NOTCH EFFECT TO THE FATIGUE LIFE

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BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **NOTCH EFFECT TO THE FATIGUE LIFE**

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NOTCH EFFECT TO THE FATIGUE LIFE

TEH WENG KHUIN

Thesis submitted in fulfillment of the requirements
for the awards of the degree of
Bachelor of Mechanical Engineering

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Specially dedicated to

My beloved family and those who have guided and inspired me

Throughout my journey of learning

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ABSTRACT

This thesis is about the study on the notch effect to the fatigue life on the ASTM 1018 mild steel by using theoretical approach and experiment. The objective of this thesis is to study notch effect to the fatigue life. The thesis describes the stress concentration present on the notched specimen and its effect to the fatigue life on the specimen. The structural three-dimensional solid modeling of both smooth and notched specimen was developed by using the computer aided drawing software, SOLIDWORK 2012. The finite element analysis on the stress distribution was then performed by utilizing MSC NASTRAN. The maximum stress for specimens also was found by calculation using formula. The fatigue lives of both smooth and notched specimens were predicted by calculation using stress-life approach. Manson's approach on notched specimen also used to predict the fatigue for notched specimens. The fabrication for both smooth and notched specimen is conducted by utilizing the computer numerical control lathe machine. Then, the fabricated specimens are tested in rotating bending fatigue by using fatigue test machine. The results were analysis by comparing to theoretical results and found that Manson's approach is the more accurate way to predict the fatigue life for notched specimens. From the results, it found that the notched specimen will have a lot shorter fatigue life compared to the smooth specimen also the fatigue characteristic for both smooth and notch specimen is proven to be different from the observation of distinct fatigue behavior of them.

ABSTRAK

Tesis ini adalah mengenai kajian ke atas kesan takuk kepada hayat lesu pada ASTM 1018 keluli lembut dengan menggunakan pendekatan teori dan eksperimen. Objektif projek ini adalah untuk mengkaji kedudukan kesan kepada hayat lesu. Tesis ini menggambarkan tekanan penumpuan hadir pada spesimen bertakuk dan kesan kepada hayat lesu pada spesimen itu. Pemodelan tiga dimensi struktur kedua-dua spesimen lancar dan bertakuk dibangunkan dengan menggunakan komputer dibantu perisian lukisan, SOLIDWORK 2012. Analisis unsur terhingga terhadap agihan tekanan kemudiannya dilakukan dengan menggunakan MSC NASTRAN. Tekanan maksimum bagi spesimen juga didapati melalui pengiraan menggunakan formula. Hayat lesu spesimen kedua-dua lancar dan bertakuk telah diramalkan oleh pengiraan menggunakan pendekatan tekanan hidup. Pendekatan Manson pada spesimen bertakuk juga digunakan untuk meramalkan fatigue bagi spesimen bertakuk. Fabrikasi untuk kedua-dua spesimen lancar dan bertakuk dijalankan dengan menggunakan komputer kawalan numerikal Lathe mesin. Kemudian, spesimen fabrikasi diuji dalam berputar lesu lenturan dengan menggunakan mesin ujian fatigue. Keputusan itu analisis dengan membandingkan keputusan teori dan mendapati bahawa pendekatan Manson adalah cara yang lebih tepat untuk meramal hayat lesu bagi spesimen bertakuk. Daripada keputusan, ia mendapati bahawa spesimen yang bertakuk akan mempunyai banyak lebih pendek hayat lesu berbanding spesimen yang lancar juga ciri-ciri fatigue untuk kedua-dua spesimen lancar dan kedudukan terbukti menjadi berbeza daripada pemerhatian perlakuan fatigue yang berbeza daripada mereka.

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LIST OF SYMBOLS

ε_s	Surface strain
ϕ	hysteresis angle
N	Fatigue life/ cycle
S_f	Fatigue strength
S_{ut}	Ultimate tensile stress
σ_{max}	Maximum stress
K_f	Fatigue stress concentration factor (Neuber constant)
K_t	Stress concentration factor
S_y	Yield strength
M	Bending moment
I	Moment of inertia
σ_0	Nominal Stress
S_e	Endurance limit
${N_f}^{(n)}$	Fatigue life for notched specimen

LIST OF ABBREVIATION

ASTM	American Society for Testing and Materials
AISI	American Iron and Steel Institute
Fe	Iron
C	Carbon
Mn	Manganese
P	Phosphorus
S	Sulphur
Cr	Chromium
Si	Silica
Ni	Nikel

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In materials science, fatigue is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values are less than the ultimate tensile stress limit, and may be below the yield stress limit of the material but higher than the endurance limit of the material.

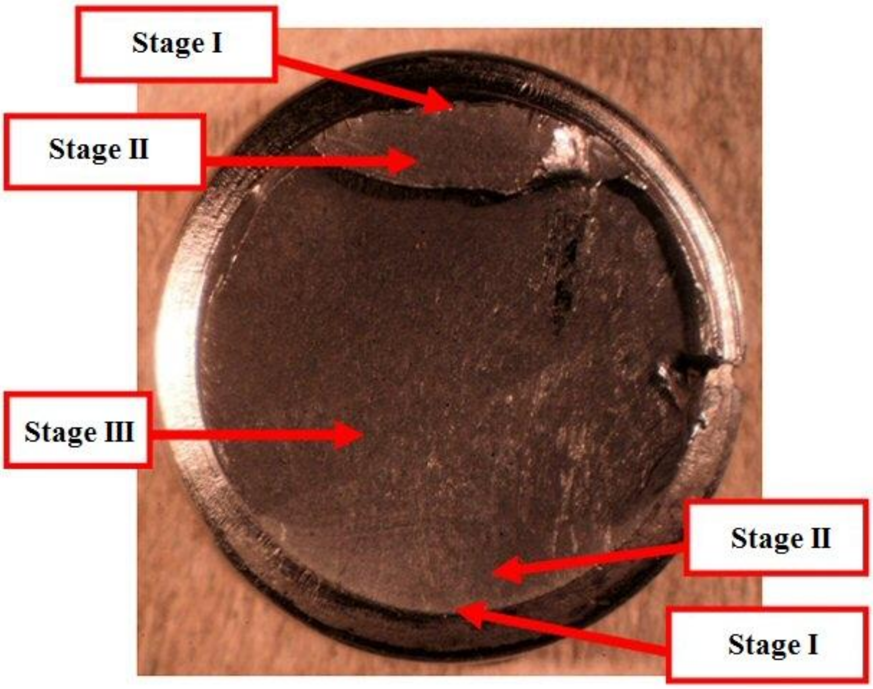


Figure 1.1: Fatigue failure due to reverse bending

Source: http: www.rsime.com

Fatigue occurs when a material is subjected to a continuously of repeated loading and unloading. As shown in Figure 1.1, if the loads are above a certain threshold known as the endurance limit, microscopic cracks or stage I crack will begin to form at the surface. Then the crack will continue to propagate, stage II. Eventually a crack will reach a critical size, and the structure will suddenly fracture, stage III. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Hence, round holes and smooth transitions or fillets are therefore important to use in designing a structure in order to increase the fatigue strength of the structure.

In many engineering components in service are subjected to various combinations of cyclic and static loadings. Besides, they often contain variety of stress concentrations such as grooves, fillets and holes. Therefore, the local elastic–plastic stresses and strains around the stress riser are frequently in multi-axial situations due to their complex geometrical shape, even under uniaxial loading. It has been observed that fatigue failure of the components usually occur as a result of crack initiation and growth from these stress risers. Thus, correct estimations of stress/strain concentration and crack development especially in the critical region for practical machine design in service loading.

Structure exhibition inevitable geometric discontinuous which are called notches. Such notches can be described by several geometric parameters; the notch length, the notch angle and the notch radius. The present of a notch in a structure is more dangerous than simple reduction net cross section. This effect is generally called the "notch effect". Normally the notch effect is ordinary notch-weakening effect, namely shorter lifetime of notched specimen compared with smooth specimen.

The notch effect in fracture is characterized by the fact that the critical gross stress of a notched structure is less that the critical net stress which acts on the remaining ligament under notch tip. The notch effect in fracture is sensitive to structure geometry, scale effect and loading mode. For in fatigue, even the critical stress at the notch tip is far lower than the ultimate tensile stress of the components; it will have the possibility to fail as the components reach a particular cycle in the cyclic loading. The present of the notch will worsen the condition of the components by having stress concentration at the notch and exceed the fatigue limit further. As a result, the cycle to failure of a notched component will be lower than smooth component.

1.2 PROBLEM STATEMENT

All the moving components may have the risk to fail as fatigue. Fatigue life for a simple beam or bar are predictable, but if there are any discontinuity, sudden change of coss-section, flaw or crack (notch) present that will be a different story. Since the notch will cause stress concentration on it so it will accelerate the failure of the component due to fatigue.

Most engineering components contain geometrical discontinuities, such as shoulders, keyways, and grooves, generally termed notches. When a notched component is loaded, local stress and strain concentrations are generated in the notch area. The stresses often exceed the yield limit of the material in the small region around the notch root, even at relatively low nominal elastic stresses. When a notched component is subjected to cyclic loading, cyclic inelastic strains in the area of stress and strain concentrations may cause formation of cracks and their subsequent growth could lead to component fracture. For cracks that nucleate from a shallow or blunt notch, the fatigue behavior is often dominated by crack nucleation. Cracks that nucleate from a sharp notch often nucleate rather quickly due to the elevated local stresses, and crack growth often dominates the fatigue behavior in this case. Hence, it is important to identify the notch effect in fatigue compare to smooth specimen.

The type of materials used in the experiment is mild steel. Mild steel is the most common high volume steel in production as its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains 0.16–0.29% carbon; therefore it is neither brittle nor ductile. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. Mild steel have very wide application region from small parts like bolt and nuts to big structure as structural steel in construction and part in the car manufacturing industry. Besides, mild steel is also used to build railway axles a rotating part in train. Hence, these parts will have the risk to fail as fatigue (Madia, 2008). Investigation on the fatigue behavior on mild steel components is vital to ensure the reliability of the component during service.

1.3 OBJECTIVE

I. To study the notch effect contributes to the fatigue life for mild steel.
II. To study the difference of fatigue characteristic between notched and smooth specimens

1.4 PROJECT SCOPE

I. Design smooth and notched specimens using computer modeling software.
II. Fabricate the smooth and notched specimens.
III. Perform stress and strain analysis using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN software.
IV. Perform fatigue analysis using stress-life approach and Manson's Approach for Notched specimen.
V. Compare the fatigue life between the smooth and notched specimens.

1.5 HYPOTHESIS

Notched specimen will have stress concentration at the notch position as a result it will have lower cycle fatigue life compared to smooth specimen.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION OF FATIGUE

Fatigue is the process responsible for the majority of service failures of engineering components and structures, and consequently its many ramifications have been intensively studied by physicists, metallurgists and engineers (Eeles, 1968). The process consists essentially of three separate stages, which is stage I crack initiation, stage II crack propagation and Stage III sudden fracture, which are affected differently by external variables. The mechanisms responsible for the development of these stages, the parameters which control them and the empirical relationships derived for the use of design engineers are discussed on the basis of the most recent available information. The duration for each stage will be depend on the shape of the component like the present of the notch will have totally different duration for each stage of fatigue. Attention is drawn to those areas where further fundamental or applied research is required, and some of the limitations of existing theories are mentioned.

Fatigue is defined by the ASTM as the process of progressive localized permanent structural change occurring in a material subjected to conditions which produce fluctuating stresses and strains at some point or points and which may culminate in cracks or complete fracture after a sufficient number of fluctuations (Eeles, 1969).

From the continuing efforts of research scientists and engineers throughout the world, there is now a much better understanding of the nature of the mechanism of the fatigue process and of the effect of the numerous operational factors which influence it, although this knowledge tends to be more qualitative than quantitative. It would be fair, therefore, to say that the state of the art is making reasonable progress, but is still a long way from enabling an accurate prediction of the endurance or life of an engineering structure under given service loading and environmental conditions. Hence, the prediction on the fatigue life of the component is for reference. Especially for notched component, the behaviour of it in fatigue is quite peculiar even the critical stress at the notch tip is far lower than the ultimate tensile stress of the components; it will have the possibility to fail as the components reach a particular cycle in the cyclic loading. In engineering application the safety factor should be set high enough to prevent any accident from happening (Eeles, 1969).

The complexity of the fatigue phenomenon is due in part to the fact that progressive fracture is a sequence of at least two processes which are the crack initiation and crack propagation. There may be controlled by two different sets of criteria.

2.1.1 Difference of Flexural Bending and Rotating Bending (Surface strain amplitude ε_s)

Under Flexural Bending

For a round specimen subjected to flexural bending with surface strain amplitude, ε_s which the point that is same distance from the deflection axis αα (strain axis), such as A and B in Figure below, will have exactly the same strain and stress levels. Consequently, these points have the same hysteresis loop as shown in Figure 2.1c. Note that the loading axis ZZ in this case coincides with the deflection axis αα (Megahed, 1995).

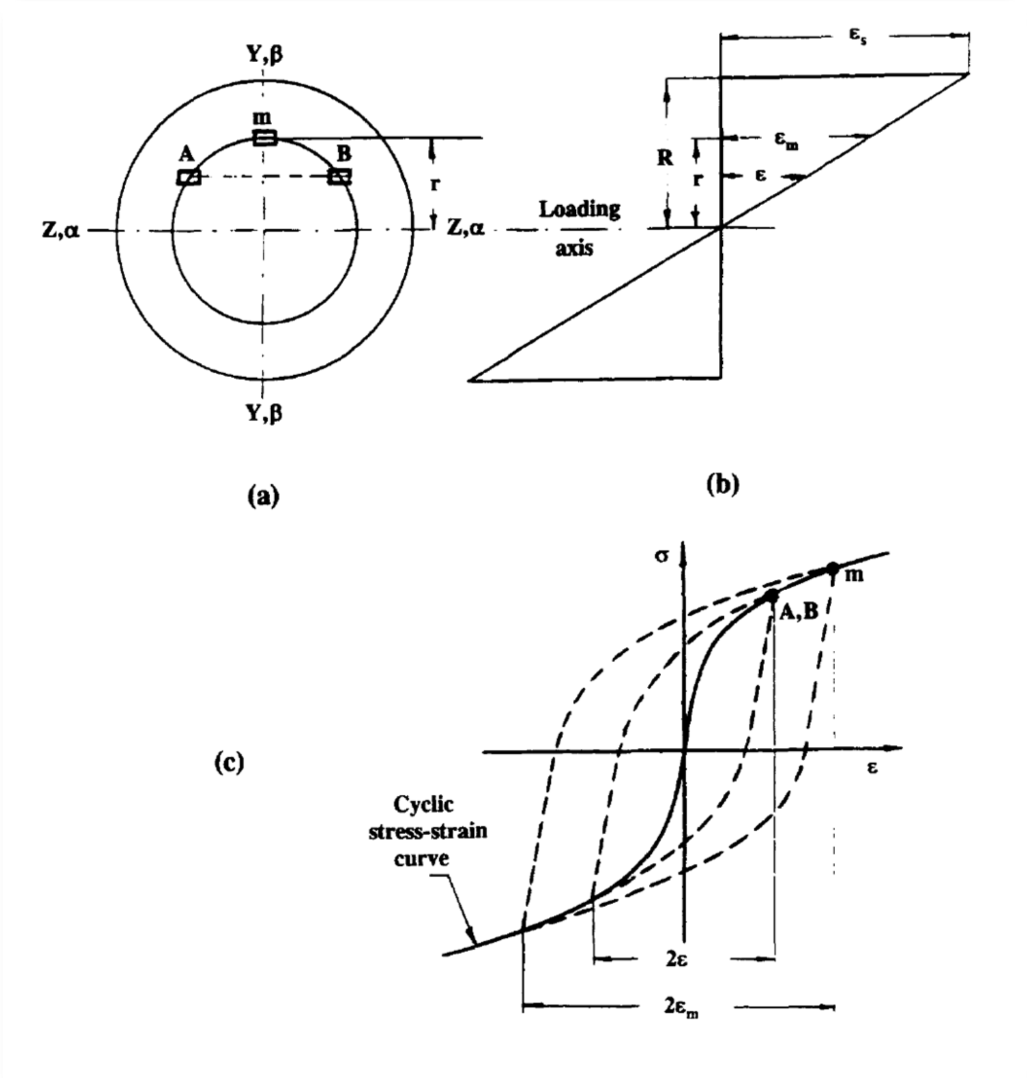


Figure 2.1: Stress distribution in flexural bending from axial strain cyclic properties

Source: Megahed (1995)

Under Rotating Bending

For the same cross-section of the round specimen, now subjected to rotating bending with surface strain amplitude αα. The two elements A and B are at the same distance from the strain axis αα. (deflection axis). Therefore, the two elements are at the same strain level, e, as shown in Figure 2.2b. On the other hand, the two elements now share the same hysteresis loop also, but are not, at any given moment in time, at the same stress level, owing to rotation, as shown in Figure 2.2c. Point A is moving towards a higher stress level, whereas point B is moving towards a lower one. Each point will ultimately reach a maximum strain level era, when they achieve the maximum vertical distance R from the strain axis. Because of rotation, the stress-strain relation for all points along a circle with radius r is represented by one hysteresis loop. Therefore the section will deflect about the axis αα, which makes an angle ϕ with the loading axis ZZ. The angle ϕ is designated the hysteresis angle to indicate the presence of hysteresis loops on the radii of the section.

When the behaviour is elastic, as in high-cycle fatigue, the hysteresis loops degenerate to an elastic line. Therefore the hysteresis angle vanishes. In this case, the rotating bending problem can be treated as a flexural bending problem, wherein the loading and strain axes always coincide.

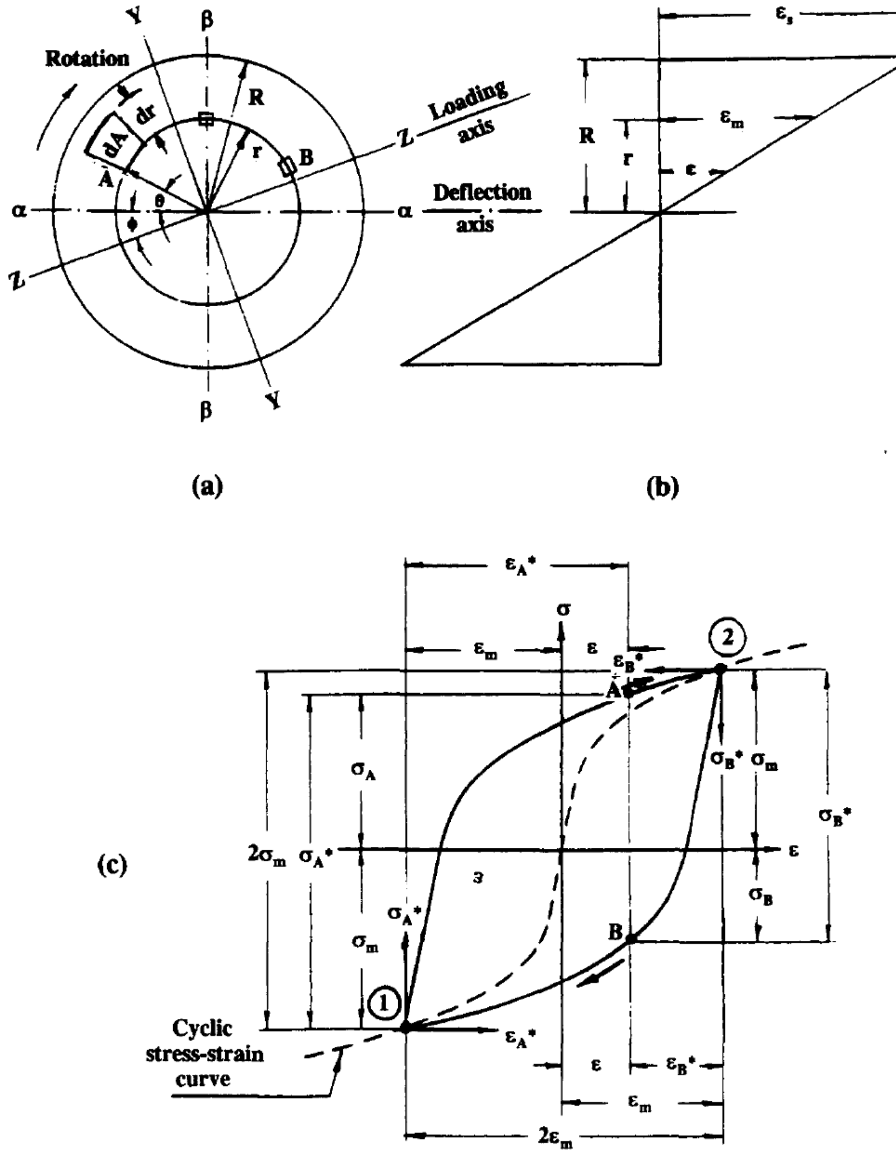


Figure 2.2: Stress distribution in rotating bending from axial strain cyclic properties

Source: Megahed (1995)

2.2 NOTCH

In machines most of its components have notches like shoulder and holes. Most of the time stress concentration will occur at these notches and the maximum stress will also at the same point. So, in order to prevent fatigue failure of the machine's components, it is important to assure the fatigue limit of this kind of components is higher than the maximum stress at the notch root (M. Makkonen, 2001).

2.2.1 Reason of Analyzing the Notch Effect and Behaviour

Most engineering components contain geometrical discontinuities or notches. When a notched component is loaded, local stress and strain concentrations generated at the notch root can exceed the yield limit of the material, even at relatively low nominal elastic stresses. Cyclic inelastic strains may cause nucleation of cracks in the notch region and their subsequent growth could lead to component fracture.

Therefore, accurate evaluation of the deformation and fatigue crack nucleation life of notches are important to reliable performance of notched component behaviour.

2.2.2 Notch Opening Angle Effect

The effect of notch opening angle on the stress concentration factor was considered for the limiting cases. The effect appears to be significant for the shallow notches under torsion, and for the deep notches under bending. It should be noted that for sharp and shallow notches under torsion the stress concentration varies depending on the notch opening angle ω and then the difference between the results of $\omega=0$ and 90° is more than twice (Noda, 2004).

2.2.3 Notch Size Effects

The notch size effect can be explained with two factors which are the statistical size effect and the effect of the stress gradient or called as geometric size effect.

The statistical size effect is when a component is subjected to an alternating load; there will be a number of micro-cracks initiated in its volume. For a larger specimen there will be larger micro-cracks found. Thus, for larger specimen it will have higher probability of large initiated crack and hence lower fatigue limit. According to Makkonen (2001), the size effect in plain specimens is results from the statistical size effect alone. When there is no notch in present, it is clear that the critical crack position wil be at the surface where the maximum stress located.

The geometric size effect comes into picture with notched specimens. The stress distribution in the vicinity of grooves, shoulders and other discontinuities becomes non-linear, and high stress peak will appears. Also, the stress gradient is steeper in small equally shaped specimens. Hence, for a equal-sized crack initiated in two different size specimens the stress intensity factor in crack is higher in a larger specimen.

The size of the specimens is one of the factors that cause variables to the fatigue life. Hence, in the analysis to study the effect of notch to the fatigue life the size of the specimens shall be fixed in order to prevent inaccurate of the result.

2.3 CHARACTERISTIC OF FATIGUE FAILURE IN ROTATING BENDING

The characteristic of fatigue fracture in rotating bending specimen can be separated to three zones (Eleiche, 1995). The first one represents the crack initiation zone. The dark markings running on diagonal directions indicate the presence of various cracks in different planes, which joined up together. This zone has a smooth appearance, owing to the rubbing action as cracks propagate through the tested section. The second zone represents the crack propagation phase with a less smooth appearance, indicating that cracks extended more rapidly. The third zone is the area wherein then final crack occurred, when the net section became too small to support the applied load, and the specimen fractured at this reduced area.

2.3.1 Fatigue Characteristic of Smooth Specimen

For smooth specimen, there seems to be a tendency for the crack to extend preferentially in a direction opposite to that of rotation, in complete matching with the stress distribution over the section under rotating bending, as shown in Megahed, 1995. The more the specimen is restricted within the low cycle fatigue regime, the greater the increase in the hysteresis angle, and consequently the greater the tendency of the crack to propagate in the opposite direction of rotation. Finally, the figure also indicates that most of the file of smooth specimens in rotating bending fatigue tests is attributed to the crack initiation phase. Cracks propagate from one side only while the other side is still within the initiation phase. (Eleiche, 1995; Megahed, 1995).

2.3.2 Fatigue Characteristic of Notched Specimen

For notched specimen, the actual measured lives in virgin notched specimens are greater than the predicted lives based on crack initiation model (Eleiche, 1995). This indicates that notched specimens have extremely longer proportions of lives during the crack propagation phase than those in the initiation phase. These prove the reliability of the investigated materials, wherein the life to propagate a crack from initiation to a critical size is substantial. This provides an additional design margin.

According to Akiniwa (2004), for circumferentially notched specimens, fatigue fracture started from the surface or very near the surface. The slip deformation was responsible for crack initiation in high cycle and very high cycle regimes. The fatigue strength of notched specimens was lower than that of smooth specimens.

2.4 PREDICTION OF FATIGUE LIFE

There are three fatigue life methods used in design and the analyses are the stress-life method, the strain-life method, and linear-elastic fracture mechanic method. These methods attempt to predict the life in number of cycles to failure for specific level of loading. The life of cycle between $1 < N < 10^3$ is classified as low cycle fatigue, whereas high-cycle fatigue is considered to be $N > 10^3$ cycles.

2.4.1 The Stress-Life Method

The Stress-Life method (also referred to as the S-N method) was the first approach used in an attempt to understand and quantify metal fatigue. The Stress-Life approach is generally categorized as a high-cycle fatigue methodology, and is still widely used in design applications where the applied stress is primarily within the elastic range of the material and the resulting fatigue lives are long.

The stress-life method is not so suitable in low cycle applications, where the applied strains have a significant plastic component due to the high load level. For these kinds of applications, a Strain-Life Fatigue Analysis is more appropriate.

2.4.2 The Strain-Life Methodology

The strain-life methodology is based on the observation that in many critical locations such as notches the material response to cyclic loading is strain rather than load controlled. This arises from the fact that whilst most components are designed to confine nominal stresses to the elastic region, stress concentrations such as notches often cause plastic deformation to occur locally. The material surrounding the plastically deformed zone remains fully elastic and so the deformation at the notch root is considered to be strain controlled.

The strain-life method assumes similitude between the material in a smooth specimen tested under strain control and the material at the root of a notch. For a given loading sequence, the fatigue damage in the specimen and the notch root are considered to be similar and so their lives will also be similar.

The cyclic stress-strain response of the material at the critical location is determined by characterizing the behavior of smooth specimens subjected to similar loading, the local stress-strain history. The local stress-strain history must be determined, either by analytical or experimental. Stress analysis procedures such as finite element modeling, or experimental strain measurements are usually required.

In performing smooth specimen tests which characterize fatigue performance, it must be recognized that fundamental material properties are being measured which are independent of component geometry. Phenomena such as cyclic hardening or softening, cycle dependent stress relaxation, and loading sequence effects are all taken into consideration.

According to Eleiche, Manson and Hrischberg suggest that in uniaxial push–pull of notched specimen, it is assumed that the crack initiation is similar at the root of the notch and the smooth specimen under the same local strain amplitude. Furthermore, it is proposed that crack propagation phase is similar beyond the notch field and the smooth specimen under the nominal strain, ε_n. Consequently, the life of notched specimen, $N^{(n)}$, can be obtained using the following formula (2.1) where ${N_f}^{(\varepsilon)}$ and ${N_f}^{(\varepsilon n)}$ are lives obtained from strain-life curve of smooth specimens as shown in Figure 3.9 at strains ε_n and ε, respectively.

$$ {N_f}^{(n)} = \left[{N_f}^{(\varepsilon)} - 4({N_f}^{(\varepsilon)})^{(0.6)}\right] + 4[{N_f}^{(\varepsilon n)}]^{(0.6)} \tag{2.1} $$

2.4.3 Fatigue Strength

Fatigue strength is used to describe a property of materials: the amplitude of cyclic stress that can be applied to the material without causing fatigue failure. It is very important to identify the fatigue strength of a specimen in order to ensure the specimen will fail as fatigue. By using the obtained fatigue strength, the number of cycle to failure of the specimens can be easily predicted.

$$ \textit{Fatigue Strength, } S_f = aN^b \textit{ (N is cycle to failure)} \tag{2.2} $$

$$ a = \frac{(fS_{ut})^2}{S_e} $$

$$ b = -\frac{1}{3} log\left(\frac{fS_{ut}}{S_e}\right) $$

2.4.4 Stress Concentration and Notch Sensitivity

Existence of irregularities or discontinuities, such as grooves, holes or notches in a part increases the theoretical stresses significantly in the immediate vicinity of the discontinuity. Hence, for these kinds of materials, the effective maximum stress in fatigue is,

$$ \sigma_{max} = K_f \sigma_0 \tag{2.3} $$

The factor K_f is called fatigue stress concentration factor where,

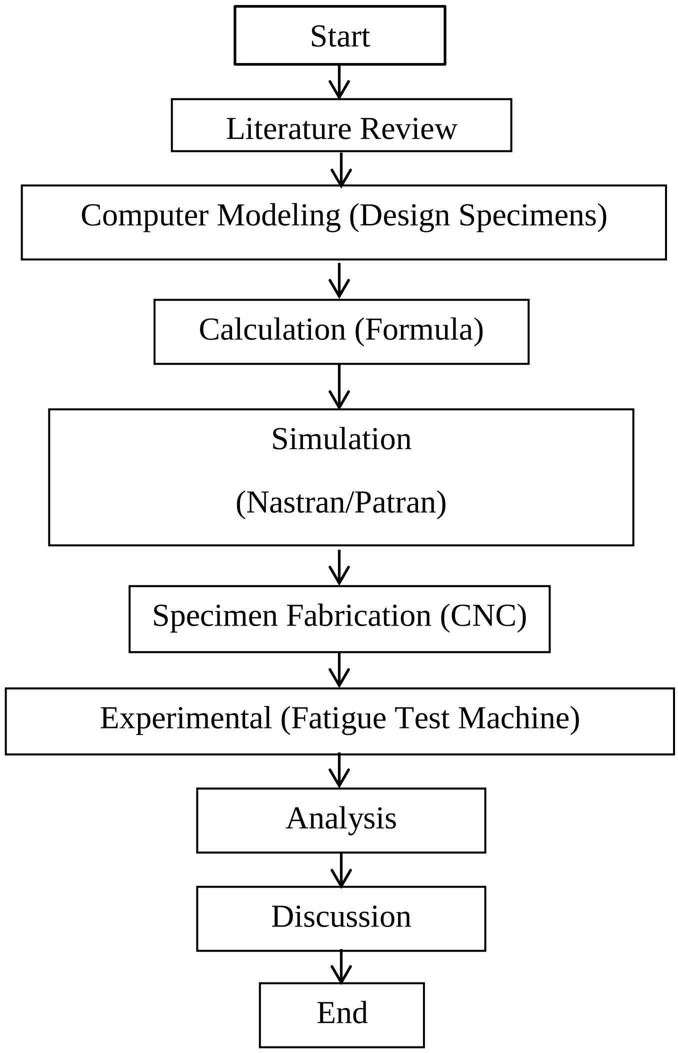
$$\textit{Fatigue concentration factor}, K_f = 1 + \frac{K_t - 1}{1 + \sqrt{(\frac{a}{r})}} \text{ (Neuber constant)} \quad (2.4)$$

$$\sqrt{a} = 0.246 - 3.08(10^{-3})S_{ut} + 1.51(10^{-5}){S_{ut}}^2 - 2.67(10^{-8}){S_{ut}}^3$$

CHAPTER 3

METHODOLOGY

3.1 PROCESS FLOW



3.2 MATERIAL AND SPECIMENS

3.2.1 Material

The material chosen in the analysis of the notch effect to the fatigue life is the mild steel since it is the most common and most used in the engineering application. The mild steel type used in the study is the AISI1018 grade and its chemical composition is tested by using the spectrometer available in UMP and listed in Table 3.1.

Table 3.1: Chemical Composition of AISI1018 Mild Steel

AISI No.		1018
CHEMICAL COMPOSITION (%)	Fe	96.60
	C	0.50
	Mn	0.76
	P	0.01
	S	0.00
	Cr	1.04
	Si	0.11
	Mo	0.22
	Ni	0.16

The mechanical properties of the AISI1018 mild steel like ultimate tensile strength (S_{ut}), yield strength (S_y), modulus of elasticity and etc. are listed in Table 3.2 where all these properties will be used in the calculation and simulation on the specimens.

Table 3.2: Mechanical Properties of AISI1018 Mild Steel

MECHANICAL PROPERTIES	METRIC
TENSILE STRENGTH, ULTIMATE	440 MPa
TENSILE STRENGTH, YIELD	370 MPa
MODULUS OF ELASTICITY	205 GPa
POISSON RATIO	0.29
SHEAR MODULUS	80 GPa
Density	7.87 g/cc

Source: www.azom.com/article.aspx?ArticleID=6115

3.2.2 Specimens Design

It is a must to design the specimens by referring to the international acknowledged standard like ASTM or the ASM standard in order to obtain the correct results for the test. The dimension for smooth specimen is designed by referring to the ASTM standards for the fatigue test as shown in Figure 3.1. Due to the limitation of the available fatigue machine in the laboratory, the end connection of the specimens is unable to follow the standards. Only the area of interest for the fatigue test (test section) is following the ASTM standards. For the notched specimen, it was planned to have three different notch opening angle specimens, again due to there is just one type of V-shaped insert (Figure 3.2) available for the CNC lathe machine in the lab so only one type notch specimens is fabricated. The notch on the specimen is positioned by referring to the minimum cross section location of the smooth specimen and the minimum cross section on the test section for both smooth and notched specimens is the same with 6mm in diameter.

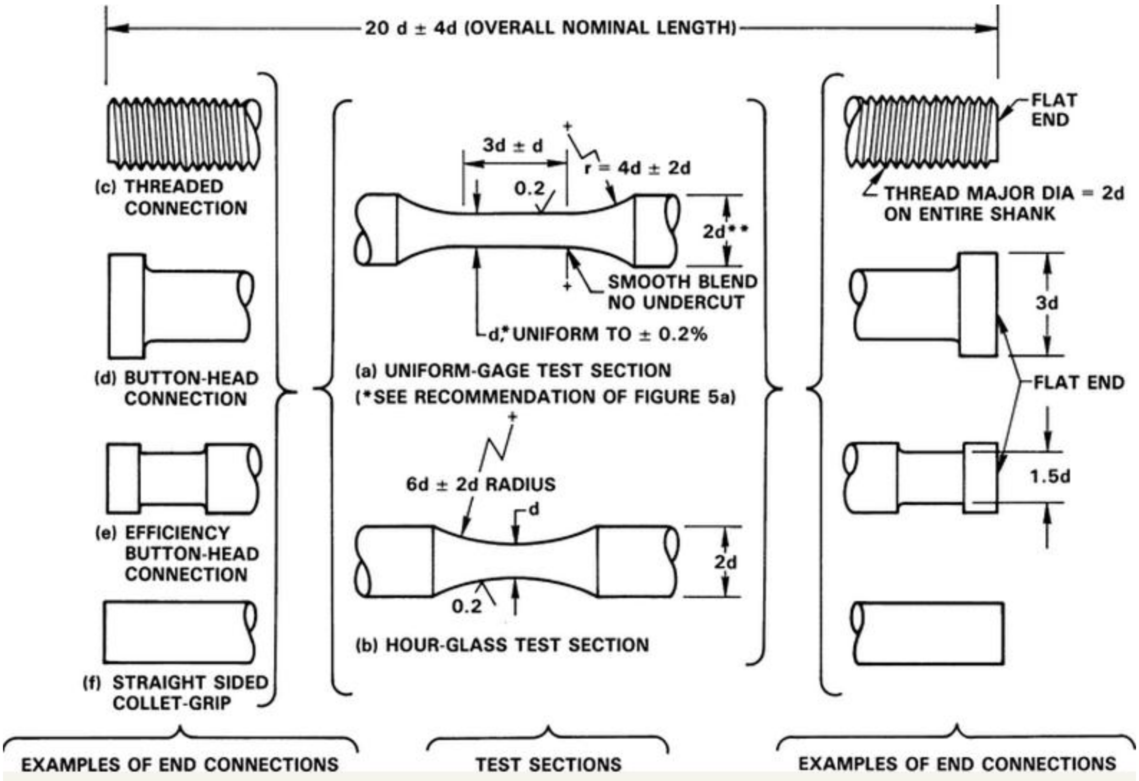


Figure 3.1: Recommended dimension for fatigue test (ASTM E606)

Source: http://www.astm.org/

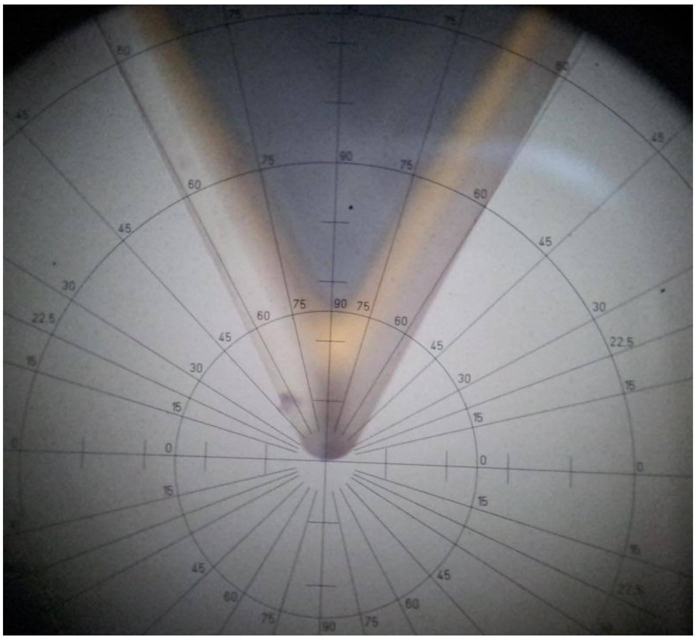
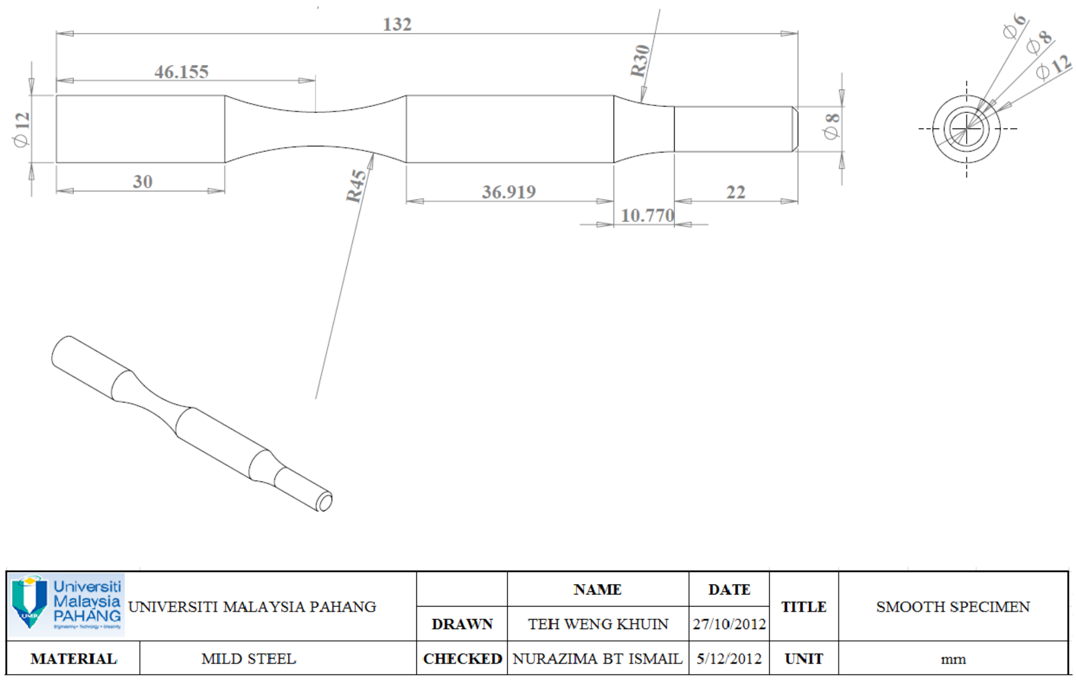


Figure 3.2: Cutting tool to create notch profile

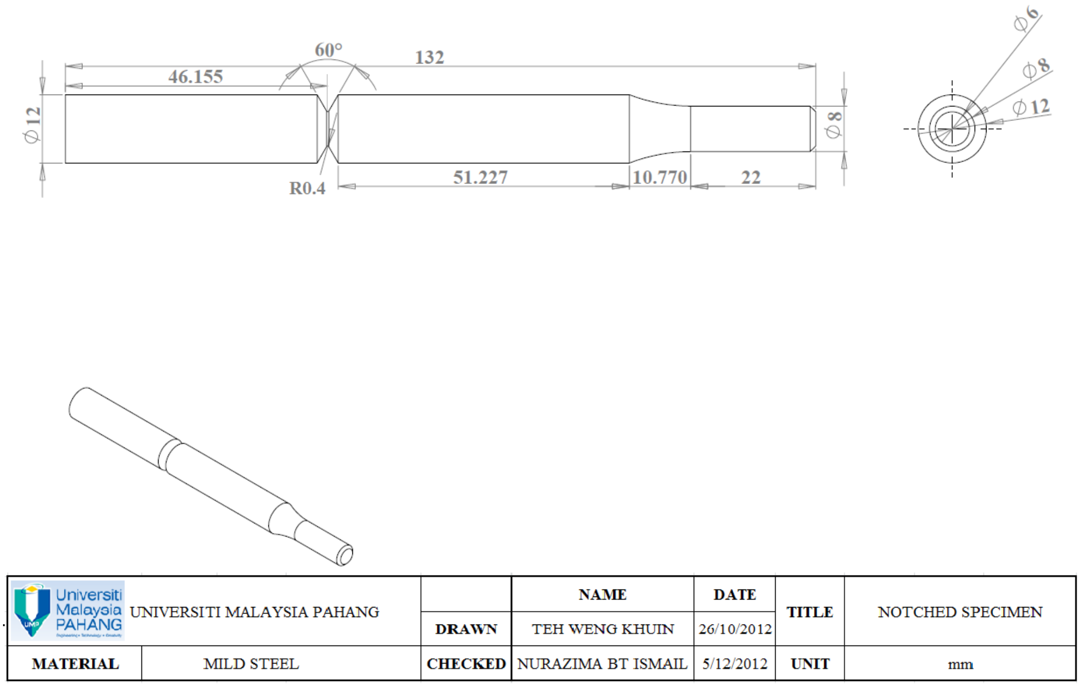
3.3 COMPUTER MODELING

After the limitation the standards for the dimensions of specimens are identified. The specimens are designed with the aid of computer modeling software. The software being used for the computer design is the SOLIDWORK 2012 Student Edition. The technique involve in the computer design is just some simple sketching on the plane, revolved base function and chamfer. There are two type specimens are designed which are the smooth specimen and notched specimen.

In the design step, there are some concern needs to be considered like limitation of the available fatigue test machine and the standards of the dimension. The fatigue test machine available in UMP is a rotating bending fatigue machine where the specimen is fixed into the machine by one end is fitted into the bearing where the bending force is applied and the other end is clamped by the clamper at the spindle. The diameter for end connection of the specimens must be at 12mm at one end and 8mm at the other for the specimens to fit into the fatigue machines. So, in order to overcome this limitation both end of the specimen is designed as shown in Figure 3.3. At the end connection 8mm diameter is designed to have 22mm length so that the specimen is able to slide into the bearing and leave enough space for the other end to insert into the clamper located at the spindle. Then the specimen will have a smooth curve in order to increase the diameter to be the same as the other end connection of the specimen without creating any significant stress concentration. Hence, a section with uniform diameter with length of 99.23mm is created where the test section for both notched and smooth specimens will be located.



(a)



(b)

Figure 3.3: Design of the specimen. (a) Smooth (b) Notched

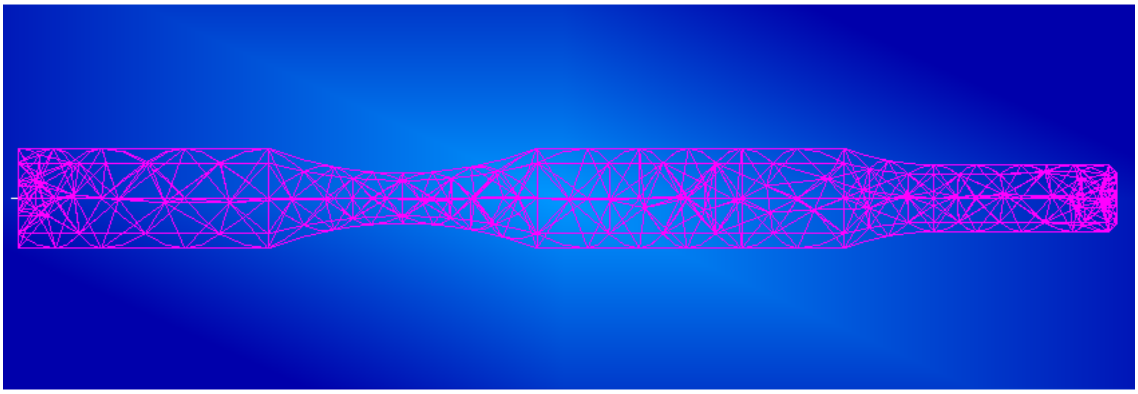
3.4 IDENTIFY MAXIMUM STRESS AND LOCATION

3.4.1 Stress Profile Simulation (NASTRAN/PATRAN)

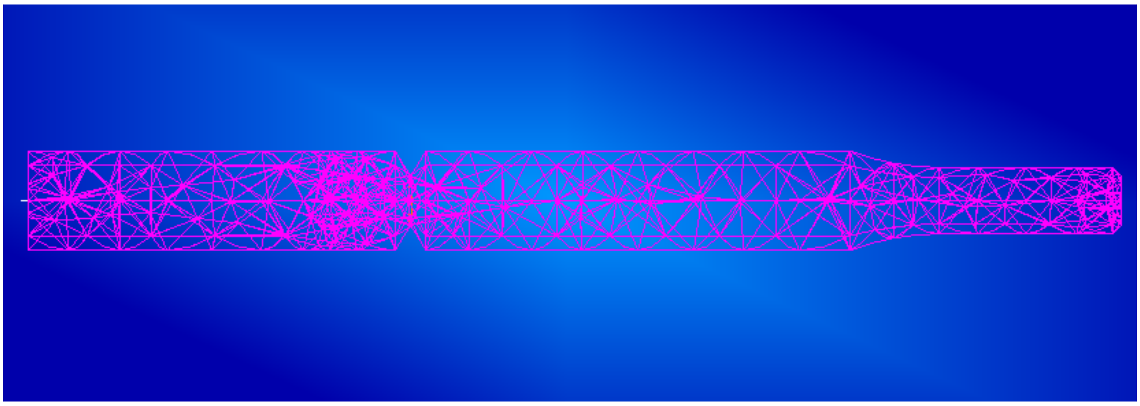
Software simulation is the easiest way to simulate the respond of the specimens is different loading condition applied on it. By using the software simulation, the result of the fatigue test on the designed specimen can be accurately predicted before actual test is carried out. If the result shown by the simulation could not satisfy the purpose of the project, computer modeling can be redo by changing the specimen's design until it serves its purpose. This will save the time and money to redo the fabrication of the specimen if the test is fail in the actual experiment stage.

The simulation software used is the Nastran/ Patran software which is used to do the finite element analysis on the specimen, for example calculate and locate the stress, strain and displacement at any point of the specimens. In this project, it is very important to assure the maximum stress position is same as the designated position for the specimen to fail as fatigue. If not, redesign of the specimen is needed.

Before starting the simulation process by using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN software, first, the MSC Patran software is initiated and some setting like the unit setting is done by choosing metric unit. Then, a drawing file of the specimen from SOLIDWORK 2012 with ACIS format is imported to the MSC PATRAN software followed by importing the mild steel mechanical properties into the designated column. Meshing of the drawing is done by choosing tet mesh function with tet10 selected, the meshing of the specimens are shown in Figure 3.4.



(a)

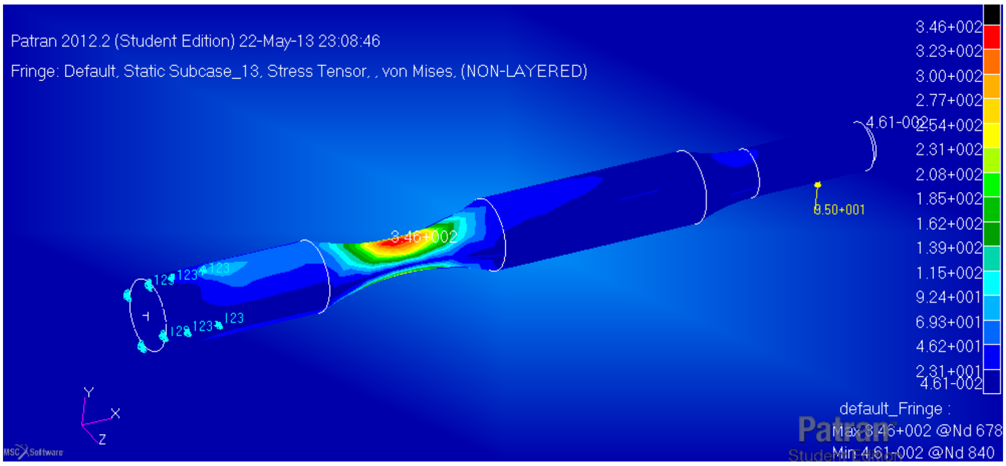


(b)

Figure 3.4: Meshing of specimen (a) Smooth (b) Notched

After that, the material properties inserted earlier is applied to the meshed drawing. From the meshed drawing the nodes which will be clamped during the fatigue test is fixed by setting the transition to be zero in the displacement function. For the node where the force applied, value is being added with the force function. Then, the analysis of stress, strain and displacement is selected and an OP2 output file is requested from the analysis function. The OP2 file is then analyzed by using the MSC NASTRAN software and the result is read and displayed by using MSC PATRAN software. The stress distribution is shown in Figure 3.5. The strain distribution for both specimens are also being analyzed and shown in Figure 3.6.

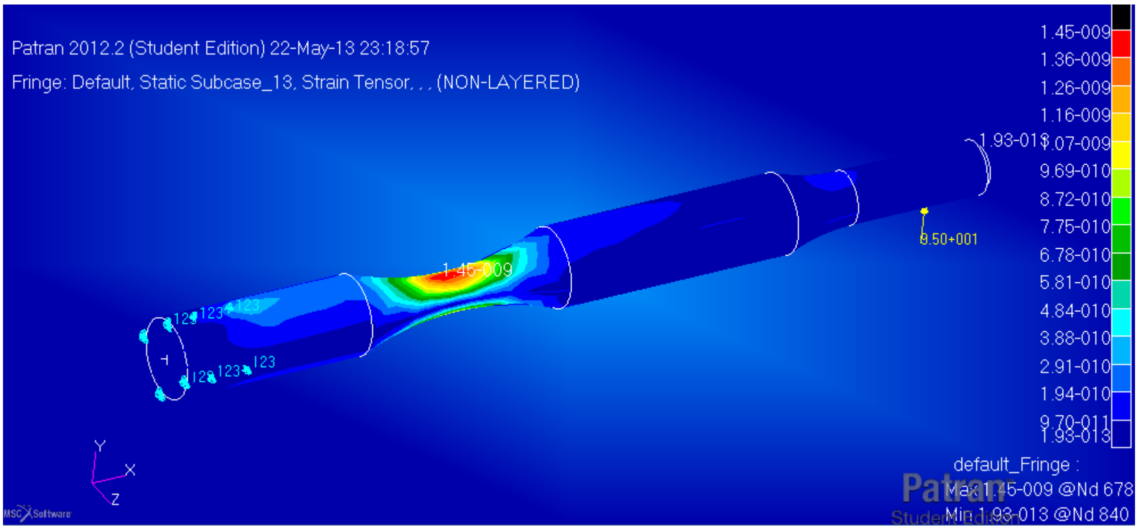
It is noticed that the maximum stress is located at the lowest cross section region for both smooth and notched specimens. For smooth specimens it is located at the middle of the curve region while the notched specimen is located at the notch root. Besides, the maximum strain is also happened at the same position as the maximum stress. It is predicted that the fatigue will happen at the maximum stress and maximum strain region. Then, the simulation is carried out for all the amount of force to be applied in the test in order to find out the maximum stress for each applied force. The maximum stress values are then used to find out the fatigue life by using formula.



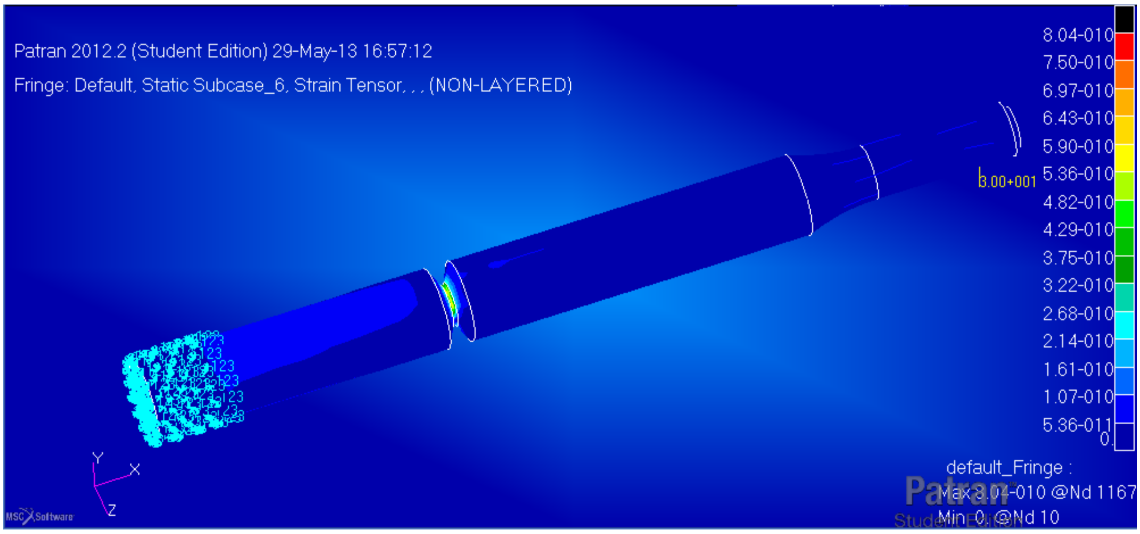
(a)

(b)

Figure 3.5: Stress distribution of specimen (a) Smooth (b) Notched



(a)



(b)

Figure 3.6: Strain distribution of specimen (a) Smooth (b) Notched

From the result, it clearly shows that the maximum strain tensor position is same as the position of maximum stress. Hence, the concern of failing at other position due to many changes of dimension along the specimen can be eliminated.

3.4.2 Calculation by Using Formula

When the design is ready, there are some calculations is done by using formula in order to find out the location of maximum stress in order to assure the specimen will failed at the designated position.

The formula below is used to calculate the nominal stress on the specimen as the specimen is subjected to a rotating motion with force applied onto it. The formula is consists of two component of stress, bending stress and torsional stress.

$$Nominal\ Stress, \sigma_0 = \frac{Mc}{I} + \frac{Tr}{J} \tag{3.1}$$

In fatigue test to be carried out, only bending stress is being considered and the torsional stress will be ignore. This is due to the main contribution to the torsional stress is the frictional force from the bearing where the specimen insert into and the friction coefficient of the ball bearing is very small with approximately C_f = 0.005. Hence, the only stress present is the bending stress as a result of the force applied at one end of the specimen.

Hence,

$$Nominal\ Stress, \sigma_0 = \frac{Mc}{I} \tag{3.2}$$

$$Moment\ of\ Inertia,\ I = \frac{\pi D^4}{64} \tag{3.3}$$

$$Bending\ Moment,\ M = F_y x \tag{3.4}$$

For smooth specimen,

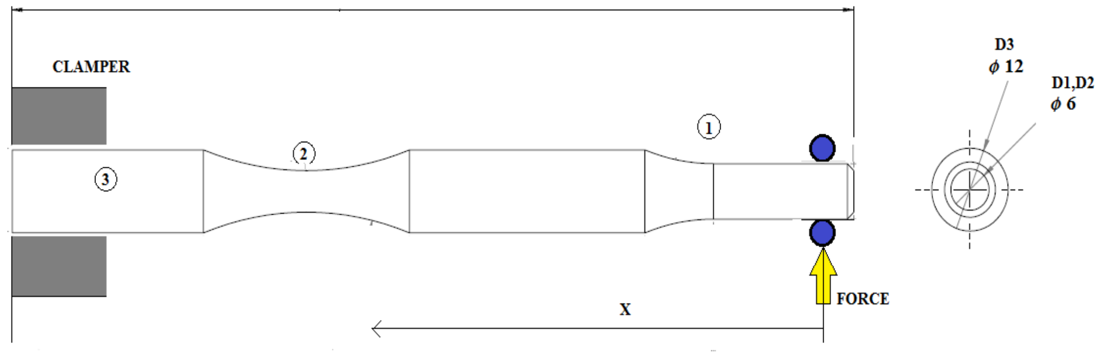


Figure 3.7: Loading Condition for Smooth Specimen

Let the subjected bending force, $F_y = 75$ N by utilizing equation (3.2), (3.3) and (3.4):

$$\text{At point 1, } x = 0.022 \text{ mm}, D_2 = 0.008 \text{ m}, c = 0.004 \text{ m}$$

$$M_1 = (75)(0.022) = 1.65 \text{ N.m}$$

$$I_1 = \frac{\pi(0.008)^4}{64} = 2.0106 \text{ x } 10^{-10} \text{ m}^4$$

$$\text{Stress at point 1, } \sigma_1 = \frac{(1.65)(0.004)}{2.0106 \text{ x } 10^{-11}} \text{ Pa} = 32.8257 \text{ MPa}$$

$$\text{At point 2, } x = 0.07785 \text{ mm}, D_2 = 0.006 \text{ m}, c = 0.003 \text{ m}$$

$$M_2 = (75)(0.07785) = 5.8388 \text{ N.m}$$

$$I_2 = \frac{\pi(0.006)^4}{64} = 6.3617 \text{ x } 10^{-11} \text{ m}^4$$

$$\text{Stress at point 2, } \sigma_2 = \frac{(5.8388)(0.003)}{6.3617 \text{ x } 10^{-11}} \text{ Pa} = 275.3404 \text{ MPa}$$

$$\text{At point 3, } x = 0.114 \text{ mm}, D_3 = 0.012 \text{ m}, c = 0.006 \text{ m}$$

$$M_3 = (75)(0.114) = 8.55 \text{ N.m}$$

$$I_3 = \frac{\pi(0.012)^4}{64} = 1.0179 \text{ x } 10^{-9} \text{ m}^4$$

$$\text{Stress at point 3, } \sigma_3 = \frac{(8.55)(0.006)}{1.0179 \text{ x } 10^{-9}} \text{ Pa} = 50.3991 \text{ MPa}$$

From the calculation it is obvious that the maximum stress position for the smooth specimen is located at point 2 as shown in the simulation earlier. Hence, the specimen is predicted to fail due to fatigue at point 2 due to the rotating bending.

For notched specimen,

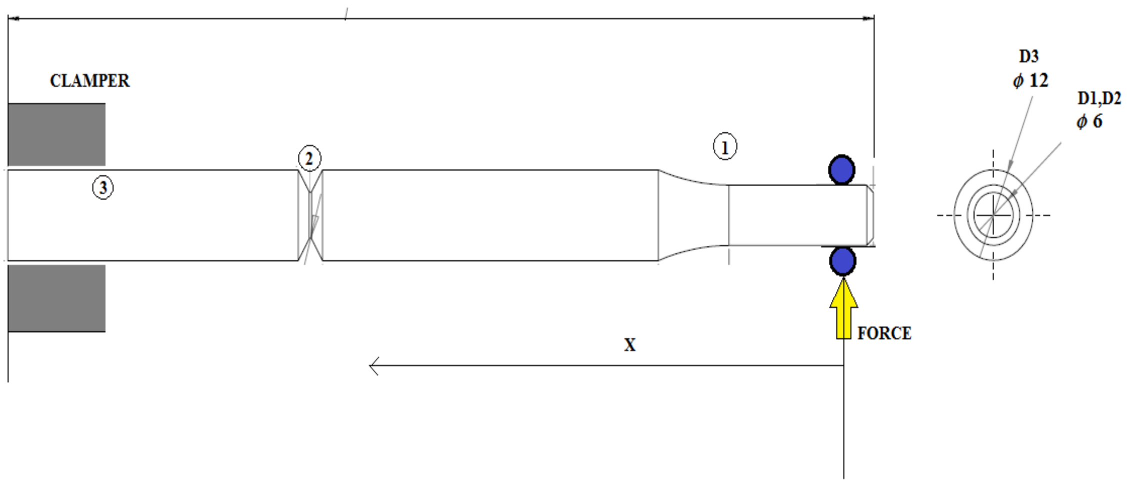


Figure 3.8: Loading Condition for Notched Specimen

Let the subjected bending force, $F_y = 75$ N and by utilizing equation (3.2), (3.3), (3.4):

At point 1, x = 0.022 mm, D_1 = 0.008 m, c = 0.004 m

$$M_1 = (75)(0.022) = 1.65 \text{ N.m}$$

$$I_1 = \frac{\pi(0.008)^4}{64} = 2.0106\text{x } 10^{-10} \text{ m}^4$$

$$\text{Stress at point 1, } \sigma_1 = \frac{(1.65)(0.004)}{2.0106 \, x \, 10^{-11}} \text{ Pa} = 32.8257 \text{ MPa}$$

At point 2, x = 0.07785 mm, D_2 = 0.006 m, c = 0.003 m (without consider stress concentration)

$$M_2 = (75)(0.07785) = 5.8388 \text{ N.m}$$

$$I_2 = \frac{\pi(0.06)^4}{64} = 6.3617 \text{ x } 10^{-11} \text{ m}^4$$

$$\text{Stress at point 2, } \sigma_2 = \frac{(5.8388)(0.003)}{6.3617 \text{ x } 10^{-9}} \text{ Pa} = = 275.3404 \text{ MPa}$$

At point 3, x $= 0.114$ mm, D_3 = 0.012 m, c = 0.006 m

$$M_3 = (75)(0.114) = 8.55 \text{ N.m}$$

$$I_3 = \frac{\pi(0.012)^4}{64} = 1.0179 \times 10^{-9} \text{ m}^4$$

Stress at point 3, $\sigma_3 = \frac{(8.55)(0.006)}{1.0179 \times 10^{-9}}$ Pa = 50.3991 MPa

From the calculation it is obvious that the maximum stress position is point 2 in notched component but it is noticed that the value is same as the maximum stress at point 2 in smooth specimen. This is due to the notch effect didn't taking into account, only the dimension and the cross section is consider in the calculation.

3.5 RANGE OF STRESS/ FORCE FOR FATIGUE FAILURE

From Table 3.2, it is known that the ultimate tensile strength, S_{ut} of AISI 1018 mild steel is 440 MPa, hence the maximum stress on the specimen must lower than 440 MPa to assure the specimen will fail as fatigue instead of tear apart by the bending force.

Let,

$$S_{max} = S_{ut} = 440 \text{ MPa} = \frac{Mc}{I} \quad \text{(c = 0.003m for maximum stress position)}$$

$$I = \frac{\pi(0.006)^4}{64} = 6.3617 \times 10^{-11} \text{ m}^4$$

Yield,

$$440 \text{ MPa} = \frac{M(0.003)}{6.3617 \times 10^{-11}}$$

$$M = 9.3305 \text{ N.m} = F_y x \qquad (x = 0.07785 \text{ m})$$

$$F_y = \frac{9.3305}{0.07785} \text{ N}$$

$$F_y < 119.8523 \text{ N}$$

From the calculation above by using equation (3.2),(3.3) and (3.4), it is known that in order to have the specimen failed under fatigue the applied force must be lower that F = 119.8523 N.

Besides knowing the upper limit of the force or stress to apply on the specimens, iti is important to identify the minimum value of force or stress required for the specimen to fail due to fatigue. In the case for fatigue failure of mild steel, as the maximum stress in the specimen reaching a specific value the specimen will not break, no matter how great the number of cycles. The strength corresponding to this value is call the endurance limit Se, or the fatigue limit. Any stress lower than this value happened on the specimen will not make it fail as fatigue.

For most of the rotating specimens with ultimate tensile strength lower than 1400 MPa, the endurance limit is estimated to be half of its ultimate tensile strength value. But the value might deviate significantly form the actual laboratory test of mechanical of the specimens. It is unrealistic to expect the endurance limit of a mechanical or structural member to match the mechanical specification obtained in the laboratory. Some differences include the material, manufacturing process, environment and design of the specimen might influence the endurance limit of the specimens. Hence, the predicted value of the endurance limit is required to taking account of the endurance limit modifying factor. According to Marin, those identified factors factor are including surface condition, size, loading, temperature and etc. an Marin equation is therefore written as

$$\textit{Endurance limit, } S_e = k_a k_b k_c k_d k_e k_f \, \mathrm{S_e}' \tag{3.5}$$

$$S_e' = 0.5(S_{ut}) \tag{3.6}$$

$$\mathrm{S_{ut}} = 440 \text{ MPa (from Table 3.2)}$$

$$\mathrm{f} = 0.9$$

$$k_a = 0.8988 \text{ , } k_b = 1.0259 \text{ , } k_c = k_d = k_e = k_f = 1$$

$$\mathrm{S_e}' = 0.5(440\mathrm{MPa}) = 220 \text{ MPa}$$

$$S_e = (0.8988)(1.0259)(220) = 202.8576 \text{ MPa}$$

The Marin is applied into the endurance limit in order to make the estimation since the endurance test for the specimen is not available. From the calculation, the endurance limit is known to be 202.8576 MPa. Hence, for the fatigue test the maximum stress for both types of specimens must be assured to be more than 202.8576 MPa. From Figure 3.8a the maximum stress is located at point 2,

Predicted endurance limit = 202.8576 MPa

$$\text{Bending moment, } M_2 = \frac{\sigma_0 I}{c} = \frac{(202.8576)(6.3617 \text{ x } 10^{-11})}{0.003}$$

$$= 55.2569 \text{ N}$$

Hence, the applied force must be at least 55.2569 N in order for fatigue failure happened to the specimens.

Then, the range of bending force to be applied for the fatigue test without consider stress concentration is 55.2569 N < F < 119.8523 N in order to have fatigue failure on the specimen with the maximum range of stress at 202.8576 MPa < σ_{max} < 440 MPa.

3.6 PREDICTION ON THE SPECIMENS' FATIGUE LIFE (FORMULA)

Stress-life Approach

As the position where the maximum stress located and the range of the stress or force for the fatigue failure are identified, it will be easier to predict the time and cycle need to be run until the specimen fail due to fatigue. The fatigue life can be roughly calculated by using formula.

Fatigue Strength, S_f can be obtained by using equation below:

$$\textit{Fatigue Strength, } S_f = aN^b \textit{ (N is cycle to failure)} \tag{3.7}$$

$$a = \frac{(fS_{ut})^2}{S_e}$$

$$b = -\frac{1}{3} log\left(\frac{fS_{ut}}{S_e}\right)$$

$$\textit{Endurance limit, } \mathrm{S_e} = 202.8576 \text{ MPa}$$

$$\mathrm{a} = \frac{((0.9)(440))^2}{202.8576} = 773.0349 \text{ MPa}$$

$$\mathrm{b} = -\frac{1}{3}\log\left(\frac{(0.9)(440)}{(202.8576)}\right) = -0.09683$$

$$S_f = aN^b$$

For smooth specimen,

Let,

$$\mathrm{S_f} = \text{maximum stress from previous calculation} = 275.3404 \text{ MPa}$$

$$\mathrm{N} = \left(\frac{275.3404}{773.0349}\right) \wedge \frac{1}{-0.09683} = 42673 \text{ cycles}$$

Then, all the fatigue cycle from in the range of the applied force is calculated and the time and number of cycle for the specimen to fail is shown in Table 3.3.

Table 3.3: Fatigue life prediction by stress-life approach (Smooth Specimen)

F (N)	Maximum stress, σ (MPa)	Fatigue life, N (Calculation, Stress-life approach)	Time (minute)
45	163	9573968	2659.44
50	182	3066209	851.72
55	201	1099660	305.46
60	219	453526	125.98
65	237	200607	55.72
70	255	94197	26.17
75	273	46572	12.94
80	292	23247	6.46
85	310	12534	3.48
90	328	6998	1.94
95	346	4030	1.12

For notched specimen, stress concentration must be taking into account for calculating the effective stress in fatigue.

$$\sigma_{max} = K_f \sigma_0 \tag{3.8}$$

$$\textit{Fatigue concentration factor, } K_f = 1 + \frac{K_t - 1}{1 + \sqrt{(\frac{a}{r})}} \text{ (Neuber constant)} \tag{3.9}$$

$$\sqrt{a} = 0.246 - 3.08(10^{-3})S_{ut} + 1.51(10^{-5}){S_{ut}}^2 - 2.67(10^{-8}){S_{ut}}^3$$

Where S_{ut} is in kpsi, 440MPa=63kpsi

$$\sqrt{\mathrm{a}} = 0.1052\sqrt{\mathrm{in}} = 0.5295\sqrt{\mathrm{mm}}$$

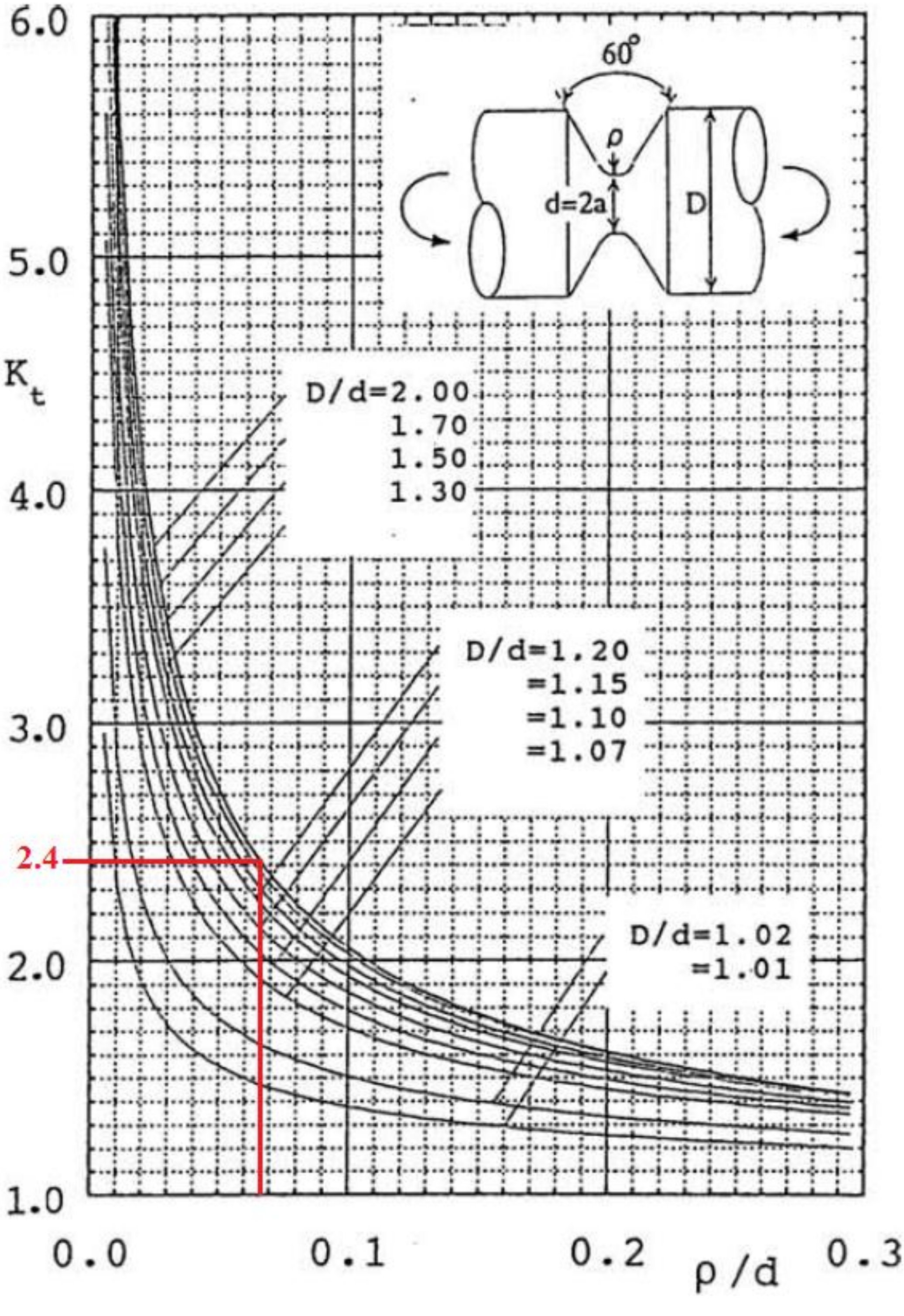


Figure 3.9: Chart of theoretical stress-concentration factor K_t.

Source: Noda, Takase (2006)

$$\frac{\mathrm{D}}{\mathrm{d}} = \frac{12}{6} = 2$$

$$\frac{\mathrm{r}}{\mathrm{d}} = \frac{2}{6} = 0.33$$

Referring Figure 3.4, $\mathrm{K_t} = 3.3$ and using equation (3.8) and (3.9)

$$\mathrm{K_f} = 1 + \frac{2.4 - 1}{1 + (\frac{0.5295}{\sqrt{0.4}})} = 1.76$$

Maximum stress at notch, $\sigma_{\mathrm{max}} = 1.76(275.3404) = 485.15\mathrm{MPa}$

$$\mathrm{N} = \left(\frac{485.15}{773.0349}\right)^{\wedge\frac{1}{-0.09683}} = 123 \text{ cycles}$$

Then, all the fatigue cycle for notched specimens from in the range of the applied force is calculated and the time and number of cycle for the specimen to fail is shown in Table 3.4.

Table 3.4: Fatigue life prediction by stress-life approach (Notched Specimen)

F (N)	σ_f (MPa) (Concentration Factor)	N (Formula)
30	192	1764858
35	224	359218
40	256	90465
45	287	27787
50	319	9327
55	351	3475
60	383	1412
65	415	616
70	447	286
75	479	140
80	511	72

The calculated fatigue cycles for applied force higher than 75N are invalid since the maximum stress is already beyond the ultimate tensile stress of the specimens.

Manson's Approach

In the literature, Manson and Hrischberg suggest that in uniaxial push–pull of notched specimen, it is assumed that the crack initiation is similar at the root of the notch and the smooth specimen under the same local strain amplitude. Furthermore, it is proposed that crack propagation phase is similar beyond the notch field and the smooth specimen under the nominal strain, ε_n. Consequently, the life of notched specimen, $N^{(n)}$, can be obtained using the following formula (3.10) where $N_f^{(\varepsilon)}$ and $N_f^{(\varepsilon n)}$ are lives obtained from strain-life curve of smooth specimens as shown in Figure 3.9 at strains ε_n and ε, respectively.

$$N_f^{(n)} = \left[N_f^{(\varepsilon)} - 4(N_f^{(\varepsilon)})^{(0.6)}\right] + 4[N_f^{(\varepsilon n)}]^{(0.6)} \tag{3.10}$$

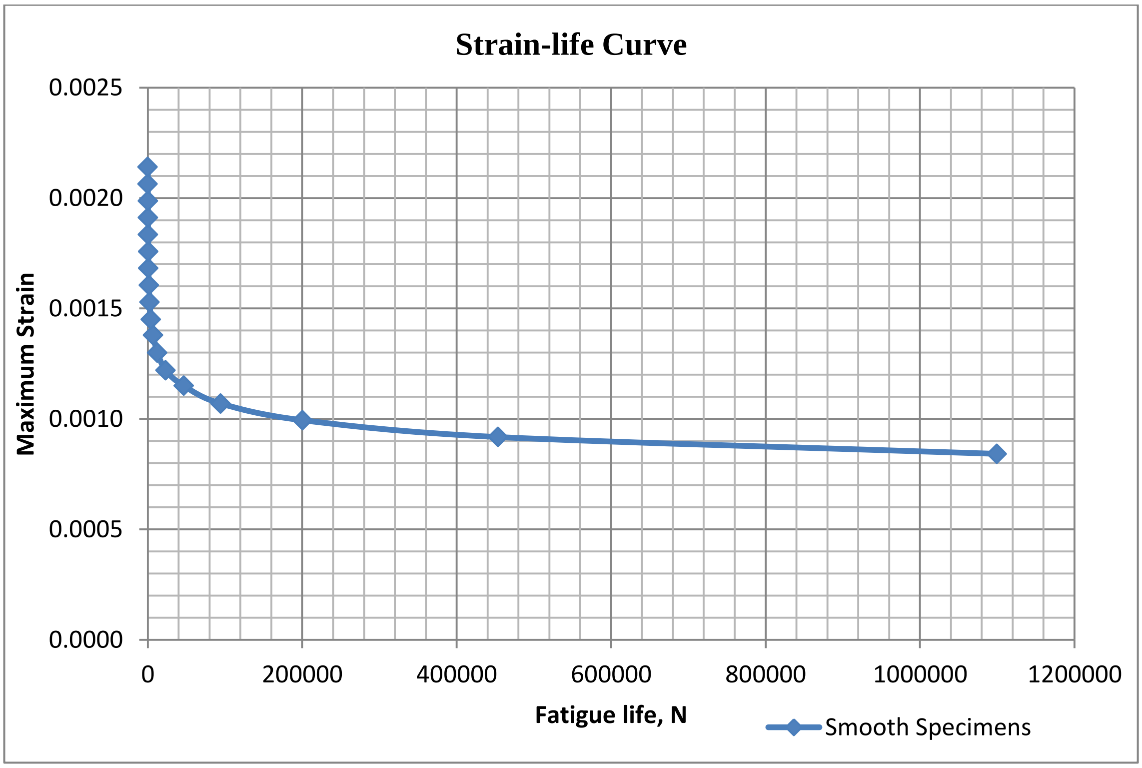


Figure 3.10: Strain-life curve for smooth specimen from calculation

The fatigue life of notched specimens are then calculated from equation (3.10) by referring to Figure 3.9 based on the nominal strain and notch root strain for each force applied on the notched specimens obtained from the simulation using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN software. Then, the calculated values are shown in the Table 3.5.

Table 3.5: Fatigue life prediction by Manson's approach (Notched Specimen)

F (N)	Maximum strain at notch root, ε (10^3) (Simulation)	Fatigue life, N (Calculation, Manson approach)
30	0.80	2792931
35	0.94	688995
40	1.07	217864
45	1.21	86534
50	1.34	39966
55	1.47	19915
60	1.61	11006
65	1.75	6447
70	1.88	4021
75	2.01	2568
80	2.14	1687

3.7 SPECIMENS FABRICATION

After all the software simulation and modeling is done and satisfied, hardware mode will be started for the project. A set of physical specimens need to be fabricated in order to carry out the actual experiment. The specimen to be fabricate must be accurate in its dimension and free from defects as a slightest mistaken done on the specimen will cause the result to be inaccurate.

Figure 3.11: Computer numerical controls lathe machine

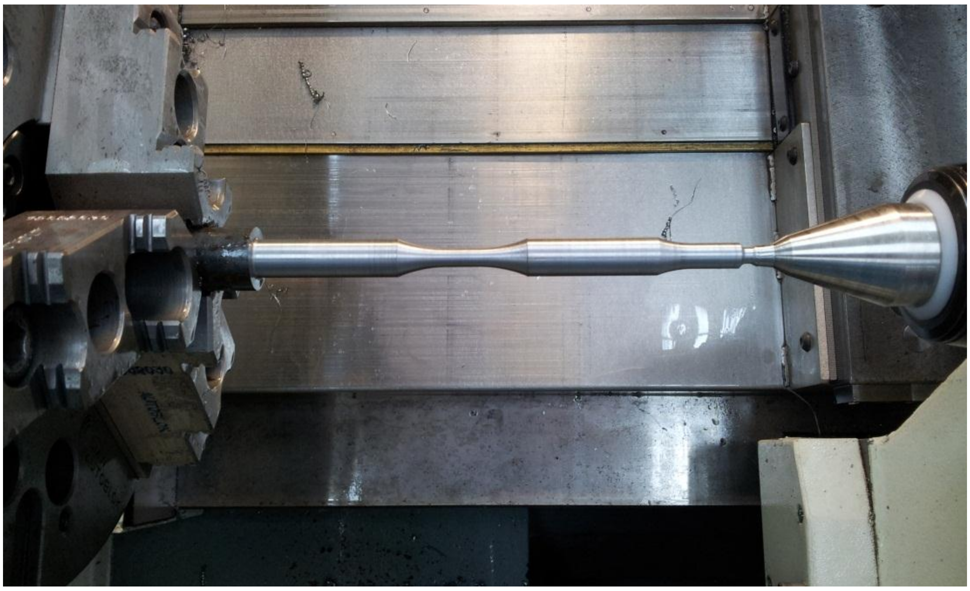


Figure 3.12: Specimen fabrication using CNC lathe machine

As the specimens used in the fatigue test required very high precision in dimension and finishing, computer numerical control (CNC) machine (Figure 3.11) is used for the specimens’ fabrication. The specification of the CNC lathe machine used is shown in Table 3.6.

Table 3.6: Specification of CNC lathe machine

Model	CNC Universal lathe GILDEMEISTER NEF 400
Number of tool in magazine	12
Max swing diameter over bed	385 mm
Max turning diameter over bed	350 mm
Cros travel (X)	255 mm
Longitudinal travel (Z)	800 mm
Spindle head	170 h5 Size
Spindle bore	87 mm
Diameter in the front bearing	130 mm
Chuck diameter	200 mm
Drive output	11.5 kW
Speed range	0-4500 rpm
Machine weight	3700 kg

Source: http://www.dmg.com/en,turning,nef400nd

Before starting any fabrication with CNC machine, the first step is to identify the types of cutting tool required. There are five types of cutting tool with respective function needed to produce both smooth and notched specimens: roughing, finishing, curving, drilling and parting. As these tools are prepared and installed into the CNC machine, all of the tools are calibrated with the aid of the positioning scope (as shown in Figure 3.13). Then the reference point of all the tools is set.

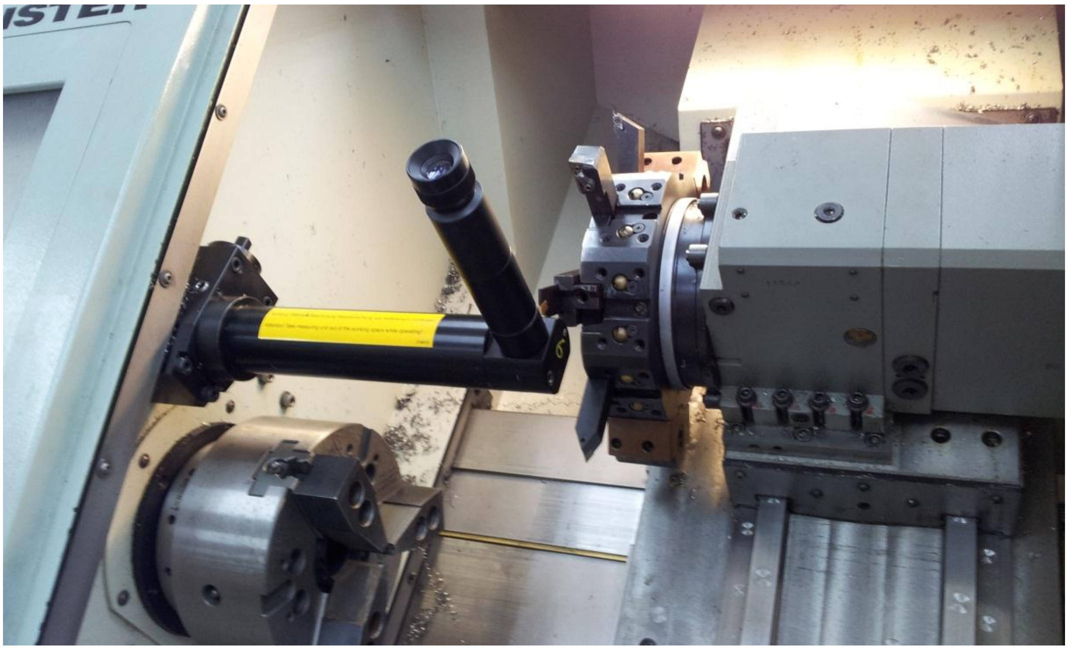


Figure 3.13: Tools calibration by using positioning scope

Next, the machine clamping force and the tailstock is calibrated. The specimens to be fabricated are small in size and the material used (mild steel) is low in strength, as the first attempt of the fabrication failed when the specimen break apart (shown in Figure 3.14) due to the high pressure of the tailstock. So, the CNC machine's clamping force and tailstock pushing pressure need to be lowered from the default pressure.

Figure 3.14: Failure during fabrication due to high tail stock pressure

After everything has been setting up, a set of program based on the design of the specimens is inserted into the machine. In constructing the program, there are a few aspect need to be considered like avoid the moving part from over travelled and knock other components of the machine, the spindle speed (rpm), feed rate of the cutting tools and etc.

The fabrication is divided into two parts. The first part is the preparation of the materials before actual fabrication. The materials undergo facing, drilling and step is done on one end of the materials where these end will later be supported at the tailstock of the machine.

After all materials are prepared, the fabrication is started by performing simulation of the fabrication steps. The simulation is carried out step by step in order to identify any mistake in the program. Once the simulation is done and no error found actual fabrication can be carried out.

The fabrication is started by roughing process where surface of the materials is removed until the designated diameter. Besides, the rough dimensions like chamfer and curve part of the specimens will be drawn out in this process. Then the process is followed by making the curve part for the smooth specimens or notch for the notched specimens. Next, finishing process is performed; the feed rate and spindle speed is controlled in order to obtain the identical surface finish of all the specimens which surface finish is one of the factors affecting fatigue life. The fabrication by CNC machine is ended by parting process where the specimens are separated with the excessive part then the specimens are taken out from the machine. Lastly, the unwanted parts at both end of the fabricated specimens is removed by using saw and smoothen using filing tool. An anti-corrosion agent is sprayed on the specimens to protect it from rusting before the fatigue test.

3.8 FATIGUE TEST

The actual specimen will undergo the fatigue test experiment which it will be subjected by cyclic torsional force as well as bending force. There are two types of specimen will be used which are the smooth specimens and notched specimens. Also, different bending force will be applied on each set of the smooth specimen and notched specimen. The result of the experiment will be compared with the simulation result. Besides, the result will be used to support on the assumption and hypothesis that made before in the discussion.

The testing is carried out by utilizing the fatigue test machine available in the material lab in Universiti Malaysia Pahang (Figure 3.15). The fatigue test machine is a simple rotating bending machine with an AC-powered motor used to rotate the specimen. The specification of the fatigue machine is as shown in Table 3.7. The other end of the specimen is rested in a bearing where bending force applied by adding tension to the spring connected to the bearing block. The force can be produced is in the range of 0-300N. The machine is built in with a digital counter (Figure 3.16) that will indicate the rotate cycle as the specimen is rotated.

Figure 3.15: Fatigue testing machine

Table 3.7: Specification of fatigue testing machine

Model	Gunt Hamburg WP 140
Voltage	230V
Frequency	50Hz
Nominal power	0.4kW

Source: http://www.selkagmbh.com/index.php?cName=fatigue-test-c-34

Figure 3.16: Digital counter on the fatigue test machine

The test is started by measuring and marking 10 mm at one end of the specimens where will be clamped to the spindle. This step is to assure all of the specimens will be placed at the same position in the machine in order to avoid any error in the results.

Then, the specimen is put into the machine by sliding the smaller diameter into the bearing followed by inserting the other end to the spindle until it reached the marking done previously. The clamper at the spindle is tightened with spanners and the protection cage is put on the machine. As, everything is set the power of the machine is turned on and the digital counter is reset to zero.

Next, the spindle is turned on at the same time the load is adjusted to the desired value. The behavior of the specimen is observed throughout the test, any vigorous vibration and the behavior before the specimen break is recorded. As the specimen failed the machine is turned off and the number of cycle indicated in the digital counter is recorded. Then, the broken specimen is removed from the fatigue test machine and the breaking surface pattern is observed and recorded. The test is repeated for different amount of force applied.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Maximum Stress on Specimens

Calculate By Using Formula

`The maximum stresses for the smooth specimens are calculated by using equation (3.2) for the range of loading 30 N to 95 N. In the calculation the smooth specimens is assumed to be a straight bar without any stress concentration even though the tested zone for smooth specimens are in curve shape.

From the calculated results the point where the diameter is the smallest have the highest stress value for. Hence, that point is considered as the maximum stress region and the specimens are going to fail in fatigue at the same region.

The maximum stresses for notched specimens are calculated by using the same equation with the smooth specimens but all the calculated value is multiplied with the fatigue stress concentration factor, k_f. This is due to there are stress concentration occur for the notched specimens, the notched specimens will have higher maximum stress compared to the smooth specimens even though the bending moment is same for both smooth specimen and notched specimen at the same distance from the load.

The maximum stress and bending moment of smooth and notched specimens is shown in Table 4.1.

Table 4.1: Bending moment and maximum stress of specimens

F (N)	Smooth Specimen		Notched Specimen	
	B.Moment, M (N.m)	σ (MPa) (Formula)	B.Moment, M (N.m)	σ (MPa) (Formula with concentration factor)
30	2.34	119	2.34	194
35	2.72	139	2.72	226
40	3.11	159	3.11	259
45	3.50	179	3.50	291
50	3.89	198	3.89	323
55	4.28	218	4.28	356
60	4.67	238	4.67	388
65	5.06	258	5.06	420
70	5.45	278	5.45	453
75	5.84	298	5.84	485
80	6.23	317	6.23	517
85	6.62	337	6.62	550
90	7.01	357	7.01	582
95	7.40	377	7.40	614

Stress Analysis (Nastran/Patran)

The maximum stress region and maximum strain region for the smooth specimen and the notched specimen are found by using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN software.

From Figure 4.1, it could clearly noticed that for the smooth specimen the maximum stress and maximum strain region is throughout the most region of the tested zone which indicate that there is no or just a little stress concentration present for the smooth specimens.

While in Figure 4.2 the maximum stress and maximum strain region for notched specimen seem to be concentrated at the notch root which is same as the earlier assumption. Also, the value of the maximum stress is noticed to be far higher than the smooth specimen for the same load applied.

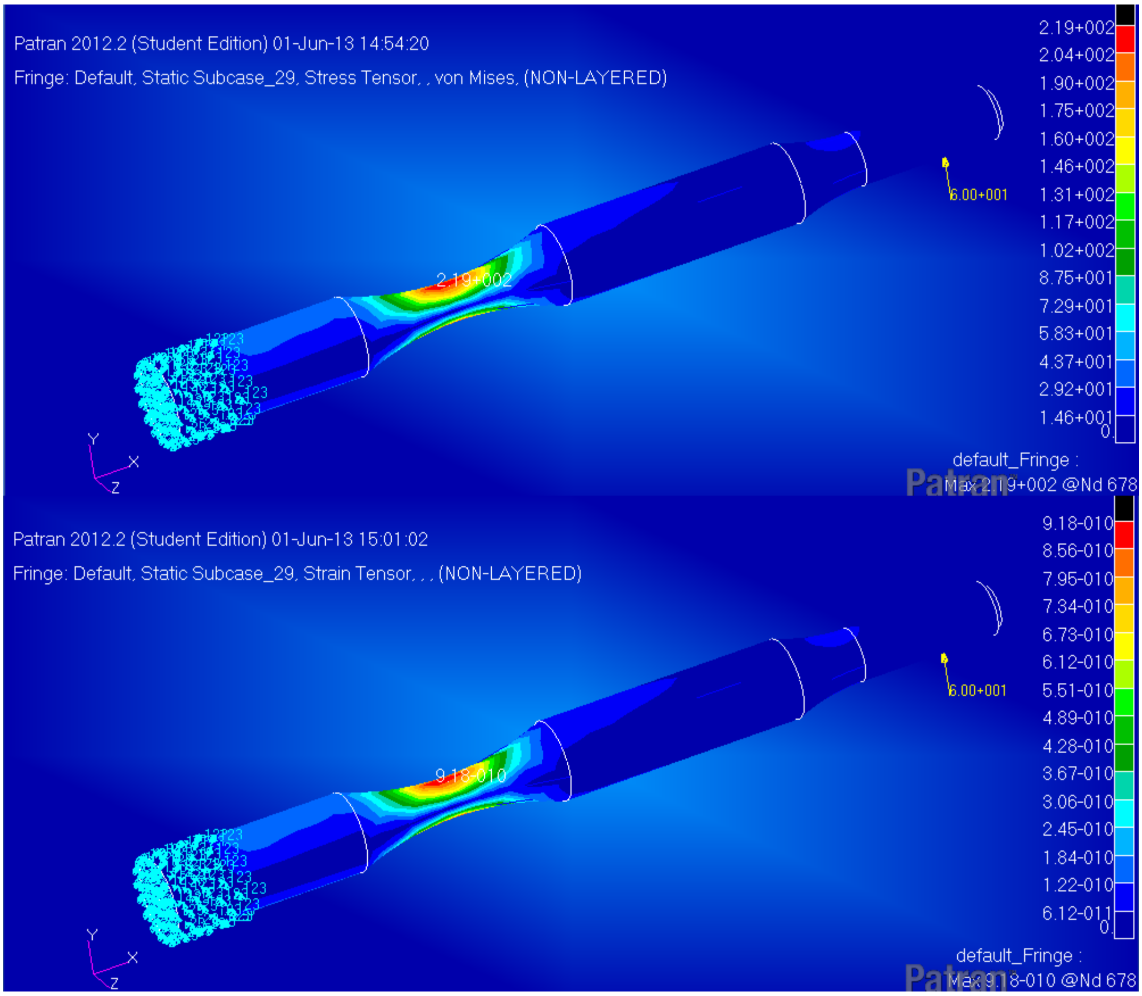


Figure 4.1: Maximum stress and maximum strain for smooth specimen at 60N load applied

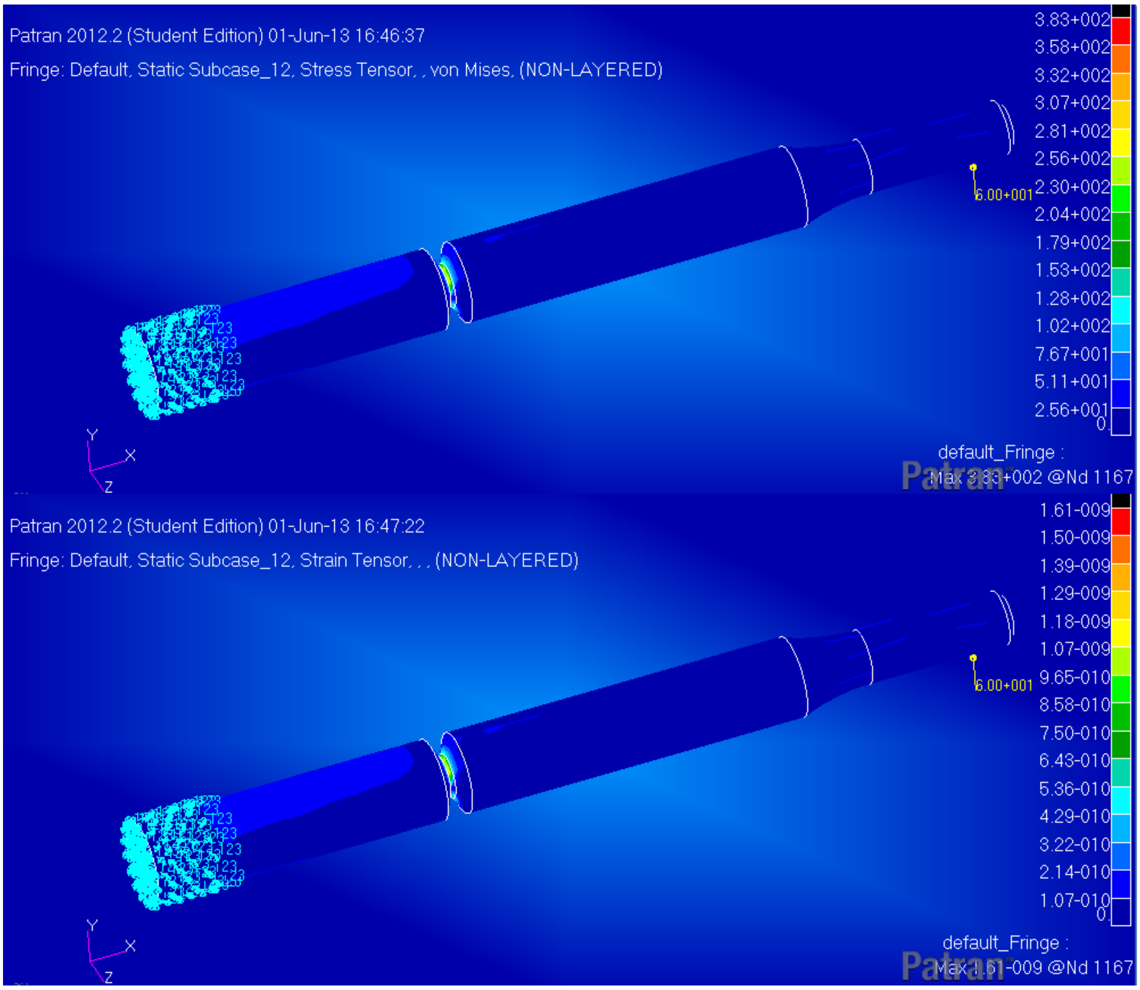


Figure 4.2: Maximum stress and maximum strain for notched specimen at 60N load applied

In Table 4.2, it is showing the maximum stress and maximum strain simulated by using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN for different value of load applied to both notched and smooth specimens. From the table, it is noticed that the maximum stress for both specimens increase as the applied force increases. The maximum strain for both specimens is also increase as the applied load increase.

The values in red colour in Table 4.2 are those stresses lower than the endurance limit or higher than the ultimate tensile stress of the material used for the specimens. Hence, for the load in those range the specimen will either will not fail due to fatigue or fail with just a few cycle run on it. For example during the experiment for notched specimen at load of 80 N, the specimen break before the loading is adjusted to 80 N. Also, for the experiment of 55 N loading on the smooth specimen, the specimen was not failed even after 2 hours of continuous run which the cycle exceeded 400000 cycles. Hence, it was assumed that the specimen will not fail at that loading value and any value lower than it.

So, for smooth specimens the range of loading applied in the experiment is from 60 N to 95 N while for notched specimens the range of loading applied should be 35 N to 70 N. But, in the experiment the value higher and lower than the suggested range is tested to prove that the whether assumption is valid.

Table 4.2: Maximum stress and maximum strain of specimens at different loading (Nastran/Patran)

F (N)	Smooth Specimen		Notched Specimen	
	Maximum stress, σ (MPa) (Simulation)	Maximum strain, ε (10^{-3}) (Simulation)	Maximum stress, σ (MPa) (Simulation)	Maximum strain, ε (10^{-3}) (Simulation)
30	109	0.46	192	0.80
35	128	0.54	224	0.94
40	146	0.61	256	1.07
45	163	0.69	287	1.21
50	182	0.77	319	1.34
55	201	0.84	351	1.47
60	219	0.92	383	1.61
65	237	0.99	415	1.75
70	255	1.07	447	1.88
75	273	1.15	479	2.01
80	292	1.22	511	2.14
85	310	1.30	543	2.28
90	328	1.38	574	2.41
95	346	1.45	606	2.55

By comparing to the calculated maximum stresses for the smooth specimens with the result of simulation by using MSC.PATRAN and analyzed utilizing the MSC.NASTRAN software, it is noticed that the values are not differing too much with just as much as 1.35% of the different (shown in Table 4.3). So, the early assumption of the smooth specimens have no stress concentration occur at the tested zone is valid.

The simulation results for maximum stress are assumed to be the more accurate value and hence it was use for the further analysis and calculation for the fatigue life for the smooth specimens.

Table 4.3: Deviation between calculated and simulated maximum stress for smooth specimens

F (N)	Smooth Specimen		
	Maximum stress, σ (MPa) (Formula)	Maximum stress, σ (MPa) (Simulation)	Deviation (%)
30	110	109	-1.04
35	128	128	-0.38
40	147	146	-0.57
45	165	163	-1.35
50	184	182	-0.85
55	202	201	-0.45
60	220	219	-0.57
65	239	237	-0.68
70	257	255	-0.77
75	275	273	-0.85
80	294	292	-0.57
85	312	310	-0.66
90	330	328	-0.73
95	349	346	-0.79

It is the same goes to the notched specimens, by comparing both the calculated results and the simulation results MSC.PATRAN and analyzed utilizing the MSC.NASTRAN, it was found that the deviation (shown in Table 4.4) of them are very low with the maximum deviation of only 1.42%. This shows that the stress concentration factor, k_f found in section 2.4.4 is valid.

Table 4.4: Deviation between calculated and simulated maximum stress for notched specimens

F (N)	Notched Specimen		
	Maximum Stress, σ (MPa) (Formula with concentration factor)	Maximum stress, σ (MPa) (Simulation)	Deviation (%)
30	194	192	-1.07
35	226	224	-1.07
40	259	256	-1.07
45	291	287	-1.42
50	323	319	-1.38
55	356	351	-1.35
60	388	383	-1.33
65	420	415	-1.31
70	453	447	-1.29
75	485	479	-1.28
80	517	511	-1.26
85	550	543	-1.25
90	582	574	-1.42
95	614	606	-1.40

4.1.2 Fatigue Life

By referring to the experimental results in Table 4.5 and Table 4.6 for the fatigue life for both smooth and notched specimens, it is noticed that the failure cycle is more than 10^3 which is considered as high cycle fatigue. For the high cycle fatigue stress life approach is a simpler way to predict the fatigue life.

The theoretical fatigue life of smooth specimens is calculated by using formula of stress-life approach and the result is compared with the experiment result in Table 4.5. From the values, it is noticed that the fatigue cycle for both in theoretical and experiment results are increase exponentially with the decrease of the force/ stress applied.

The experimental result obtained is just in the range of loading between 60 N to 9 5N. This is due to the smooth specimen was not break at the loading of 55 N applied after 2 hours of experiments conducted. This is as predicted earlier that fatigue failure will not occur for the maximum stress lower than the endurance limit of the material used which is 220 MPa for the ASTM 1018 mild steel used in the smooth specimens. Also, the smooth specimen is broken apart before reaching the loading of 100 N.

The experiment result of smooth specimens showing highest deviation compared to the theoretical predicted result from the calculation with 33.40% at 85 N of load applied and lowest deviation of 13.04% at 75 N of load applied. The deviation from the predicted or the theoretical may due to some factors like the vibration, damaged during fabrication, rusting at the tested zone and etc.

Table 4.5: Calculated and experiment results for fatigue life of smooth specimens

F	Smooth Specimen		
	Fatigue life, N (Theoretical Prediction, Stress-life approach)	Fatigue life, N (Experiment)	Deviation (%)
45	9573968	-	-
50	3066209	-	-
55	1099660	-	-
60	453526	375129	17.29
65	200607	171829	14.35
70	94197	79112	16.01
75	46572	40497	13.04
80	23247	19569	15.82
85	12534	8348	33.40
90	6998	5179	25.99
95	4030	2726	32.36

Despite the result from the experiment showing the deviation of up to 33.40% compared to the theoretical results but the characteristic of the specimens responded to the different amount of loading or the maximum stress are almost the same with the theoretical prediction.

This could be seen from Figure 4.3, the trend of the experiment result (blue line) are following the theoretical prediction (red line) path closely. Also, the experiment results curve will be an infinite flat line at the stress of 220 MPa since during the experiment the specimen was not failing at the maximum stress under 220 MPa. This goes same for the theoretical prediction; it will show an infinite horizontal line at the stress of 220 MPa. Which mean the specimens will not break at the maximum stress under the endurance limit which is 220 MPa in this case.

So, it could be assume that the stress-life approach is suitable for the prediction of the fatigue life of smooth specimens with the limit of it must be in high cycle fatigue which is higher than 10^3 cycles.

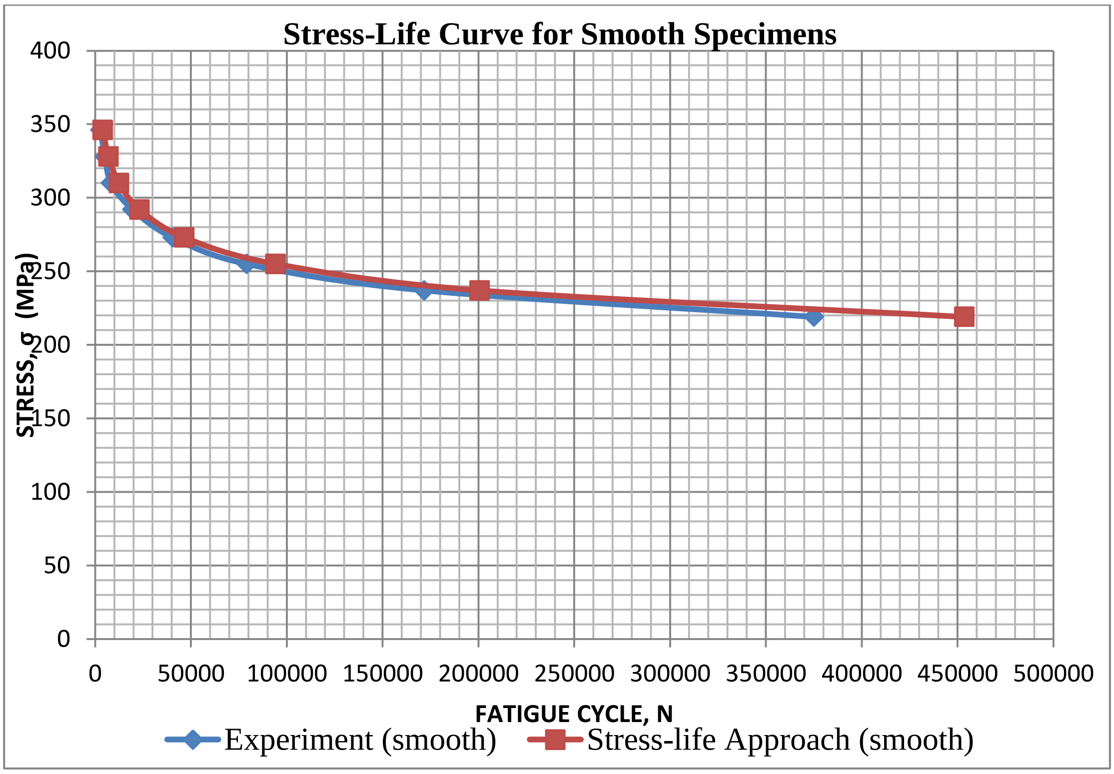


Figure 4.3: Stress-life curve for smooth specimens

For the notched specimens, besides calculating the fatigue life with stress life approach, Manson's approach formula is also used to predict its fatigue life since in the literature it is proposed that Manson approach is a more accurate way to predict the fatigue life of notched specimens.

The calculated and experiment results for smooth and notched specimens is shown in Table 4.6. From the values, it is noticed that the fatigue cycle for both in calculation and experiment results are increase exponentially with the decrease of the force/ stress applied.

The experimental results for notched specimens are just obtained for the load value between 35 N and 75 N. For the loading of 30 N applied to the notched specimens, after the experiment ran for about 2 hours the specimen was still intact and this proven that the specimens will not fail for the maximum is less than the endurance limit. The endurance limit used in the notched is 220 MPa while the maximum stress in the notched specimen in 55 N of loading is 192 MPa. Also, for the loading of 75 N the specimen was broken before the load is adjusted to that value due to the maximum stress in the notched specimen was exceeding the ultimate tensile stress at 440 MPa.

By comparing the experiment results and the calculation by stress life approach, the experiment results showing great deviation from the calculated values. The highest deviation is 1042.53% at 70 N of load applied and the lowest deviation is 25.40% at 35 N of load applied. The deviation is too large and it is far beyond the accepted value.

For the comparison between experiment results and the calculated value from by using Manson's approach it is showing accepted deviation with the highest deviation of 61.10% at 35 N load applied and lowest deviation of 8.45% at 65 N of load applied.

Based on the deviation of the experiment results compared to both calculated values from stress-life approach and Manson's approach, it could be seen that the Manson's approach is the more accurate way to predict the fatigue life of the notched specimens.

Table 4.6: Calculated and experiment results for fatigue life of notched specimens

F (N)	Notched Specimen				
	Fatigue life, N (Calculation , Stress-life approach)	Fatigue life, N (Calculation, Manson approach)	Fatigue life, N (Experiment)	Deviation (%) (compare to stress-life approach)	Deviation (%) (compare to Manson's approach)
30	1764858	2792931	-	-	-
35	359218	688995	267985	25.40	61.10
40	90465	217864	154603	-70.90	29.04
45	27787	86534	66074	-137.79	23.64
50	9327	39966	34003	-264.57	14.92
55	3475	19915	16501	-374.79	17.14
60	1412	11006	8594	-508.83	21.92
65	616	6447	5902	-857.59	8.45
70	286	4021	3270	-1042.53	18.69
75	140	2568	1270	-806.19	50.55
80	72	1687	-	-	-

The experimental results (red line) and the theoretical prediction using stress-life approach (blue line) are plotted out in Figure 4.4. From the plotted graph it could be clearly seen that the experiment result did not follow the trend of the stress life approach prediction.

The experiment results showing very large deviation to the stress life approach prediction with a less steep graph. Also, there is a point that the two curves are crossing each other and from that it could be said that both crave is in a different trend. From that, it could be said that the stress-life approach prediction is not accurate for notched specimen fatigue.

Besides, in actual case the number of fatigue cycle is a lot more compared to the stress-life approach prediction and it is up to 10 times of the predicted cycle. This is a very large difference and it is a far beyond accepted error in predict the fatigue life of notched specimen and hence it could be assumed that the stress-life approach is not suitable in predicting the fatigue life for notched specimen.

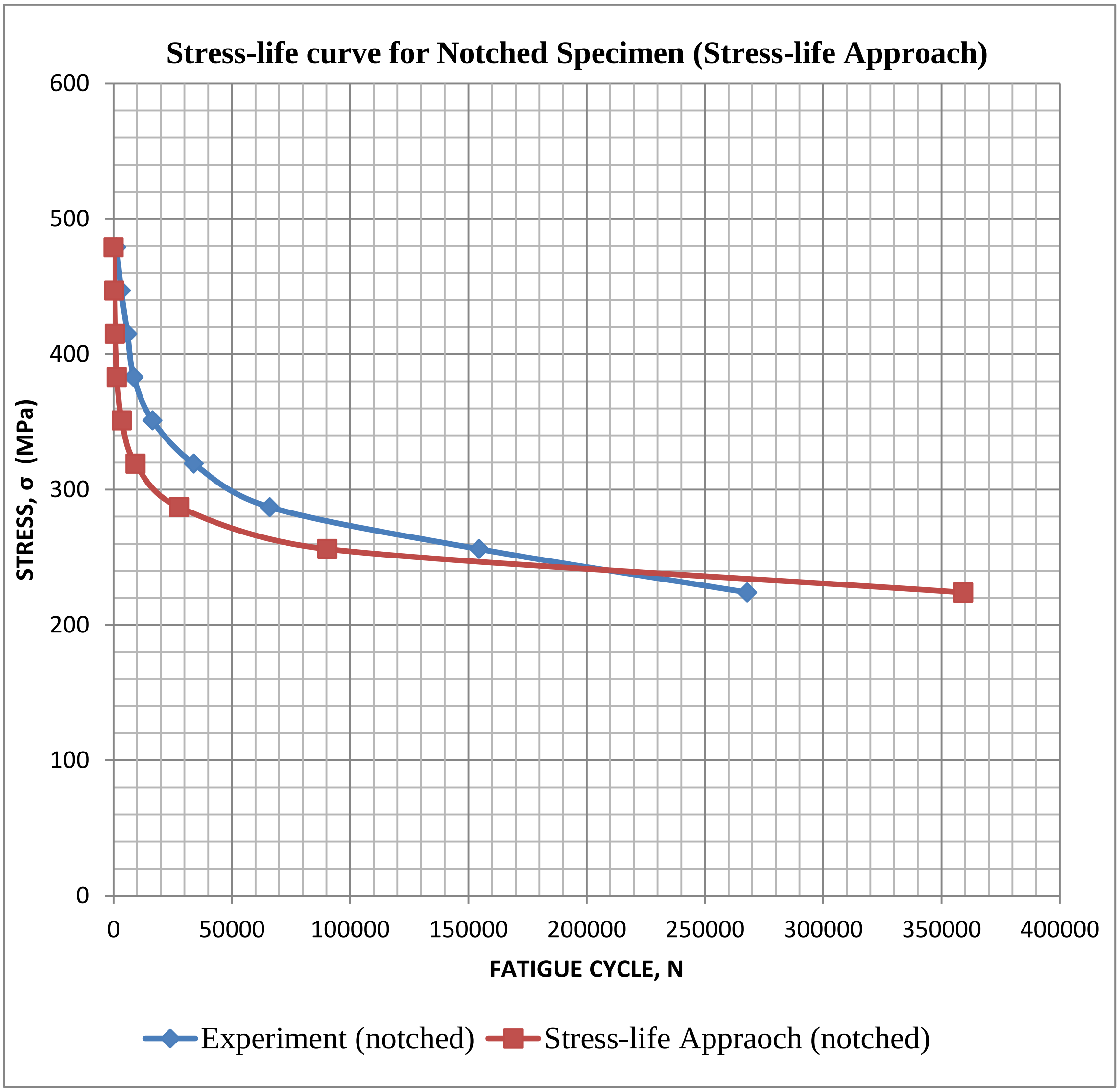


Figure 4.4: Stress-life curve for notched material

The Manson's approach for notched specimens is used to predict the fatigue life of the v-notched specimens used in the experiment. The strain-life curve of Manson's approach on notched specimen is plotted out for both experiment results and the theoretical prediction and shown in Figure 4.5.

The trend of the experiment results curve (blue line) is following the Manson's approach prediction curve (red line) closely during the high strain value and lower number of fatigue cycle. It is started to deviate more for the higher fatigue cycle and lower strain value. But, the deviation is at as much of 61.10% which is acceptable as for most engineering application the safety factor is set to be at least 4 times of the prediction.

The factors causing the increasing of the deviation might due to some factors like rising of the temperature after long run of the machine, vibration, rusting at the tested zone in the specimens, damage at the tested zone during fabrication and etc.

As a whole, the Manson's approach predicts the notched specimen fatigue life accurately as it could be seen in Figure 4.5 that the trends of both curves are behaving in the similar manner. In the experiment the notch specimen was not failing at the loading lower than 35 N at the strain value of 9.04×10^3 where at that point the maximum stress is lower than the endurance limit which same as the early theoretical prediction for fatigue.

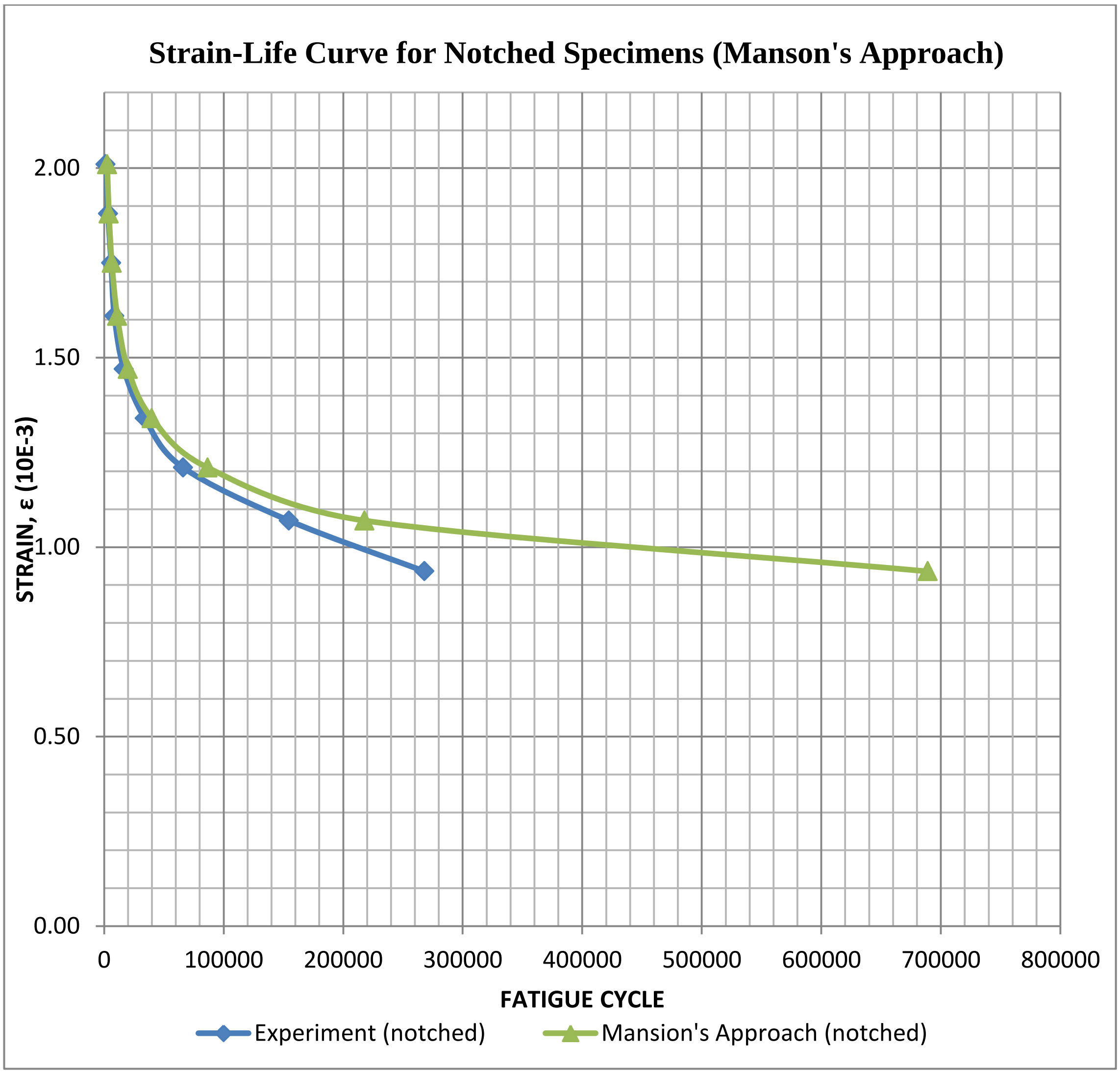


Figure 4.5: Strain-life curve for notched specimens (Manson's Approach)

The smooth specimens and the notched specimens fatigue life is compared in Table 4.7. Although the tested range for smooth specimens and notched specimens is different but there are some overlap in these range. And the overlapped range that could be compared is when the applied load is in between 60 N to 75 N.

In this range, the notched specimens fatigue life are just achieved up to 4.13% of the fatigue life for smooth specimens at the same amount of load applied. This indicates that with the present of notch in the specimen, the fatigue life of the specimen is shortening by at least 24 times of the specimen without notch in it.

Table 4.7: Comparison between fatigue life of smooth specimens and notched specimen

F	Fatigue life, N (Experiment)		Percentage of cycle achieved for the same load (%)
	Smooth Specimen	Notched Specimen	
30	-	-	-
35	-	267985	-
40	-	154603	-
45	-	66074	-
50	-	34003	-
55	-	16501	-
60	375129	8594	2.29
65	171829	5902	3.43
70	79112	3270	4.13
75	40497	1270	3.14
80	19569	-	-
85	8348	-	-
90	5179	-	-
95	2726	-	-

The Figure 4.6 is showing the fatigue life of both smooth specimens and notched specimens at the specific amount of load applied on it.

It could be clearly see that the range of load applied on the smooth specimens for it to fail as fatigue higher than the notched specimen. Also, at the same amount of load applied, the smooth specimen showing a lot longer fatigue life compared to the notched specimens.

Besides, it could be seen that the endurance limit of the smooth specimen is happened at the higher amount of load than the notched specimen which in this case it is 60 N for the smooth specimens and 35 N for the notched specimens. The smooth specimens will not fail as fatigue for loading under 60 N while the notched specimens need to be under 35 N to achieve that.

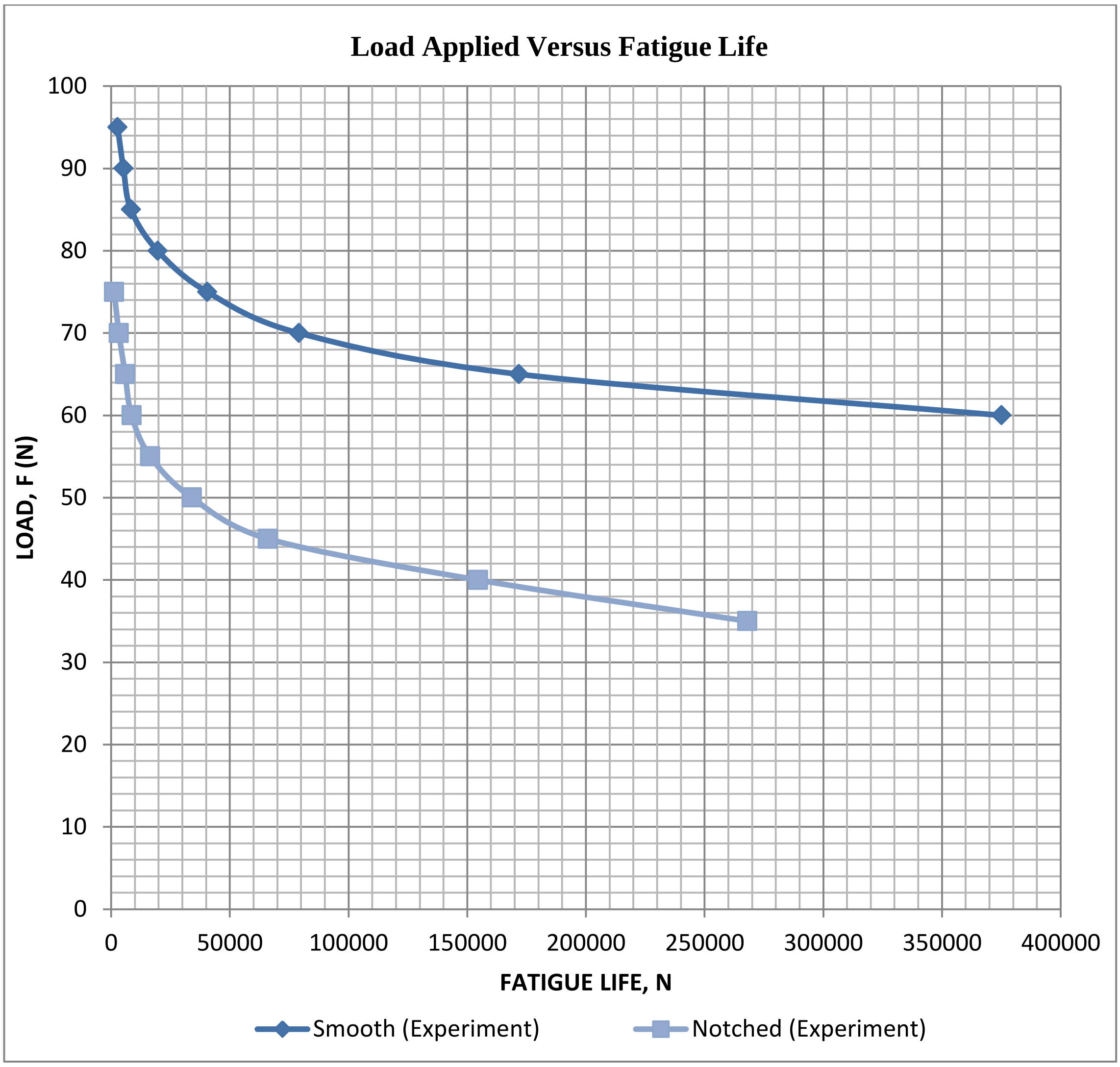


Figure 4.6: Load applied versus fatigue life for smooth and notched specimen

4.1.3 Breaking Characteristic of Specimens

In the test the breaking behaviour for each of the tested specimens was carefully observed. From the observation, both smooth specimens and notched specimens were showing very distinct behaviour before broken apart.

For all the smooth specimens regardless of the amount of loading applied, it causing vigorous vibration on the test machine for few minutes before it was broken while the notch specimens were just break in a sudden manner without giving out any warning sign. This is due to the smooth specimens and notched specimens will undergo very different duration of each fatigue breaking stage. According to the literature, Manson proposes that for highly notch-sensitive materials, crack initiation and failure would occur at approximately the same number of cycles. So, it could be said that the notched specimen is undergone a very short stage II crack propagation and the vibration before the smooth specimen broken is assumed to be due to the stage II cracking taking place.

Beside the breaking behaviour, the fracture surface for both smooth specimens and notched specimens show a very distinct pattern. For the notched specimens, the fracture surfaces were flat like a clean cut as shown in Figure 4.7. This might be due to the notched specimens have all the stress concentrated at the notch root and the crack is just propagate to the center of the specimens directly. Also, notched specimens have very short stage II crack and hence branch crack will have not enough time to take place. As a result, the crack surface is smooth and flat. While the surface of smooth specimens were very rough and the cracking is in a zigzag pattern as shown in Figure 4.8 which resulted in an uneven fracture surface. In smooth specimens the maximum stress is less concentrated hence the crack propagation might not propagate in a straight line. Besides, smooth specimens have longer stage II crack hence branch crack will happened and left a rough and uneven crack surface.

Figure 4.7: Crack surface of notched specimen

Figure 4.8: Crack surface of smooth specimen

4.2 DISCUSSION

4.2.1 Notch Effect To Fatigue Life

Stress Concentration

Notch present in the specimen will cause stress concentration to its notch root. The stress concentration on the notched specimens where at the notch root it will experience a lot higher in stress compare to the smooth specimens when the same amount of bending force applied on it. Hence, it will undergo less cycle before rupture compared to the smooth specimens. Low carbon steel and mild steel has a banded ferrite/pearlite microstructure In mild steel, ordinary notch-weakening effect, namely shorter lifetime of notched specimen compared with smooth specimen.

Cracking Characteristic

In fatigue failure, it could be divided into three stages. Stage I, the initiation of one or more microcracks due to cyclic plastic deformation followed by crystallographic propagation extending to two to five grains of its original size. Stage II is the progresses from microcrack to macrocracks. Stage III is occurring during the final stress cycle when the remaining material cannot support the load result in a sudden fast fracture.

Smooth specimens will have longer stage I crack compared to notched specimens. This is due to the notched specimens will have very high stress at the notch root due to the stress concentration. And this high in stress will help in accelerate the microcrack forming at the notch root while the smooth specimens need to take higher number in cycle or longer time for the crack initiation stage.

Notched specimens will experienced higher in maximum stress is not the only contribution to its lower fatigue life. As the maximum stress is concentrated in one point at the notch root of the notched specimens, the duration of each stages of the cracking experienced by the notched specimens will be totally different from the smooth specimens. The duration of each stage of cracking will contribute to the fatigue life of the specimens. This could be proved by the behavior of the specimens before it failed or torn apart during the fatigue test on both specimens.

When the smooth specimens are subjected to the rotating bending moment the machine’s vibration is moderate but as it is approaching to failure the whole machine vibrates vigorously and this happened to all smooth specimens with other amount of forces applied on it. Obviously, there is something happen in the specimens and cause the vibration. For the reason of the vigorous vibration of the fatigue machine is believe caused by the stage II of the fatigue failure. The stage II is progresses from microcracks to macrocracks. In this stage, the specimens is weaken and unstable hence causing the vibration. In this stage the cracked surfaces open and close under the cyclic loading, rubbing together while tearing the specimen apart. The cracked surface for smooth specimens was uneven. This could be explained by the maximum stress at the smooth specimens are not as concentrated like in notched specimens and its long stage II crack where branch crack is taking place. Hence, during the crack propagation the crack will not just propagate in the normal direction to the stress but in an unorganized zigzag pattern.

Notched specimens will have very short crack propagation stage or known as stage II, Manson proposes that for highly notch-sensitive materials, crack initiation and failure would occur at approximately the same number of cycles. This could be proven by all notched specimens failed without giving out any signal like the smooth specimens did. It just breaks in a sudden manner without causing any vigorous vibration. The breaking surfaces of the notched specimens are like a clean cut in the direction normal to the bending stress and leaving a flat and smooth surface (Figure 4.9) without any uneven cracking like in the smooth specimens.

From the surface where the specimens torn apart, it could easily notice that there are two tone of the cracking pattern. As shown in Figure 4.9 the outer circle is lighter in its tone while the inner circle has a darker tone. This could be explained that the specimen undergo two different stages of cracking. One is the cracking propagation stage and the other is the sudden crack stage (smaller circle indicate by red arrow) when the specimens broken.

Figure 4.9: Fatigue crack characteristic of notched specimen

4.2.2 Experimental Results Versus Theoretical Prediction

From the result from the experiment, the prediction by using calculation for smooth specimens is very close to the actual value while the experimental results for notched specimens showing higher deviation compared to its calculated results.

The deviation could be due to some external factor like vibration, damaged during fabrication, rusting at the notch root and etc. There is considerable amount of vibration present during the experiment. It is unavoidable as the source of vibration is from the motor of the fatigue machine itself. This vibration is the main cause of the deviation of the experimental results from the calculated values. The vibration is assumed to have more effect on the notched specimens. As the vibration present, it will cause some irregular forces/ stress on the specimens. The notched specimens will have stress concentration on the notch roots, even a small amount of additional force acting to the specimens it will be amplified and result in considerable amount of stress to the notch roots. As a result lower the fatigue cycle of the notched specimens.

Although in the fatigue experiment the only force applied to the specimens is the bending moment but is believed that there are still small amount of torsional stress present during the test. This is contributed by the frictional force from the bearing which held one end of the specimen. The coefficient of friction for ball bearing is around 0.001 to 0.0015. So, the frictional force that causing the torsional stress is very small and might be insignificant for low cycle fatigue.

Besides, rising in temperature may cause changes in the specimen mechanical properties. As the fatigue machine run for a long period, the bearing might get heated up and the frictional force might increase as well. And more or less this will affect the result of the test. Unfortunately there is no way to figure out the torsional stress acting to the specimens as there is no such sensor in the fatigue test machine use in the test. The only way is to ignore it and assume it to be in an insignificant amount.

During fabrication the inserts or the cutting tools might get wore or cracked. Sometimes these damages are very small and unable to identify by naked eyes. As continue using these inserts will result in inaccurate dimension of the specimens even worse it will cause some cracks to the specimens especially at the most fragile area like the notch root. The cracks might happened in micron and it will be difficult to notice even inspection has been done after the fabrication. Crack on the notch root during fabrication is the main reason for the significant deviation of the fatigue test results to the theoretical results from both calculation and simulation results.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

As conclusion, the early hypothesis in this project that the notched specimens will have lower fatigue life compared to the smooth specimens due to its stress concentration. The fatigue life for the notched specimens will just have up to 4.13% of the fatigue life of smooth specimens for the same amount of load applied.

The stress concentration will happened in the sudden changes of cross section like notch. This is proven by the simulation using MSC PATRAN and analyzed utilizing the MSC.NASTRAN software where its stress value is a lot higher than at the same location on the smooth specimens that have the same cross section area. There fatigue stress concentration found by calculation is proven correct by comparing the calculated stress by taking fatigue concentration into account and the simulation result from MSC PATRAN.

Stress concentration at the notch for notched specimens was not just contributing lower number of fatigue cycle for notched specimens. In fact, it also change the fatigue breaking characteristic for the notch specimens where it will have extremely short stage II crack propagation compared to the smooth specimens as suggested by Manson that for highly notch-sensitive materials, crack initiation and failure would occur at approximately the same number of cycles.. The crack surface also showing a very distinct pattern compared to the smooth specimens due to its breaking characteristic. The crack surfaces of the notched specimens are smooth and flat due to the stress concentration and its short stage II crack compared to the rough and uneven crack surface on smooth specimens resulted from its long stage II crack where branch cracking happened and no stress concentration on it.

From the analysis of the results, it was found that the stress-life approach prediction is just suitable in the prediction of the smooth specimens fatigue life. When it come to the prediction on the notched specimen, it shows a very large error and it may be concluded that stress approach is not suitable in the prediction of the fatigue life of notched specimens. On the other hand, the Manson approach on the notched specimens fatigue life prediction is more suitable for the notched specimens in this project. It show a lot lower deviation from the actual results and have the same trend of the plotted graph with the actual result. So, it may say that it is the better and more suitable approach in notched specimens fatigue life prediction.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

In this project, the main problem is the fatigue machine where it has a notable vibration during the experiment and this may cause the experiment results to be less accurate. So, it would be suggest that for future research the fatigue life of the specimens should be tested on a more advance fatigue test machine with more advance function to help in getting more accurate results.

There is only one notch type tested in this project which is the v-notch. Since for different type of notch might have different notch effect on fatigue life so it would be better to study all of them in order to get the accurate prediction of fatigue life for all notch type component in engineering application to prevent any accident from happening.

Different type of materials is also suggested for future research since all material will have different molecular structure. Hence, their respond to the notch and stress concentration might be different.

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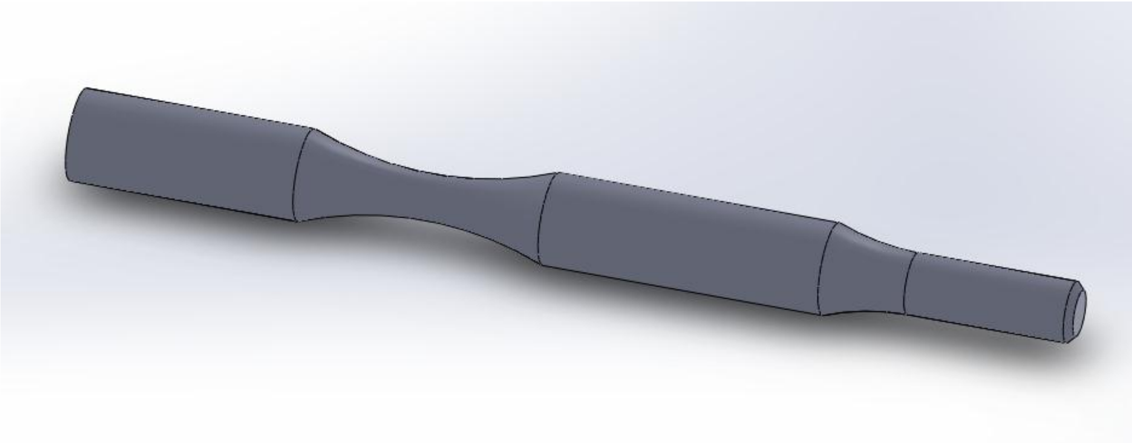
APPENDIX A

GANTT CHART

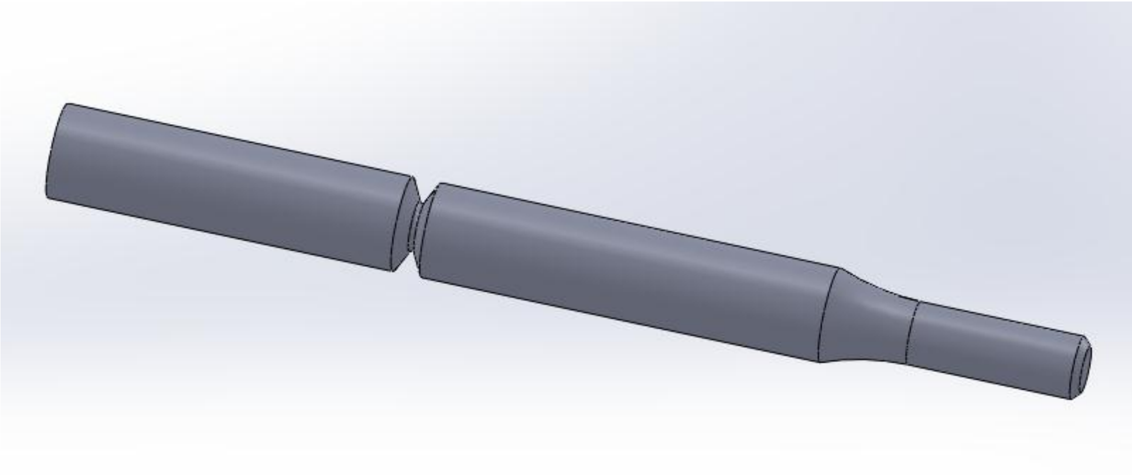
	Scope	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
PSM 1	Receive Project Title	■													
	Brainstorming	■	■												
	Collect Journal		■	■	■										
	Extract Relevant Information				■	■									
	Literature Review					■	■	■							
	Computer Modeling						■	■	■						
	Calculation								■	■	■				
	Simulation (Nastran/Patran)									■	■	■			
	PSM1 Completion												■	■	■
PSM 2	Specimen Fabrication		■	■	■	■	■								
	Experiment						■	■	■	■					
	Results Analysis									■	■	■			
	Discussion										■	■	■		
	Thesis Completion													■	■

APPENDIX B

DESIGN DRAWING



A1: Smooth Specimen Design 3D Drawing



A2: Notched Specimen Design 3D Drawing

APPENDIX C

FABRICATION IMAGE

C1: Fabricated Smooth Specimen by Using CNC Lathe Machine

C1: Fabricated Notched Specimen by Using CNC Lathe Machine