in accordance with a specific situation. In the first case automotive spot weld components are tested with two different synthetic spectra and the result is extrapolated to new service spectra. In the second case, the fatigue properties of a rock drill component are analyzed both by constant amplitude tests and by spectrum tests and the two reference test sets are compared. In the third case, butt welded mild steel is analyzed with respect to different load level crossing properties and different irregularity factors.

Nolting et al. (2007) were investigated the effect of variable amplitude loading on the fatigue life and failure mode of adhesively bonded double strap (DS) joints made from clad and bare 2024-T3 aluminum. They concluded that the fatigue life of a variable amplitude loading spectra can be calculated with reasonable accuracy using an effective stress range vs. life fatigue curve. The effective stress range vs. failure life curve is dependent on the bond geometry and therefore this curve must be developed for component geometry of interest. The effective stress range vs. life fatigue curve should be used to predict the fatigue life of clad specimens if the failure mode of the clad specimens is expected to be adhesive failure (i.e., if the spectrum includes large overload cycles).

Molent et al. (2007) have been evaluated the spectrum fatigue crack growth using variable amplitude data. This paper summarizes a recent semi-empirical model that appears to be capable of producing more accurate fatigue life predictions using flight load spectra based on realistic in-service usage. The new model described here provides an alternative means for the interpretation of full-scale and coupon fatigue test data, and can also be used to make reliable life predictions for a range of situations. This is a very important capability, particularly where only a single full-scale fatigue test can be afforded and should lead to more economical utilization of airframes.

2.4 SURFACE TREATMENT

The surface treatment of a component is a common site for initiation of fatigue crack. Therefore, the manner in which in the surface is prepare during manufacturing of the components has a vital role in dictating the initiation life for the surface fatigue cracks. There exists a variety of surface treatment such as carburizing, nitriding, and flame hardening which is design to impart high strength, wear resistance or corrosion resistance locally in the near surface regions of the material.

Nitriding is often used high strength aluminum and titanium alloy to improve fatigue performance (Novovic et al., 2004; Bell et al., 1998). Nitriding is now widely used in manufacturing for surface hardening of ferrous and non-ferrous materials. Nitriding ia a well-known case hardening process in which nitrogen is introduced into the surface of a solid ferrous alloy by holding the alloy at a suitable temperature in contact with a nitrogenous gas (usually ammonia) or a liquid cyanide bath (ASM, 1991). The nitriding temperature for all steels is generally between 530 and 580^{0}C. The principle reasons for nitriding are:

(i) To obtain high surface hardness
(ii) To increase wear resistance and anti-galling properties

(iii) To improve fatigue life

(iv) To obtain a surface that is resist to the softening effects of heat at temperatures up to the nitriding temperature.

Although, at suitable temperature, all steels are capable of forming iron nitrides in the presence of nascent nitrogen, the nitriding results are more favorable in those steels containing one or more of the major nitride forming alloying elements. Unalloyed carbon steels are not suitable for nitriding as they form an extremely brittle case that spills readily and the hardness increase in the diffusion zone small. Of the alloying elements commonly used in commercial steels, aluminum, chromium, vanadium, and molybdenum are beneficial in nitriding as they form hard nitrides that are stable up to the nitriding temperature. Since aluminum is the strongest nitride former of the common alloying elements, aluminum-containing steels (0.85-1.25% Al) yield the best nitriding results in terms of total alloy content. Chromium-containing steels can approximate these results if their chromium content is high enough.

Farrahi and Ghadbeig (1995) carried out an investigation into the effect of various surface treatments on fatigue life of a tool steel. The effects of nitriding, nitrocarburizing and shot peening on fatigue behavior of AISI D3 cold work tool steel were investigated. They found out that nitriding and nitrocarburizing treatments may improve abrasive-wear resistance of this material by increasing surface hardness and the peening is the best treatment to improve the fatigue life of AISI D3 tool steel.

Karaoğlu (2002) conducted an investigation on the wear of plasma nitrided AISI 5140 low-alloy steel in relation to the effect of parameters such as temperature, time and nitrogen partial pressure. The work carried out by this author indicated that the case depth and compound layer thickness that are formed during nitriding increased with increasing process temperature and time and that, although the wear resistance improved considerably after the plasma nitriding, for achieving the maximum resistance to wear, process parameters should be chosen to minimize the compound layer thickness and maximize the surface hardness and case depth.

Hosmani et al. (2005) investigated the nitriding behavior of a Fe–7Cr alloy at 580 °C in a gas mixture of ammonia and hydrogen, when the nitriding potential was varied from 0.03 to 0.818 $atm^{-1/2}$. The nitrided zone in this material was observed to be composed of two different regions, one with finely dispersed small CrN continuous precipitates in α-Fe grains and another, near the surface, where the precipitates were observed to coarsen in a discontinuous manner leading to a lamellar CrN/α-Fe morphology. The maximum hardness in the nitrided zone and the nitriding depth were both observed to increase with increasing nitriding potential, as long as no iron nitride layer developed at the surface of the specimens. Also, the nitriding depth was observed to depend roughly linearly on the square root of the nitriding potential.

2.5 CONCLUSIONS

Different types of the fatigue life prediction method and durability assessment approach have been reviewed in this chapter in conjunction with surface treatment and variable amplitude. Many researchers have carried out their research based on the fatigue life, durability assessment, surface treatment and variable amplitude. Most of the methods available in literature reviews are used for the study. The next chapter will be concentrated on the methodology will be presented in the

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The fatigue life of engineering structure principally depends upon that of its critical structure members. There is an increasing within the internal combustion engine industry in the ability to produce design that safe, reliable, light in weight, economic and easy to produce. Nowadays, increasing demands in develop and deliver the reliable products in a timely manner necessary more testing to be coupled with the CAE procedures such as the finite element analysis and fatigue life analysis. In this chapter, the proposed fatigue analysis, stress-life method, structural modeling, material information and loading information are presented.

3.2 PROJECT FLOWCHART

Figure 3.1 shows the overall flowchart of the project

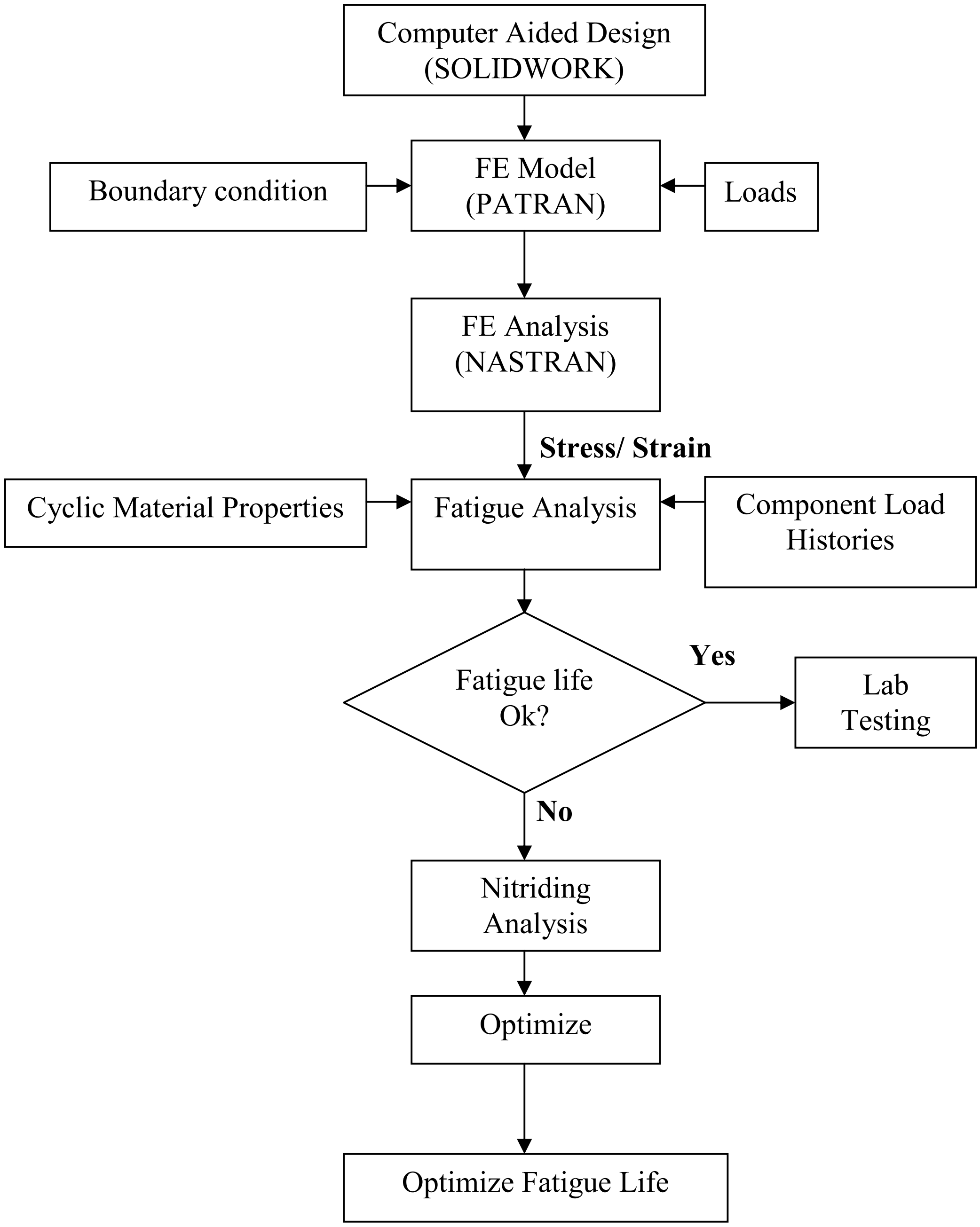


Figure 3.1: Flowchart of the project

3.3 STRUCTURAL MODELING

The Figure 3.2 shows 3D structural modeling of cylinder block in two different views. This structural modeling was developed using the computer aided design (SOLIDWORK) software.

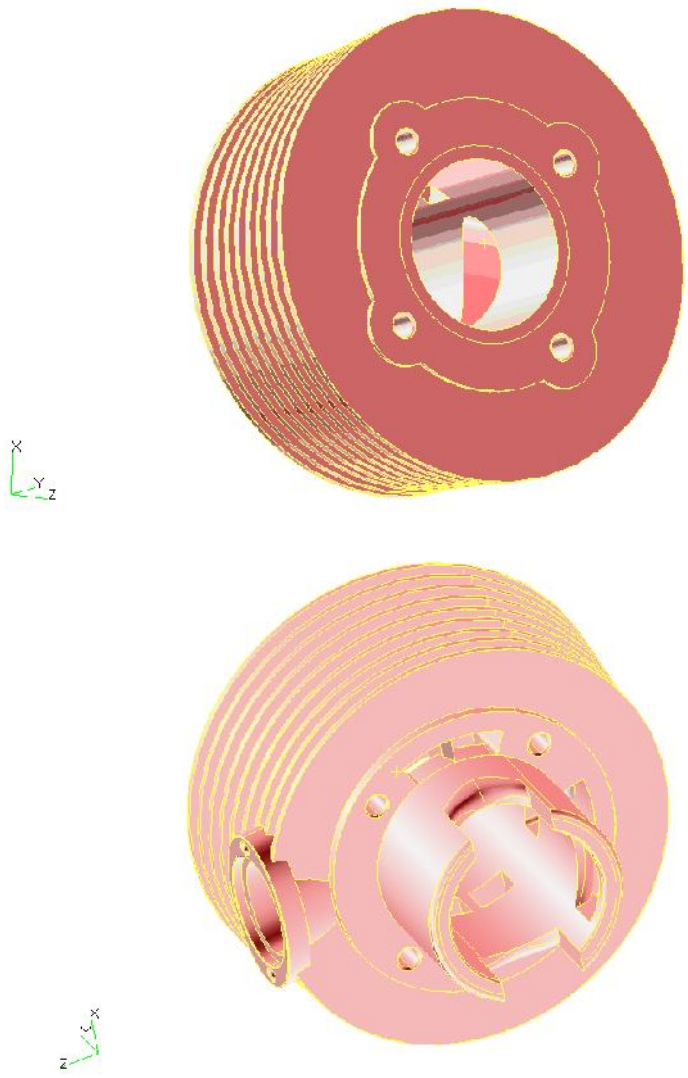


Figure 3.2: 3D structural modeling of the cylinder block (two different views)

3.4 FINITE ELEMENT MODELING

Three-dimensional model geometry was developed in SOLIDWORK software. A parabolic tetrahedral element was used for the solid mesh. Sensitivity analysis was performed to obtain the optimum element size. These analyses were performed iteratively at different element length until the solution obtained appropriate accuracy. Convergence of stresses was observed, as the mesh size was successively refined. The element size of 8 mm was finally considered. A total of 131873 elements and 76239 nodes were generated at 8 mm element length. Figure 3.3 shows the finite element modeling with two different views.

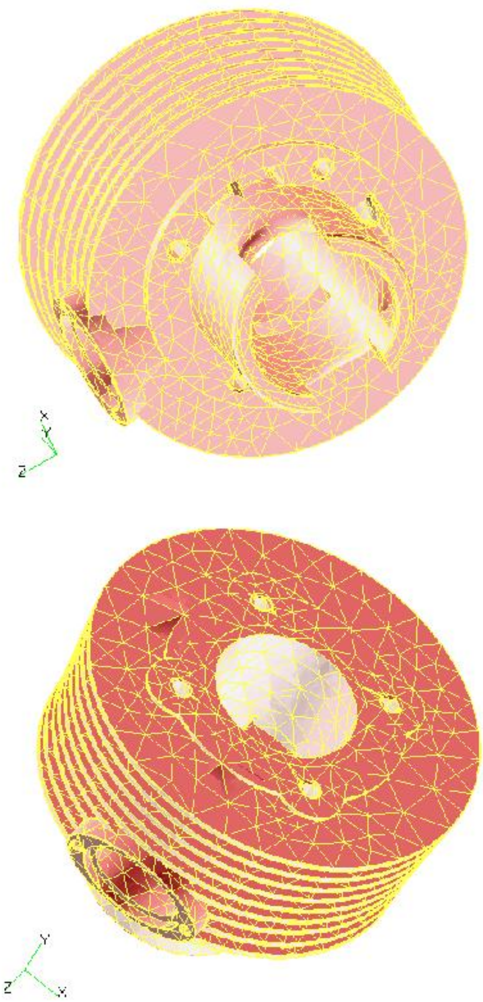


Figure 3.3: 3D finite element modeling of the cylinder block (two different views)

3.5 FATIGUE LIFE ANALYSIS

Fatigue analysis has traditionally been performed at a later stage of the design cycle. This is due to the fact that the loading information could only be derived from the direct measurement, which requires a prototype (Bannantine et al., 1990; Stephens et al., 2001). Multybody dynamics (MBD) (Kim et al., 2002) is capable of predicting the component loads which enable designer to undertake a fatigue life assessment even before the prototype is fabricated. The purpose of analyzing a structure early in the design cycle is to reduce the developed time and cost. This is achieved by determining the critical region of the structure and improving the design before prototype are built and tested. Three computational processes of finite element are utilized to perform the fatigue life analysis using CAE tools. The processes of the finite element base fatigue analysis are as follows:

(i) Multibody dynamic simulation- to determine the loading on a component based on system inputs

(ii) Finite element (FE) analysis- to determine the stress/strain state of a component foe a given load condition

(iii) Fatigue analysis- to calculate the fatigue life for the component of interest and identify the critical locations.

The fatigue analysis is used to compute the fatigue life at a single location in a structure. For multiple locations the process is repeated using geometry information applicable for each location. The required inputs for the fatigue analysis are shown in Figure 3.4. The three input information are description of the material properties, loading histories and geometry. The details of these are as follows:

(i) Material information- cyclic or repeated material based on a constant amplitude testing

(ii) Load histories information- measure or simulated load histories applied to a component. The term “loads” is used to represent forces, displacement, accelerations, etc.

(iii) Geometry information- relates the applied loads histories to the local stresses and strain at the location of interest. The local stresses and strains information are usually derived from the FE result.

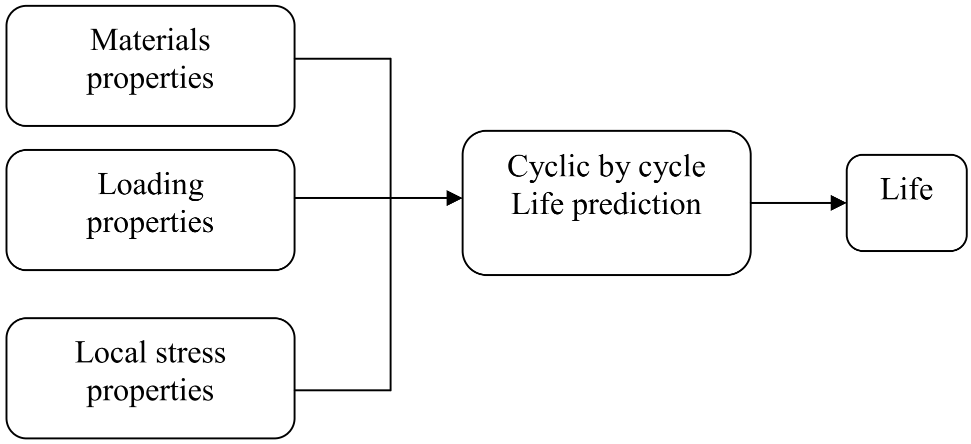


Figure 3.4: Schematic diagram of the fatigue life estimation

The FE model based fatigue analysis can be considered as a complete engineering analysis for the component. The fatigue life can be estimated for every element in the finite element model, and the contour plots of life damage can be obtained. Te geometry information is provided by the FE results for each load case applied independently. Appropriate materials are also provided for the desired fatigue analysis method. An integrated approach to fatigue life analysis combines multibody dynamic analysis, and the fatigue analysis into a consistent entity for the prediction of the fatigue life of a component (Rahman et al., 2007b).

3.6 STRESS- LIFE METHOD

The stress life *(S-N)* method was first applied over hundred years ago (Wöhler, 1867) and consider nominal elastic stresses and how they related to life. This approach to the fatigue analysis of components works well for situations in which only elastic stresses and strains are present. However, most components may appear to have nominally cyclic elastic stresses but stress concentration are present in the component may result in load cyclic plastic deformation (Rahman et al., 2007b).

The *S-N*, method was first approach used in an attempt to understand and quantify metal fatigue. It was the standard fatigue design method almost 100 years. The *S-N* approach is still widely used in design applications where the applied stress is primary within the elastic range of the material and the resultant lives (cycles to failure) are long, such as power transmission shaft. The stress-life method does not work well in low-cycle applications, where the applied strain have significant plastic component. The dividing line between low and high cycle fatigue depends on the material being considered, but usually falls between 10 and 10^5 cycles [Banantine et al., 1990].

This method is also distinguished from the other fatigue analysis and design technique by several features: [Lee et al., 2005]

(i) Cyclic stresses are the governing parameters for the fatigue failure.
(ii) High-cyclic fatigue conditions are present (high number of cycles to failure and little plastic deformation due to cyclic loading

During fatigue testing, the test specimen is subjected to alternating loads until failure. The loads applied to the specimen are defined by either a constant stress range (S_r) or constant stress amplitude (S_a). The stress range and stress amplitude are defined as Eq. (3.1) and (3.2), respectively.

$$S_r = S_{max} - S_{min} \tag{3.1}$$

$$S_a = \frac{S_r}{2} = \frac{(S_{max} - S_{min})}{2} \tag{3.2}$$

Typically, for fatigue analysis, it is a convection to consider tensile stresses positive and compressive stresses negative. The magnitude of the stress range or amplitude is the controlled (independent) variable and the number of cycles to failure is response (dependent) variable. The number of cycles to failure is the fatigue life

(N_f), and each cycle is equal to two reversals (2 N_f). The symbols of stresses and cycles mentioned previously are illustrated in Figure 3.5.

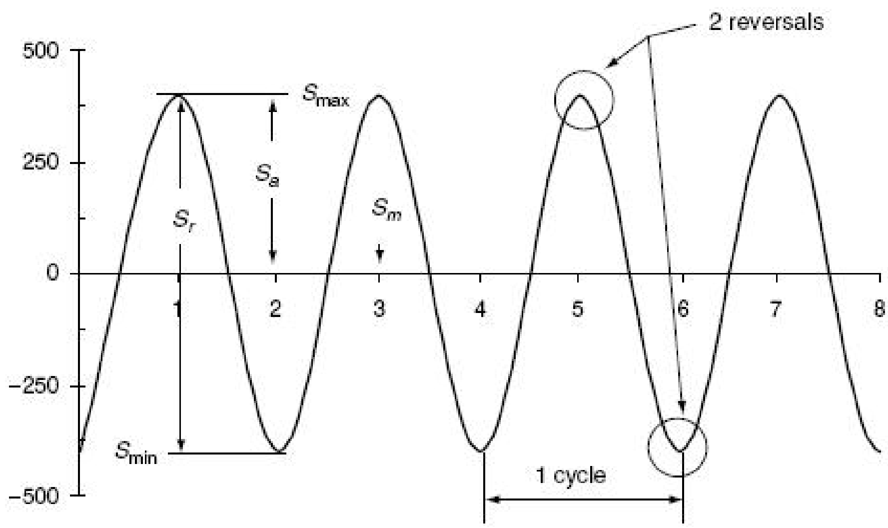


Figure 3.5: Symbols used with cyclic stresses and cycles.

Most of the time, *S-N* fatigue testing is conducted using fully reversed loading. Fully reverse indicates that loading is alternating about zero mean stress. The mean stress (S_m) is defined as

$$S_m = \frac{(S_{max} + S_{min})}{2} \tag{3.3}$$

Exceptions exist when stress life testing is performed for specimens for which this type of lading is physically nit possible or is unlikely. One example is the fatigue testing of spot welded specimens. Cyclic loading varying from zero to tension is used in fatigue testing on specimens with the single spot weld, because compression may cause local buckling of the thin sheet metal.

Actual structural components are usually subjected to the alternating loads with a mean stress. Two parameters, the stress ratio *(R)* and the amplitude ratio *(A)*, are often used as representations of the mean stress applied to an object. The stress ratio is defined as the ratio of minimum stress to maximum stress:

$$R = \frac{S_{\min}}{S_{\max}} \tag{3.4}$$

The amplitude ratio is the ratio of the stress amplitude to mean stress:

$$A = \frac{S_a}{S_m} = \frac{1 - R}{1 + R} \tag{3.5}$$

The stress-life approach was the first well-developed approach to the fatigue analysis. It is suitable to predict high cycle fatigue and has been extensively used in automotive industry. Fatigue life depends primarily on loads, materials, geometry and environmental effects and it's usually described by *S-N* curve. The stress-based approach considers the controlling parameters for fatigue life to nominal stress. The relationship between the nominal stress amplitude and fatigue life is often represented as *S-N* curve, which can expressed in Eq. (3.6)

$$\sigma_a = \sigma'_f (2N_f)^b \tag{3.6}$$

where σ_a is stress amplitude, σ'_f is a fatigue coefficient, $2N_f$ is the reveals to failure and b is the fatigue strength exponent (Rahman et al., 2007b). The *S-N* curves shows in Figure 3.6.

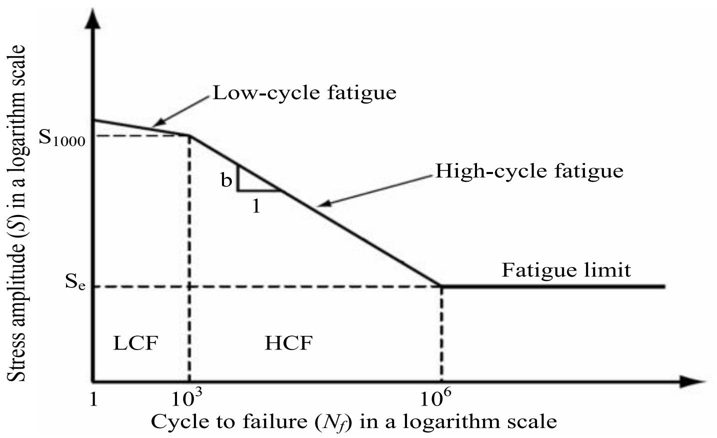


Figure 3.6: *S-N* curve

3.7 MEAN STRESS CORRECTION METHOD

From the perspective of applied cyclic stresses, fatigue damage of component correlates strongly with the applied stress amplitude or applied stress range and is also influenced bye the mean stress (a secondary factor). In the high- cycle fatigue region, normal mean stresses have a significant effect on fatigue behaviour components. Normal mean stresses are responsible for the opening and closing state microcracks. Because the opening of microcracks accelerates the rate of crack propagation and the closing of microcraks retards the growth of cracks, tensile normal mean stress are detrimental and compressive normal mean stresses are beneficial in terms of fatigue strength. The shear mean stress does not influence the opening and closing state of microcraks, and not surprisingly, has little effect on crack propagation. There is very little or no effect of mean stress on fatigue strength in the low- cycle fatigue region in which the large amount of plastic deformation erase any beneficial or detrimental effect of a mean stress (Lee et al., 2005).

The modified Goodman and Gerber equations are given by Eq. (3.7) and (3.8) respectively:

$$\frac{\sigma_a}{S_e} + \frac{\sigma_m}{S_u} = 1 \tag{3.7}$$

$$\frac{\sigma_a}{S_e} + \left(\frac{\sigma_m}{S_u}\right)^2 = 1 \tag{3.8}$$

where σ_a is altering stress in the presence of mean stress, S_e is alternating stress for equivalent completely reversed loading, σ_m is mean stress, and S_u is ultimate tensile strength. The typical representation of these mean stress equations is shown in Figure 3.7

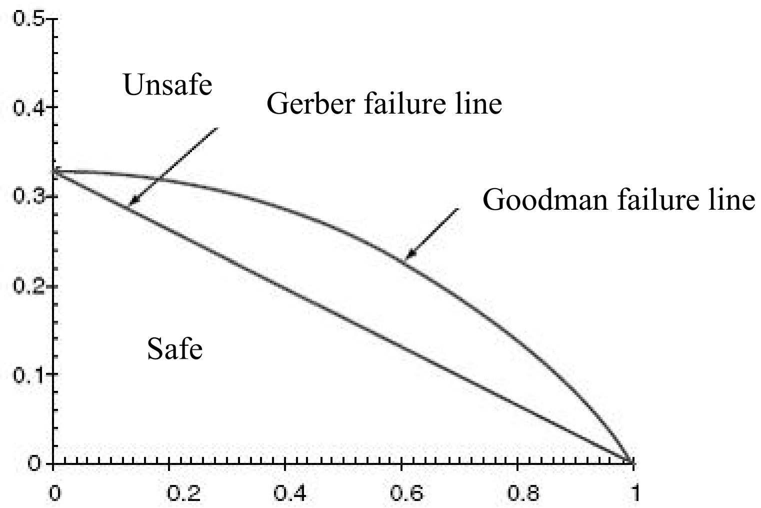


Figure 3.7: Comparison of Mean Stress equation

Mean stresses are detrimental when they reduce the fatigue resistance, and beneficial when they improve the fatigue resistance of the material (Rahman et al., 2006).

3.8 MATERIAL INFORMATION

Material model and material properties play an important role in the result of FE method. The material property is one of the major inputs which are the definition of how material behaves under cyclic loading condition. The cyclic material properties are used to calculate the elastic-plastic stress-strain response and the rate at fatigue damage accumulate due to each fatigue cycle. The material parameters required depend on the analysis methodology being used. Normally, these materials are measured experimentally and available in various handbooks (Juvinalle and Marshek, 1991). A set of aluminum alloys is considered in this project. The mechanical and cyclic properties of the AA6061-T6-80-HF are tabulated in Table 3.1.

Table 3.1: Mechanical and cyclic properties of the AA6061-T6-80-HF aluminum alloy

Materials properties	**Aluminum Alloy AA6061-T6-80-HF**
Monotonic Properties	
Young's modulus, E, GPa	70
Ultimate tensile strength, S_u , MPa	260
Yield Strength, S_y (MPa)	240
Density (kg/m^3)	2710
Cyclic and Fatigue Properties	
Fatigue limit S_f @ 2×10^8 cycles (MPa)	126.29
Strength Coefficient, *K* (MPa)	402
Strain hardening exponent, *n*	0.043
Fracture toughness, *K1C* (MPa-m1/2)	29

Source: Rahman et al. (2007b)

3.8 LOADING INFORMATION

Loading is another major input to the finite element based fatigue analysis. Several types of variable amplitude loading history were selected from the Society of Automotive Engineers (SAE) profiles. The component was loaded with three time histories, corresponding to typical histories for transmission, suspension and bracket components at different load levels. The detailed information about these histories can be referred in the literature (Tucker and Bussa, 1977).These histories were scaled to two peak strain levels and used as full-length histories. The positive mean variable amplitude load-time histories are shown in Figure 3.8. The considered load-time histories are based on the SAE's profile. The abscissa is the time, in seconds (Rahman et al., 2007).

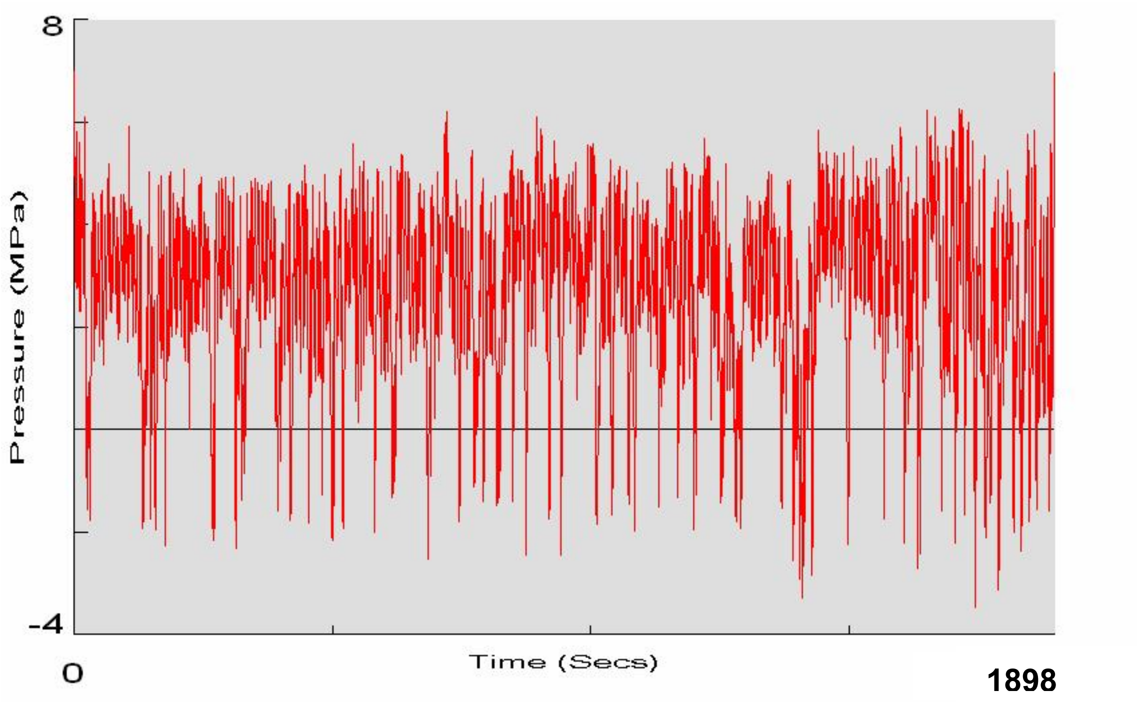


Figure 3.8: Positive mean variable amplitude loading histories

3.10 CONCLUSIONS

The mechanism of the fatigue are quite complex and still only partially understood. This chapter describe fatigue analysis, stress-life method, mean stress correction, material information and loading information. The structural model of cylinder block was developed using the computer aided design software. The finite element modeling and analysis were performed utilizing finite element analysis code. The set of aluminum alloys is consider in this study. The finite element model of component was analyzed using the linear elastic approach. Fatigue stress-life approach was used and sensitivity analysis on fatigue life is discussed. The results and discussion will be presented in the next chapter.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses the finite element modeling, selection of the mesh type, identification of mesh convergence, linear static stress analysis, fatigue analysis, material optimization. In fatigue analysis will discuss about nitriding treatment that used to improve the fatigue life. For the material optimization, there are two methods that used to make comparison between aluminum materials. The methods are mean stress correction and effect of surface finish.

4.2 FINITE ELEMENT MODELING

In the finite element model of the cylinder block of two-stroke engine, there are several contact areas (examples: cylinder head, gasket, hole and bolt, etc) concerning multi-point constraints (MPC). Therefore constraints are employed for the following purposes:

(i) Specify the prescribe enforce displacements
(ii) To simulate the continuous behavior of displacement in the interface area
(iii) To enforce rest condition in the specified directions at grid points of reaction

Because of the complexity of geometry and loading on the cylinder block, a 3D FE model was adopted which shown in Figure 4.1. The loading and constraints on the cylinder block are shown in Figure 4.2. A linear static analysis was carried out on the cylinder block.

Three-dimensional model geometry was developed in SOLIDWORK software. A 10 nodes tetrahedral element was used for the solid mesh. A sensitivity analysis was performed to obtain the optimum element size. These analysis were performed iteratively a different element lengths until the solution obtain appropriate accuracy. Convergence of the stresses was observed, as the mesh size was successively refined. The element size of 8 mm was finally considered. A total of 76239 elements and 131878 nodes were generated at 8 mm element length. A pressure of 7 MPa was applied on the surface of combustion chamber and the constraints were applied on the bolt-hole for all six degree of freedom. This preload is obtained according to the RB and W recommendations (Shigley et al., 2004). Three-dimensional FEM model, loading and constraints on the cylinder block is shown in Figure 4.2.

Figure 4.1: 3D Finite Element Model

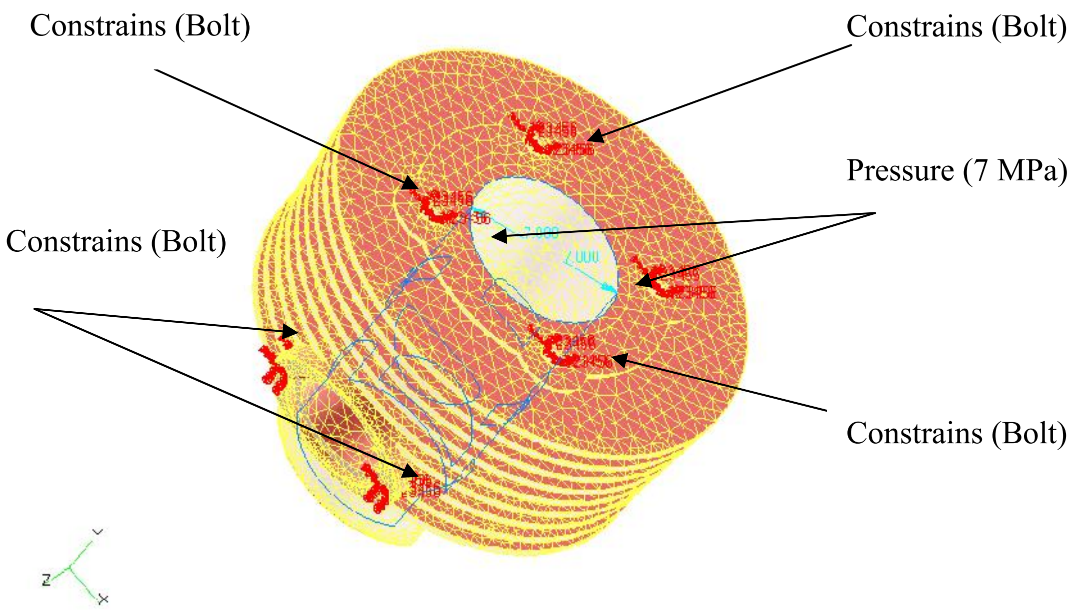


Figure 4.2: Loading and Constraints

4.3 SELECTION OF THE MESH TYPE

Mesh study is performed on the FE model to ensure sufficiently fines sizes are employed for accuracy of calculated results but at competitive cost (CPU time). In the process, specified field variable is selected and its convergence is monitored and evaluated. Selecting the right techniques of meshing are based on the geometry, model topology, analysis objectives and engineering judgment. Triparametric solid with the topological shape of the brick or wedge can be meshed either hexahedral or wedge element. Any other form of the triparametric solid can only be meshed with tetrahedral elements. Solid that have more than six faces must first be modified and decomposed before meshing. The auto tetrahedral meshing approach is highly automated technique for meshing solid regions of the geometry. It crates a mesh of tetrahedral elements for any closed solid including boundary representation solid. Tetrahedral meshing produces high quality meshing for boundary representation solids model imported from the most CAD system. Since the tetrahedral is found to be the best meshing technique, the 4 nodes tetrahedral (TET 4) element version of the cylinder block was then used for the initial analysis. In the addition, the TET 4 compared to the 10 nodes tetrahedral (TET10) element mesh using the same global mesh length for the highest loading conditions (7.0MPa) in the combustion chamber.

Figure 4.3 shows the comparison between the maximum principle, tresca and von-Mises. The result shows that the TET 10 mesh predicted higher stresses than TET 4 mesh for maximum principle, tresca and von-Mises stresses. Figure 4.4 shows the FEM with TET 4 and TET 10 using the same global mesh length.

Figure 4.5 shows the von-Mises stresses contour for TET 4 and TET 10 meshes element at a high load level. As shown in Figure 4.5, there is quit difference between the two, but the TET 4 mesh is still capable of identifying critical areas. The TET 10 mesh is presumed to represent a more accurate solution since TET 4 meshes are known to be dreadfully stiff. TET 4 employed a linear order interpolation function while TET 10 used quadratic order interpolation function. For the same element size, the TET 10 is expected to be able to capture the high stress concentration associated with the bolt holes. Both of the meshes have some distorted elements cause error to the modeling in areas of elevated stress.

Figure 4.5 shows that the TET 10 mesh predicts higher von-Mises stresses than the TET 4 mesh. Specifically, the TET10 mesh predicts the highest von-Mises stresses 232 MPa. The fatigue life of cylinder block is predicted using positive mean variable amplitude loading conditions. Figure 4.6 shows the fatigue life computed using the Coffin-Manson criteria for TET4 and TET10 meshes. Units are the logarithm of seconds to failure, where 1 second refers to the 50 cycle's simulation.

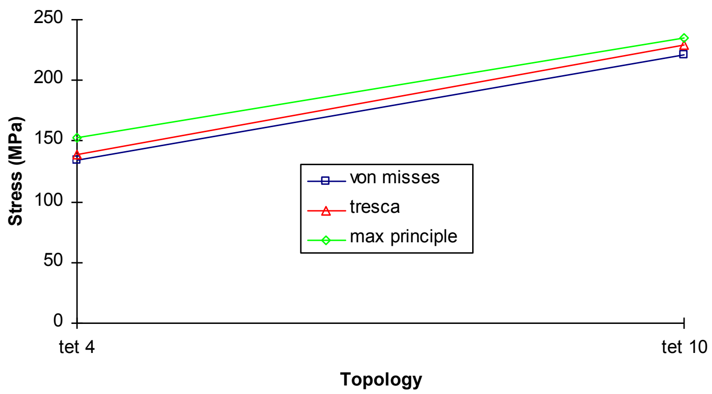
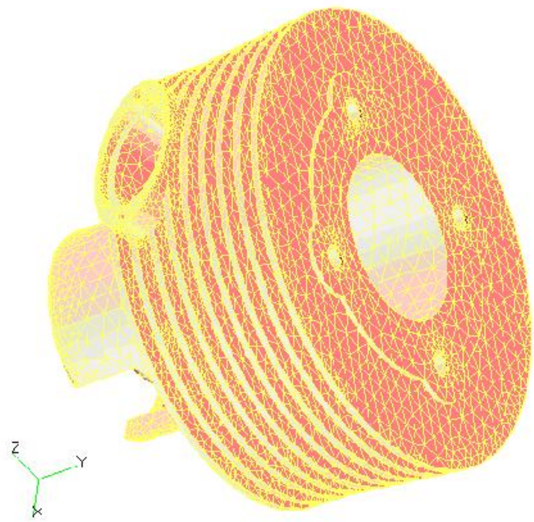
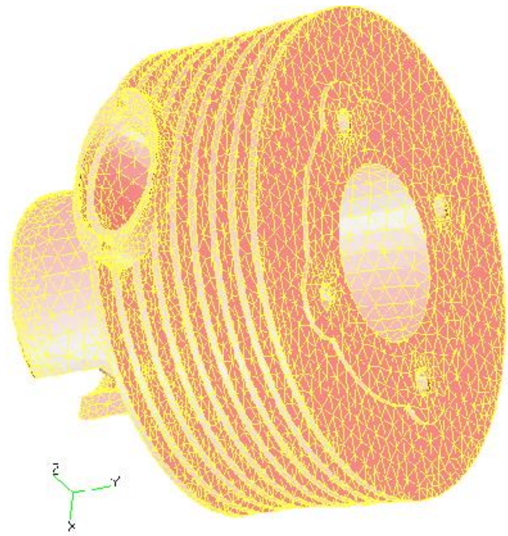


Figure 4.3: Comparison between TET10 and TET4 using maximum principle stresses

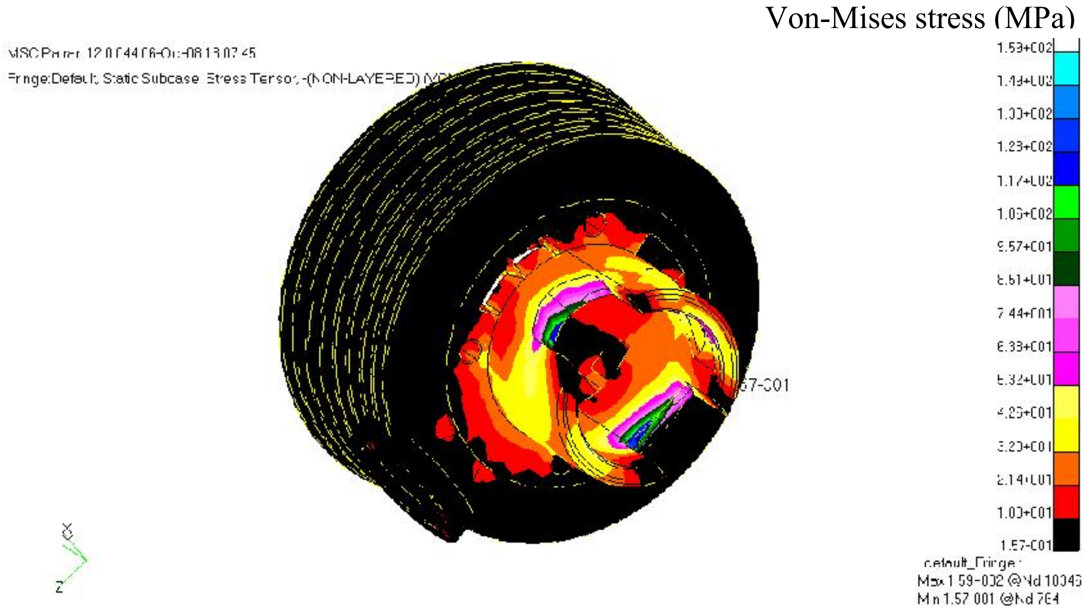


(a) TET10, 76239 elements

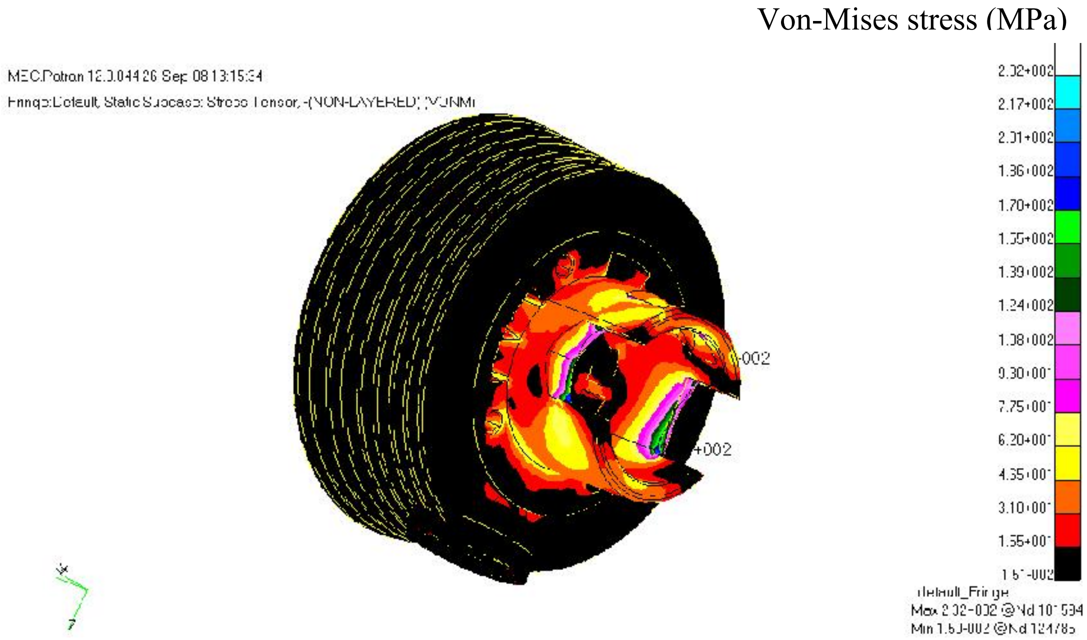


(b) TET4, 76030 elements

Figure 4.4: Finite element modeling for (a) TET10 (b) TET4 using he same global mesh length



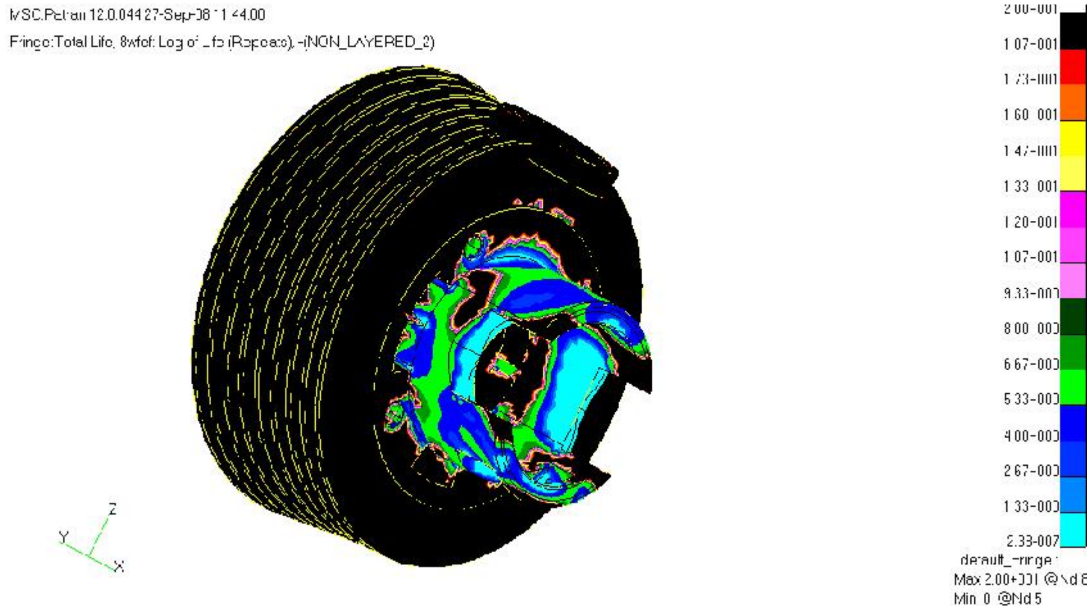
(a)



(b)

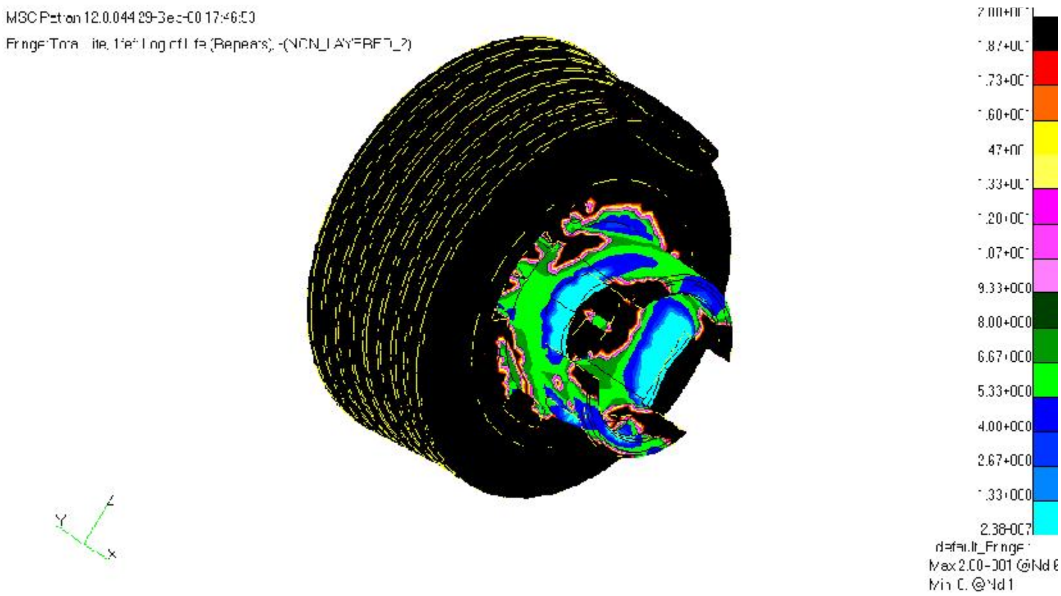
Figure 4.5: Von-Mises stress contours (a) TET4 and (b) TET10 meshes at high load level.

Log of life (sec)



(a) TET10

Log of life (sec)



(b) TET4

Figure 4.6: Predicted fatigue life contour plotted for TET10 and TET4 meshing using Coffin-Manson method

4.4 IDENTIFICATION OF MESH CONVERGENCE

The convergence of the stress was considered as the main criteria to select the mesh size. Detailed refinement at the critical points would result in extremely lengthy analysis time and was, therefore, avoided. The finite element mesh was generated using the tetrahedral elements length of 8 mm (76239 elements), 10 mm (67828 elements), 15 mm (46457 elements) and 37.1245 mm (17954 elements). The maximum principal stresses were checked for convergence at the critical location, as shown Figure 4.7. It is observed that the convergence has been obtained for the global mesh size of 8 mm due to it's tends to the actual stress value. Therefore, the mesh size 8 mm with 76239 elements was used for the FE analysis due to the limitation of the computational time and storage capacity. Figure 4.7 shows the variation of the stress at the critical points of components. Due to the higher stress concentration at the fillet of the cylinder block, large stress gradient existed at the location and thus, more refined mesh size was implemented.

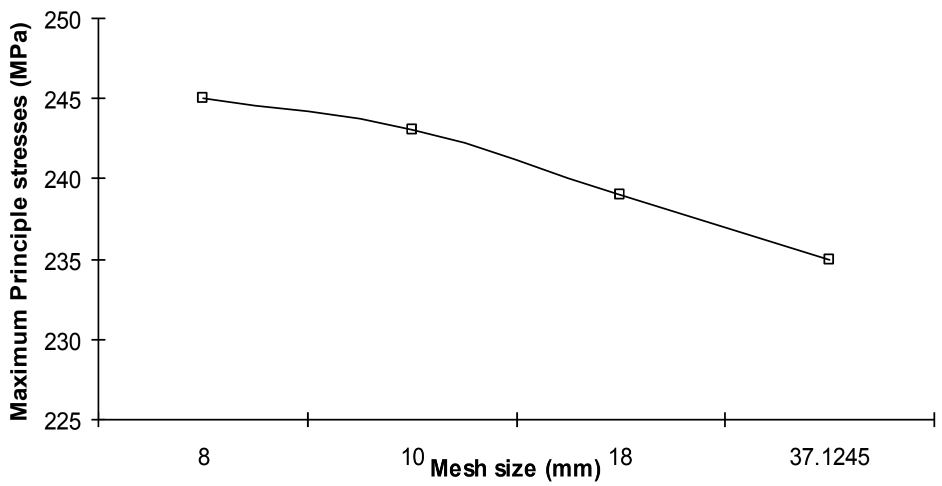


Figure 4.7: Maximum principle stresses versus mesh size for TET10

4.5 STRESS ANALYSIS RESULTS

The linear static analysis was performed using MSC. NASTRAN software to determine the stress and strain results from the finite element model. The material utilized in this work consists of a linear elastic, isotropic material. The choice of the linear elastic material model is essentially mandated. Model loading consist of the applied mechanical load, which is modeled as the load control and the displacement control. The bolt-holes areas were found to experience the highest stresses. The result of the maximum principle stresses and strains are used for the subsequent fatigue life analysis and comparisons. The maximum principal stresses distributions of the cylinder block for the linear static analysis is presented in Figure 4.8 for positive mean loading. From the acquired results, the maximum principle stresses of 245 MPa occurring at node 101594 was obtained.

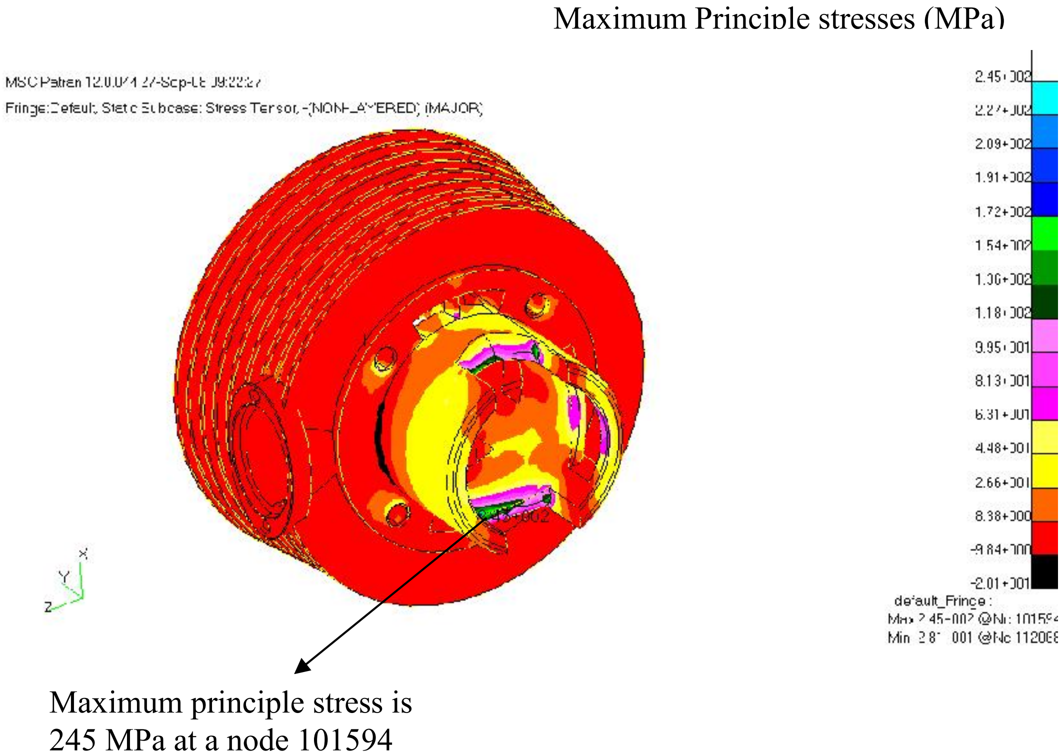


Figure 4.8: Maximum principle stresses contour with positive mean loading

4.6 FATIGUE ANALYSIS RESULTS

The fatigue life of the cylinder block is predicted for material AA6061-T6-80-HF and positive mean loading condition material acting on the cylinder block using the stress-life approach. The materials *S-N* curves are considered in this analysis. The fatigue equivalent unit is 3000 cpm (cycle per min) of the time history. The result of the predicted life of the cylinder block corresponding 99.8% ratability value is shown in Figure 4.9. The critical location is also shown in Figure 4.9 at node 1416. The predicted minimum and maximum fatigue life are 0 and 10^{20} sec respectively. The rain-flow cycle counting method was employed in this analysis to counts the number of cycles and to determines their range and mean. The fatigue life is expressed in seconds of the variable amplitude loading conditions. It is observed that the bolt-hole edge of the cylinder block is the most critical positions among the component.

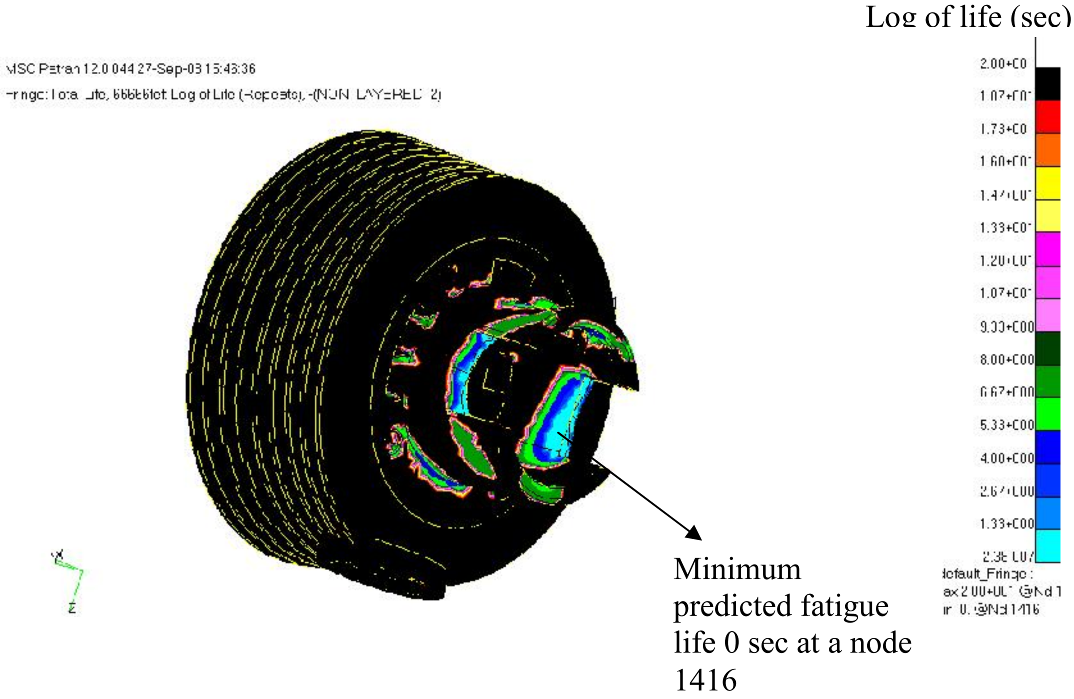


Figure 4.9: Predicted life contour with positive mean loading

4.7 EFFECT OF NITRIDING TREATMENT

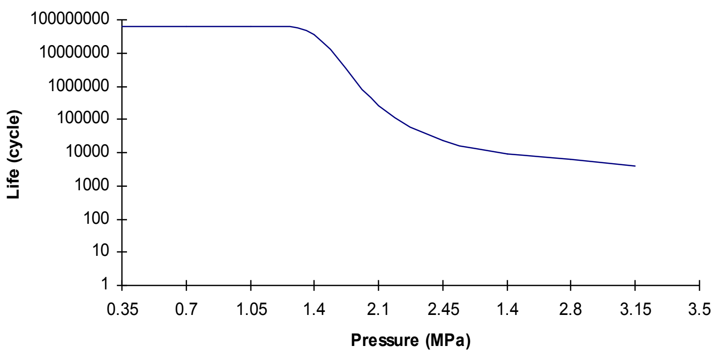
The free surface of component is common site for the fatigue failure. Therefore, the manner in which the surface is prepared during manufacturing of the component has a vital role in dictating life for the fatigue. There exists a variety surface treatment such as carburizing, nitriding, and flame hardening, inductions hardening etc, which are designed to impart high strength, wear resistance locally in the near surface regions of the material. The nitriding was performed using gas nitriding furnace at 550^0C for 48 hours in ammonia atmosphere.

Surface treatment produced compressive residual surface stresses can prolog the fatigue life. The aluminum alloy AA6061-T6-H8 using positive mean loading condition is considered in this study. Nitriding that produce compressive residual surface stress are useful. The treatments cause the maximum tensile stress to occur below the surface. Nitriding is increase the endurance limit. It is very beneficial for fatigue strength. This process has the combined effect of producing a higher strength material on the surface as well as causing volumetric changes, which produce residual compressive surface stresses. The great improvement in fatigue life is due primarily to the residual compressive stresses.

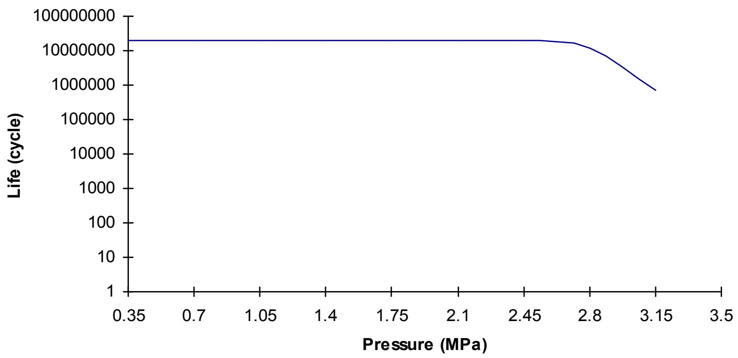
In this study, different pressure are used in identify the critical location at cylinder block. The pressures are 7 MPa, 4.5 MPa and 3.5 MPa. The result of the analysis shows that when the pressure is decrease; the critical locations also will decrease. Figure 4.9 shows the nitriding treatment in fatigue analysis using pressure 3.5 MPa. Table 4.1 gives the comparison between without treatment and nitriding surface treatment using positive mean loading condition. Figure 4.10 shows the effect of nitrided treatment.

Table 4.1: Comparison between Nitriding Treatment and Without Treatment

Pressure	Life (cycle)	
	Without Treatment	Nitriding Treatment
3.50	Broken	Broken
3.15	4089	$6.89X10^5$
2.80	13777	$1.84X10^6$
2.45	$5.4X10^4$	Beyond cutoff
2.10	$2.7X10^5$	Beyond cutoff
1.75	$2.34X10^6$	Beyond cutoff
1.40	$5.26X10^7$	Beyond cutoff
1.05	Beyond cutoff	Beyond cutoff
0.70	Beyond cutoff	Beyond cutoff
0.35	Beyond cutoff	Beyond cutoff



(a) Without Treatment



(b) Nitriding Treatment

Figure 4.10: Comparison between (a) Without treatment and (b) Nitriding treatment using positive mean loading condition.

4.8 MATERIAL OPTIMIZATION

4.8.1 MEAN STRESS CORRECTION METHOD

Two mean stress correction methods, Goodman and Gerber are used in this study. Table 4.3 lists the comparison between the without treatment and material with treatment for the positive mean loading conditions. It is observed that the Goodman mean stress correction method is the most conservative prediction for all material. In addition, the material AA5083-87-CF gives the most conservative results while AA7075-HV-T6 gives superior results. It is also observed that the material with treatment approach gives the higher life than the material without treatment.

Table 4.2: Comparisons between the materials with and without treatment *S-N* Approaches

Material	Without Treatment			Nitriding Treatment		
	No correction	Goodman	Gerber	No correction	Goodman	Gerber
6061-T6-H8	629	151	643	1710	3150	5952
5083-87-CF	2108	32	1158	1.37X10 ^{5}	37	28367
2024-HV-T4	1.5×10^{5}	10913	8.99×10^{4}	2.09×10^{8}	1.51×10^{7}	1.25×10^{8}
2219-HV-T81	7.76×10^{4}	8074	49691	3.74×10^{6}	2.89×10^{6}	2.39×10^{7}
7075-HV-T6	8.94×10^{5}	1.71×10^{5}	7.03×10^{5}	6.29×10^{8}	1.33×10^{8}	5.44×10^{8}

4.8.2 EFFECT OF SURFACE FINISH

A very high proportion of all fatigue failure start at the component surface and so surface conditions become an extremely important factor influencing fatigue strength. Differences in surface effects are due to differences in surface roughness,microstructure, chemical composition, and residual stress (Stephens et al., 2001). The correction factor for surface finish is sometimes used as a qualitative description of surface finish such as polished or machined (Bannantine et al., 1990; Stephens et al., 2001). The surface factors as function s of ultimate tensile strength involving different surface finish conditions such as grinding, machining, hot rolling and forging (Juvinall and Marshek, 1991) .Tables 4.3 summarizes the comparison between materials with and without treatment for surface finish using positive mean loading condition. From Table 4, the correction factor for surface finish with treatment give higher life than surface finish without treatment. It also observed that polished surface finish is the best compare to ground, good machined and poor machined surface finish.

Table 4.3: Comparisons between the materials (a) Without Treatment and (b) Nitriding Treatment for surface finish

Material	Fatigue life (Cycles) Without Treatment			
	Polished	Ground	Good Machined	Poor Machined
6061-T6-H8	1876	1469	1034	765
5083-87-CF	2108	1599	1306	920
2024-HV-T4	1.5×10^{5}	6.32×10^{4}	33850	18092
2219-HV-T81	7.76×10^{4}	37138	21744	8844
7075-HV-T6	8.94×10^{5}	3.7×10^{5}	1.8×10^{5}	48377

(a) Without Treatment

Material	Fatigue life (Cycles) Nitriding Treatment			
	Polished	Ground	Good Machined	Poor Machined
6061-T6-H8	1.11×10^{4}	88932	65487	28378
5083-87-CF	1.37×10^{5}	49617	26834	10770
2024-HV-T4	2.04×10^{8}	8.1×10^{7}	3.82×10^{7}	8.59×10^{6}
2219-HV-T81	3.74×10^{7}	1.67×10^{7}	8.78×10^{6}	2.46×10^{6}
7075-HV-T6	6.92×10^{8}	2.87×10^{8}	1.36×10^{8}	3.07×10^{7}

(b) Nitriding Treatment

4.9 CONCLUSIONS

The material information used on monotonic and cyclic behaviors is well presented in this chapter. The finite element modeling and analysis of two-stroke engine has also been presented. Two stress-life models have been used to account for the mean stress effect. The effect of mean stress, effect of nitriding treatment and effect of surface treatment have been investigated. Detailed fatigue element models were discussed and modal analysis was performed to determine the dynamic characteristic. The summary of the finding will be present in the next chapter and also recommendations.

CHAPTER 5

CONCLUSIONS

5.1 INTRODUCTION

This analysis addressed several facets fatigue analysis in a set of aluminum alloys in cylinder blocks of two-stroke engine. This chapter summarizes the important finding from the analysis carried out in this project. It also includes some suggestions for the further work.

5.2 CONCLUSIONS

A computational approach of the fatigue analysis methodology for the life prediction is presented. Based on findings, the following conclusions can be made with regard to the fatigue life of the cylinder block of two-stroke engine:

(i) No locations with serious failure potential were predicted for a target life.
(ii) The high stress ranges have been found to give most of the damage
(iii) Material 5083-87-CF gives the most conservative results while AA7075-HV-T6 gives the superior results using positive mean loading condition.
(iv) It is observed that Goodman mean stress correction gives most conservative result
(v) The nitriding and polished combinations have been found the great influences on the fatigue life

Therefore, the stress-life approaches can be used as efficient and reliable means for the sign-off durability of a prototype engine with actual service environments at the early stage of development

5.3 RECOMMENDATIONS

There is still scope for further study to improve the fatigue life. This section described some of the promise for extending the work investigated in this study. The recommendations are

(i) Testing the prototype components of two-stroke engine

(ii) The determination of the fatigue life of the components in the elevated temperature.

REFERENCES

ASM Handbook, vol. 4, Heat Treating. 1991. p. 379

Bannantine, J.A., Comer, J.J. & Handrock, J.L. 1990. *Fundamentals of Metal Fatigue Analysis*. New York: Prentice-Hall.

Bell, T., Mao K. & Sun, Y.1998. Surface engineering design: Modeling surface engineering systems for improved tribological performance. *Surface and Coatings Technology*. 108-109(1-3): 360-368

Berger, C., Eulitz, K.G., Hauler,P., Kotte, K.L., Maundorf, H. & Schu¨tz W, et al. 2002. Betriebsfestigkeit in Germany: an overview. *International Journal of Fatigue*. 2(4): 603-625.

Conle, F.A. & Mousseau, C.W. 1991. Using vehicle dynamic simulation and finite element result to generate fatigue life contours for chassis component. *International Journal of Fatigue* 13(3): 195-205

Farrahi, G.H., Lebrun, J.L. & Courtin, D.1995. Effect of shot peening on residual stress and on fatigue life of spring steel. *Fatigue Fracture Engineering Material Structure.* 18: 211–220

Hosmani, S.S., Schacherl, R.E. & Mittemeijer, E.J. 2005. Nitriding behavior of Fe–4wt%V and Fe–2wt%V alloys. *Material Science Technology.* 53(5): 2069-2079

Johannesson, P., Svensson T. & de Mare, J. 2003. Fatigue life prediction based on variable amplitude tests-methodology. Presented at the conference: Cumulative Damage, Seville.

Juvinall, R.C. and Marshek, K.M. 2000. *Fundamentals of Machine Component Design.* New York: John Wiley & Sons.

Karaoglu, S.2002. Structural characterization and wear behavior of plama-nitrided AISI 5140 low-alloy steel. *Materials Characterization*. 49: 349-357

Kim, H.S., Yim, H.J. & KIM, C.M. 2002. Computational durability prediction of body structure in prototype vehicles. *International Journal of Automotive Technology*. 3(4): 129-136

Koster, W.P. &. Field, M. 1973. Effect of Machining Variables on the Surface and Structural Integrity of Titanium. *Proceedings of the North American Manufacturing Research Conference*. *SME.* 2: 67-87

Lee, Y., Pan, J., Hathaway, R. and Barkey, M. 2005. *Fatigue Testing and Analysis: Theory and Practice*: New York: Butterworth

Molent, L., McDonald, M., Barter, S. & Jones, R. 2007. Evaluation of spectrum fatigue crack growth using variable amplitude data. *International Journal of Fatigue.*
30(7): 119-137

Nadot Y. & Denier, V. 2003. Fatigue failure of suspension arm: experimental analysis and multiaxial criterion . *International Journal of Fatigue*. 11(3): 485-499

Nolting, AE. , P.R.Underhill and D.L. DuQuesnay. 2007. Variable amplitude fatigue of bonded aluminum joints. *International Journal of Fatigue*. 30(7): 178–187

Novovic, D., Dewes, R.C., Aspinwall, D.K., Voice, W. & Bowen, P. 2004. The effect of machined topology and integrity on fatigue life. *International Journal Machine Tools & Manufacture*. 44: 125-134.

Rahman, M.M., Ariffin, A.K., Abdullah, S. & Rosli, A.B. 2007a. Effect of Nitriding Treatment on Fatigue life for Free Piston Linear Engine Component using Frequency Response Method: *A Finite Element Approach. SDHM*. 3(4): 189-209

Rahman, M.M., Ariffin, A.K., Jamakuddin, N. & Haron, C.H.C. 2006a. Fatigue Behavior of 6000 Series Aluminum Alloys on Cylinder Block of Free Piston Linear Engine Using Total Life Approach. *Jurnal Mekanikal UTM*. 21: 1-15

Rahman, M.M., Ariffin, A.K., Jamakuddin, N. & Haron, C.H.C. 2007b. Finite element based durability assessment for a new free piston linear engine component. *International Journal of Structural Durability and Human Monitoring. SDHM*. 3(2): 352-360

Rahman, M.M., Ariffin, A.K. 2006b.Effect of surface finish and treatment on the fatigue behaviour of vibrating cylinder block using frequency response approach. *An International Journal of Applied Physics and Engineering.* 7(3): 352-360

Shigley, J.E., Mischke C.R. & Budynas, R.G. 2004. Mechanichal Engineering Design. 7th Edn, New York: McGraw Hill.

Srikantan, S., Yerrapli S. & Keshtkaqr, H. 2000. Durability design process for truck body structures. *Internal Journal of Vehicles Design*. 23(1/2): 94-108

Stephens, R.I., Fatemi, A., Stephens, R.R. & Fuchs, H.O. 2000. *Metal Fatigue in Engineering*. New York: John Wiley & Sons, Inc.

Svensson, T., Johannesson. P. & Jacques de Maré. 2004. Fatigue life prediction based on variable amplitude tests—specific applications. *International Journal of Fatigue*. 27(8): 966-973

Torres, M.A.S. & Voorwald, H.J.C. 2002. An evaluation of shot peening, residual stress and stress relaxation on the fatigue life of AISI 4340 steel. *International Journal Fatigue.* 24(8): 877-886

Tucker, L. & Bussa. S. 1977.*The SAE Cumulative Fatigue Damage Test Program: Fatigue under Complex Loading, Analysis and Experiments.* Wetzel, R.W. (ed.) PA: Society of Automotive Engineers.

Wöhler, A. 1867. Wöhlers Experiment on the Strength of Metals. *Engineering.* 4: 160-161.