EFFECT OF MICROSTRUCTURE ON PLAIN STRAIN FRACTURE TOUGHNESS OF CARBON STEEL

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EFFECT OF MICROSTRUCTURE ON PLAIN STRAIN FRACTURE TOUGHNESS OF CARBON STEEL

MUHAMAD HANIF BIN MUHAMAD

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

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JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

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

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Dedicated, truthfully for supports,
encouragements and always be there during hard times,
to my beloved family

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ABSTRACT

This project is about to study the effect of microstructure on plain strain fracture toughness of carbon steel. The objectives for this project are to study the effect of microstructure on plain strain fracture toughness of carbon steel and to study the effect of transformation structure on fracture toughness (K_{1C}). This project involves preparation 26 specimens of low carbon steel which is the mild steel. Two notch diameters (5.6 mm and 4.2 mm) and two notch angles (α) namely 60° and 80° have been used to observe the fracture toughness of the steel. By full annealing heat treatments process, it can used to differentiate the microstructure of the steel and its effect on the fracture toughness is also observed. Mounting process is done for two of the specimen before observation of the microstructure using Optical Microscope. The tensile test done and the fracture toughness can be getting from the calculation. It has been found that the heat treatment specimens are softer and brittle but for the no heat treatment specimens it is stronger and harder. Fine grained structure improved fracture toughness. Higher notch angles give lower fracture toughness and lower notch diameter gives lower fracture load. For 60° angle, lower notch diameter give higher fracture toughness. For 80° angle, lower notch diameter give lower fracture toughness. Microstructure of steel has the strong influence on the value of K_{1C}. The finer grain structure has been found to have higher value of K_{1C} than a coarse and wider grained structure. Non heat treated samples are stronger and harder but for the heat treatment sample it is softer and brittle.

ABSTRAK

Projek ini adalah untuk mengkaji kesan mikrostruktur pada terikan mudah, kekuatan patah keluli karbon. Objektif bagi projek ini adalah untuk mengkaji kesan mikrostruktur pada terikan mudah, kekuatan patah keluli karbon dan untuk mengkaji kesan transformasi struktur pada keliatan patah (K_{1C}). Projek ini melibatkan penyediaan 26 spesimen keluli karbon rendah iaitu keluli lembut. Dua takuk diameter (5.6 mm and 4.2 mm) dan dua sudut takuk (α) iaitu 60 ° dan 80 ° telah digunakan untuk memerhatikan keliatan patah keluli. Mengikut proses rawatan haba penuh penyepuhlindapan, ia boleh digunakan untuk membezakan mikrostruktur keluli dan kesannya terhadap keliatan patah juga diperhatikan. Proses mounting dilakukan kepada dua spesimen sebelum pemerhatian mikrostruktur menggunakan Mikroskop Optik. Ujian tegangan dilakukan dan keliatan patah boleh didapati melalui pengiraan. Keputusan didapati bahawa spesimen rawatan haba adalah lebih lembut dan rapuh tetapi untuk spesimen tiada rawatan haba ia lebih kuat dan lebih keras. struktur berbutir kecil meninggikan kekuatan patah. Sudut takuk yang lebih tinggi memberikan kekuatan patah yang lebih rendah dan diameter takuk yang lebih rendah memberi bebanan patah yang lebih rendah. Untuk sudut 60°, takuk yang lebih rendah diameter memberi kekuatan patah yang lebih tinggi. Untuk sudut 80°, takuk yang lebih rendah diameter memberi kekuatan patah yang lebih rendah. Mikrostruktur keluli mempunyai pengaruh yang kuat ke atas nilai K_{1C}. Struktur bijian halus telah didapati mempunyai nilai yang lebih tinggi K_{1C} daripada struktur berbutir kasar dan lebih luas. Sampel tiada rawatan haba lebih kuat dan lebih keras tetapi untuk sampel rawatan haba ia lebih lembut dan rapuh.

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LIST OF SYMBOLS

mm	Millimeter
MPa	Mega Pascal
%	Percent
kN	Kilo newton
K_{1C}	Fracture toughness
°	Degree
D	Total diameter
Fe	Iron
C	Carbon
Mn	Manganese
S	Sulphur
Si	Silicone
d	Notch diameter
α	Notch angles
^{o}C	Degree Celsius
Cr	Cromium
Mo	Molybdenum
m	Meter
Ni	Nickel
Ti-6A1-4V	Titanium Alloy
Sn	Stannum
rpm	Revolution per minutes
min	minutes

N	Spindle speed
CS	Cutting speed
d	Diameter of raw material
f	feed
v_f	Feed rate
d_o	Diameter of raw material initial
d_f	Diameter of raw materil final
rev	Revolution
P_f	Fracture load
Fe_3C	Cementite
CCRB	Circumferentially cracked round bar
CNC	Computer numeric control

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
MS	Malaysian Standard
AISI	American iron and steel institute
CT	Compact tension
ANSI	American National Standards Institute
SENB	Single edge notch bending
UTM	Universal testing machine
PMMA	Polymethyl methacrylate
PS	Polystyrene

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The measure of resistance to crack propagation is termed as fracture toughness (Dieter, 1988). In general machine components and structural components are designed over sized in order to avoid failure. This leads to consumption of more material and over weight problem. Hence such efforts are not cost effective. This problem is basically due to non availability of fracture toughness data to the design engineers. In view of this fracture toughness data are very useful in designing machine and structural components which are safe but not over sized and overweight.

Fracture toughness is measured in terms of K_{1C} (plane-strain fracture toughness) where K stands for stress intensity factor at the crack tip, I- denotes that the fracture toughness test is performed in tensile mode and C-denotes that the value of K is critical. When K attains critical value then crack propagation becomes unstable and results in fracture of the components. K_{1C} is a basic material property like yield strength. For low strength and high ductility materials like low carbon steels which find wide applications in the making of pipes for nuclear power plants (Knott, 1979), J_{1C} (J-integral) is determined instead of K_{1C} due to heavy amount of plastic deformation at the crack tip. In such cases K_{1C} is not a valid data (Dieter, 1988; Wei et al., 1982).

K_{1C} is normally determined by using compact-tension (CT) specimen or single edge notch bend (SENB) or three-point loaded bend specimens which are standardized by ASTM (Dieter, 1988). In these techniques, specimen preparations and test are quite tedious and time consuming. K_{1C} determination by round notched tensile specimen is quick and tensile test can be used instead of universal testing machine (UTM). It can also be used in preliminary selection of fracture tough materials from a vast lot.

Another advantage of such specimen is their radial symmetry, which makes them particularly suitable for studying the impact of the microstructure on fracture toughness of steel. Namely, due to the radial symmetry of heat transfer, the formation of a microstructure along the circumferential area is completely uniform. Further, this method also has significance in measuring the fracture toughness of hard and brittle alloys, since their high notch sensitivity does not allow the creation of a fine crack in the CT or SENB specimen by fatigue or makes it extremely difficult.

1.2 PROBLEM STATEMENT

Commercial ultrahigh strength, low alloy steels used in high performance aerospace system may develop fatigue and stress carrions cracks during service and lead to catastrophic failure. Fracture toughness is a critical fracture parameter for design against crack propagation of the ultrahigh strength steel. Recent research has studied the effect of microstructure parameter that control the mechanical property such as differenced in retained pearlite level, amount of proeutectoid ferrite, iron and alloy carbide distribution and grain size. However, it is not clear from the information exactly how the microstructure influence the facture toughness. In this project, the carbon steel will be studied to determine the effect of transformation structure on K_{1C} and to find the effect of microstructure on plain strain fracture toughness of carbon steel.

1.3 OBJECTIVE

i. To study the effect of microstructure on plain strain fracture toughness of carbon steel.
ii. To study the effect of transformation structure on fracture toughness (K_{1C})

1.4 PROJECT SCOPE

i. The material used is low carbon steel (mild steel AISI 1025).
ii. Perform the preparation of 26 specimens with certain notch and diameter. There is also different in the diameter of the notch.
iii. Perform full annealing heat treatments process to differentiate the microstructure of the steel.
iv. Perform the metallographic observation using the Optical microscope.
v. Perform the tensile test.
vi. Determine the fracture toughness by calculation.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

As part of the project, the analysis of the literature was done as it uses to have a further understanding of the project. The materials that used for the literature review were from journals, books and other sources. The review was to find out the relevance of the project and it must have a significant relation to the project.

2.2 MICROSTRUCTURE

Metals are crystalline when in the solid form. The crystal structure of a solid metal refers to the internal structure or arrangement of the atoms in an ordered, repeating, and three dimensional patterns. Normal metallic objects are polycrystalline, which means they consist of an aggregate of many very small crystals. These crystals are called grains. Some metallic objects, such as castings, have very large grains that can be resolved with the naked eye and these structures are referred to as macrostructures. Typically, the grains of a metal object are very small, and cannot be viewed with the naked eye. The structural features of the small grains are observed using an optical microscope or metallograph, or an electron microscope, at magnifications greater than 100 times. Structures requiring this range of magnification for their examination are called microstructures (Copper Development Association, 2012).

The most important aspect of any engineering material is its structure. The structure of a material is related to its composition, properties, processing history and performance. And therefore, studying the microstructure of a material provides information linking its composition and processing to its properties and performance. Interpretation of microstructures requires an understanding of the processes by which various structures are formed.

Physical Metallurgy is the science which provides meaningful explanations of the microstructures, through understanding what is happening is inside a metal during the various processing steps. Metallography is the science of preparing specimens, examining the structures with a microscope and interpreting the microstructures.

The structural features present in a material are a function of the composition and form of the starting material, and any subsequent heat treatments and or processing treatments the material receives. Microstructural analysis is used to gain information on how the material was produced and the quality of the resulting material. Microstructural features, such as grain size, inclusions, impurities, second phases, porosity, segregation or surface effects, are a function of the starting material and subsequent processing treatments. The microstructural features of metals are well defined and documented, and understood to be the result of specific treatments. These microstructural features affect the properties of a material, and certain microstructural features are associated with superior properties (Copper Development Association, 2012).

2.2.1 Microstructural analysis

Macrostructural and microstructural examination techniques are employed in areas such as routine quality control, failure analysis and research studies. In quality control, microstructural analysis is used to determine if the structural parameters are within certain specifications. It is used as a criterion for acceptance or rejection. The microstructural features sometimes considered are grain size, amount of impurities, second phases, porosity, segregation or defects present. The amount or size of these features can be measured and quantified, and compared to the acceptance criterion. Various techniques for quantifying microstructural features, such as grain size, particle or pore size, volume fraction of a constituent, and inclusion rating, are available for comparative analysis (Smith et al., 2006).

Microstructural analysis is used in failure analysis to determine the cause of failure. Failures can occur due to improper material selection and poor quality control. Microstructural examination of a failed component is used to identify the material and the condition of the material of the component. Through microstructural examination one can determine if the component was made from specified material and if the material received the proper processing treatments. Failure analysis, examining the fracture surface of the failed component, provides information about the cause of failure.

Failure surfaces have been well documented over the years and certain features are associated with certain types of failures. Using failure analysis it is possible to determine the type of stress that caused the component to fail and often times determine the origin of the fracture.

Microstructural analysis is used in research studies to determine the microstructural changes that occur as a result of varying parameters such as composition, heat treatment or processing steps. Typical research studies include microstructural analysis and materials property testing. Through these research programs the processing - structure - property relationships are developed (Copper Development Association, 2012).

2.2.2 Metallography

Metallography is the study of the structure of metals. It includes the techniques used to prepare specimens for examination, examining the specimen and interpreting the structures. Specimen preparation is an important part of metallography. A specimen must be appropriately prepared to ensure correct observation and interpretation of the microstructure. Specimen preparation consists of sample selection, sectioning, grinding, polishing, and etching. Adequate sample selection provides a statistically reliable description of the material quality. The number, location and orientation of the samples examined are important parameters in sample selection. Sectioning, grinding and polishing are used to prepare a flat specimen with a mirror like finish. Care must be taken during sample preparation not to introduce artifacts which lead to invalid microstructure interpretations (Copper Development Association, 2012).

Sometimes it is beneficial to examine the specimen in the as polished condition. The as polished condition is useful for examining the microstructures of materials whose constituents exhibit large differences in light reflectivity after polishing. Porosity and inclusions are examples of features that are easily observed in the as polished condition. But most materials are etched to reveal the microstructure. Etching is a controlled corrosion process resulting from electrolytic action between surface areas of different potential. Etching reveals the microstructure of a material by selective dissolution of the structure. Specimens are then examined using optical and electron microscopes (Nath et al., 2006). There are also many other techniques used to characterize the structure of metals, but this article will concentrate on microstructural characterization.

2.3 PLAIN STRAIN

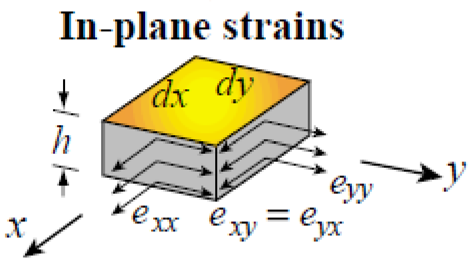

Figure 2.1: Notational conventions in-plane strain of a thin plate in plane stress

Source: (Colorado, 2011)

Hardness and tensile strength of a material generally increase with increasing pre-strain, and the rate of material removal in adhesive and abrasive wear processes is inversely proportional to hardness (Archard, 1953).

In plane strain, one deals with a situation in which the dimension of the structure in one direction, say the z-coordinate direction, is very large in comparison with the dimension of the structure in the other two directions (x-and y-coordinates axes), the geometry of the body is essentially that of a prismatic cylinder with one dimension much larger than the others.

The applied forces act in the x-y plane and do not vary in the in the z direction. Some important practical applications of this representation occur in the analysis of dams, tunnels and other geotechnical works. Also such small-scale problems as bars and rollers compressed by forces normal to their cross section are amenable to analysis in this way.

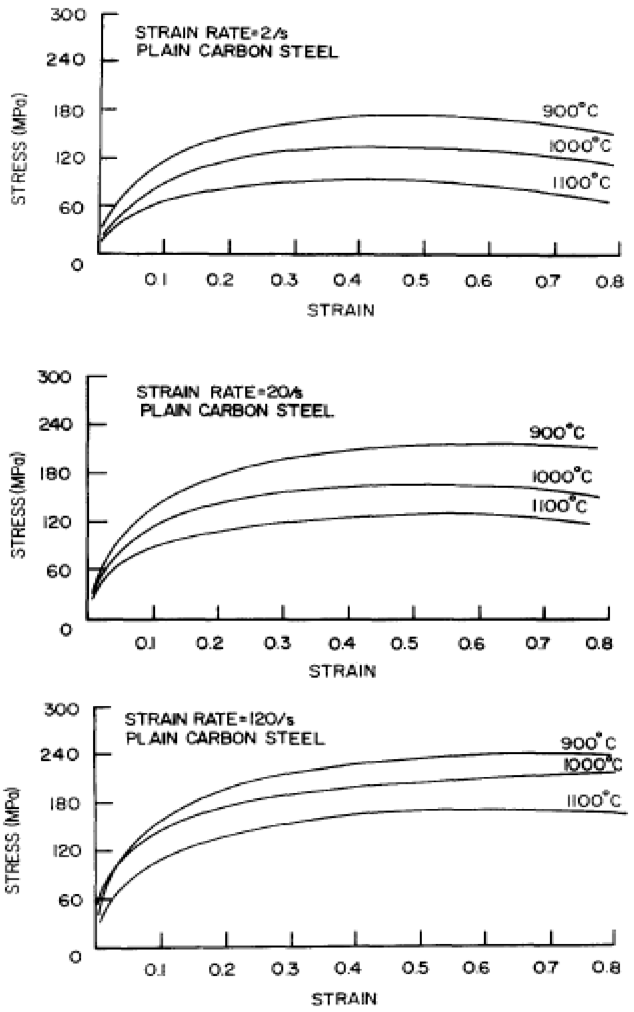

Figure 2.2: Cam plastometer flow-stress measurements for a plain carbon steel:strain rate (a) = 2s^{-1};(b) = 20s^{-1}; (c) = 120s^{-1}.

Source: (Baragar, 1987)

2.4 FRACTURE TOUGHNESS

Although the measurement of fracture toughness has been standardized for quite some time, fracture toughness (K_{1C}) is occasionally measured using specimens of non-standard shape. The use of round notched and precracked tensile specimens is quite frequent. The advantage of such specimens is their radial symmetry, which makes them particularly suitable for studying the impact of the microstructure on fracture toughness of metals. Namely, due to the radial symmetry of heat transfer, the formation of a microstructure along the circumferential area is completely uniform.

This is also of significance in measuring the fracture toughness of hard and brittle alloys, since their high notch sensitivity does not allow the creation of a crack by fatiguing or makes it extremely difficult. In such alloys, the fatigue crack can be created in a specimen before final heat treatment. In such specimens the plain strain state is obtained at a somewhat smaller size than in conventional compact-tension (CT) specimens. The key problems in measuring fracture toughness using round notched and precracked specimens are linked to the eccentricity of the fatigued area, sometimes also with the blunting of the fatigue crack tip and in hard, high speed steels even with the disturbing e.ect of larger carbide clusters, which represent the weak spots on or near the fracture surface.

From previous study, it have been said that the smaller the grain size, the higher the strength of the metal (Nath et al., 2006). It seem that when notch angle decreases (sharper notch), it is observed that K_{1C} decreases (Bayram et al., 1999).

The next figure 2.3 will show the stress strain diagram of the brittle fracture and the ductile fracture toughness for alloys.

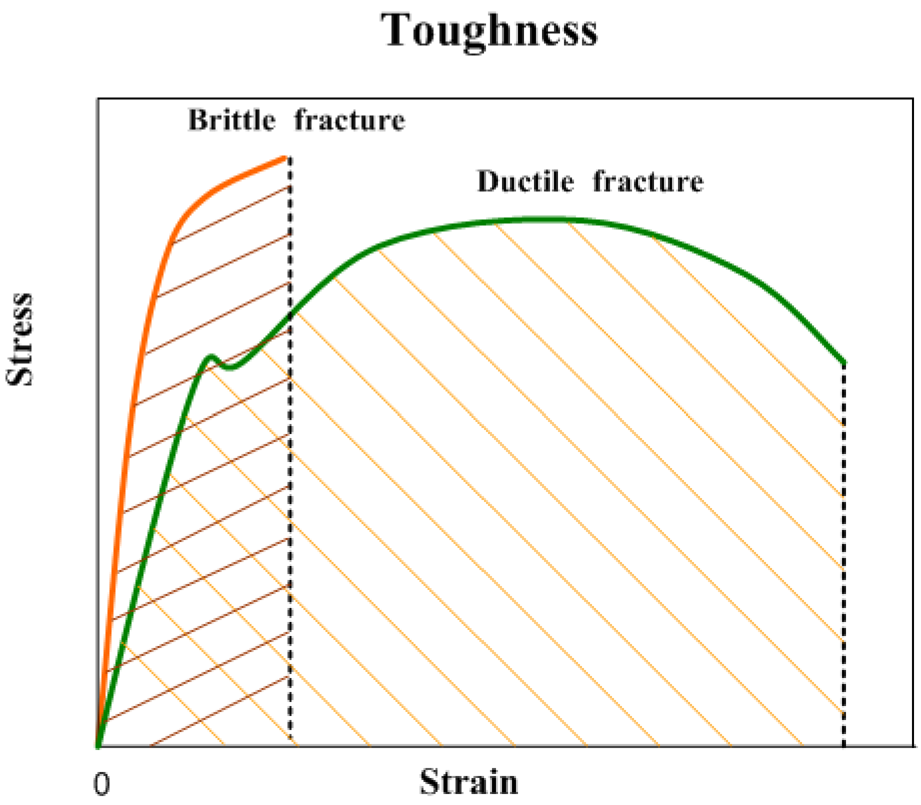

Figure 2.3: Stress strain diagram.

Source: (Kopeliovich, 2011)

For the plain strain fracture toughness, for thin samples, the value fracture toughness K_{1C} decreases with increasing sample thickness, b. When performing a fracture toughness test, the most common test specimen configurations are the single edge notch bend (SENB or three-point bend), and the compact tension (CT) specimens, but in this experiment the testing is done by using the tensile test.

Table 2.1: Room-temperature plain strain fracture toughness values

Material	K_{1C}	
	MPa m$^{1/2}$	**psi in$^{1/2}$**
	Metals	
2024-T351 Aluminium	36	33000
4340 Steel (tempered @ 260°C)	50.0	45800
Titanium Alloy (Ti-6A1-4V)	44-66	40000-60000
	Ceramics	
Aluminium Oxide	3.0-5.3	2700-4800
Soda-lime glass	0.7-0.8	640-730
Concrete	0.2-1.4	180-1270
	Polymers	
Polymethyl methacrylate (PMMA)	1.0	900
Polystyrene (PS)	0.8-1.1	730-1000

Source: (Callister, 2000)

2.5 CARBON STEEL

Steel is an alloy formed between the union of iron and smaller amounts of carbon. Carbon seems to the most appropriate material for iron to bond with. Carbon works as a strengthening instrument in steel. It further solidifies the structures inherent in iron. By tinkering with the different amounts of carbon present in the alloy, many variables can be adjusted such as density, hardness and malleability. Increasing the level of carbon present will make the steel more structurally delicate, but also harder at the same time.

Steel is more or less classified by its inherent carbon content. High-carbon steel is traditionally used for fashioning cutting tools and dies because one of its distinguishing features is great hardness. Steel with a lower to medium level of carbon will typically be reserved for metal sheeting for use in construction, due to its increased hardness and malleability (Carbon Steel, undated).

Steels containing only carbon as the specific alloying element are know as carbon steels. These steels can also contain up to 1.2% manganese and 0.4% silicon. Residual elements such as nickel, chromium, aluminium, molybdenum and copper, which are unavoidably retained from raw materials, may be present in small quantities, in addition to ‘impurities’ such as phosphorous and sulphur.

Steels are described as mild, medium- or high-carbon steels, according to the percentage of carbon they contain. Mild steel is an iron alloy that contains less than 0.25% carbon. Medium carbon steel having carbon content ranging from 0.25 to 0.70% improves in the machinability by heat treatment. High carbon steel is steel containing carbon in the range of 0.70 to 1.05% and is especially classed as high carbon steel. In this experiment, mild steel is used based on the stock that has from the faculty store.

Mild steel is very reactive and will readily revert back to iron oxide (rust) in the presence of water, oxygen and ions. The readiness of steel to oxidize on exterior exposure means that it must be adequately protected from the elements in order to meet and exceed its design life.

Prior to painting, new mild steel surfaces should be inspected for millscale, rust, sharp edges, laminations, burr marks and welding flux, forming or machine oils, salts, chemical contamination or mortar splashes on them, all of which must be removed.

Table 2.2: Properties of plain carbon steel

Material	**0.2% C Steel**	**0.4% C Steel**	**0.8% C Steel**
Density (10^3 kgm^{-3})	7.86	7.85	7.84
Thermal conductivity (Jm^{-1}K^{-1}s^{-1})	50	48	46
Thermal expansion (10^{-6}K^{-1})	11.7	11.3	10.8
Young's modulus (GNm^{-2})	210	210	210
Tensile strength (MNm^{-2})	350	600	800
Elongation (%)	30	20	8

Source: (Raghavan, 2001)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, in order to make this experiment is being done smooth and in the schedule, a flow of method was used. The analysis starts off with project planning by using a Gantt chart and a flow chart. The flow chart acts as a guide to successfully carry out this case study step by step while the Gantt chart helps to make sure that the project is within its timeframe. Data acquisition by using accelerometer is the backbone of this project, therefore using appropriate and precise steps is imperative in order to achieve the expected result. Once this has been done, the tensile test need to be done to find the maximum load in order to find the fracture toughness. Finally the analysis of the whole project may be tabulated and concluded in the following chapter.

3.2 FLOW CHART METHODOLOGY

To achieve the objectives of the project, methodology were constructed based on the scope of product as a guiding principal to formulate this project successfully. The terminology of the work and planning for this project are shown in the flow chart Figure 3.1. This is to make sure that the experiment is in the right direction.

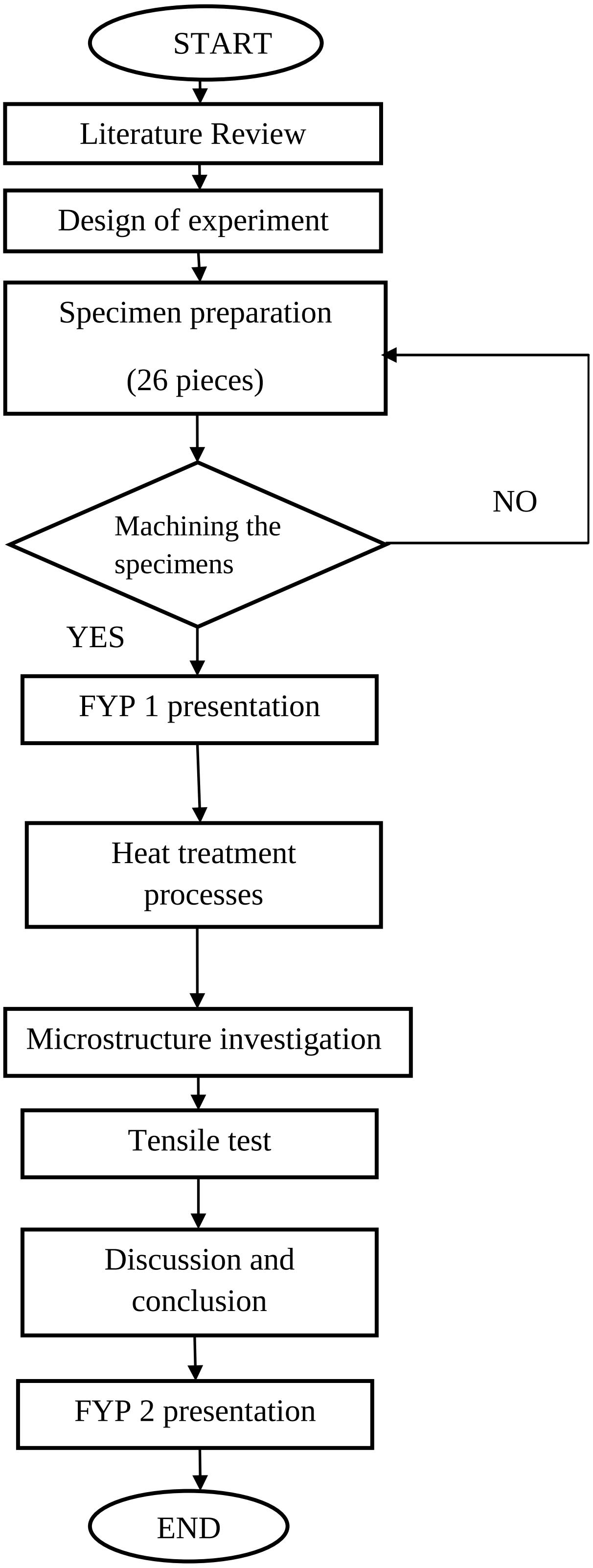

Figure 3.1: Overall flowchart

3.3 PROCEDURE

The procedure to run these analyses are consists of specimen preparation until data analysis and results are shown in Figure 3.2.

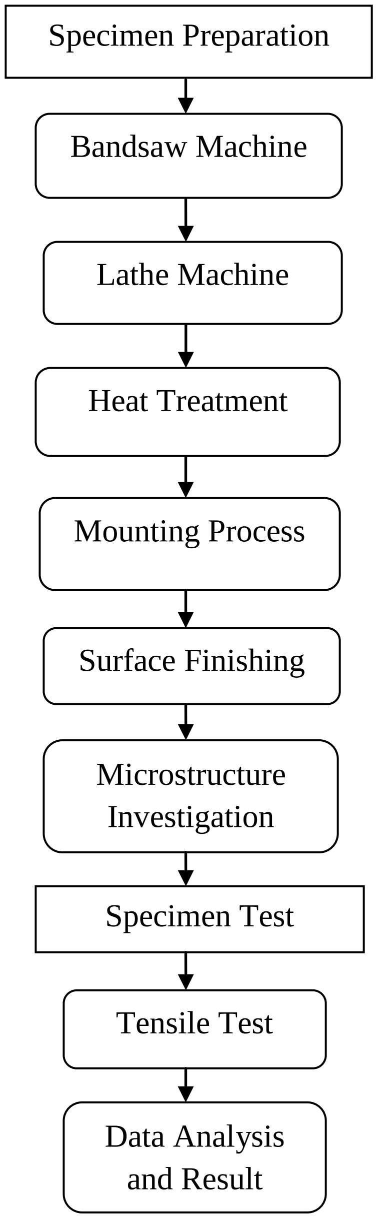

Figure 3.2: Methodology flowchart

3.4 DESIGN OF EXPERIMENT

The important things that need to be done are the design of experiment. From all the discussions, the things need to be done are selecting the right material that is low carbon steel (mild steel). From the material composition test done, spark emission spectrometer is used to check the composition of the sample. The material that are selected is low carbon steel AISI 1025. Then the machining processes are done to specify the design of the specimen that can be getting from the journal and that are fitted for the tensile test.

After that, the heat treatment that consists of one heat treatment that are full annealing processes are done after the specimen have been heated for certain temperature and certain time. Then, two samples from heat treated material and unheated material need to be observing the microstructure using the optical microscope. Next is the experiment to see the maximum load in order to find the fracture toughness of the low carbon steel by using tensile test machine. Finally, after the fractured of the material, the data needed to be collected and the effect and fracture toughness can be discussed.

3.4.1 Specimens preparation

After the design of experiment process end, the material preparations are done. The material that needed to be tested is low carbon steel. There are 26 pieces of raw material that are prepared before machining process to specify the design with the length of each pieces are 110 mm and the diameter is 20 mm. 24 specimens with notch have been prepared for tensile test by reducing the diameter from 20 mm to 7 mm diameter. Cylindrical specimens without notch having diameter 7 mm also have been prepared for microstructure observation. Specimens with notch are shown schematically in Figure 3.3. Specimens have been prepared as specification with following dimensions:

Specimen diameter (D) : 7 mm

Inner diameter of notch (d) : 5.6 mm and 4.2 mm (two inner diameter notches have been used).

Notch angle (α) : 60^{o} and 80^{o} (two notch angles have been used)

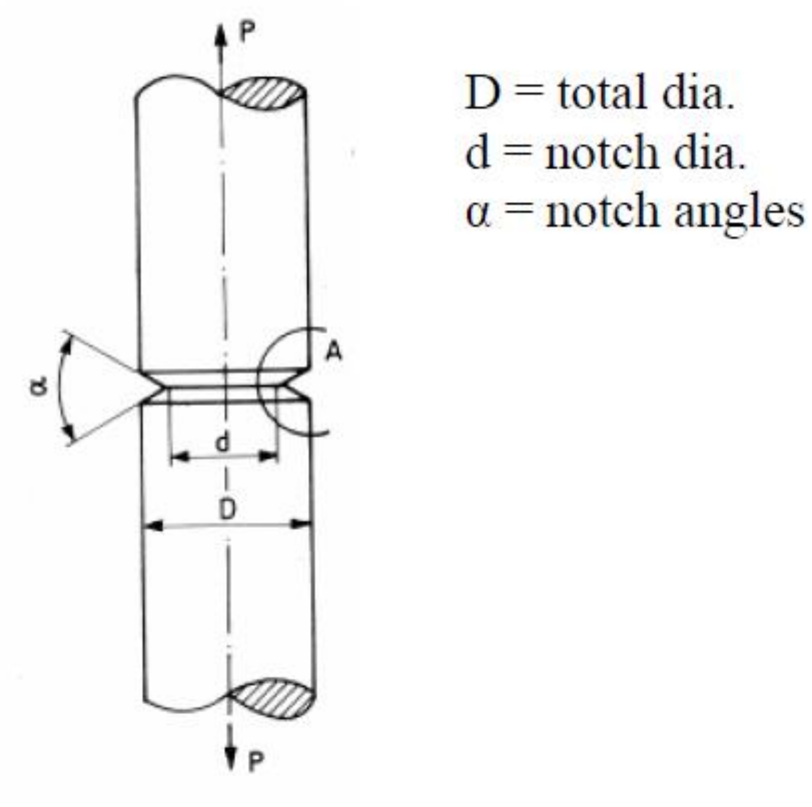

Figure 3.3: Schematic representation of round notched tensile specimen.

Source: (Nath et al., 2006)

The raw materials that can be getting from the warehouse are shown in the Figure 3.4. The length of the raw material is 110 mm with the 20 mm diameter.

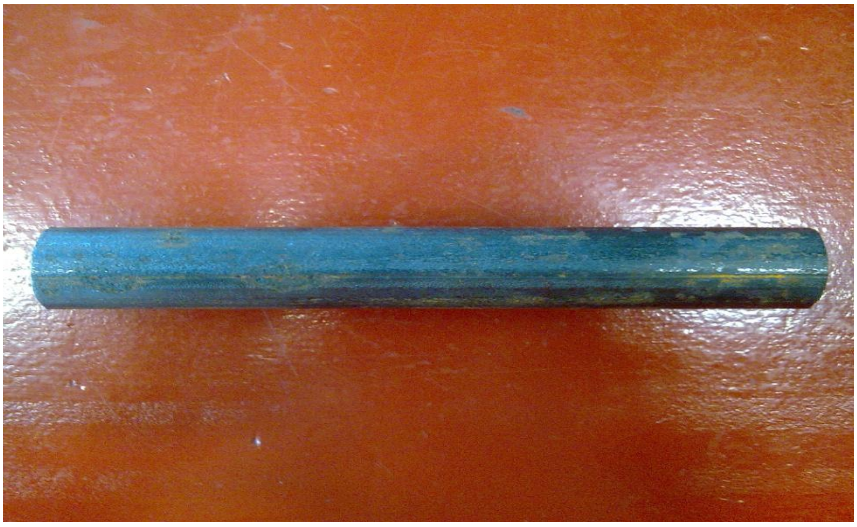

Figure 3.4: Raw material before machining.

3.4.1.1 Material

The material chosen for this experiment is mild steel where the carbon content of this steel is only 0.24% and is suitable for low carbon steel specification. The type of this steel is AISI 1025 mild steel. It was provided by the shape of cylindrical bar that has the length of 110 mm and 20 mm of diameter. This steel have low strength, high ductility and easy for machining process. Low carbon steel rod whose composition is given in Table 3.1 below is used in the present investigation. The diameter of the rod is 20 mm. From the percentage of carbon, the material according to AISI is AISI 1025.

Table 3.1: Chemical composition of steel used, wt%

Chemical composition	**Reading**			
	1	**2**	**3**	**Average (%)**
Iron (Fe)	98.2	98.2	98.2	98.2
Carbon (C)	0.253	0.235	0.231	0.240
Manganese(Mn)	0.448	0.462	0.447	0.453
Sulphur (S)	0.0084	0.0088	0.0090	0.0087
Silicone (Si)	0.0711	0.0632	0.0616	0.0653
Chromium (Cr)	0.132	0.135	0.136	0.134
Molybdenum(Mo)	0.0226	0.0237	0.0290	0.0251
Nickel (Ni)	0.111	0.109	0.111	0.110
Stannum (Sn)	0.0119	0.0121	0.0130	0.0123

3.4.1.2 Machining

The type of machining that needed to reduce the diameter of the raw material into the specific design of work piece is the turning process using lathe machine. Parameter such as feed rate, feed, the spindle speed and the depth of cut needed to be calculated before starting the process to produce a good finishing. The type of lathe machine that was used is ERL-1340 LATHE (ERL series) that was developed by SHIN CHUAN MACHINERY IND.CO.LTD. The tool used was carbide and has a radius of 0.2 mm. The cutting speed of low carbon steel by using high speed tool is listed in Table 3.2 below.

Table 3.2: Table for selection of cutting speed for mild steel

Material	Cutting speed (mm/min)
Mild steel	100-200

Then the spindle speed is calculated by the equation below:

$$N = \frac{CS \times 1000}{\pi d} \tag{3.1}$$

Where:

N = spindle speed (rpm)

CS = Cutting speed (mm/min)

d = diameter of raw material (mm)

From table 3.2, taking cutting speed ranging from 100 to 200 and substitute into equation 3.1

$$N = \frac{100 \times 1000}{\pi(20)}$$

$$= 1592 \text{ rpm}$$

The Table 3.3 below shows the feed rate based on the specimen.

Table 3.3: Table for selection of feed based on material

Material	Feed, f (mm/rev)
Mild steel	0.13
Brass	0.1
Aluminium	0.25

The feed rate is calculated as the equation below:

$$v_f = f \times N \tag{3.2}$$

Where:

f = feed (mm/rev)

N = spindle speed (rpm)

Substitute N=1592 rpm into equation 3.2 and taking the value of feed=0.13mm.rev

$$\begin{aligned} v_f &= 0.13 \times 1592 \\ &= 206.96 \text{ mm/min} \end{aligned}$$

The deep of cut is calculated as the equation below:

$$d = \frac{d_0 - d_f}{2} \tag{3.3}$$

Where:

d_0 = Diameter of raw material initial (mm)

d_f = Diameter of raw material final (mm)

Substitute d_0 with 20 mm and d_f with 7 mm in the equation 3.3.

$$d = \frac{20 - 7}{2}$$

$$= 6.5 \text{ mm}$$

Due to the calculated parameters that cannot be applied to the lathe machine manufactured by SHIN CHUAN MACHINERY IND.CO.LTD., the chosen parameters that are applied to the machine that are close to the calculated parameters. Using high speed spindle speed, H with speed of 1600 rpm and the gear used is LCTW1.

The procedures that were done are the lathe machine was switched on and makes sure the safety of us and machine was ensured so that the process will be smooth. Do not forget to wear goggle and safety boot. The specific parameters that were determined in the calculation were set up to the machine so that the finishing will be smooth. The raw material was attached to the spindle and was checked whether it is centralized so that there are no nipples at the end of the material.

Then, to make sure the work piece is not vibrating during machining process, a drill was made to the end of the work piece using centre drill that is a diameter of 2 mm and 5 mm length. Next, live center was attached to the drilled hole and make sure is rotates along with the work piece as a support to make sure the work piece is not vibrating during the process. Then, the machine was started using 1600 rpm of spindle speed and the feed that was 0.2 mm or 0.1 mm was slowly feed to the material. After the machining process is done, the work piece was measured using vernier calliper to make sure whether the specimens are machined according to the specific design. Then, the steps were repeated for other 25 pieces. The last step is to make sure all the power supply is off after finished using the machine. 5S is being done to make sure the cleanliness of the workplace.

Figure 3.5, 3.6 and 3.7 below shows the lathe machine that been used, turning process in the making and the workpiece after the machining process.

Figure 3.5: Conventional lathe machine ERL-1340 LATHE (ERL series)

Figure 3.6: Turning process

Figure 3.7: Workpiece (7 mm)

The other step to be done is to make the notch at the centre of the specimens, which are the 60^o and 80^o for the 5.6 mm and 4.2 mm inner diameter of notch. Below is the table showing the specimens quantity for the experiment.

Table 3.4: Specimen quantity for experiment

Notch diameter (d) : 5.6mm				**Notch diameter (d) : 4.2mm**				**Specimens for microstructure analysis**	
Notch + Heat Treatment		Notch + without Heat Treatment		Notch + Heat Treatment		Notch + without Heat Treatment		Heat treatment	No heat treatment
Notch angle(α)								1	1
60°	80°	60°	80°	60°	80°	60°	80°		
3	3	3	3	3	3	3	3		

The notch is done for the 24 specimens with 60° and 80° notches. The tool to make the notch is shown in Figure 3.8 and Figure 3.9 below and specimen after notch finishing is shown in Figure 3.10.

Figure 3.8: Tool for 60° notch

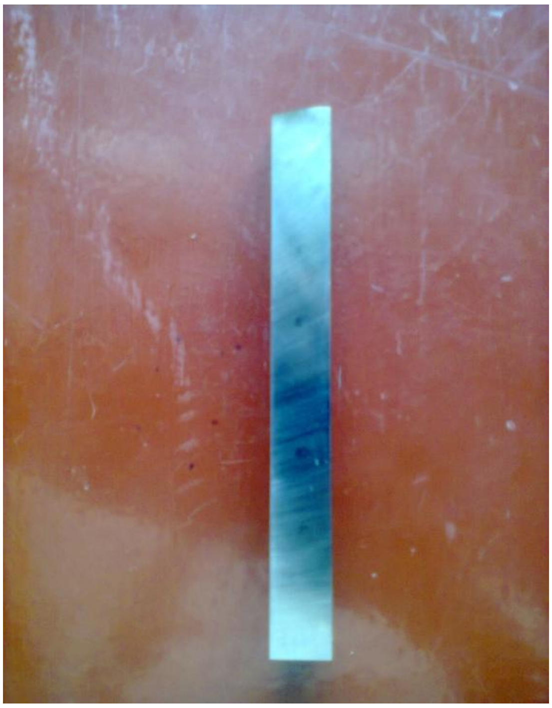

Figure 3.9: Tool for 80° notch

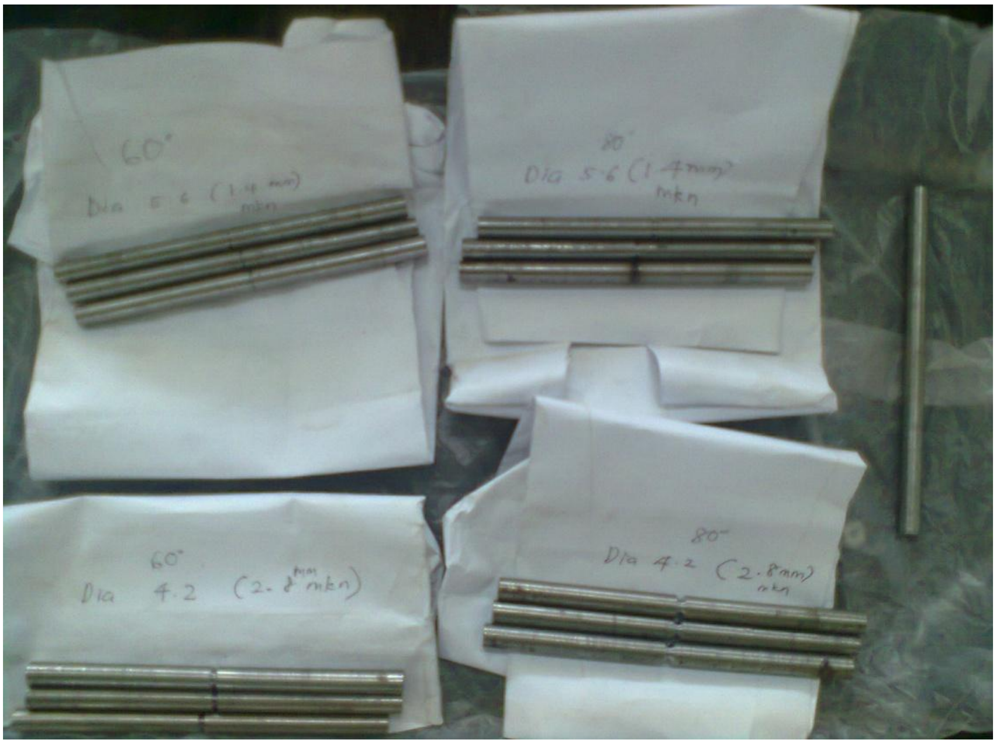

Figure 3.10: Specimens after notching process

3.4.2 Heat treatment

Heat treatment is a one way to change the strength of steel, change the microstructure and the grain size of the steel. For this experiment, only a heat treatment processes is done that are full annealing. The brand of the furnace that was used is ThermoConcept. Since tensile test exhibited very low ductility, so normalizing heat treat is dropped from the present study. Full annealing heat treatment consists of heating the 13 samples up to 900^{o}C for half an hour followed by furnace cooling. At the end, the furnace is switched off and samples are allowed to cool inside the furnace until its cool completely.

After heat treatment, samples have been cleaned by emery paper before tensile test. Two other samples with diameter 7 mm and unnotched is being made also as the comparison samples where one samples is annealing and one of it is as-received.

The procedures that to be done are the furnace was heated up until it reaches the temperature of 900°C. After the furnace has reached the specific temperature, all the work piece was putted in the furnace and was held in the furnace for 30 minutes. Then, furnace cooling is done by switched off the power supply and sample is allowed to cool inside the furnace. Next, the work piece was taken out and being clean by emery paper. The Figure 3.11 shows the condition of the specimens after the full annealing process.

Figure 3.11: Specimens after full annealing

Figure 3.12 shows the type of furnace that been used to do the full annealing heat treatment samples.

Figure 3.12: ThermoConcept furnace

3.4.3 Microstructure checking using Optical Microscope

Optical microscope is one way to check the microstructure of material after the heat treatment. The optical microscope generates an image that gives the viewer the impression of three dimensions. The use of optical microscope is to get the image of surface fracture and to define the type of microstructure that is happening to the material.

In this experiment, the two samples for comparison that are unnotched is being cut for each of it. Mounting have to be done before it can be seen using the optical microscope. The optical microscope is using 100X and 200X magnification. The Figure 3.13 below shows the optical microscope used to investigate the microstructure.

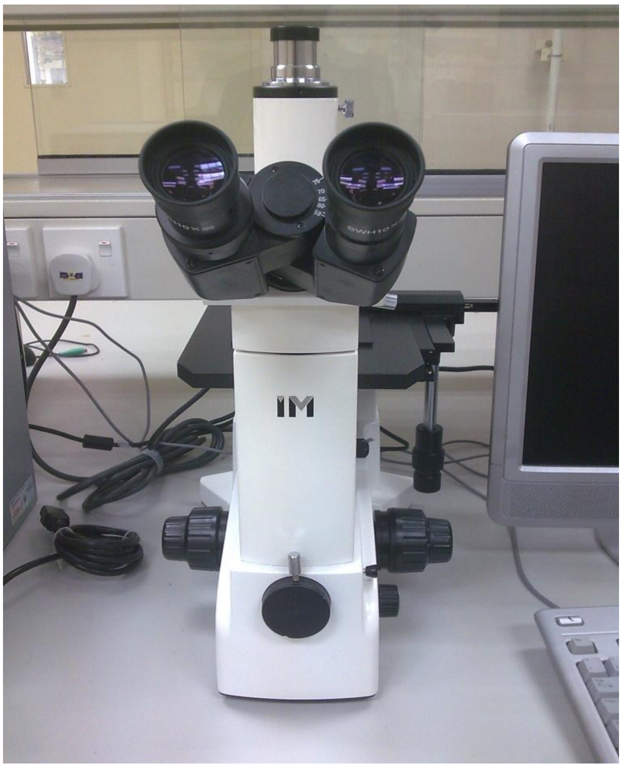

Figure 3.13: Optical microscope

3.4.4 Tensile test

Every 24 specimens of the material have to undergo the tensile test. From this test, the maximum load or fracture load (P_f) of each of the specimens can be get and from the test. Based from the P_f, the fracture toughness (K_{1C}) can be getting from the calculation using the formula below (Wang, 1996).

$$K_{1C} = \frac{\{0.932P\sqrt{D}\}}{(d^2\sqrt{\pi})} \tag{3.4}$$

The tensile machine that has been used is Instron Tensile Test Machine. A cross-head speed of 1 mm/min is maintained throughout the tensile test. Figure 3.14 below the Instron tensile test machine that been used for tensile test.

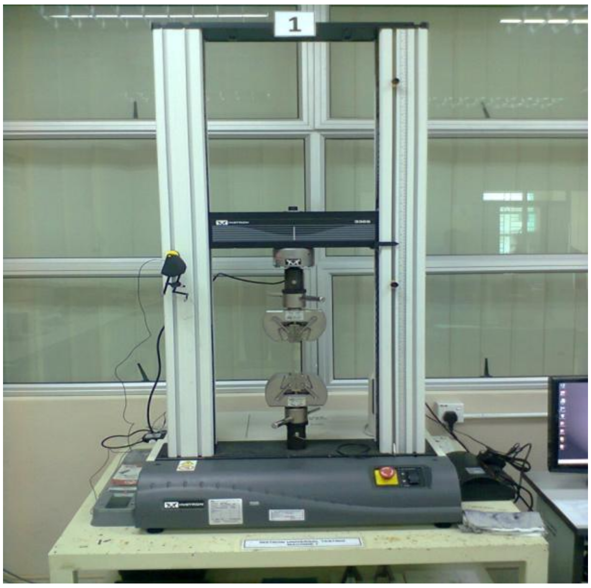

Figure 3.14: Instron tensile test machine

CHAPTER 4

RESULTS & DISCUSSION

4.1 INTRODUCTION

The analysis processes is the process to gather the result form any simulation process, theoretical equation or experiment process. The analysis method that are used in this project is the experiment of the mild steel that has been heat treated by full annealing heat treatment and non heat treated specimens due to certain notch diameter (d) to be subjected to maximum load or fracture load (P_f) from tensile test. In this project, the tensile testing has been conducted to define the maximum load that can be succeed by the specimens to failure in a certain range of applied stress which is a cross-head speed of 1 mm/min is maintained throughout the tensile test with two conditions of heat treatment process microstructure and non heat treatment process microstructure.

The purpose of this experiment is to study the effect of microstructure change from full annealing heat treatment processes affected the maximum load of the mild steel and the fracture toughness of the material and do the comparison from the as-received (non heat treated) specimens. Based on the studies, it was shown that the further heat treatment process is conducted in certain temperature, the material will resulted in lower fracture toughness compared to the non heat treated specimens that has not undergoes heat treatment processes.

4.2 MATERIAL COMPOSITION

The material composition for the specimens has been analyzed using spectrometer machine. The main purpose of this analysis is to define the percentage of carbon and iron type of material used in present study. The percentage of the chemical composition for this material is shown in Table 4.1. This analysis is also important to define the temperature that can be used for the heat treatment processes. The carbon percentage for the material used to become specimens in this experiment is 0.24%. Based on the composition, the grade for this material referring to American Iron and Steel Institute (AISI) is AISI 1025.

Table 4.1: Chemical composition of the specimens

Chemical composition	**Reading**			
	1	**2**	**3**	**Average (%)**
Iron (Fe)	98.2	98.2	98.2	98.2
Carbon (C)	0.253	0.235	0.231	0.240
Manganese(Mn)	0.448	0.462	0.447	0.453
Sulphur (S)	0.0084	0.0088	0.0090	0.0087
Silicone (Si)	0.0711	0.0632	0.0616	0.0653
Chromium (Cr)	0.132	0.135	0.136	0.134
Molybdenum(Mo)	0.0226	0.0237	0.0290	0.0251
Nickel (Ni)	0.111	0.109	0.111	0.110
Stannum (Sn)	0.0119	0.0121	0.0130	0.0123

4.3 MICROSTRUCTURE INVESTIGATION

In order to see determine whether the microstructure changes effect the fracture toughness or not, microstructure investigation has been done under optical microscope. Optical microscope of as-received steel sample at magnification 100X and 200X respectively. Hypoeutectoid steel is the steel that consist less than 0.8 percent of carbon. The full annealing heat treatment process usually applied for hypoeutectoid steels with less than 0.3 percent carbon. Percentage of carbon of this specimen is 0.24, which means this process is valid to be used.

For hypoeutectoid steel steel after annealing consist of proeutectoid ferrite + pearlite. Pearlite is the mixture of α ferrite and cementite (Fe_3C) (Smith et al, 2006). Here, black region shows pearlite and white region shows the proeutectoid ferrite. After heat treatment has been done using temperature 900°C for 30 minutes, the pearlite colonies which are the black region are coarser and the average grain size pearlite is increasing than the non heat treated specimens. It shows that the pearlite region is become wider and the proeutectoid ferrite becomes finer. The weight percentage of carbon is also increase. This have make the heat treatment specimens are softer and brittle but for the as-received specimens it is stronger and harder.

4.3.1 Mild steel with no heat treatment process

The type of microstructure for no heat treatment is the grain in white is proeutectoid ferrite and the grain in black is pearlite. It is done in two magnifications that are 100X and 200X. The Figure 4.1 and Figure 4.2 shows the observation of the microstrusture under 100X and 200X magnification.

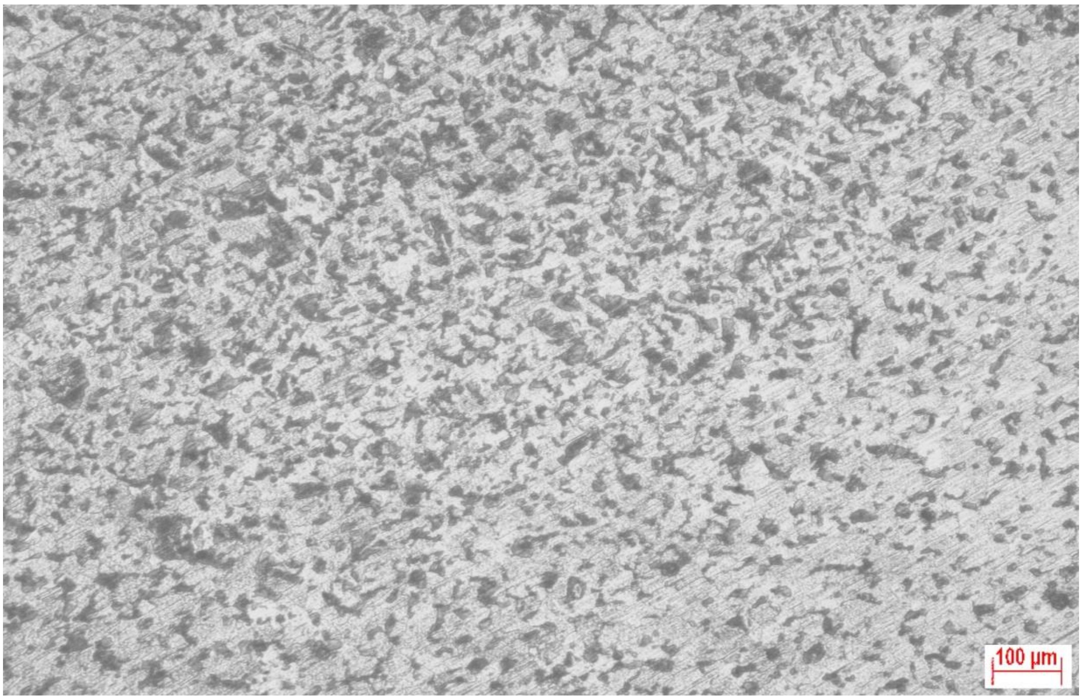

Figure 4.1: The microstructure under 100X magnification

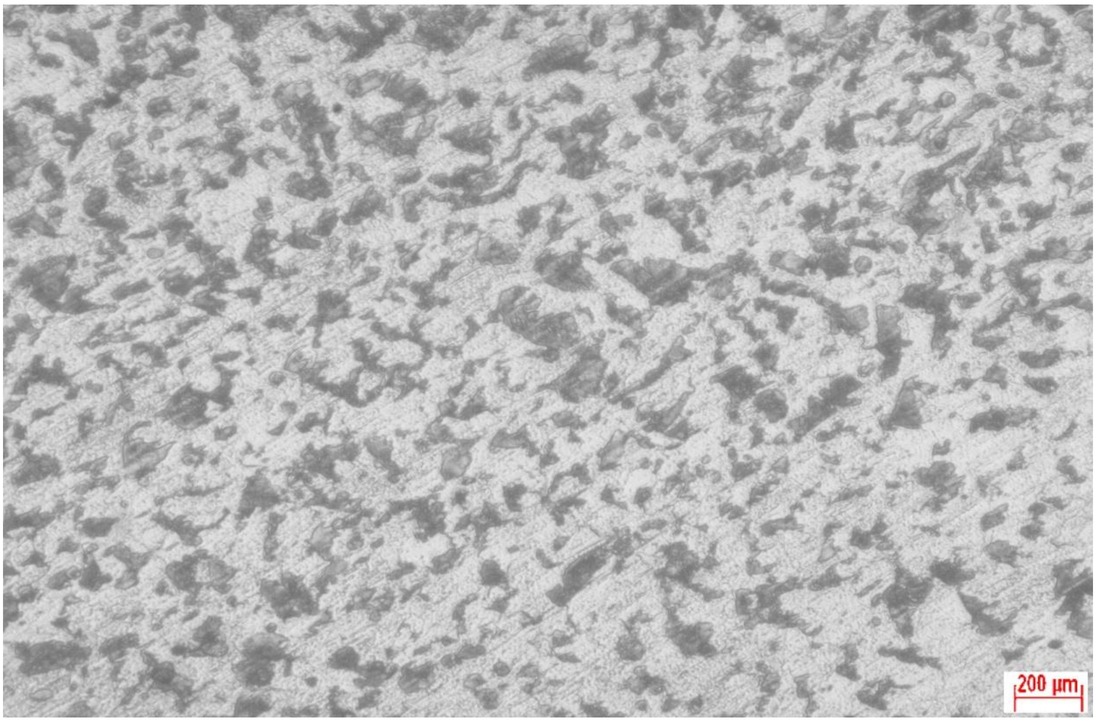

Figure 4.2: The microstructure under 200X magnification

4.3.2 Mild steel with heat treatment process

After heat treatment has been done using temperature 900°C for 30 minutes, the pearlite colonies which are the black region are coarser and the average grain size pearlite is increasing than the non heat treated specimens. It shows that the pearlite region is become wider and the proeutectoid ferrite becomes finer. The weight percentage of carbon is also increase. This have make the heat treatment specimens are softer and brittle but for the as-received specimens it is stronger and harder. Figure 4.3 below shows the observation of the microstructure under 200X magnification for the mild steel with the full annealing heat treatment process.

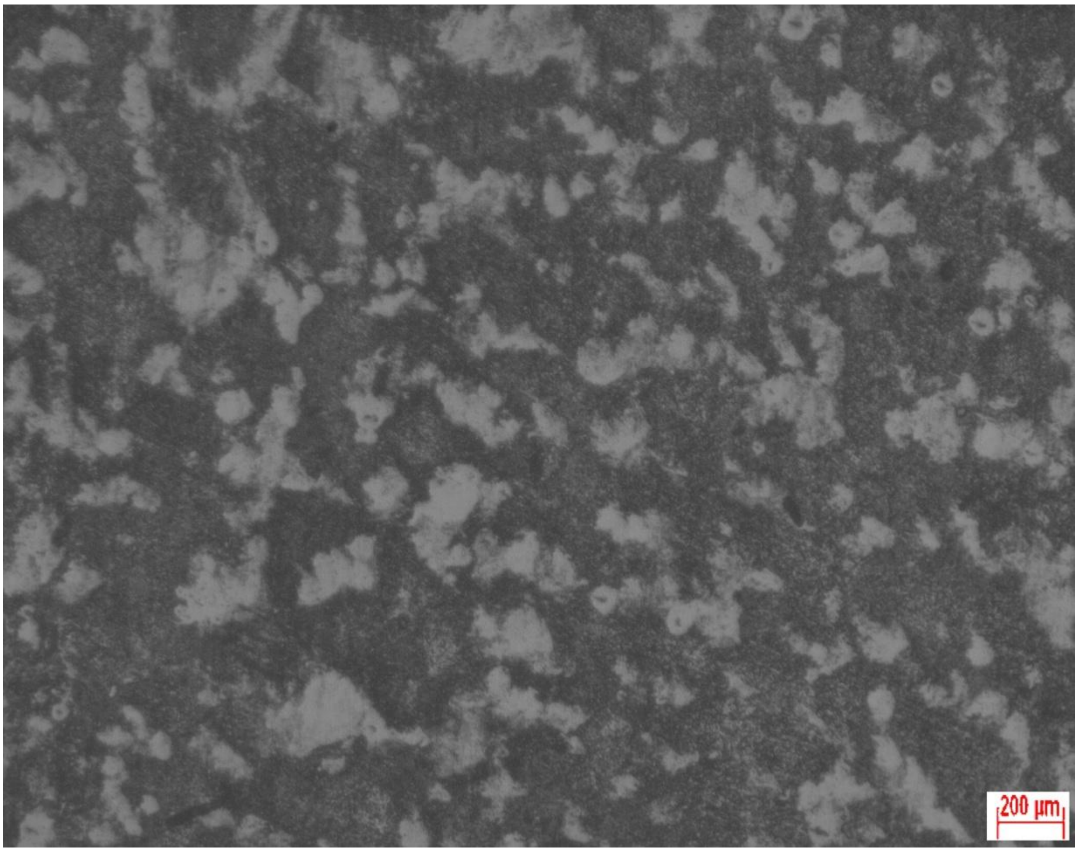

Figure 4.3: The microstructure under 200X magnification

4.4 TENSILE TEST PROPERTIES

From the the full annealing heat treatment process, microstructure indicated and being observed. Then, there is one more test to see and get the maximum load or fracture load (P_f) by the tensile test. The Instron tensile test machine have been used with A cross-head speed of 1 mm/min is maintain throughout the tensile test. To get the fracture load (P_f), the circumferentially cracked round bar (CCRB) specimen is fixed at the jaw of the tensile test machine and it undergo the tensile test until it broke. From this, the maximum load can be measured and by this data the fracture toughness (K_{1C}) can be calculated. The Table 4.2 below shows the result.

Table 4.2: Fracture load and fracture toughness for every specimen condition

Types of Samples	**Fracture Load (P_f), kN**		**Fracture Toughness (K_{1c}), MPa $m^{1/2}$**	
	60°	80°	60°	80°
No Heat Treatment, Inner Notch Diameter 5.6mm	16.25	15.58	22.80	21.86
Heat Treatment, Inner Notch Diameter 5.6mm	15.67	15.73	21.98	22.07
No Heat Treatment, Inner Notch Diameter 4.2mm	9.91	8.41	24.72	20.97
Heat Treatment, Inner Notch Diameter 4.2mm	9.70	8.21	24.19	20.48

From the data collected from and represented at Table 4.2, two graph to show the variation of fracture toughness with notch angle for heat treatment specimens and no heat treatment specimens have been plotted using Microsoft Excel. Figure 4.4 shows variation of fracture toughness with notch angle of heat treatment samples and Figure 4.5 shows variation of fracture toughness with notch angle of no heat treatment samples. Figure 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13 shows the graph of load vs extension from the tensile test. Table 4.3 until Table 4.10 shows the result of fracture load (P_f).

From the data on Table 4.2, it can be observed that the fracture load (P_f) and the fracture toughness (K_{1C}) of heat treatment steel have been decrease as it annealed but have been increased for notch 80° compare to 60° angle data. There is only slight an error for the data 80° angle for 5.6 mm notch diameter where it can be seen no heat treatment specimen have the lower value for fracture load compare to heat treatment samples. This happens due to some temperature drop when do the heat treatment or the roughness of the samples is a bit not good. This effect cause the fracture toughness of 80° angle for 5.6 mm inner diameter get the same problem.

For notch angle, a higher angle of notch give the lower value of the fracture toughness. It show the less angle of notch give more pressure to the samples throughout the tensile test. For 60° notch angle, 4.2 mm notch diameter have lower fracture load and it give higher K_{1C} but for 80° notch angle shows 4.2 mm notch diameter have lower fracture load and give a lower K_{1C} value. The best can be solve here is the lower notch angle have given higher K_{1C} but the main focus can be solve is heat treatment process have make the grain size of the pearlite wider and make the steel more softer and low in strength. Thats why the as-received specimen give higher value of K_{1C}.

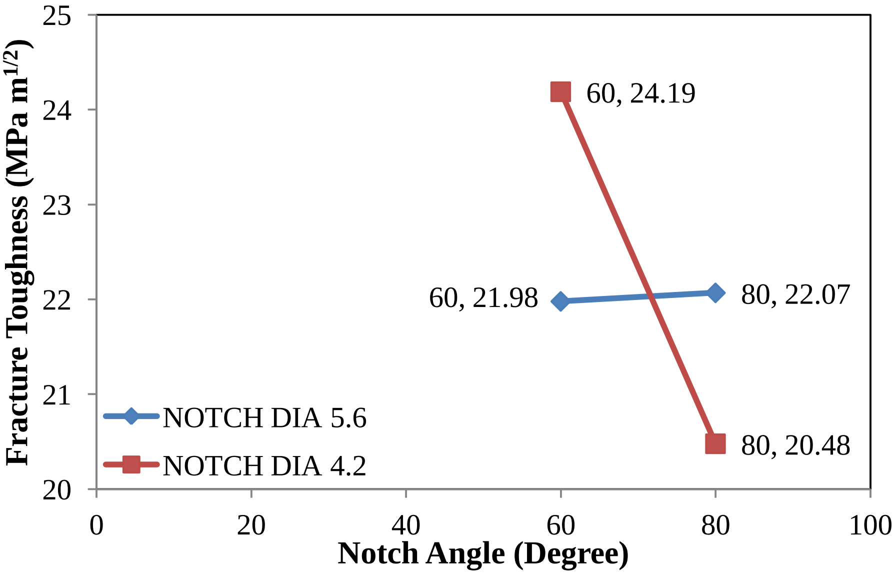

Figure 4.4: Variation of fracture toughness with notch angle of heat treatment samples

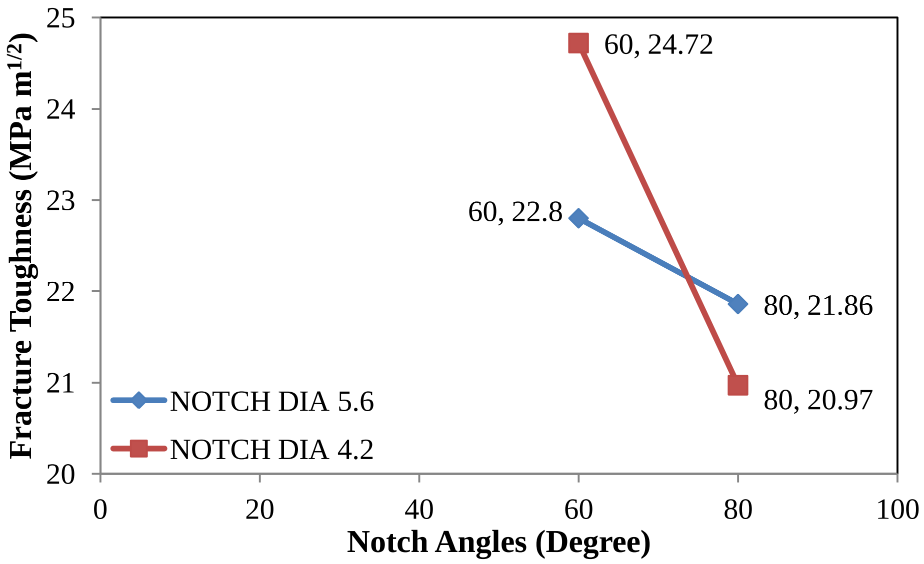

Figure 4.5: Variation of fracture toughness with notch angle of no heat treatment samples

4.4.1 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 5.6 mm, heat treatment, notch angle 60°

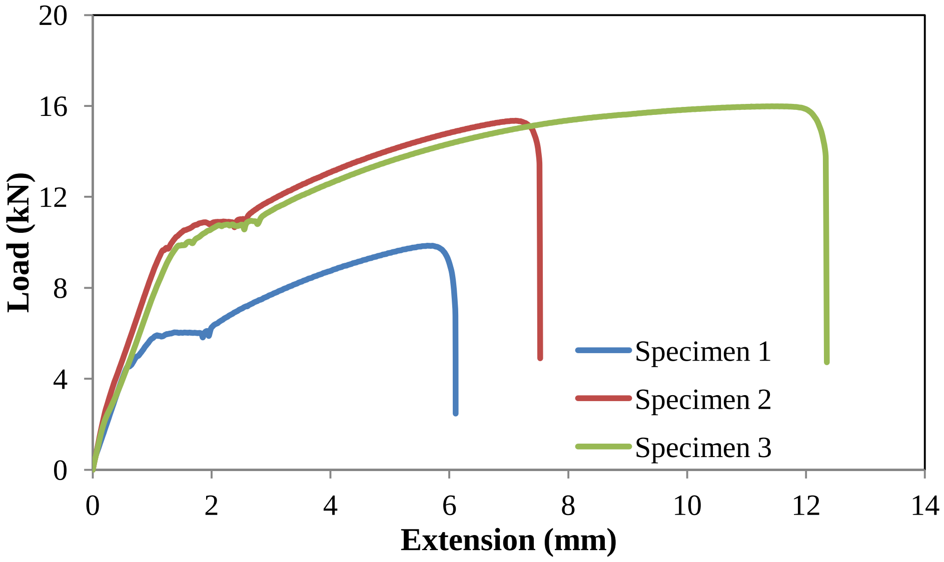

Figure 4.6: Graph load vs extension for three specimen for notch diameter (d) 5.6 mm, heat treatment, notch angle 60°

Table 4.3: Result of fracture load (P_f) for notch diameter (d) 5.6 mm, heat treatment, notch angle 60°

	Fracture load (P_f), [kN]
Specimen 1	9.85
Specimen 2	15.35
Specimen 3	15.98

The best fracture load to be choosen is the average fracture load = 15.67 kN

Sample of calculation:

$$K_{1C} = \frac{\{0.932P\sqrt{D}\}}{(d^2\sqrt{\pi})} \tag{3.4}$$

Where:

P = Maximum load or fracture load (P_f)

D = Specimen diameter = 7 mm = 0.007 m

d = Notch diameter = 5.6 mm or 4.2 mm = 0.0056 m or 0.0042 m

Taking the value of the fracture load to be 15.67 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(15.67kN)\sqrt{0.007}\}}{(0.0056^2\sqrt{\pi})}$$

$$= 21.98 \text{ MPa m}^{1/2}$$

4.4.2 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 5.6 mm, without heat treatment, notch angle 60°

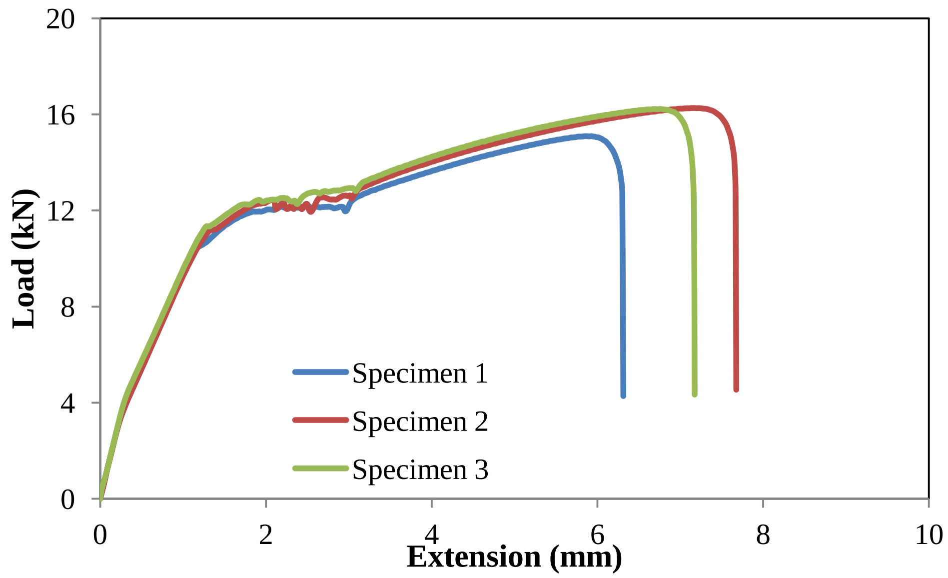

Figure 4.7: Graph load vs extension for three specimen for notch diameter (d) 5.6 mm, without heat treatment, notch angle 60°

Table 4.4: Result of fracture load (P_f) for notch diameter (d) 5.6 mm, without heat treatment, notch angle 60°

	Fracture load (P_f), [kN]
Specimen 1	15.09
Specimen 2	16.27
Specimen 3	16.22

The best fracture load to be choosen is the average fracture load = 16.25 kN

Taking the value of the fracture load to be 16.25 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(16.25kN)\sqrt{0.007}\}}{\left(0.0056^2\sqrt{\pi}\right)}$$

$$= 22.80 \text{ MPa m}^{1/2}$$

4.4.3 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 5.6 mm, heat treatment, notch angle 80°

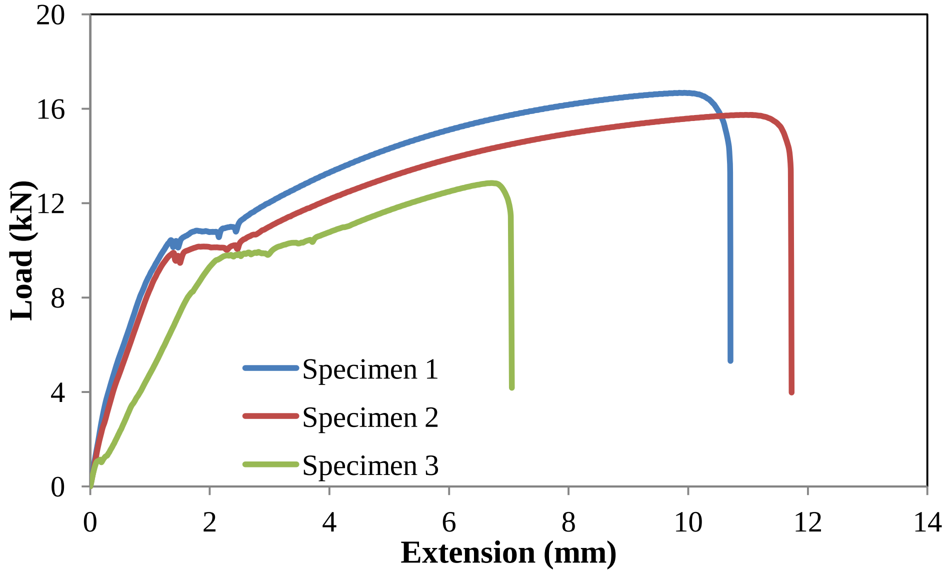

Figure 4.8: Graph load vs extension for three specimen for notch diameter (d) 5.6 mm, heat treatment, notch angle 80°

Table 4.5: Result of fracture load (P_f) for notch diameter (d) 5.6 mm, heat treatment, notch angle 80°

	Fracture load (P_f), [kN]
Specimen 1	16.67
Specimen 2	15.73
Specimen 3	12.85

The best fracture load to be choosen is the fracture load = 15.73 kN

Taking the value of the fracture load to be 15.73 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(15.73kN)\sqrt{0.007}\}}{\left(0.0056^2\sqrt{\pi}\right)}$$

$$= 22.07 \text{ MPa m}^{1/2}$$

4.4.4 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 5.6 mm, without heat treatment, notch angle 80°

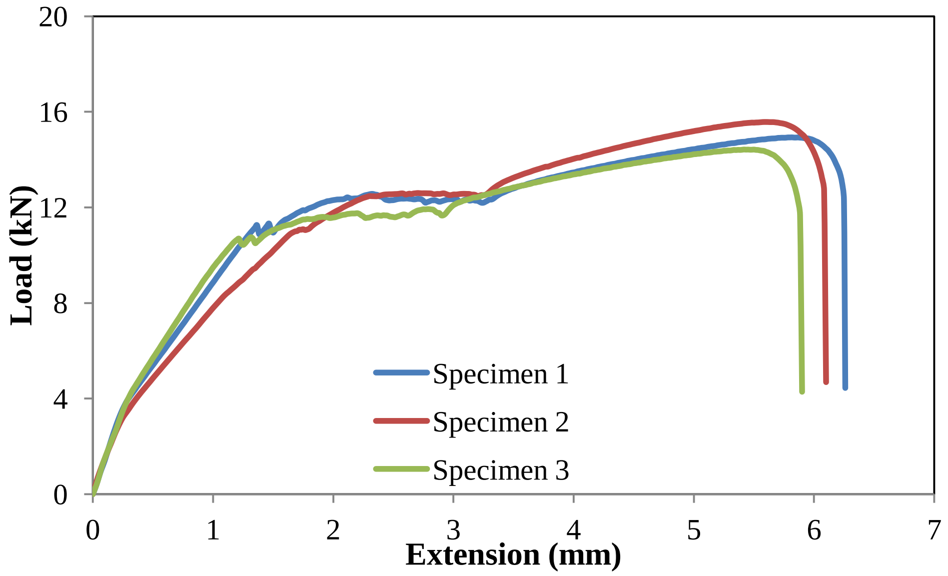

Figure 4.9: Graph load vs extension for three specimen for notch diameter (d) 5.6 mm, without heat treatment, notch angle 80°

Table 4.6: Result of fracture load (P_f) for notch diameter (d) 5.6 mm, without heat treatment, notch angle 80°

	Fracture load (P_f), [kN]
Specimen 1	14.93
Specimen 2	15.58
Specimen 3	14.42

The best fracture load to be choosen is the fracture load = 15.58 kN

Taking the value of the fracture load to be 15.58 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(15.58kN)\sqrt{0.007}\}}{(0.0056^2\sqrt{\pi})}$$

$$= 21.86 \text{ MPa m}^{1/2}$$

4.4.5 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 4.2 mm, heat treatment, notch angle 60°

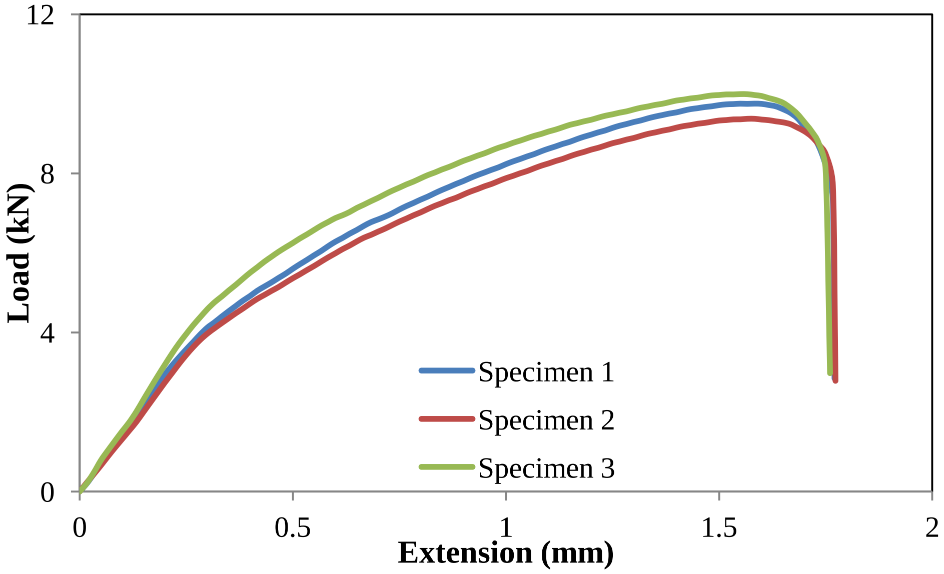

Figure 4.10: Graph load vs extension for three specimen for notch diameter (d) 4.2 mm, heat treatment, notch angle 60°

Table 4.7: Result of fracture load (P_f) for notch diameter (d) 4.2 mm, heat treatment, notch angle 60°

	Fracture load (P_f), [kN]
Specimen 1	9.75
Specimen 2	9.37
Specimen 3	9.99

The best fracture load to be choosen is the average fracture load = 9.70 kN

Taking the value of the fracture load to be 9.70 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(9.70kN)\sqrt{0.007}\}}{\left(0.0042^2\sqrt{\pi}\right)}$$

$$= 24.19 \text{ MPa m}^{1/2}$$

4.4.6 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 4.2 mm, without heat treatment, notch angle 60°

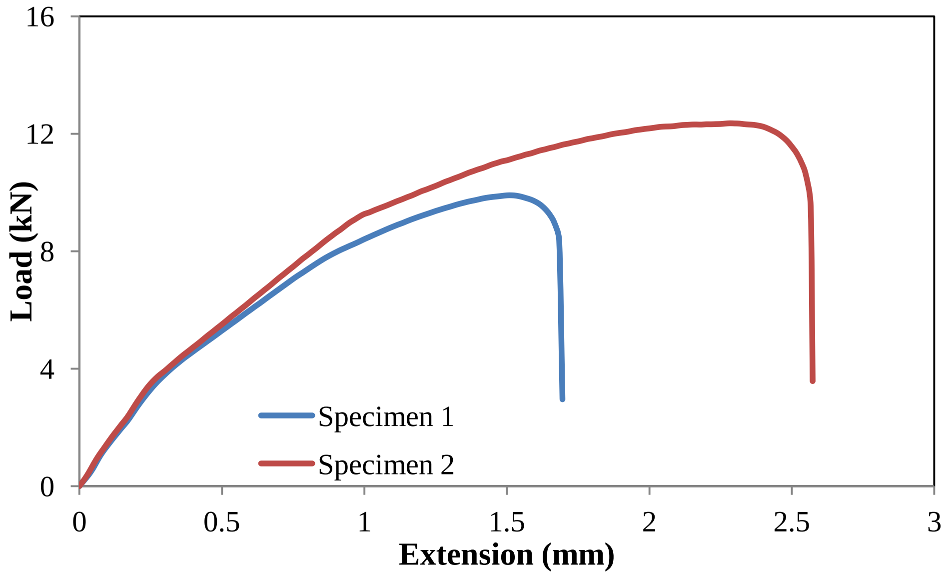

Figure 4.11: Graph load vs extension for two specimen for notch diameter (d) 4.2 mm, without heat treatment, notch angle 60°

Table 4.8: Result of fracture load (P_f) for notch diameter (d) 4.2 mm, without heat treatment, notch angle 60°

	Fracture load (P_f), [kN]
Specimen 1	9.91
Specimen 2	12.36

The best fracture load to be choosen is the fracture load = 9.91 kN

Taking the value of the fracture load to be 9.91 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(9.91kN)\sqrt{0.007}\}}{(0.0042^2\sqrt{\pi})}$$

$$= 24.72 \text{ MPa m}^{1/2}$$

4.4.7 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 4.2 mm, heat treatment, notch angle 80°

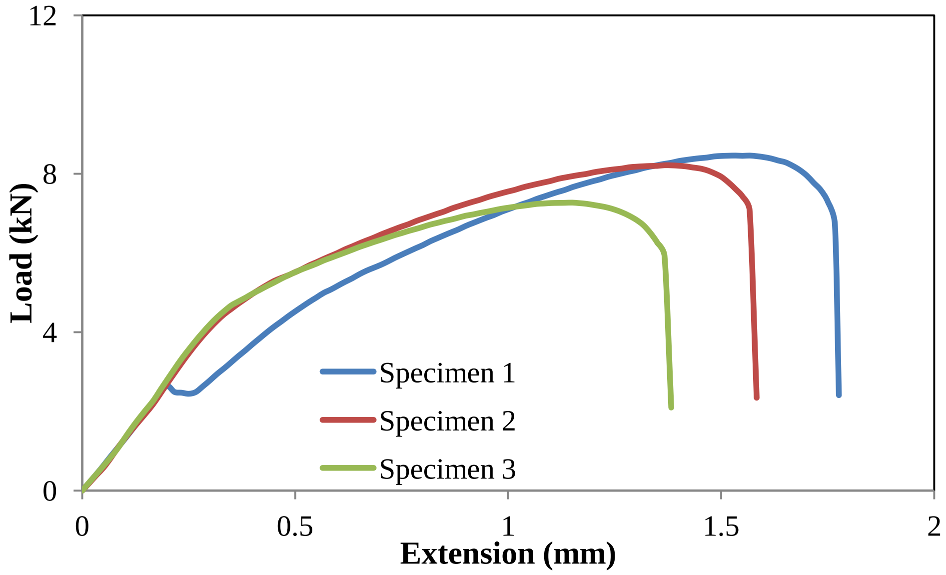

Figure 4.12: Graph load vs extension for two specimen for notch diameter (d) 4.2 mm, heat treatment, notch angle 80°

Table 4.9: Result of fracture load (P_f) for notch diameter (d) 4.2 mm, heat treatment, notch angle 80°

	Fracture load (P_f), [kN]
Specimen 1	8.46
Specimen 2	8.21
Specimen 3	7.27

The best fracture load to be choosen is the fracture load = 8.21 kN

Taking the value of the fracture load to be 8.21 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(8.21kN)\sqrt{0.007}\}}{\left(0.0042^2\sqrt{\pi}\right)}$$

$$= 20.48 \text{ MPa m}^{1/2}$$

4.4.8 Fracture toughness (K_{1C}) calculation for notch diameter (d) : 4.2 mm, without heat treatment, notch angle 80°

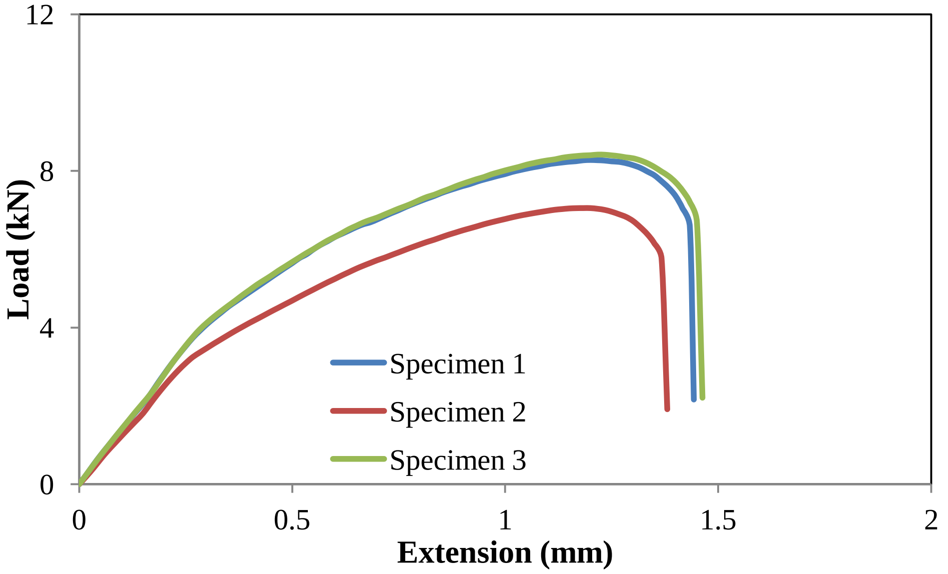

Figure 4.13: Graph load vs extension for two specimen for notch diameter (d) 4.2 mm, without heat treatment, notch angle 80°

Table 4.10: Result of fracture load (P_f) for notch diameter (d) 4.2 mm, without heat treatment, notch angle 80°

	Fracture load (P_f), [kN]
Specimen 1	8.28
Specimen 2	7.05
Specimen 3	8.41

The best fracture load to be choosen is the fracture load = 8.41 kN

Taking the value of the fracture load to be 8.41 kN and substitute into equation 3.4

$$K_{1C} = \frac{\{0.932(8.41kN)\sqrt{0.007}\}}{(0.0042^2\sqrt{\pi})}$$

$$= 20.97 \text{ MPa m}^{1/2}$$

4.5 ROLE OF MICROSTRUCTURE

Microstructure of steel has a strong influence on the fracture toughness (K_{1C}) of low carbon steel. This has been clearly observed in the present investigation. The fracture toughness of no heat treated sample has been found higher than full annealed steel sample for the same notch depth and notch angle. For example, K_{1C} value for no heat treated sample with inner notch diameter 5.6mm and notch angle 60° is 22.80 MPa $m^{1/2}$ compared to same notch and inner notch diameter is 21.98 MPa $m^{1/2}$ for full annealing sample.

This differences can be explained based on the basis of microstructure of the heat treatment sample and no heat treatment samples. In the microstructure, the black region is pearlite and white region is proeutectoid ferrite. There are several parameter that differ to compared the microstructure which is the austenite grain size for no heat treatment sample are smaller than annealed sample and pearlite colony (black region) is also smaller of finer in no heat treatment sample compared to the pearlite colony in annealed steel sample.

These parameters have make no heat treatment specimen are stronger and harder compared to annealed sample. The fine grain structure gives better resistance to crack propagation that give higher K_{1C} due to higher grain boundary (Dieter, 1988) that acts as the mild barrier to crack propagation. Pearlite with finer interlamellar spacing is stronger than coarser pearlite (Rollason, 1973). This observations with respect to microstructure are consistent with the result of previous journal (Bayram et al., 1999; Nath et al., 2006).

4.6 ROLE OF NOTCH DIAMETER AND NOTCH ANGLE

It has been observed that samples with lower notch diameter (4.2mm) will give the lower fracture load (P_f) and lower K_{1C} compared to higher notch diameter (5.6mm) for same notch angle of 80° angle. But for 60° notch angle, it has been observed that sample with lower P_f will give higher K_{1C}. This shows that for a given notch diameter as notch angle decreases (sharper notch), it is observed that K_{1C} will increases. By this observation, the effect of notch angle on K_{1C} are not consistent with the result of previous journal (Bayram et al., 1999; Nath et al., 2006).

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter will conclude the overall project from the beginning to the end. Some recommendations on the project and to improve the result will be given.

5.2 CONCLUSION

The effect changes of microstructure by the heat treatment processes and no heat treatment done to the low carbon steel has been evaluated by tensile test under a cross-head speed that maintain throughout the process. This project was done successfully with the objective have been achieved. However, during the time of the project, there are problems occurred such as machining processes problem, environmental error and a few experiments apparatus problem. These problems need to be solved in order to get a better and more accurate result in the future.

Based on the tensile test conducted for this project, the results were obtained and some conclusions on the results can be drawn from this study:

(i) The microstructure of steel has the strong influence on the value of K_{1C}. The finer grain structure has been found to have higher value of K_{1C} than a coarse and wider grained structure. No heat treatment samples are stronger and harder by the way the heat treatment sample softer and brittle.

(ii) Fracture toughness of the non heat treated specimens is higher than the heat treated specimen due to the transformation structure.

(iii) Fracture toughness of steel material can be successfully determined by circumferentially cracked round bar (CCRB) specimen. The value of K_{1C} obtained by this round notched tensile sample is comparable with other methods like compact tension specimen, three point loaded bend specimen, the centre cracked and double-edge cracked plate.

(iv) Higher value of notch angle gives the lower value of K_{1C}.

(v) Lower notch diameter gives a lower fracture load (P_f).

5.3 RECOMMENDATIONS

There are some recommendations needed to be improved in order for the results to be more accurate. For this section, some recommendations will be discussed.

5.3.1 Machining process

In order the specimen design to be accurate, more accurate method or apparatus needed to be done. In this case, modern machine should be used like CNC because the product of this machine is should be accurate in order to make sure the result also accurate and is according to the design. When using the lathe machine, there are not all machines that are working well and accurate. Some of it already not functions well. Only one machine should be used to avoid errors. Vernier calliper has to be used to do the measurement after finished the machining in order to avoid errors.

5.3.2 Future works

When the tensile test process, it is depending on many factors such as notch diameter, notch angle, the stress applied and the heat treatment processes that increase and change the hardness and strength of the specimen. It can see here that all this factor also affect the fracture toughness. Therefore in the next research, the same method or other method can be used to investigate the notch or angle as the main factor for fracture toughness. Another factor that affecting the fracture toughness is the heat treatment processes. For the next research, the other and different heat treatment process and method can be use to investigate the effect that changes the properties of the material to increasing or decreasing the hardness of the material.

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APPENDIX A

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 1

Project Progress	**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**
Get the project title and arrange discussion time with supervisor	🟩													
Built the basic knowledge about the project	🟩	🟩	🟩											
Do research and collect the information	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
State objective, scope and importance of the study			🟩	🟩										
Review study of fracture toughness journal and thesis					🟩	🟩								
Survey for the raw material						🟩	🟩							
Study of additional condition occur for carbon steel						🟩	🟩							
Confirmation of design for specimens preparation							🟩	🟩						
State the overview of the experiment’s procedure								🟩	🟩	🟩	🟩			
Take raw material from warehouse and prepare half of the specimens									🟩	🟩	🟩	🟩	🟩	🟩
Provide the expected result base on previous research											🟩	🟩	🟩	
Submit draft thesis for final year project 1														🟩
Final year project 1 presentation														🟩

PROJECT PLANNING (GANTT CHART): FINAL YEAR PROJECT 2

Task / Week	**W 1**	**W 2**	**W 3**	**W 4**	**W 5**	**W 6**	**W 7**	**W 8**	**W 9**	**W 10**	**W 11**	**W 12**	**W 13**	**W 14**	**W 15**	**W 16**
Reduce diameter of specimens (26 samples)	🟩	🟩	🟩	🟩												
Notching process				🟩	🟩	🟩										
Heat treatment							🟩									
Mounting process								🟩								
Tensile test								🟩	🟩	🟩						
Grinding, polishing for microstructure investigation											🟩					
Microstructure investigation by optical microscope												🟩				
Tabulate result								🟩	🟩	🟩						
Analysis the result								🟩	🟩	🟩	🟩	🟩	🟩			
Final Year Project 2 Presentation														🟩		
Writing analysis report									🟩	🟩	🟩	🟩	🟩	🟩	🟩	
Submitting report writing																🟩