EFFECT OF SPECIMEN SIZE ON FRACTURE TOUGHNESS OF MILD STEEL

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I certify that the project entitled "Effect of Specimen Size on Fracture Toughness of Mild Steel" is written by Mohd Syafiq Bin Mohd Saufi. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality forthe award of the degree of Bachelor of Engineering. I herewith recommend that it will be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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

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Dedicated, truthfully for supports,
Encouragements and always be there during hard times,
My beloved family.

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ABSTRACT

This project was conducted to investigate the effect of specimen size on fracture toughness of mild steel. Fracture toughness is an indication of the amount of stress required to propagate a pre-existing flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, service of a material or component. In this experiment, the specimen size was chosen as a main parameter to analyse the fracture toughness of mild steel. The specimen size was divided into two parameter to be investigated, there is thickness and notch depth of the specimen. The specimen geometry was referred to the ASTM E399-74 standard and the test applied for the fracture toughness is single edge notch bending. From the test results, when the thickness of the specimen increase the fracture decreases until the thickness reach the critical dimension and the fracture was become constant. For the notch depth, when the notch depth decreases the fracture of the specimen also decreases until the notch depth reach the critical dimension and the fracture toughness was become constant. The thickness and notch depth of the specimen is main parameter to analyze the fracture toughness of the material or specimen because each of the specimens will reach the critical dimension and constant the fracture toughness value.

ABSTRAK

Projek ini telah dijalankan untuk mengkaji kesan saiz spesimen ke atas keliatan patah keluli lembut. Keliatan patah merupakan satu petunjuk kepada jumlah tekanan yang diperlukan untuk menyebarkan kecacatan pada bahan. Ia adalah sifat kecatatan bahan yang tidak dapat dielakkan sepenuhnya dalam pemprosesan dan fabrikasi bahan atau komponen. Dalam eksperimen ini, saiz spesimen telah dipilih sebagai parameter utama untuk menganalisis keliatan patah keluli lembut. Saiz spesimen telah dibahagikan kepada dua parameter yang untuk dianalisis iaitu ketebalan dan kedalaman takuk spesimen. Geometri spesimen adalah mengikut kepada standard ASTM E399-74 dan ujian yang digunakan untuk mengalisis keliatan patah ‘single edge notch bending’. Daripada keputusan ujian, apabila ketebalan spesimen meningkatkan keliatan patah berkurangan sehingga ketebalan mencapai dimensi kritikal dan menyebabkan keretakan itu menjadi malar. Manakala untuk kedalaman takuk pula, apabila kedalaman takuk berkurang keliatan patah pula menurun sehingga kedalaman takuk mencapai dimensi kritikal dan keliatan patah menjadi malar. Kedalaman takuk dan ketebalan spesimen adalah parameter utama untuk menganalisis keliatan patah bahan kerana setiap spesimen akan mencapai dimensi kritikal dan menyebabkan keliatan patah menjadi malar.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Fracture toughness is an indication of the amount of stress required to propagate a pre-existing flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities, or it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components. This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture. Fracture toughness, in the most general of definitions, is the ability of a material to withstand fracture in the presence of cracks.(NDT Resource Center, 2008)

Fracture toughness is measured in terms of K_{IC} (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_{IC} is a basic material property like yield strength. (M.O. Lai,1984)

This project is to investigate the fracture toughness or the basic material property of mild steel. Mild steel is the most common form of steel as its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel has low carbon content (up to 0.3%) and is therefore neither extremely brittle nor ductile. It becomes malleable when heated, and so can be forged. It is also often used where large amounts of steel need to be formed, for example as structural steel. Although, the material is use in many application the toughness of the material or the product is important to be investigated, to make sure the product will run and operate safety. In this project, the material fracture toughness is investigated in term of specimen sizes by using Single Edge Notch Bend test. The specimen size is characterized into two parameter; which is specimen thickness and notch depth. Each of the parameter will give the different value of critical dimension and fracture toughness in order to produce the toughness material. When the productions and industries used the mild steel, the testing procedure is needed to produce effective, toughness and safety product.

1.2 PROBLEM STATEMENT

Mild steel is very important material used in automobile production. Automotive chassis is considered to be one of the significant structures of an automobile. It is usually made of a mild steel frame, which holds the body and motor of an automotive vehicle. More precisely, automotive chassis or automobile chassis is a skeletal frame on which various mechanical parts like engine, tires, axle assemblies, brakes, steering are bolted. At the time of manufacturing, the body of a vehicle is flexibly molded according to the structure of chassis. Automobile chassis is usually made of mild steel. It provides strength needed for supporting vehicular components and payload placed upon it. Automotive chassis or automobile chassis helps keep an automobile rigid, stiff and unbending. Therefore, the strength and toughness of the car chassis is very important parameter to analyze before built the car chassis due to avoid the crack occur when load is exerted. This research tries to investigate that the effect of specimen size on fracture toughness of material used in chassis manufacturing in order to get the critical dimension. The load was becomes constant when the part dimension is at critical dimension. Furthermore, this research is conducted to determine the fracture toughness of the mild steel with bending test in term of specimen thickness and notch radius to the automobile chassis.

1.3 PROJECT OBJECTIVE

The main objective of the project is to investigate the effect of specimen size on fracture toughness of mild steel. The specimen size was characterized into two parameter to be investigate:

1. The effect of specimen thickness on fracture toughness of carbon steel.
2. The effect of specimen notch depth on fracture toughness of carbon steel.

1.4 PROJECT SCOPE

- The general accepted measure of the fracture toughness of a metal is the plain strain fracture toughness, K_{IC} as measured by ASTM E399-74.However the specimen size required for valid measurement of K_{IC} need to refer ASTM E399-74 standards.
- In this project, fracture toughness will defined by perform the fracture toughness test by varying the specimen thickness and notch depth. The 27 specimens was fabricated by applying the machining process which is bandsaw machine, milling machine and wire-cut machine. The specimen was fabricating according to parameter decided that consist of 3 specimen for each different notch depth and thickness. Furthermore, by varying the notch depth, the relationship between fracture toughness and notch depth could be investigated.
- The method applied to analyzing and testing the specimens is three points bending test. The three point bending test involves bending a beam of the test material that has a notch depth across the beam at a position that is midway along the length of the bottom edge. The beam is supported at both ends, and then bent by driving a probe downward just above the notch using a universal testing machine (UTM).

CHAPTER 2

LITERATURE REVIEW

2.1 MILD STEEL

Steel is one of the major inventions that have helped mankind progress by leaps and bounds in many spheres. It is one of the most used and reused alloys. The advent of steel gave the industries the much needed momentum to grow and expand. Steel is now available in many grades and specifications. From all the types of steel, mild steel is the commonly found form. (William F.Smith, 2005)

Mild Steel is essentially a form of Carbon Steel that has low Carbon content which imparts the steel many physical and mechanical properties. It is used extensively for many Industrial applications including structural applications and constructions because of their properties. The properties of a material are determined by its composition. The material properties and mechanical characteristics of Mild Steel are crucial in deciding the area of application. These properties of the Mild Steel are determined by a series of tests. The popularity of mild steel in many industries is mainly because the material is easy to work with. The physical property of the mild steel is high malleability due to the low carbon content. As a result, steel is pliable as clay and so can be rolled and formed as required. This property enables the mild steel to be formed into bars. Mild steel also have high ductility that implies the steel can be bent into any shape or form without breaking. (S.R.Satish, 2003)

2.2 FRACTURE TOUHGNESS

Fracture toughness is an indication of the amount of stress required to propagate a pre-existing flaw. It is a very important material property since the occurrence of flaws is not completely avoidable in the processing, fabrication, or service of a material/component. Flaws may appear as cracks, voids, metallurgical inclusions, weld defects, design discontinuities or some combination thereof. Since engineers can never be totally sure that a material is flaw free, it is common practice to assume that a flaw of some chosen size will be present in some number of components and use the linear elastic fracture mechanics (LEFM) approach to design critical components. This approach uses the flaw size and features, component geometry, loading conditions and the material property called fracture toughness to evaluate the ability of a component containing a flaw to resist fracture. Fracture toughness is measured in terms of K_{IC} (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_{IC} is a basic material property like yield strength. (NDT Resource Center, 2008)

According to (Matt Gordon, 1997), the fracture toughness can be predicted by using the equation of the minimum thickness of material before plain strain behavior occurs:

$$B = 2.5\,(\frac{K_{IC}}{\sigma_y})^2 \qquad 2.1$$

B = minimum thickness to distinguish between K_C and K_{IC}
K_{IC} = fracture toughness, when the sample has a thickness less than B
σ_y = yield stress of material

(Matt Gordon, 1997), the fracture toughness of a material with a thickness equal to or greater than B, when it fractures in mode I. The expression used for determining K_{IC} is:

$$K_{IC} = Y\sigma\sqrt{\pi a} \qquad 2.2$$

K_{IC} = fracture toughness, when the sample has a thickness greater than B

Y = constant related to the sample's geometry.

a = crack length (surface crack), one half crack length (internal crack).

σ = stress applied to the material.

In general, K_{Ic} is low for brittle materials and high for ductile materials. This trend is supported by the K_{Ic} values in Table 2.1 and 2.2 shown below.

Table 2.1: K_{IC} value for the different material

Material	K_{IC} **Mpa√m**
Metals	
2024-T351 Aluminum	36
4340 steel (tempered @ 260 C)	50
Titanium Alloy	44-66
Ceramics	
Aluminum Oxide	3.0-5.3
Soda-line glass	0.7-0.8
Concrete	0.2-1.4
Polymers	
Polymethyl Methacrylate (PMMA)	1
Polystyrene (PS)	0.8-1.1

Source: (Matt McMurtry, 1997)

Table 2.2: K_{Ic} value for the different material

Metal or Alloy	K_{IC} **Mpa√m**
Mild Steel	140
Medium-carbon steel	51
Rotor steel (A533; Discalloy)	204-214
Pressure vessel steels (HY130)	170
High-strength steel (HSS)	50-154
Cast iron	6-20
Pure ductile metals (e.g.. Cu,Ni,Ag,Al)	100-350
Be (brittle , hep metal)	4
Aluminum alloys (higt strength-low strength)	23-45
Titanium alloys (Ti 6Al 4V)	55-115

Source: (M.F. Ashby and D.R.H Jones, 1980)

K_{Ic} is a measure of a material's resistance to crack growth under a sustained monotonic loading condition. K_{Ic} is an extremely important parameter for structural design since structural components designed on the basis of plane strain fracture toughness are expected to survive in service without undergoing catastrophic failure. High cycle fatigue strength is another extremely important parameter for structural design. For failure prevention design in cyclic loading, very high fatigue strength or endurance limit is required. A combination of high fatigue strength and K_{Ic} is ideal for structural components because these characteristics will increase the working stress range and safety factor for load-bearing structural components. However, plane strain fracture toughness and high cycle fatigue strength have two conflicting requirements .It is well known that the K_{Ic} of a material decreases as the yield strength of the material increases. On the other hand, for very high endurance limit or high cycle fatigue strength, the yield strength must be high. Thus a combination of very high yield strength, fatigue strength and fracture toughness is difficult to obtain in most structural materials. (S.K. Putatunda, 2000).

(H.Wang et al, 2007) has evaluated the specimens perform three point bending test to get the fracture toughness. The two halves of the broken samples were used for the measurement of the notch depth c under an optical microscope. The length c was the average of the six values at three locations of the notch in the middle and at two lateral sides of each section. The toughness value was calculated according to the following formula:

$$K_{IC} = \frac{F_C}{B} \frac{S}{W^{\frac{3}{2}}} f\left(\frac{c}{W}\right) \tag{2.3}$$

$$f\left(\frac{c}{W}\right) = 2.9\left(\frac{c}{W}\right)^{1/2} - 4.6\left(\frac{c}{W}\right)^{3/2} + 21.8\left(\frac{c}{W}\right)^{5/2} - 37.6\left(\frac{c}{W}\right)^{7/2} + 38.7\left(\frac{c}{W}\right)^{9/2} \tag{2.4}$$

Where,

Fc : Critical load

B : specimen width

s : Supporting span

$f\,(c/W)$: Stress intensity shape factor.

2.3 MATERIAL THICKNESS

Specimens having standard proportions but different absolute size produce different values for stress intensity, K_I. This results because the stress states adjacent to the flaw changes with the specimen thickness, B until the thickness exceeds some critical dimension. Once the thickness exceeds the critical dimension, the value of K_I becomes relatively constant and this value, K_{IC}, is a true material property which is called the plane-strain fracture toughness. The relationship between stress intensity K_I, and fracture toughness, K_{IC} is similar to the relationship between stress and tensile stress. The K_I, represents the level of "stress" at the tip of the crack and the fracture toughness,K_I is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs. The relation between the fracture toughness, K_{IC} and thickness is shown in Figure 2.1. (NDT Resource Center, 2008)

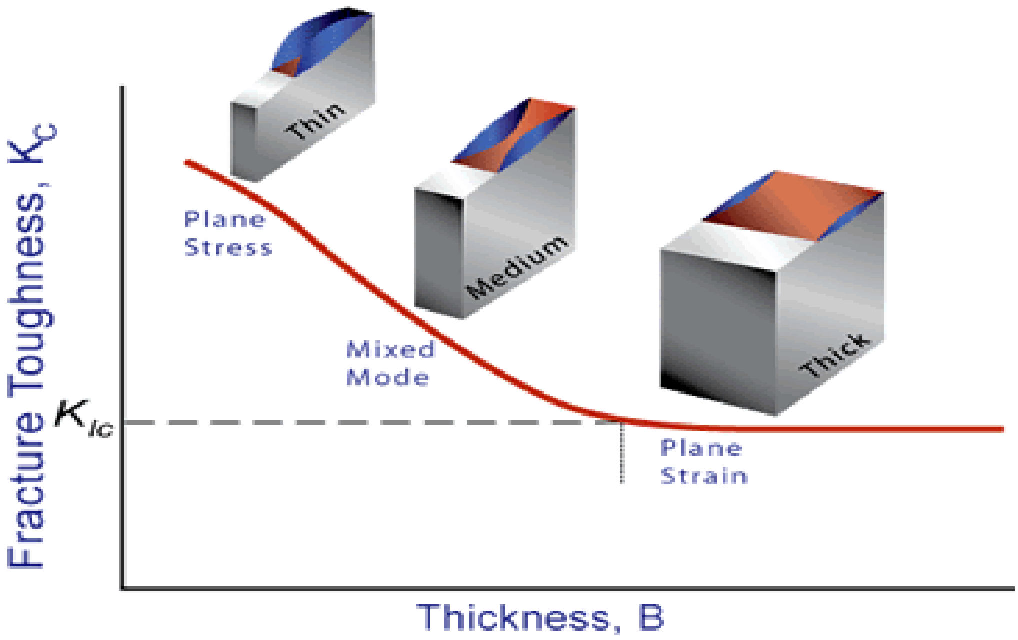


Figure 2.1: Graph Fracture Toughness, K_{IC} against Thickness, *B*

Source: (NDT Resource Center, 2008)

The critical stress-intensity factor, K_C at which unstable crack growth occurs for conditions of static loading has been generally recognized to be dependent on the thickness of the test specimen as shown in Figure 2.2. Many models have been proposed to establish quantitatively a basis for predicting this experimentally observed dependency between the fracture toughness, K_C and specimen thickness, *B*. (M.O. Lai. et.al, 1986)

From an energy balance of the fracture process, the total critical fracture energy, K_C is essentially the sum of the fraction of energy dissipated in shear lip formation and the fraction of energy dissipated in square fracture. The total fracture energy per unit fracture area is:

$$E_T = E_S + E_F \tag{2.4}$$

E_T = total fracture energy per unit fracture area.

E_S = fracture energy of the shear lip per unit area.

E_F = flat fracture regions per unit area

According to (M.O.Lai.et.al, 1986), assumed that the critical specimen thickness, *Bo*, is independent of the specimen thickness and flat fracture is a surface phenomenon. The fracture toughness resulting from this model can be shown to be:

$$K_C^2 = \frac{1}{2}\, E K_S B_O \left(\frac{B_O}{B}\right) + E K_f \left(1 - \frac{B_O}{B}\right) \qquad for\ \frac{B}{B_O} > 1 \tag{2.5}$$

$$K_C^2 = \frac{1}{2}\, E K_S B_O \left(\frac{B_O}{B}\right) \qquad for\ \frac{B}{B_O} \leq 1 \tag{2.6}$$

E = Young's modulus

K_S and K_f = Constants to be evaluated experimentally.

Bo = Critical specimen thickness

(M.O. Lai et.al, 1986) is making similar assumptions, the model gives:

$$K_C = S^2 K_{C,Max} + (1 - S) K_{IC} \tag{2.7}$$

S = fractional part of the fracture surface occupied by shear lips

$K_{C,Max}$ = the value of K_C at $B = B_O$

K_{IC} = the limiting plane strain fracture toughness as shown in Figure 2.2.

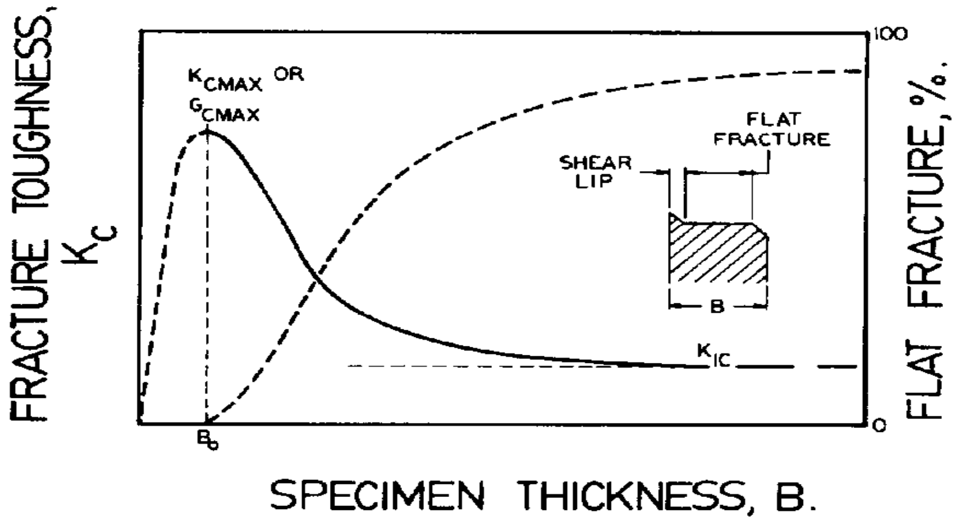


Figure 2.2: Dependence of fracture toughness on specimen thickness

Source: (M.O. Lai et.al, 1986)

(M.O.Lai et.al, 1984) has evaluated the relationship between specimen thickness *B* and the fracture toughness, *Kc* of the material Aluminum Alloy 7075-T6 is shown in Figure 2.3. *Kc* was calculated from the load-displacement at Figure 2.4 record at the point of maximum load and the corresponding crack length.

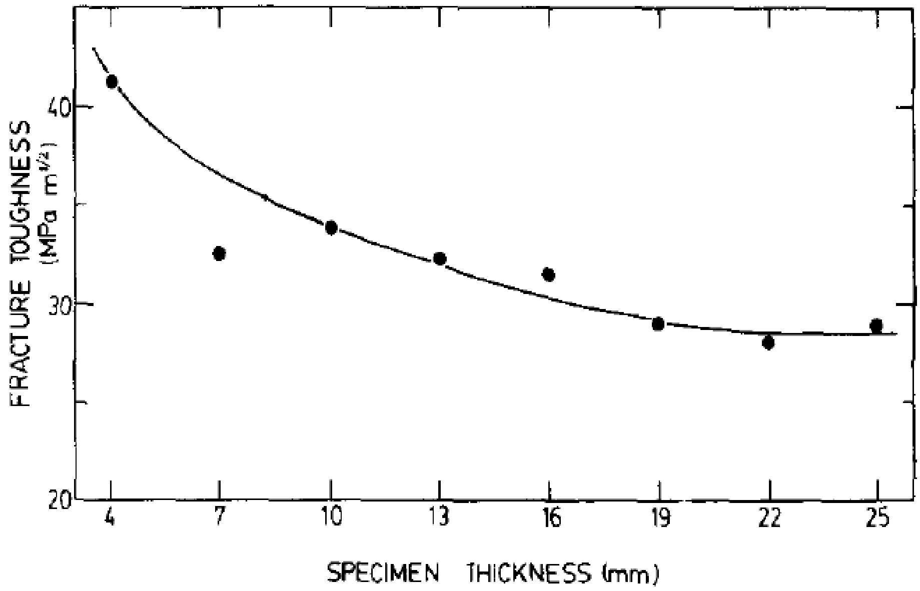


Figure 2.3: Relationship between the fracture toughness and the specimen thickness

Source: (M.O. Lai et.al, 1984)

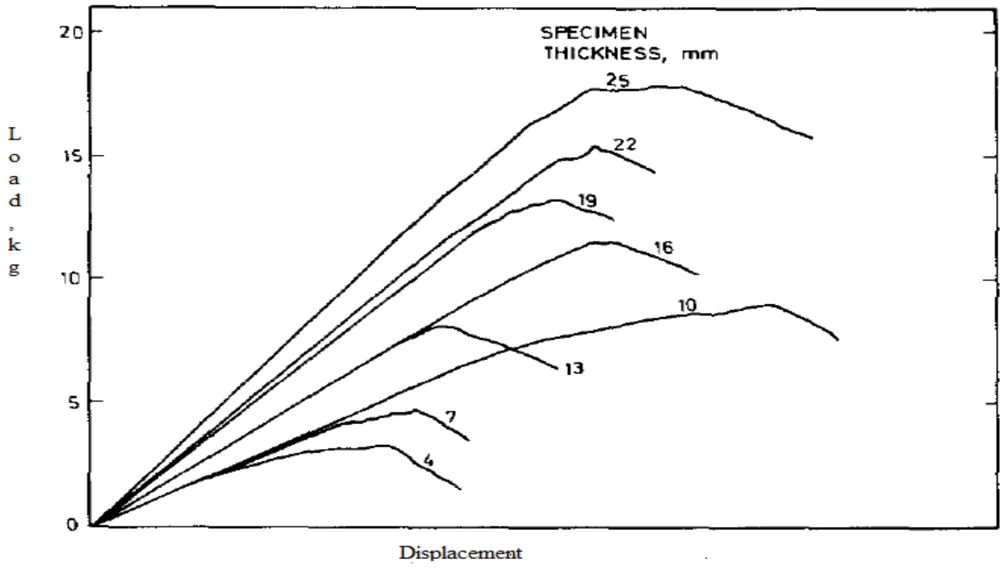


Figure 2.4: Effect of specimen thickness on the load-displacement records.

Source: (M.O. Lai et.al, 1984)

2.4 NOTCH DEPTH

The effect of notch root radius on fracture toughness measurements purpose to show that there is a linear dependence between the square root of the notch depth, ρ, and the apparent fracture toughness, $K_{I,app}$, provided that the notch depth is greater than some critical value. Below this critical value the measured value of the fracture toughness is sensibly constant. However, none of these results is for a root radius greater than one millimetre. This is particularly pertinent in view of the fact that none of the experimental results convincingly shows the linear dependence. The purpose of this is twofold is to avoids the "cut off' which occurs at small root radii and it extends the existing data into a region where any departure from a linear dependence of $K_{I,app}$ on $\sqrt{\rho}$ can easily be detected. (T. Fett*, 2005)

(G. M. Spink.et.al, 1973) was evaluate the stress required to propagate fracture from a semi-elliptical notch of semi-major axis c and semi-minor axis b (notch radius $\rho = b^2/c$) in a semi-infinite medium. His result, which applies to a state of anti-plane strain deformation, may be written:

$$\frac{\sigma_f}{\sigma_u} = \frac{1}{\left[1+\left(\frac{\rho}{c}\right)^{\frac{1}{2}}\right]} \left\{\frac{2}{\pi}\ sec^{-1}\left[\exp\left(\frac{\pi K_{1c}^2}{8\sigma_u^2 c}\right)\right] + \left(\frac{\rho}{c}\right)^{\frac{1}{2}}\right\} \tag{2.8}$$

K_{Ic} : Fracture toughness

σ_u : Stress at which an unnotched specimen would fail

ρ : Notch Radius

c : Notch depth

This result is assume valid for plane strain stress systems, hence we identify K_{IC} with the plane strain fracture toughness and σ_u is the stress at which an unnotched specimen would fail. The ratio σ_f/σ_u, is to be calculated appropriate to the testing conditions. The appropriate value of the ultimate stress in bend is difficult to estimate although experimental results indicate that it is approximately twice the value in tension. If $\left(\frac{K_{1c}}{\sigma_u} \ll 1\right)$ and we have a small scale yielding situation then equation (2.9) reduces to:

$$\sigma_f = \frac{K_{1c} + \sigma_u(\pi\rho)^{\frac{1}{2}}}{(\pi\rho)^{\frac{1}{2}}\left[1+\left(\frac{\rho}{c}\right)^{\frac{1}{2}}\right]} \tag{2.9}$$

Equation (2.8) may be written in the equivalent form:

$$K_{I,ap} = \frac{K_{IC} + \sigma_u(\pi\rho)^{\frac{1}{2}}}{\left[1+\left(\frac{\rho}{c}\right)^{\frac{1}{2}}\right]} \tag{2.10}$$

K_{Ic} : Fracture toughness

σ_u : Stress at which an unnotched specimen would fail

ρ : Notch Radius

c : Notch Depth

This equation relates the apparent fracture toughness, $K_{I,\,app}$, measured on a specimen with a blunt notch, to the material properties K_{IC} and σ_u.

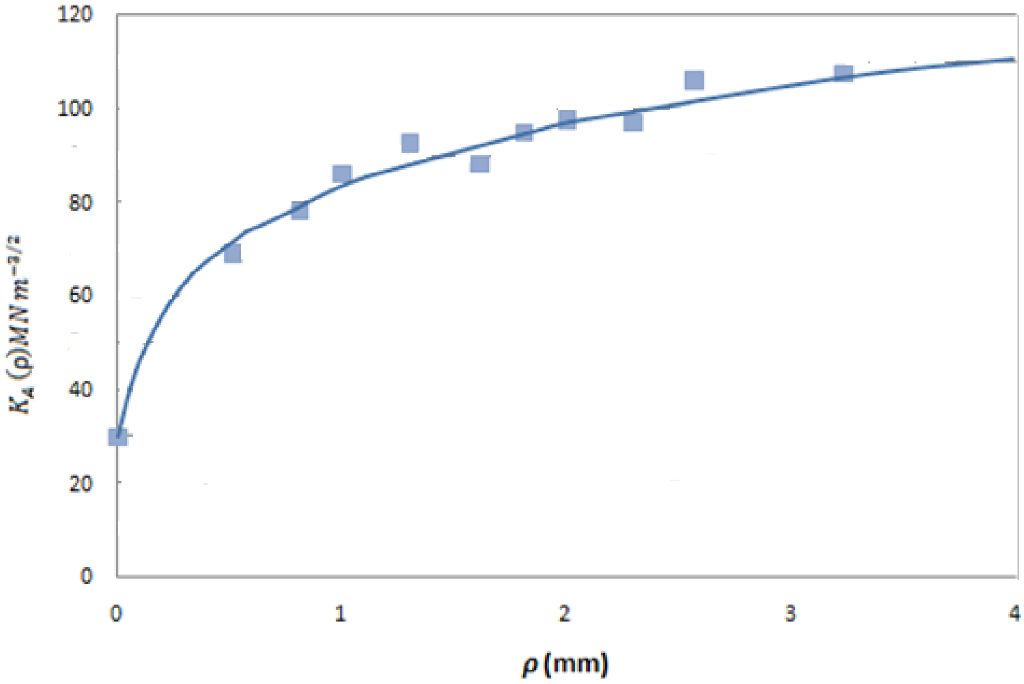


Figure 2.5: The apparent fracture toughness as a function of the notch root radius; the experimental points are compared with equation (2.10).

Source: (G. M. Spink.et.al, 1973)

The maximum load for each specimen is obtained and plotted as a function of the notch depth for different *a/W* (in Figure 2.6).The data show that the maximum load *Pmax* increases linearly with the notch radius *ρ* and decreases as *a/W* increases. (Mourad A.H .I, 2011)

The maximum loads are used to calculate the apparent fracture toughness $K_{I,app}$ by using the following equation :

$$K_{I,app} = \frac{f_1\left(\frac{a}{W}\right)P_{max}}{B(W-a)} \tag{2.11}$$

$f_1\ (a/W)$: Geometrical function
B : Specimen thickness
W : Specimen width.

The results are used to plot $K_{I,app}$ vs ρ for different values of (a/W) as shown in Figure 2.6. The results show that $K_{I,app}$ is dependent on ρ and a/W ratio. $K_{I,app}$ is almost constant in the range from ρ = 0.08 mm up to 0.16 mm for all a/W ratio. Then it increases almost in a linear relationship up to ρ ~ 0.6 mm for a/W ratio from 0.1 up to 0.6, prior it starts to increase nonlinearly with ρ up to ρ = 3 mm. However, for a/W = 0.7 up to 0.9, $K_{I,app}$ increases linearly in the range from ρ >0.16 up ρ ~ 0.25 mm prior it increases nonlinearly with p up to ρ =3 mm. That linear increase has been reported by some researchers. $K_{I,app}$ reaches a minimum value ($K_{Ic,app}$) when ρ reaches its minimum value (ρ = 0.08 mm), however, there is a critical notch radius value p_c for each a/W below which $K_{I,app}$ becomes almost independent of ρ. Therefore, the curves in Figure 2.7 consist of three regions I, II and III. In the region I there is a rapid decrease in $K_{I.app}$ followed by less rate of decrease in the region II prior the curve becomes almost a horizontal line (or reaches a lower plateau) in the region III ,$K_{I,app}$ reaches $K_{Ic.app}$ at ρ =0.16 up to 0.08 mm. A critical notch root radius below which fracture toughness is independent of ρ has been reported. (Mourad A.H .I, 2011)

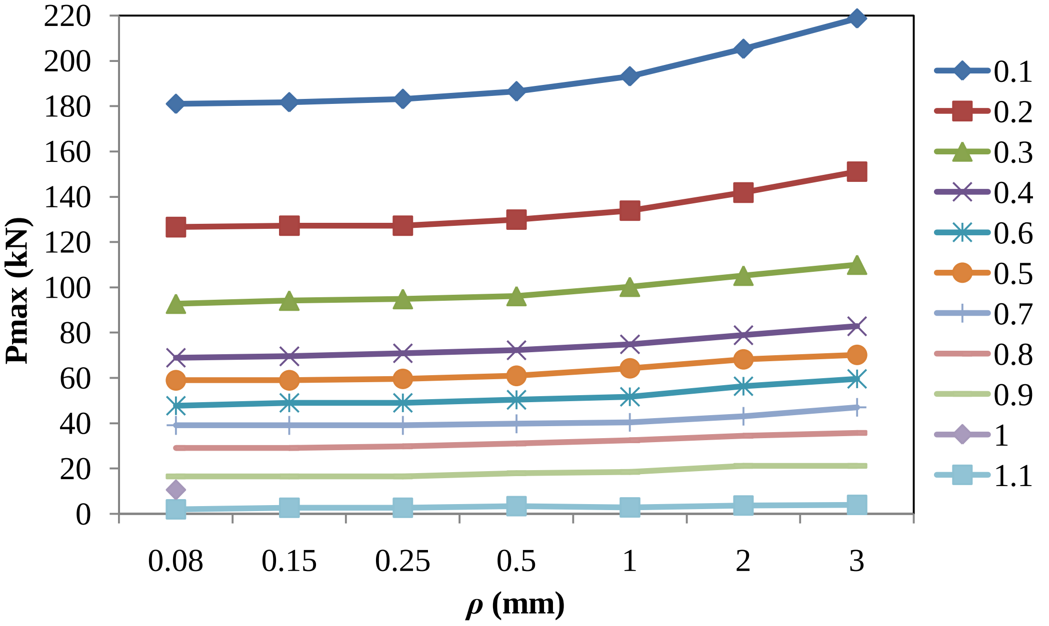


Figure 2.6: Variation of *Pmax* (kN) with *ρ* (mm) for different *a/W* ratio

Source: (Mourad A.H .I, 2011)

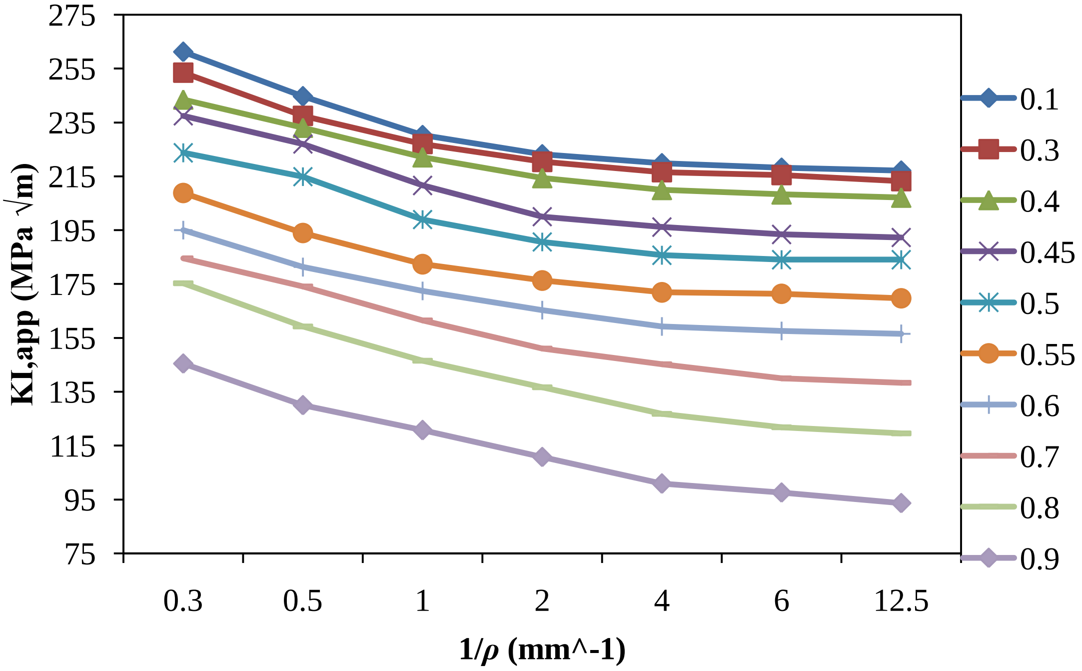


Figure 2.7: The $K_{I,app}$ vs 1/ρ for a/W ratio

Source: (Mourad A.H .I, 2011)

KI,app as a function of a/W ratio for all tested notch radii are shown in Figure 2.8. The fracture energy decreases as the ratio *a/W* increases. The behaviour shown in Figure 2.8 can be divided into three regions, (I, II and III) or 3 line segments with different slopes. For the region I the value of *a/W* is in the range of $0.1 \leq a/W \leq 0.4$, region II is for the range of $0.4 \leq a/W \leq 0.6$ (through which fracture mechanics approach is suitably applicable) and region III for the range of $0.6 \leq a/W \leq 0.9$. (Mourad A.H .I, 2011)

The measured of the work done to fracture is using Three Point Bending (TPB) specimen with different ρ (ρ =0.05, 0.25, 1, and 2 mm) and different *a/W* ratio (*a/W*=0.2, 0.3, 0.4, 0.5, 0.6 and 0.7). (Mourad A.H .I, 2011)

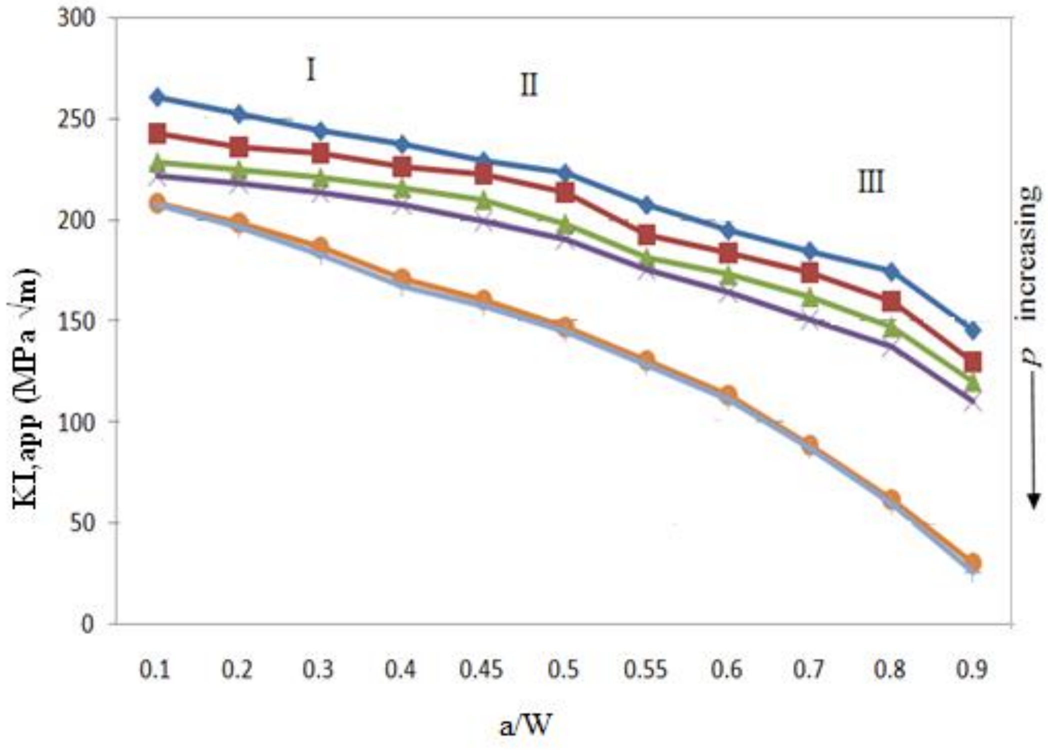


Figure 2.8: $K_{I,app}$ vs. a/W ratio for different ρ

Source: (Mourad A.H .I, 2011)

(F.J.Go´mez et.al, 2006) evaluated that the geometrical variables which affect the SENB strength are length of the notch, notch width, and sharpness of the notch. The radius of curvature at the notch tip is particularly problematic because of the difficulties of controlling and measuring its value.

The apparent fracture toughness in SENB tests with U-notches is computed from the (LEFM) equation:

$$K_C^* = \sigma_N \sqrt{\pi a} \psi \left(\frac{a}{D}\right) \tag{2.12}$$

D	: Notch length
σ_N	: Nominal stress that corresponds to the maximum load
$\psi(a/D)$	: Function that depends on the notched geometry
a	: The shape function for a cracked geometry

(R.J.Damani et a1, 1997) has evaluated in fracture toughness testing it is common for reasons of simplicity and reproducibility to use notches to approximate such cracks. Hence, because of the lower stress concentration ahead of a notch, as compared to a truly sharp crack, a greater force is required to cause a notch tip crack to extend. This deviation increases with increasing notch width and results in the commonly reported dependence of fracture toughness (K_{IC}) on notch-root radius.

(R.J.Damani et a1, 1997) was presented theory to quantify the notch-root radius. It was assumed that crack-like flaws already exist and are stochastically distributed in the microstructure. These flaws can act as fracture initiating cracks ahead of the notch-root. Fracture occurs, if the local stress intensity factor, as influenced by the notch, exceeds a critical value. The true crack tip stress intensity factor as seen by a small crack in front of a notch, K_I can be related to the apparent stress intensity factor calculated for a sharp crack, with the length of the notch, commonly calculated using standard formula, K_I^{app}, by:

$$K_I \approx \ K_I^{app}.\tanh\left(2Y\sqrt{\frac{\delta_a}{\rho}}\right) \tag{2.13}$$

δ_a : Size of the fracture-initiating defect.

Y : An appropriate geometric correction factor which ranges between 2/n for penny shaped starting cracks and l.12 for edge cracks.

The same relationship holds for the critical value of the stress intensity factor, K_{IC}, when the maximum force before fracture is used to calculate K_{IC}^{app}. Note that for $\delta_a \geq \rho$, $\tanh(2Y\sqrt{(\delta\_a/\rho)}$ tends to unity. Thus, to measure true values of fracture toughness K_{IC}, the notch root radius should be equal to or smaller than the size of the fracture initiating flaws. (R.J.Damani et a1, 1997)

The theory and equation applied from the previous research for the fracture toughness is summarizing at Table 2.3.

Table 2.3: The model of experiment that applied by the researcher for the fracture toughness analysis

Journal	Model	Parameter
G.M.Spink.et.al. (1973)	$KI, app = \frac{K_{Ic} + \sigma_u(\pi\rho)^{\frac{1}{2}}}{\left[1+\left(\frac{\rho}{c}\right)^{\frac{1}{2}}\right]}$	K_{Ic} : Fracture toughness σ_u : stress at which an unnotched specimen would fail ρ : Notch Radius c : Notch depth
Mourad A.H .I (2011)	$K_{I,app} = \frac{f_1\left(\frac{a}{W}\right)P_{max}}{B(W-a)}$	*f1 (a/W)*:Geometrical function *B* : Specimen thickness *W* : Specimen width. *Pmax* : Maximum load
F.J. Go´mez et.al (2006)	$K_C^* = \sigma_N\sqrt{\pi a}\psi\left(\frac{a}{D}\right)$	*D* : Notch length σ_N : Nominal stress that corresponds to the maximum (or fracture) load *ψ(a/D)* : Function that depends on the notched geometry *a* : The shape function for a cracked geometry
Damani.et.a1. (1997)	$K_I \approx K_I^{app}.\tanh\left(2Y\sqrt{\frac{\delta_a}{\rho}}\right)$	δ_a : Size of the fracture-initiating defect. *Y* : An appropriate geometric correction factor which ranges between 2/n for penny shaped starting cracks and l.12 for edge cracks

2.5 SINGLE EDGE NOTCH BENDING (SENB)

2.5.1 Introduction

Single-Edge Notched Bending (SENB) Test is a fracture mechanics-based test commonly used in metals and other materials, to obtain the fracture properties of asphalt binders at low temperatures. They succeeded in grading a broad range of materials with different levels of modification. The SENB test follows ASTM E399 standard and assumes that linear elastic fracture mechanics (LEFM) conditions hold. (Chailleux et.al, 2007). Figure 2.9 shows the schematic diagram for the SENB test specimen and Figure 2.10 shows the SENB process.

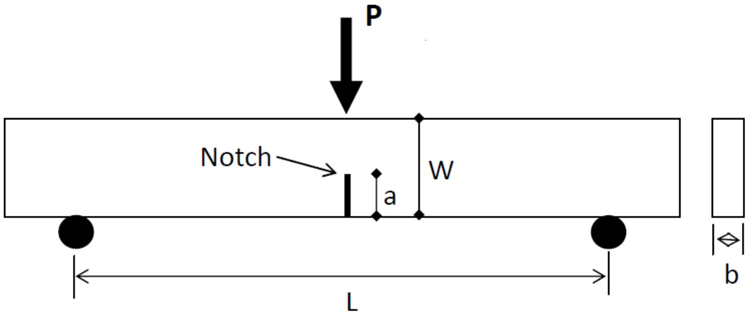


Figure 2.9: Schematic of SENB test

The equation of Fracture Toughness according to the (SENB) Test:

$$K_{1c} = \frac{P.L}{b.W^{\frac{3}{2}}}(f)\left(\frac{a}{W}\right) \tag{2.14}$$

f1 (a/W)	: Geometrical function
b	: Specimen thickness
W	: Specimen width
P	: Load
L	: Specimen length

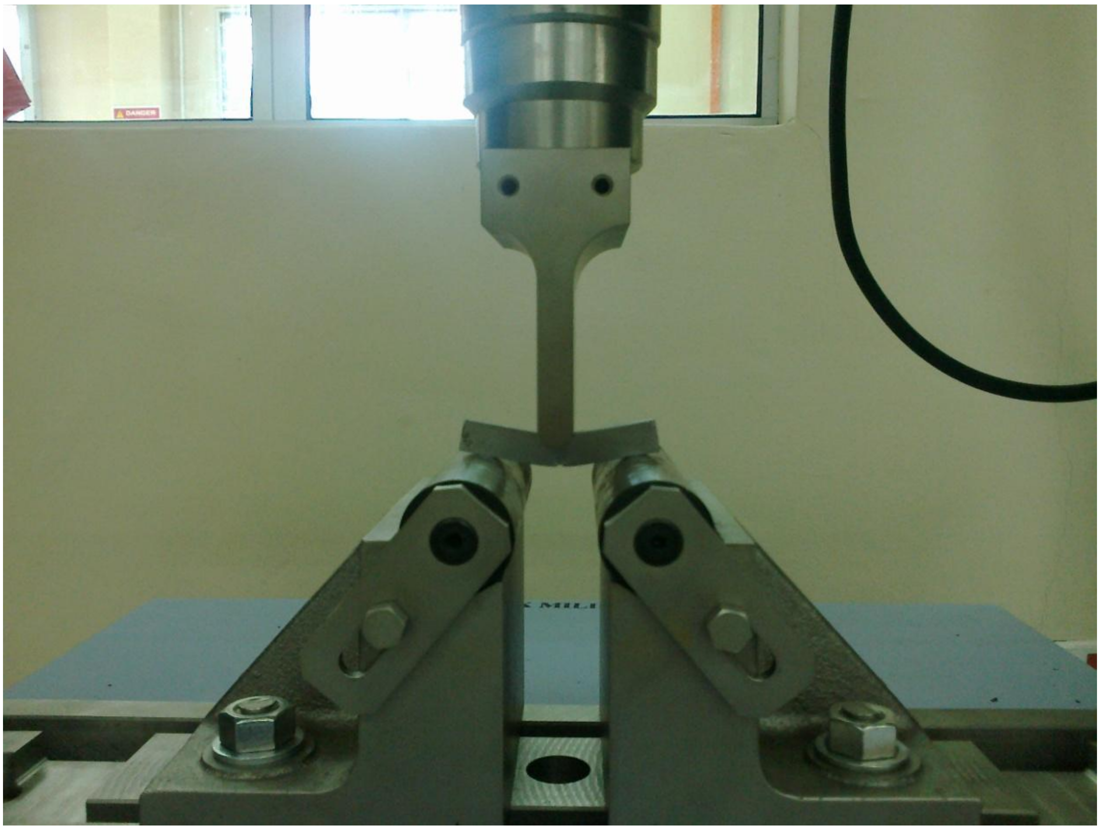


Figure 2.10: The SENB Process

2.5.2 ASTM E399

ASTM E399 involves the testing of notched specimens that have been precracked in fatigue by loading either in tension or three-point bending. Load versus displacement across the notch at the specimen edge is recorded autographically. The load corresponding to a 2% apparent increment of crack extension is established by a specified deviation from the linear portion of the record. The K_{Ic} value is calculated from this load by equations that have been established on the basis of elastic stress analysis of specimens of the types described in this method. The validity of the determination of the K_{Ic} value by this test method depends upon the establishment of a sharp-crack condition at the tip of the fatigue crack, in a specimen of adequate size. To establish a suitable crack-tip condition, the stress intensity level at which the fatigue pre-cracking of the specimen is conducted is limited to a relatively low value. The property K_{Ic} determined by this test method characterizes the resistance of a material to fracture in a neutral environment in the presence of a sharp crack under severe tensile constraint, such that the state of stress near the crack front approaches tritensile plane strain, and the crack-tip plastic region is small compared with the crack size and specimen dimensions in the constraint direction. A K_{Ic} value is believed to represent a lower limiting value of fracture toughness. This value may be used to estimate the relation between failure stress and defect size for a material in service wherein the conditions of high constraint described above would be expected. (International Standard Worldwide, 2011)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

After identifying the objective and problem regarding this project, methodology part will be done in order to complete this project according to the time frame. By using a complete structure of methodology consisting of clear illustration and well planned of project guideline, it will be an essence of the completition of this project.

There are three method has been used in evaluating the fracture toughness of mild steel . There is Single Edge Notch Bend (SENB) test , Compact Tension (CT) test and Charpy test . For this experiment SENB with ATM E399-74 is selected to use in evaluating the impact energy of mild steel.

The methodology for the project is including literature survey, specient test, data collection, data analysis and data extraction. This methods will be explained in detail in order to get clear understanding on the method that need to be done. Figure 3.1 show the flow chart of the project from the begining to end of the project and Figure 3.2 show the methodology plowchart.

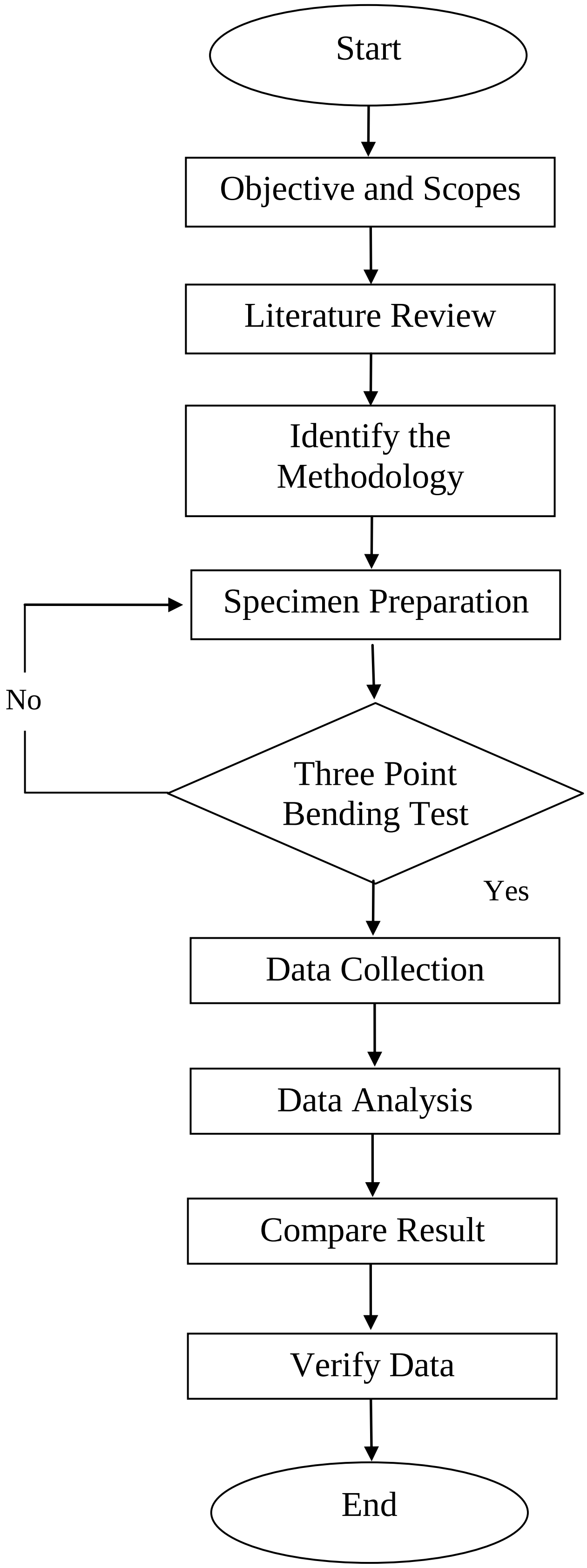


Figure 3.1 : Flowchart of overall methodology.

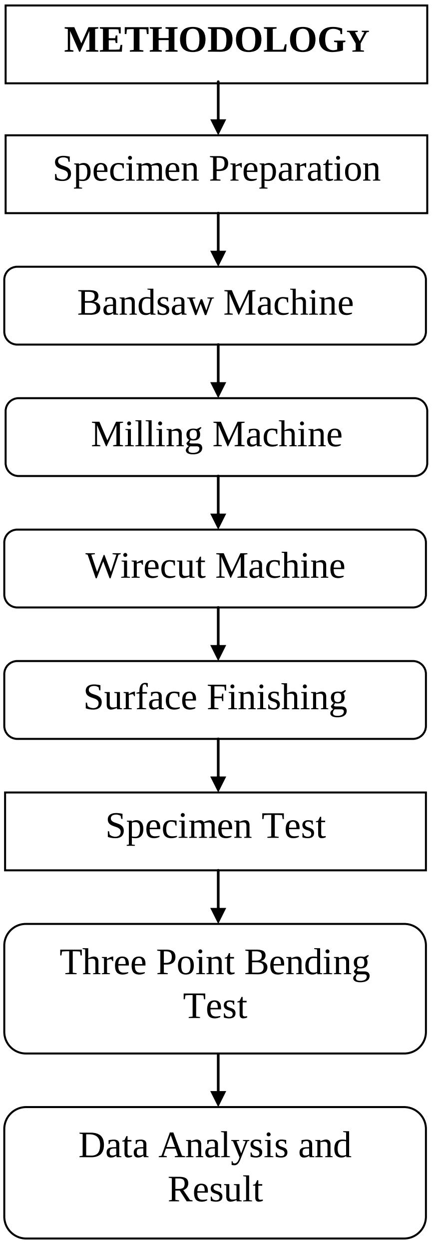


Figure 3.2 : Methodology Flowchart

3.2 MATERIAL PROPERTIES

This project was conducted to analyze the effect of fracture toughness of the mild steel. The mild steel has the property of good formability and weldability, low in strength and also low lost. The low carbon steel is a material that widely use in the industry for making deep drawing parts, chain, pipe and some mechanical parts.

Mild steel is a type of steel alloy that contains a high amount of carbon, as a major constituent. An alloy is a mixture of metals and non-metals, designed to have specific properties. Alloys make it possible to compensate for the shortcomings of a pure metal by adding other elements. The properties of the mild is depend on the amount of the chemical composition contain in the material which is carbon and other alloy mixture of metal and non-metal. The mechanical property was identified by perform the chemical composition test. The Table 3.1 show the chemical composition of mild carbon steel that use for this experiment.

Table 3.1: Chemical composition for mild steel

Component	Fe	C	Cr	Si	Mn	S
Wt %	98.2	0.24	0.134	0.0653	0.453	0.0087

From the chemical composition, the mechanical properties and the type of material can be identified. Table 3.2 shows the mechanical properties of the low carbon steel.

Table 3.2: Mechanical properties of mild steel

Mechanical properties	**Metric**
Elastic modulus	190-210 GPa
Tensile strength	440 MPa
Yield strength	370 MPa
Elongation	15 %
Hardness, Brinell	126
Density(x 1000 kg/$\mathbf{m^3}$)	7.858

From the mechanical properties in the Table 3.1, it shows that the materials that use in this experiment were AISI 1025.

3.3 SPECIMENT PREPARATION

3.3.1 Cutting Process

The raw material with 50 mm x 20 mm cross section was cut by using a horizontal band saw machine brand Everising model S-300HB as shown in Figure 3.3.

The Band saw machine was set up before according to parameter needed before starting the machine operation. The parameter should be looking for is the feed rate of the cutting blade. The cutting blade type used is important due to the material type to ensure the cutting operation will run smoothly and the quality of product. Besides that, the required specimen length and the quantity of the cutting specimen are determined and setup to panel board to running the machine automatically. The machine will stop the cutting operation automatically after all the required quantity completed. The quantity set up must be add extra one as the blade will cut the first cutting as the reference to get the desire length. Coolant is applied onto the cutting blade during the cutting operation to avoid the cutting blade from overheat due to the friction with the material.

The raw mild steel material was cut into the beam shape with dimension of 65 mm in length, 15 mm in width and 20 mm in thickness. The raw mild steel material that undergoes the cutting process is shown in the Figure 3.3. After finish the cutting operation the specimen dimension is measured by using vernier calliper to make sure the specimen dimension is same with the dimension required.

Figure 3.3: Horizontal Bandsaw Machine

Figure 3.4: Raw specimen after cutting

3.3.2 Milling Process

After the cutting process of the raw specimen done, the next step is milling process by using Partner brand. The objective of milling process is to get the true geometry that is needed for the three point bending test by referring the ASTM E399-74. To achieve this geometry, the Milling Machine as in Figure 3.5 is used to restructure the (65 mm x 15 mm x 20 mm) raw material to the desire geometry as shown in Table 3.3 and Figure 3.6.

Figure 3.5: Milling Machine

Table 3.3: Specimen Geometry for Milling Operation

Quantity	Length(mm)	Width(mm)	Thickness(mm)
9 specimen	60	10	15
9 specimen	60	10	10
9 specimen	60	10	5

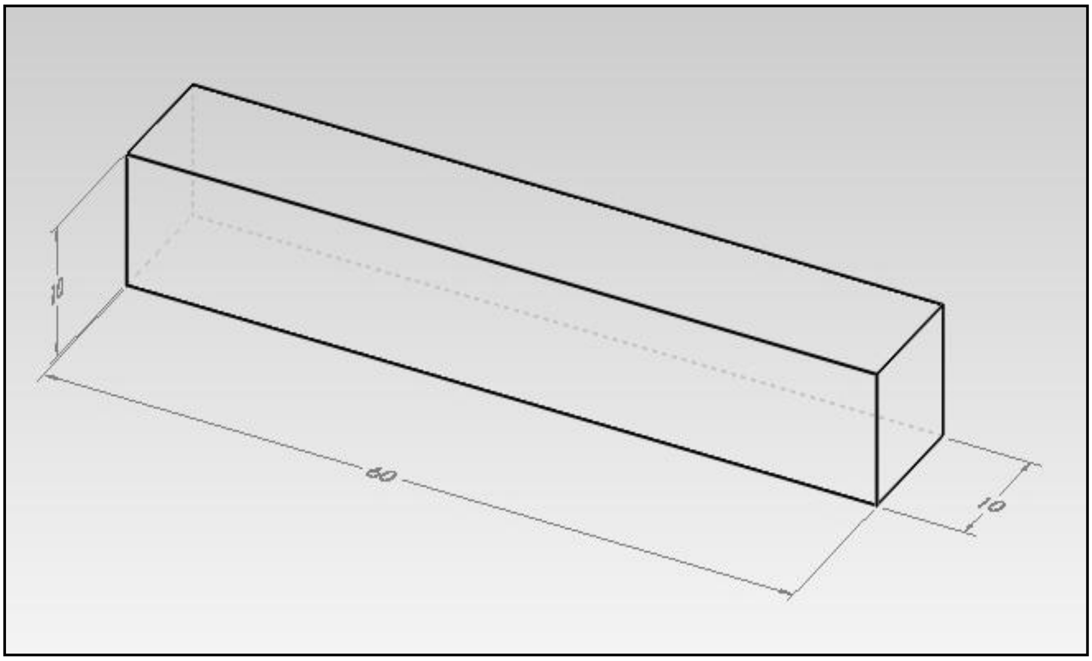


Figure 3.6: Specimen Geometry for milling machine produce

Before start the process the clamping tool need to alignment properly due to get the exact specimen dimension. The Milling machine is applied the rotating method and removing the outer material layer by layer until the geometry is achieve. The spindle speed need to determined first before starting the machining process because each material has different cutting speed as shown in Table 3.4 due to the material properties.

Spindle speed settings on the milling machine are done in RPM and the calculation is:

$$Spindle\ Speed : \frac{CS\ X\ 4}{D} \tag{3.1}$$

CS : Cutting Speed

D : Diameter of Cutter

Table 3.4: Cutting Speed Table for Milling Machine

Material	**Cutting Speed, fpm**
Plain Carbon Steel, AISI 1010 to AISI 1030	110
	100 to 140
	100
	80 to 120
AISI B1111, AISI B1112, AISI B1113, Steel	140
	110 to 200
Plain Carbon Steel, AISI 1040 to 1095	195
	80 to 120
	85
	70 to 110
	60
	30 to 80

The spindle speed obtain from calculation is 760 rpm. The cutting direction is setup to clockwise direction and the spindle is setup to 760 rpm due to calculation. Then, the axis switch is control depend on the required shaped and geometry. There are precaution step need to be taken when undergo this process to avoid the material is unsymmetrical. Before starting the process, make sure the clapping tool is alignment and the cutting tool is tightened properly. The vibrating will affected the geometry symmetrical. By clamping the material tightly will avoid the material to slide when the cutting operation. Coolant is applied onto the cutting tool during the cutting operation to avoid the cutting blade from overheat due to the friction with the material and will affected the quality of products.

3.3.3 Wirecut Process

After the shaping the material into desired geometry is done, the next step is notch depth produce process on the specimen by using wire cut machine brand AQ535L as in Figure 3.7. The copper wire with 0.25 mm diameter is used for this operation. The shape of the product is drawn on the system as in Figure 3.8 and after that converted into g-code. After g-code is produce the cutting process will run according to the code that setup. The specimen is cut into 3 type of notch depth specification as in Table 3.5.

Figure 3.7: Wirecut Machine

Figure 3.8: Shape drawing for the cutting guide

Table 3.5: Table of notch depth specification for wire cut process

Thickness (mm)	**Notch Depth (mm)**	**No of Specimen**
5	0.5	3
10	0.5	3
15	0.5	3
5	1	3
10	1	3
15	1	3
5	2	3
10	2	3
15	2	3

During the wire cut operation water need to use as a medium. The workpiece and the wire represent positive and negative terminals in a DC electrical circuit, and are always separated by a controlled gap. This gap must always be filled with a dielectric fluid, in this case deionized water, which acts as an insulator and cooling agent. Of equal importance, it flushes away the eroded particles from the work zone. Figure 3.9 show the cutting operation during cutting the notch depth for the specimen. The specimen notch geometry is shown in Figure 3.10.

Figure 3.9: Cutting Operation

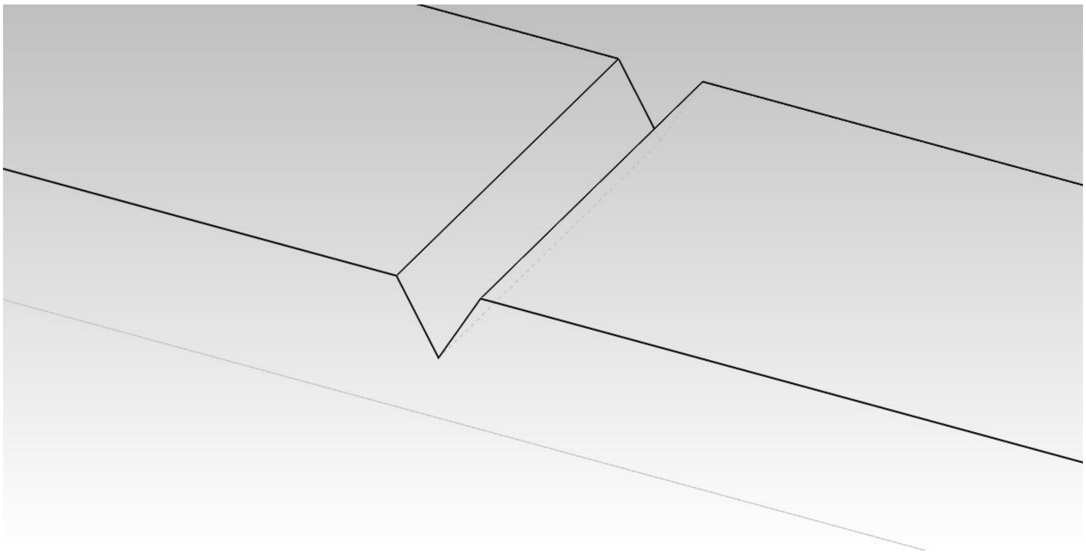


Figure 3.10: Specimen notch depth geometry

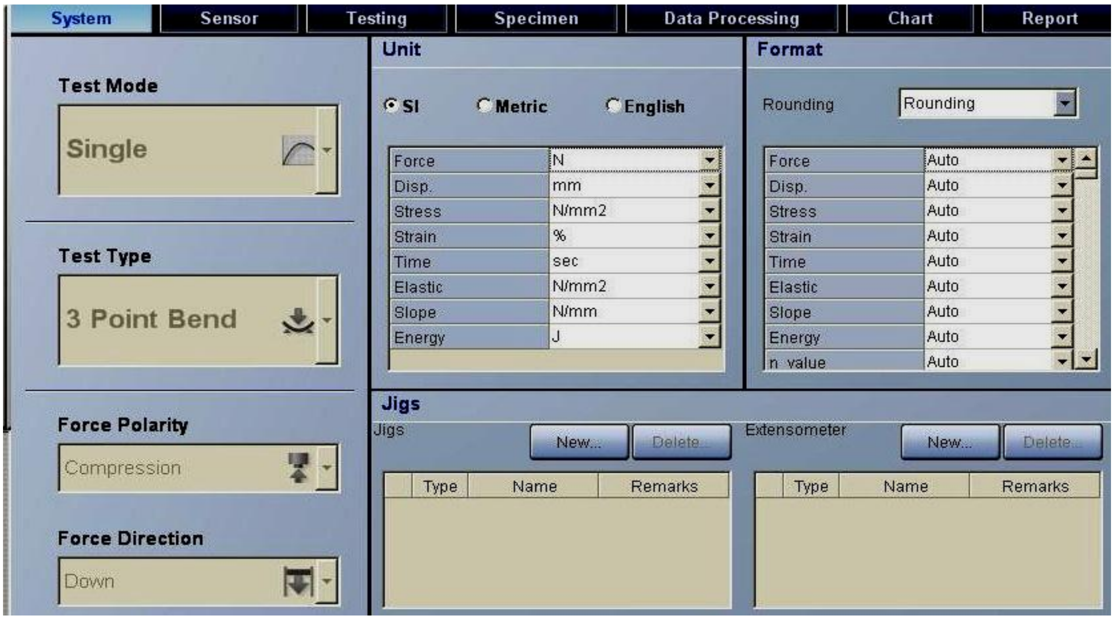
There are precaution step was taken when undergo the process to avoid the material unsymmetrical. Before starting the process the clamping tool was tightened properly to reduce or avoid the vibration because it was affected the specimen geometry that produces. By clamping the material tightly will avoid the material to slide when the cutting operation. In other hand, the machine door was closed properly and opened properly before run the machine and after finish the cutting operation to avoid water drain out. After finish the cutting operation, the water was drained out completely before open the door to avoid electric shock.

3.4 THREE POIND BENDING TEST

The Shimazu universal testing machine with 10 kN maximum load was used in this three point bending test. The basic setup in a standardized bending test involves a specimen which supported by two static supports from the bottom and an indentor that is loaded with a computer controlled setup which is controlled by the TRAPEZIUMX software.

The indentor is driven into the specimen that starts bending and deforming. A force gauge in the head of the indentor constantly measures the applied load. While the indentor is driven into the specimen, the distance (displacement of the sample under load) is measured and plotted versus the applied load. In this manner a stress or load deformation diagram is generated from which the material specific properties can be show in the result.

In this test, the Shimazu machine is setup with the 3 point bending test equipment. TRAPEZIUMX software is the main controller for Shimazu universal testing machine. Before start the test all the requirement of the bending test is setup on the TRAPEZIUMX software. The system is setup according the Figure 3.11.



Test Mode: Single

Test Type: 3 Point Bend

Force Polarity: Compression

Force Direction: Down

● SI ○ Metric ○ English

Force	N
Disp.	mm
Stress	N/mm2
Strain	%
Time	sec
Elastic	N/mm2
Slope	N/mm
Energy	J

Rounding: Rounding

Force	Auto
Disp.	Auto
Stress	Auto
Strain	Auto
Time	Auto
Elastic	Auto
Slope	Auto
Energy	Auto
n value	Auto

Figure 3.11: TRAPEZIUMX software system is setup.

The sensor is setup or indenter is setup at 90 kN force limit as shown in Figure 3.12.

Channel:

Channel: Force Amp.

Name Force

Full Scale: 100000 N

☑ Limit: 90000 N

☐ Lower Limit -0.001 N

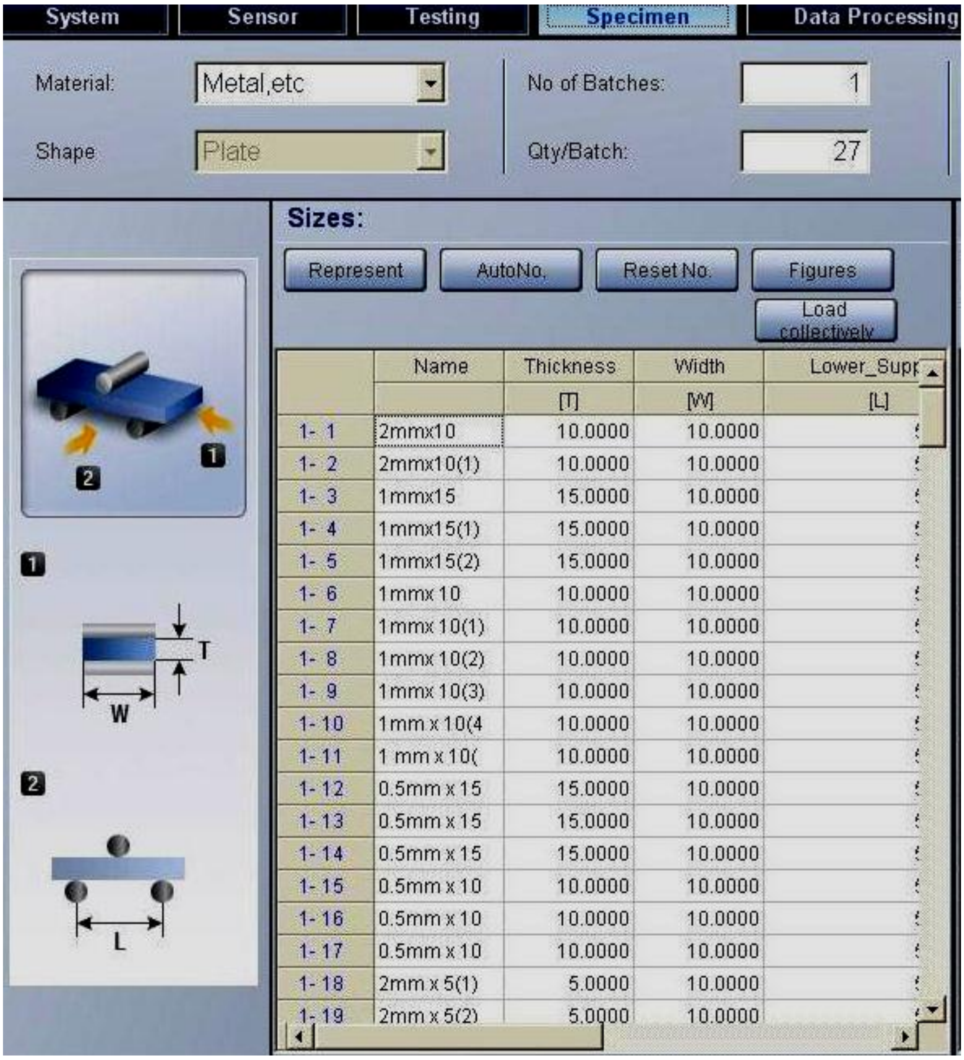
Stress

Name Stress

☐ Use True Stress

Figure 3.12: TRAPEZIUMX software sensor is setup.

After that, the specimen dimension is setup at specimen dimension list. 27 specimen is listed according to it geometry as shown in Figure 3.13.



Material: Metal,etc

Shape: Plate

No of Batches: 1

Qty/Batch: 27

	Name	Thickness [T]	Width [W]	Lower_Supp [L]
1- 1	2mmx10	10.0000	10.0000	
1- 2	2mmx10(1)	10.0000	10.0000	
1- 3	1mmx15	15.0000	10.0000	
1- 4	1mmx15(1)	15.0000	10.0000	
1- 5	1mmx15(2)	15.0000	10.0000	
1- 6	1mmx 10	10.0000	10.0000	
1- 7	1mmx 10(1)	10.0000	10.0000	
1- 8	1mmx 10(2)	10.0000	10.0000	
1- 9	1mmx 10(3)	10.0000	10.0000	
1- 10	1mm x 10(4	10.0000	10.0000	
1- 11	1 mm x 10(	10.0000	10.0000	
1- 12	0.5mm x 15	15.0000	10.0000	
1- 13	0.5mm x 15	15.0000	10.0000	
1- 14	0.5mm x 15	15.0000	10.0000	
1- 15	0.5mm x 10	10.0000	10.0000	
1- 16	0.5mm x 10	10.0000	10.0000	
1- 17	0.5mm x 10	10.0000	10.0000	
1- 18	2mm x 5(1)	5.0000	10.0000	
1- 19	2mm x 5(2)	5.0000	10.0000	

Figure 3.13: Setup the specimen dimensions and types on the TRAPEZIUMX software.

At the data processing part is selected to maximum due the get the result with maximum force and displacement. The data processing part is shown in Figure 3.14. The specimen was setup at the centre of the support and the depth is setup perpendicular to the indenter as shown in Figure 3.15.

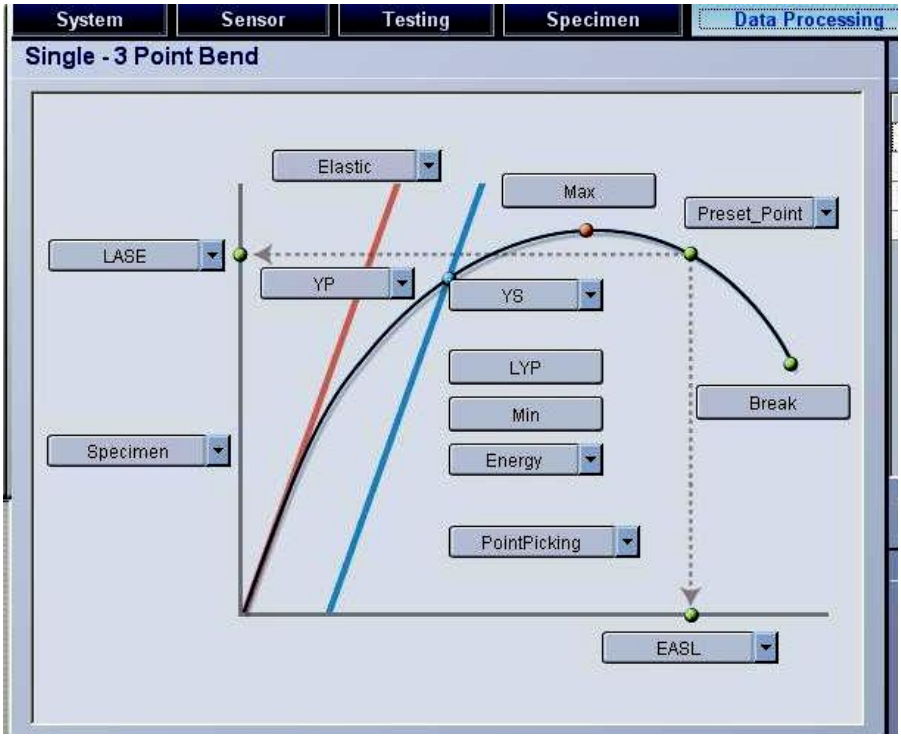


Figure 3.14: TRAPEZIUMX software data processing is setup.

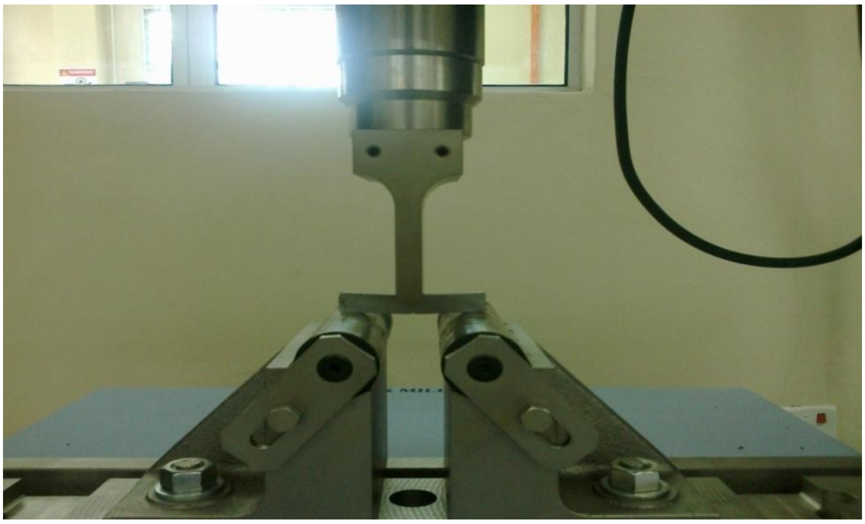


Figure 3.15: Specimen setup at the Shimazu machine before bending test.

Before the test started the force and stroke was setup to zero and manual remote was turn off. After that, start the test and the test will run properly .During the test, the graph is drawn when the indenter is driven to specimen. The indenter will analyze the force and displacement that exerted to the specimen as shown in Figure 3.16.

Name : 1mm x 5(3)

Force 4260 N

Stroke 1.594 mm

Test Speed 1 mm/min

Full Scale: 100000 N

CP ---

Break ON

Name		Max_Force	Max_Disp.
Parameter		Calc. at Entire Areas	Calc. at Enti
Pass/Fail			
Unit		N	mm
Print		☑	☑
1mmx 10	☑	16621.2	11.4806
1mmx 10(1)	☑	16785.0	9.39996
1mmx 10(2)	☑	80.9034	0.23265
1mmx 10(3)	☑	72.1296	0.24579
1mm x 10(4	☑	35.4449	0.00963
1 mm x 10(	☑	16468.6	7.36546
0.5mm x 15	☑	39494.4	12.2005
0.5mm x 15	☑	46778.4	12.4853
0.5mm x 15	☑	45481.9	12.6450
0.5mm x 10	☑	30357.1	14.9170
0.5mm x 10	☑	35832.2	14.6164
0.5mm x 10	☑	15820.2	10.9888
2mm x 5(1)	☑	5349.18	5.18194
2mm x 5(2)	☑	5639.71	4.72063
2mm x 5(3)	☑	5606.37	4.73479
1mm x 5(1)	☑	5867.34	4.84829
1mm x 5(2)	☑	5951.80	5.15946
1mm x 5(3)	☐		
1_24	☐		

Figure 3.16: During Bending test analysis.

The test is finish until the maximum force and displacement is obtained. The result of the test is showed by the Force (N) versus Displacement (mm) graph as shown in Figure 3.17. The specimen condition after bending test is shown in Figure 3.18.

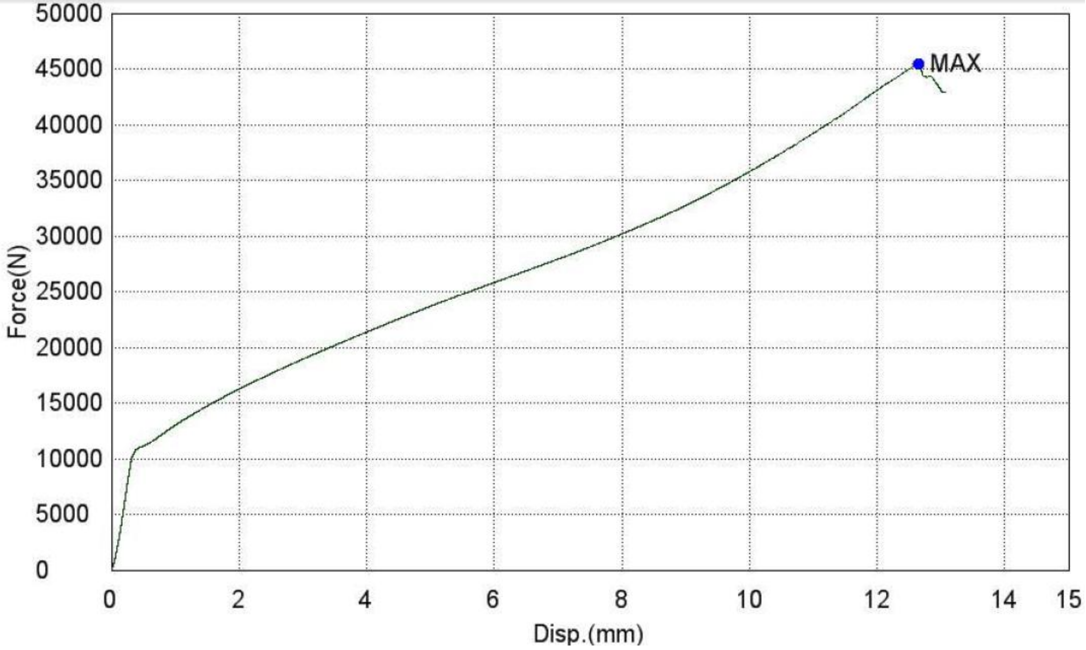


Figure 3.17: The example of result for the bending test.

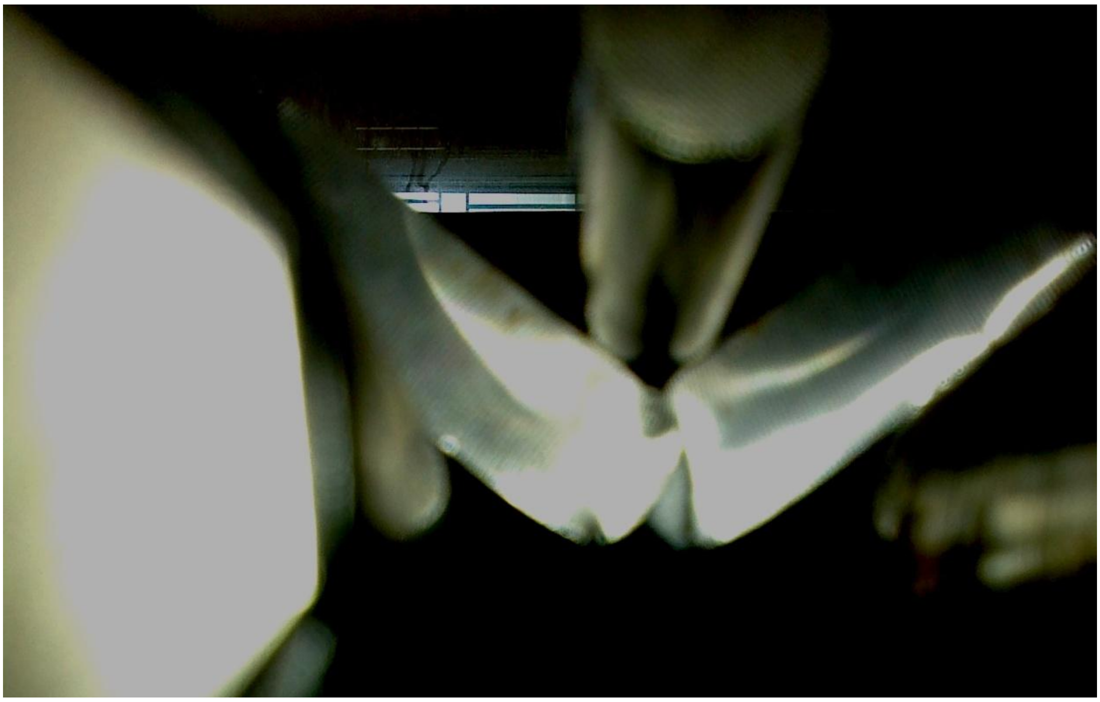


Figure 3.18: Condition of the specimen after bending test.

CHAPTER 4

EXPERIMENTAL RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will discuss the analysis result from the three point bending test. All the parameter must be considered in this chapter before making any conclusion because all the parameter applied in this test will affect the result of the bending test and fracture toughness of the material.

4.2 FORCE–DISPLACEMENT RESULT FOR DIFFERENT NOTCH DEPTH AND THICKNESS

4.2.1 Force-Displacement Graph

From the three point bending test, the force-displacement graph is recorded at the point of maximum force and the corresponding notch depth. The test is varying the notch radius and specimen thickness. Different value of the maximum force and displacement is obtained for each specimens test. Figure 4.1 to 4.6 is the results from the three points bending test for each different notch depth and specimen thickness.

Figure 4.1 shows the relation between the notch depths with different thickness. When the thickness of the specimen increase the maximum force exerted to the specimen is increase. At 5 mm thickness the maximum force is 7.2kN, at 10 mm thickness the maximum force is 25kN and at the 15 mm thickness the maximum force is 40.3kN. At thickness 5 mm the maximum force is the lowest and at the 15 mm thickness the maximum force is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different thickness. At 5 mm thickness the maximum displacement value is lowest and at the 10 mm thickness the maximum displacement is highest. From the graph, at 5 mm maximum displacement is 6.4 mm, 10 mm is 14.4 mm and 15 mm is 12.4 mm.

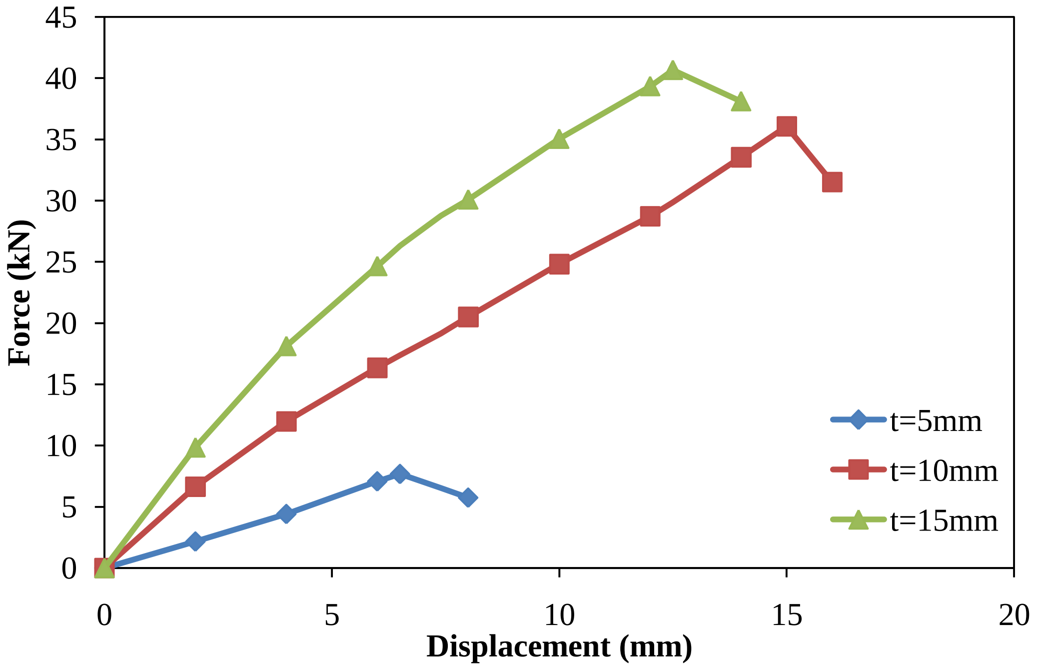


Figure 4.1: Result of 0.5mm notch depth with different thickness

Figure 4.2 shows the relation between the notch depths with different thickness. When the thickness of the specimen increase the maximum force exerted to the specimen is increase. At 5 mm thickness the maximum force is 6.1 kN, at 10 mm thickness the maximum force is 16.6 kN and at the 15 mm thickness the maximum force is 25.1 kN. At thickness 5 mm the maximum force is the lowest and at the 15 mm thickness the force maximum is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different thickness. At 5 mm thickness the maximum displacement value is the lowest and at the 10 mm and 15 mm thickness the maximum displacement is highest. The value of the maximum displacement between 10 mm and 15 mm thickness is slightly same. From the graph, at 5 mm maximum displacement is 4.8 mm, 10 mm is 9.4 mm and 15 mm is 9.1 mm.

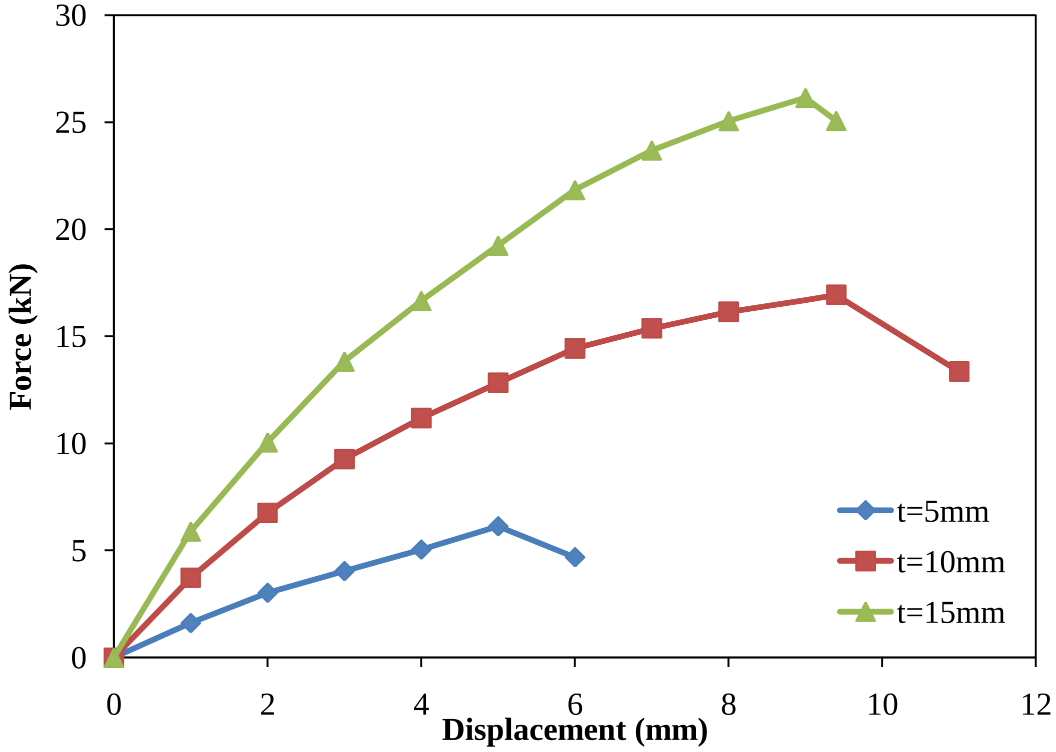


Figure 4.2: Result of 1 mm notch depth with different thickness

Figure 4.3 shows the relation between the notch depths with different thickness. When the thickness of the specimen increase the maximum force exerted to the specimen is increase. At 5mm thickness the maximum force is 5.5 kN, at 10 mm thickness the maximum force is 13.9 kN and at the 15 mm thickness the maximum force is 21.8 kN. At thickness 5 mm the maximum force is the lowest and at the 15 mm thickness the maximum force is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different thickness. At 5 mm thickness the maximum displacement value is the lowest and at the 10 mm and 15 mm thickness the maximum displacement is highest. The value of the maximum displacement between 10 mm and 15 mm thickness is slightly same. From the graph, at 5 mm maximum displacement is 4.9 mm, 10 mm is 6.8 mm and 15 mm is 6.6 mm.

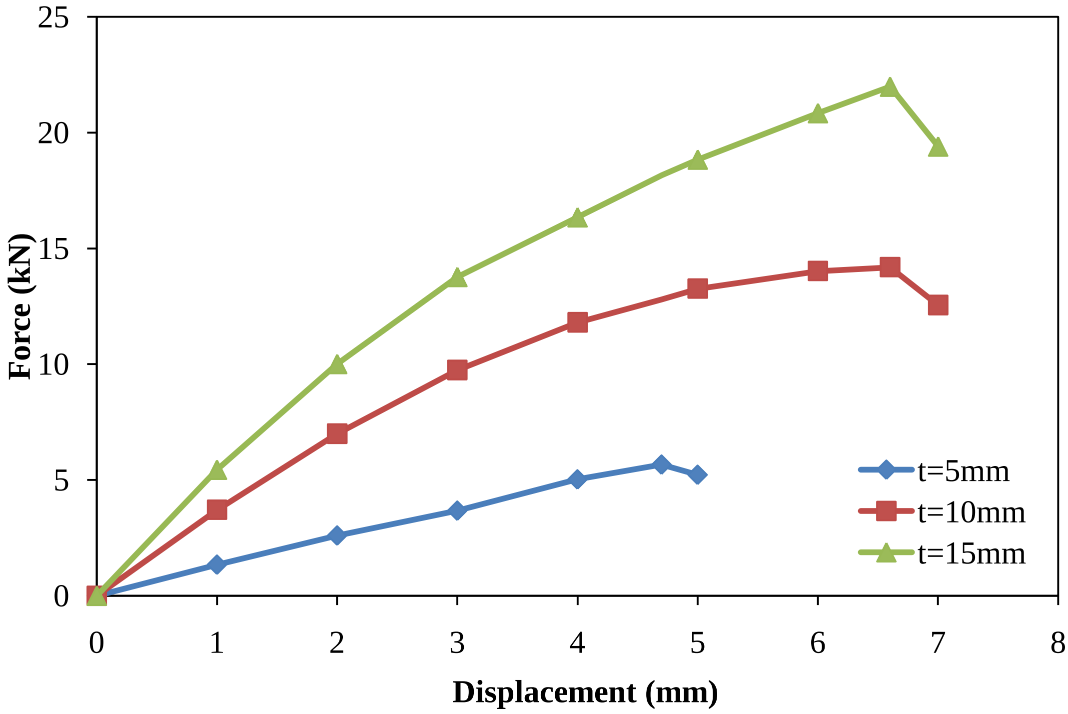


Figure 4.3: Result of 2 mm notch depth with different thickness

Figure 4.4 shows the relation between the thickness with the different notch depth. When the notch depth of the specimen decrease the maximum force exerted to the specimen is increase. At 0.5 mm notch depth the maximum force is 7.2 kN, at 1 mm notch depth the maximum force is 6.1 kN and at the 15 mm notch depth the maximum force is 5.5 kN. At notch depth 2 mm the maximum force is the lowest and at the 0.5 mm notch depth the maximum force is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different notch depth. At 2 mm notch depth the maximum displacement value is the lowest and at the 0.5 mm the maximum displacement is highest. From the graph, at 0.5 mm notch depth the maximum displacement is 6.2 mm, 1 mm is 4.8 mm and 2 mm is 4.9 mm.

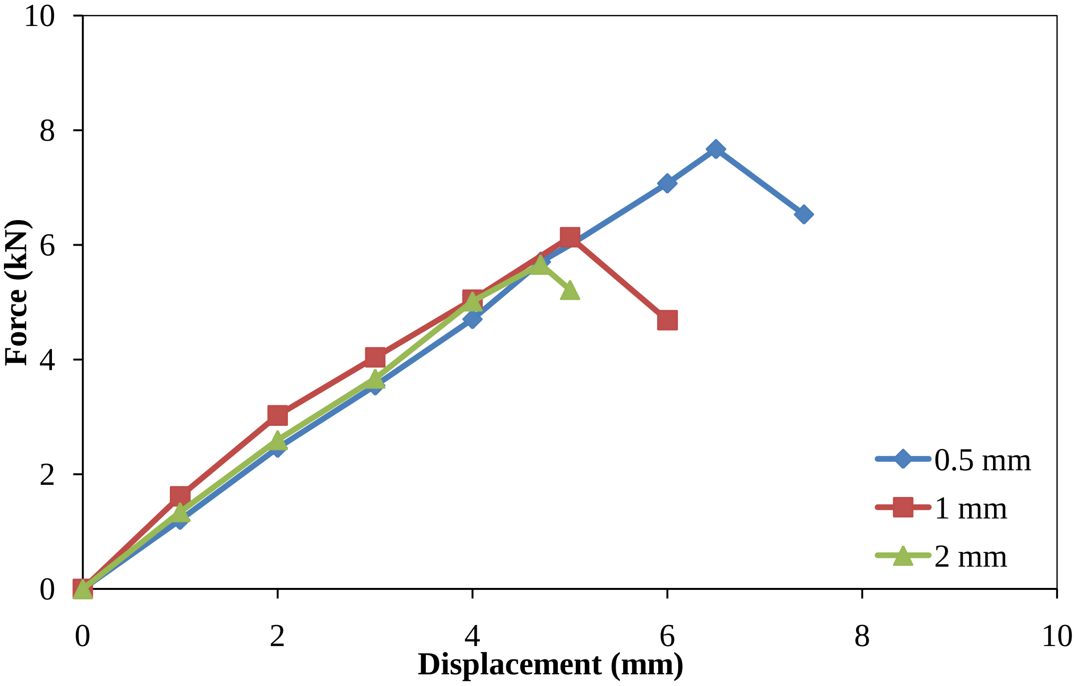


Figure 4.4: Result of 5 mm thickness with different notch depth

Figure 4.5 shows the relation between the thickness with the different notch depth. When the notch depth of the specimen decrease the maximum force exerted to the specimen is increase. At 0.5 mm notch depth the maximum force is 25 kN, at 1 mm notch depth the maximum force is 16.6 kN and at the 15 mm notch depth the maximum force is 13.9 kN. At notch depth 2 mm the maximum force is the lowest and at the 0.5 mm notch depth the maximum force is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different notch depth. At 2 mm notch depth the maximum displacement value is the lowest and at the 0.5 mm the maximum displacement is highest. From the graph , at 0.5 mm notch depth the maximum displacement is 14.4 mm, 1 mm is 9.4 mm and 2 mm is 6.8 mm.

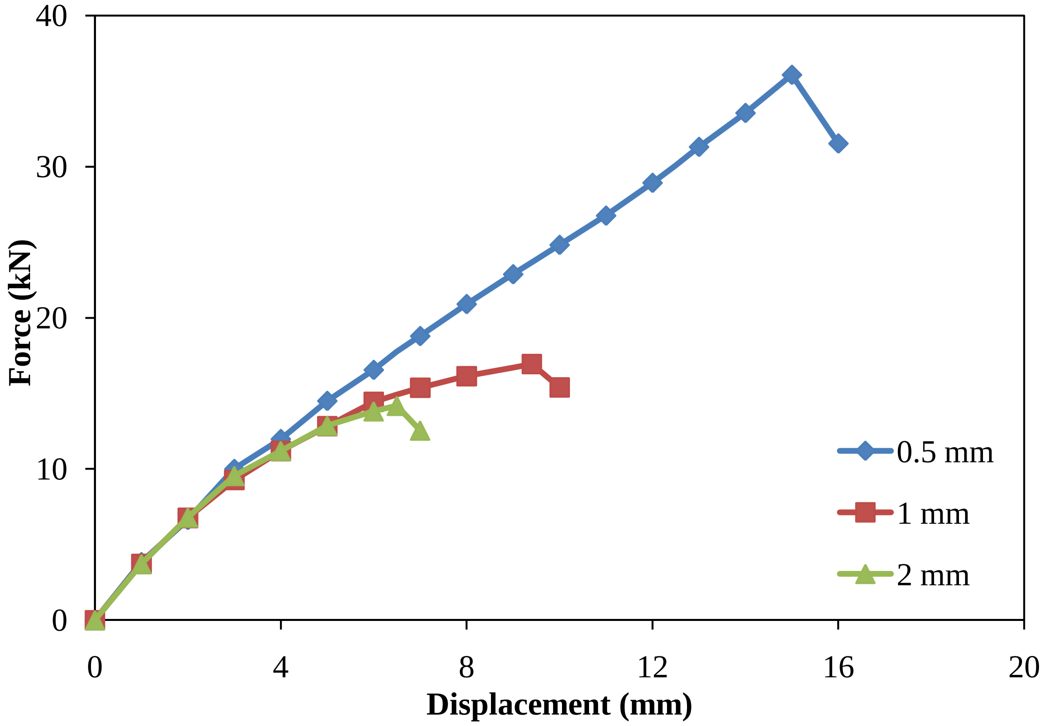


Figure 4.5: Result of 10 mm thickness with different notch depth

Figure 4.6 shows the relation between the thickness with the different notch depth. When the notch depth of the specimen decrease the maximum force exerted to the specimen is increase. At 0.5 mm notch depth the maximum force is 40.3 kN, at 1 mm notch depth the maximum force is 25.1 kN and at the 15 mm notch depth the maximum force is 21.8 kN. At notch depth 2 mm the maximum force is the lowest and at the 0.5 mm notch depth the maximum force is large. The force of the specimen is increase when the displacement increases until it reaches the maximum force. After it reaches the maximum force the force will decrease until the specimen fail. The maximum displacement value of the specimen is different for different notch depth. At 2 mm notch depth the maximum displacement value is the lowest and at the 0.5 mm the maximum displacement is highest. From the graph, at 0.5 mm notch depth the maximum displacement is 12.4 mm, 1 mm is 8.9 mm and 2 mm is 6.4 mm.

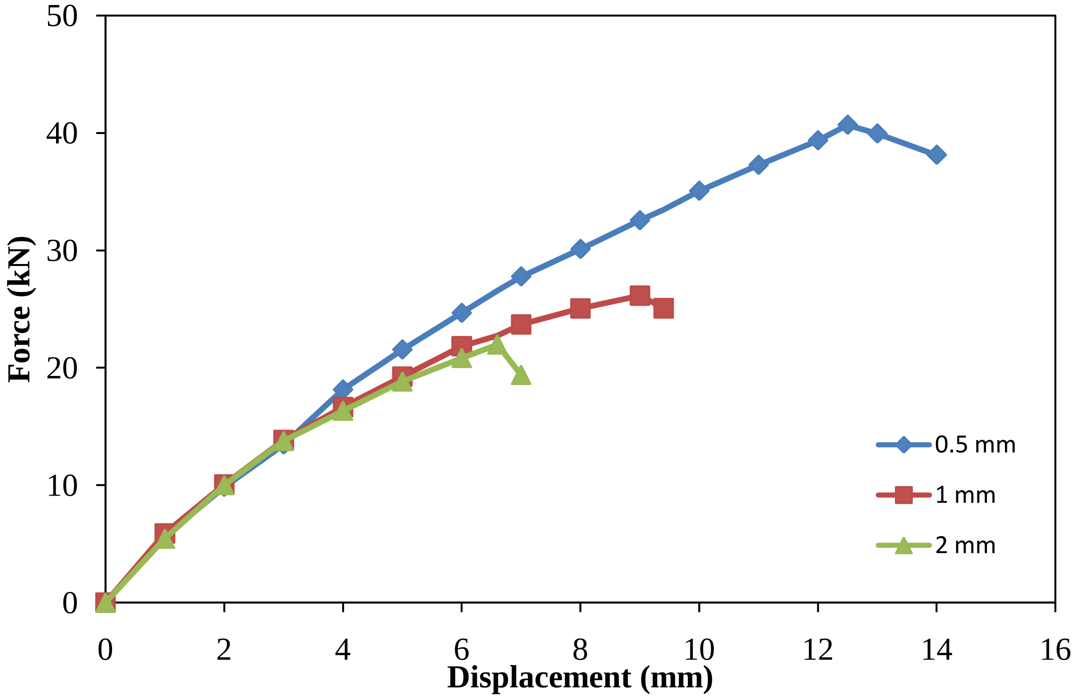


Figure 4.6: Result of 15 mm thickness with different notch depth

4.2.2 Discussion

The SENB process is the most widely used method for the case of the fracture toughness test that varies with specimen thickness and notch radius. Figure 4.1 to 4.3 show the force-displacement graph that varies the notch depth of the specimen. At Figure 4.1, the maximum force obtain is higher than Figure 4.2 and 4.3. Figure 4.1 obtain the higher value of maximum force and Figure 4.3 obtain the lowest value of maximum force. The relation between the notch depths with the maximum force is when the notch depth decreases the force is increase. It is because when the notch depth is decrease the notch area at testing point is decrease. The notch area is influence the stress intensity factor. This means that, when the notch area is increase the stress intensity factor is increase. Therefore, at the small notch area the value of stress intensity is higher. Highest force is needed to overcome the stress intensity and start to failure the specimen.

Figure 4.6 obtain the higher value of maximum force and Figure 4.4 obtain the lowest value of maximum force. The relation between the specimen thickness with the maximum force is when the thickness increases the force is increase. It is because when the thickness is increase the area of testing point is increase. Force exerted is directly proportional to the area of the specimen due the stress equation. Other than that, the size of the specimens is influence the stress intensity factor. Mean that, when the area is increase the stress intensity factor and failure ability is increase. Higher force is needed to initiate the specimen crack when the value of stress intensity is higher.

From Figure 4.1 to Figure 4.6 the value of maximum force is different. It is because the maximum force obtain from the result is different according to the specimen thickness and notch depth. For the specimens that have higher notch depth and smaller specimen thickness the value of the maximum force obtains is smaller for example 0.5 mm notch depth and 15 mm thickness have 25.13 kN maximum force that higher than others. But for the specimens that have smaller notch depth and higher specimen thickness the value of the maximum force obtains is smaller for example the 2 mm notch depth and 5 mm thickness have 5.5 kN maximum force that higher from others. The value of maximum force exerted is totally depending on the notch depth and specimen thickness.

Most tests on mild steels which have been evaluated using SENB methods so far have shown that the determined fracture values are greatly dependent on plastic deformation at the crack tip. The plastic deformation behavior is largely dependent on the stress condition given by the specimen geometry for example specimen thickness and notch depth. Even in case of geometrically identical specimens, variations of plastic deformation behavior as a consequence of notch depth can be observed prior to the onset of instable fracture (W. Seidl ,1979). As a consequence, in such cases the total deformation energies at fracture are very different. For fracture mechanics data which are determined considering the total deformation energy, notch depth value can be seen to exert a strong influence. So those, the test result are related to the (W. Seidl, 1979) theory.

4.2.3 Result of Three Point Bending Test

Table 4.1 is the result of the three point bending tests from 27 specimens with different notch depth and thickness. Each of the specimen type will be testing for three times to get the accurate result. So that, the average of the result will be analyze. From Table 4.1, the relation between notch depth and thickness of the specimen will be analyzing according to the maximum force (kN) and maximum displacement (mm) result.

Table 4.1: Three Point Bending Test Result

Parameter		
Thickness (*mm*)	**Notch Radius (*mm*)**	**Maximum Force,(*kN*)**
5	0.5	7.4 6.9 7.2
10	0.5	24.4 25.8 24.8
15	0.5	39.5 40.8 40.5
5	1	5.9 5.9 6.2
10	1	16.6 16.8 16.5
15	1	25 26.1 24.3

Table 4.1: Three Point Bending Test Result. Continued

Parameter		Maximum Force,(*kN*)
Thickness (*mm*)	**Notch Radius (*mm*)**	
5	2	5.3
		5.6
		5.6
10	2	13.3
		14.4
		14.1
15	2	21.7
		21.8
		22.1

4.3 FORCE ANALYSIS

4.3.1 Result of notch depth and thickness

Table 4.2 is the result of the three point bending tests specimens with different notch depth and thickness. From Table 4.1, the relation between notch depth and thickness of the specimen will be analyzed according to the maximum force (kN) and maximum displacement (mm) result.

Table 4.2: Force Analysis Result

Parameter		**Maximum Force (*kN*)**
Thickness (*mm*)	**Notch Radius (*mm*)**	
5	0.5	7.2
10		25.0
15		40.3
5	1	6.1
10		16.6
15		25.1
5	2	5.5
10		13.9
15		21.8

4.3.2 Force-Thickness

Figure 4.7 show the relation between Force and Thickness. Based on the figure 4.7 the value of the force (kN) exerted is increase with increases the specimen thickness. The relation between the force and the specimen thickness is directly proportional. The value of the force is smaller at 5 mm thickness and highest at 15 mm thickness for each of the notch depth .At 0.5 mm notch depth the force for 5 mm thickness is 7.2 kN, 10 mm is 25 kN and at 15 mm is 40.3 kN. For 1 mm notch depth the force for 5 mm thickness is 6.2 kN, 10 mm is 16.6 kN and at 15 mm is 25.1 kN. And for 2 mm notch depth the force for 5 mm thickness is 5.5 kN, 10 mm is 13.9 kN and at 15 mm is 21.8 kN. When notch depth is decrease and thickness is increase the force is increase for example at 0.5 mm notch depth and 15 mm thickness the force is 40.3 kN. However, when notch depth is increase and thickness decrease the force is decrease for example at 2 mm notch depth and 5 mm thickness the force obtain is 5.5 kN. According to the result obtain, the thickness dimension was influence the force exerted to the specimen. While the specimen is increase thickness increase the force exerted is increase. This trend happen because of the thickness dimension is effect the stress intensity value in the specimens. The stress intensity value is increase when the thickness is increase. Therefore the force exerted to the specimen is increase when the thickness is increase because the force exerted to the specimen need to overcome the stress intensity value to initiate the crack and to completely fail the specimen. The force exerted on the specimens is increase when the thickness is increase and the notch depth is decrease. At smaller notch depth the crack propagation consists of stable and unstable crack extension phases was occurred. The instability occurring after crack extension occurs. The higher force is needed to overcome the instability to initiate the crack until the forces reach the maximum force. While at the largest value of notch depth the only spontaneous crack extension is possible and only lowest force exerted is needed. At the lowest value of notch depth the instability occurs during the test is highest than the large value of notch depth. This happen is due to the concentration of the plastic deformation in a small area along the notch depth. This occurs when the notch depth of a shallow single-edge notch is sufficiently small compared with the thickness. The concentration of the plastic deformation is large at the small notch depth and lower at large notch depth.

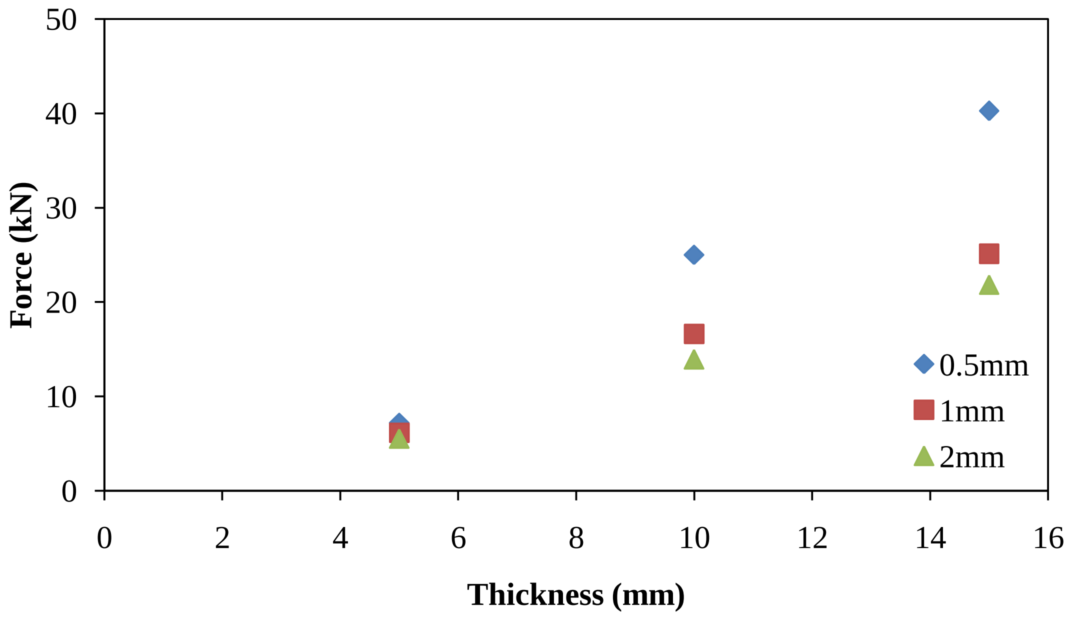


Figure 4.7: Graph Force Vs Thickness with different notch depth

4.3.3 Force-Notch Depth

From Figure 4.8 the value of the force exerted is decrease with increase the notch depth. It is because the when the notch depth is increase the stress concentrated is decrease. So that, the material is easily to bend with lower force because the stress concentrated at the notch position is less than at the part without notch. From 0.5 mm to 1 mm notch depth the force is decrease and at 2 mm notch depth above the force is become constant. At 5 mm thickness the force at 0.5 mm notch depth is 7.2 kN, at 1 mm is 6.1kN and at 2 mm is 5.5 kN. For 10 mm thickness the force at 0.5 mm is 25 kN, at 1 mm is 16.6 kN and at 2 mm is 13.9 kN. And for 15 mm thickness the force for 0.5 mm notch depth is 40.3 kN, 1 mm is 25.1 kN and at 2 mm is 21.8 kN. When notch depth is decrease and thickness is increase the force is increase for example at 0.5 mm notch depth and 15 mm thickness the force is 40.3 kN. When notch depth increase and thickness decrease the force exerted is decrease for example at 2 mm notch depth and 5 mm thickness the force obtain is 5.5kN. However, the force exerted on the specimen will become constant at the critical dimension whenever the thickness of specimen is increase. From the graph, the force exerted at 1 mm and 2 mm notch depth is slightly same and after 2 mm notch depth the force exerted is become constant. According to the result obtain, the force exerted on the specimen is decrease when the notch depth is increase and the force exerted is become constant when the notch depth exceeds the critical dimension, it is a true material property which is called the plane-strain fracture toughness. . At the smaller notch depth dimension the crack propagation consists of stable and unstable crack extension phases was occurred. The instability occurring after crack extension occurs. The higher force is needed to overcome the instability to initiate the crack until the forces reach the maximum force. While at the largest value of notch depth the only spontaneous crack extension is possible and only lowest force exerted is needed. At the lowest notch depth the instability occurs during the test is highest than the large value of notch depth. This happen is due to the concentration of the plastic deformation in a small area along the notch depth. This occurs when the notch depth of a shallow single-edge notch is sufficiently small compared with the thickness. The concentration of the plastic deformation is large at the lower notch depth and small at the large notch depth. In the other side, when the notch depth reach the critical dimension the force exerted on the specimen is become constant due the concentration of plastic deformation is become constant. Even though the notch depth is increase the force exerted to the specimen will become constant when the notch depth achieved the critical dimension.

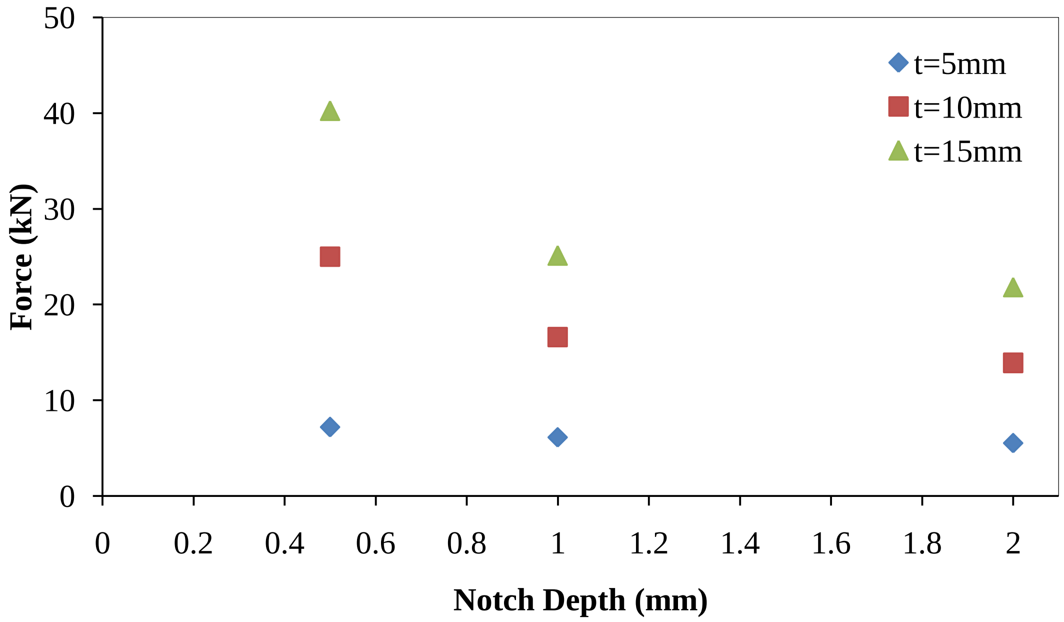


Figure 4.8: Graph Force Vs Notch Radius (mm) with different thickness

4.4 STRESS ANALYSIS

4.4.1 Result of notch depth and thickness

Table 4.3 represents the result of the stress analysis with different notch depth and thickness. From table 4.3, the relation between notch depth and thickness of the specimen will be analyzing according to stress analysis applied.

Table 4.3: Stress Analysis Result

Parameter		Stress (*MPa*)
Thickness (*mm*)	**Notch Radius (*mm*)**	
5	0.5	180.4
10		140.1
15		134.3
5	1	186.1
10		157.7
15		136.3
5	2	282.8
10		193.2
15		151.5

4.4.2 Stress-Thickness

Figure 4.7 show the Stress -Thickness graph. From figure 4.7, the value of the stress exerted is decrease when the thickness is increase. The relation between the stress and the specimen thickness is inversely proportional according to the force equation stress = Force / Area. The value of the stress is smaller at 15 mm thickness and highest at 5 mm thickness for each of the notch depth .At 0.5 mm notch depth the stress for 5 mm thickness is 180.4 MPa, 10 mm is 140.1MPa and at 15 mm is 134.3 MPa. For 1 mm notch depth the force for 5 mm thickness is 186.1MPa, 10 mm is 157.7 MPa and at 15 mm is 136.3MPa. And for 2 mm notch depth the force for 5 mm thickness is 282.8 MPa, 10 mm is 193.2MPa and at 15 mm is 151.5 MPa. When the notch depth is decrease and thickness is increase the stress exerted is decrease for example at 0.5 mm notch depth and 15 mm thickness the force is 134.3 MPa. While, when the notch depth is increase and thickness decrease the force is increase for example at 2 mm notch depth and 5 mm thickness the stress exerted is 282.8 MPa. The stress exerted on the specimen will become constant when the thickness reaches the critical thickness dimension even the thickness of specimen is increase. At 10 mm and 15 mm thickness the stress exerted is slightly same and after 15 mm thickness the stress exerted is become constant value. The stress intensity value is increase when the thickness is increase. Therefore the stress exerted on the specimen is increase when the thickness is decrease because the relation between the thickness (Area) and stress is inversely proportional. The stress exerted to the specimen need to be lower than stress intensity to initiate the crack and to achieve the maximum stress. It is occur due to increasing the area at the testing point at the middle of the specimen due to the higher value of thickness and lower value of notch depth that produce the large cross section area at the center point of testing. Thickness of the specimen was affected the stress intensity in the material and notch was effect the concentration of the plastic deformation along notch depth area. The stress intensity is increase when thickness is increase that affected the cracking ability of the specimen .The concentration of the plastic deformation is large at the small notch depth and was effect the instability during cracking. The combination of the thickness and notch depth was effected the stress exerted values because the combination is effected the cross section area of the specimen.

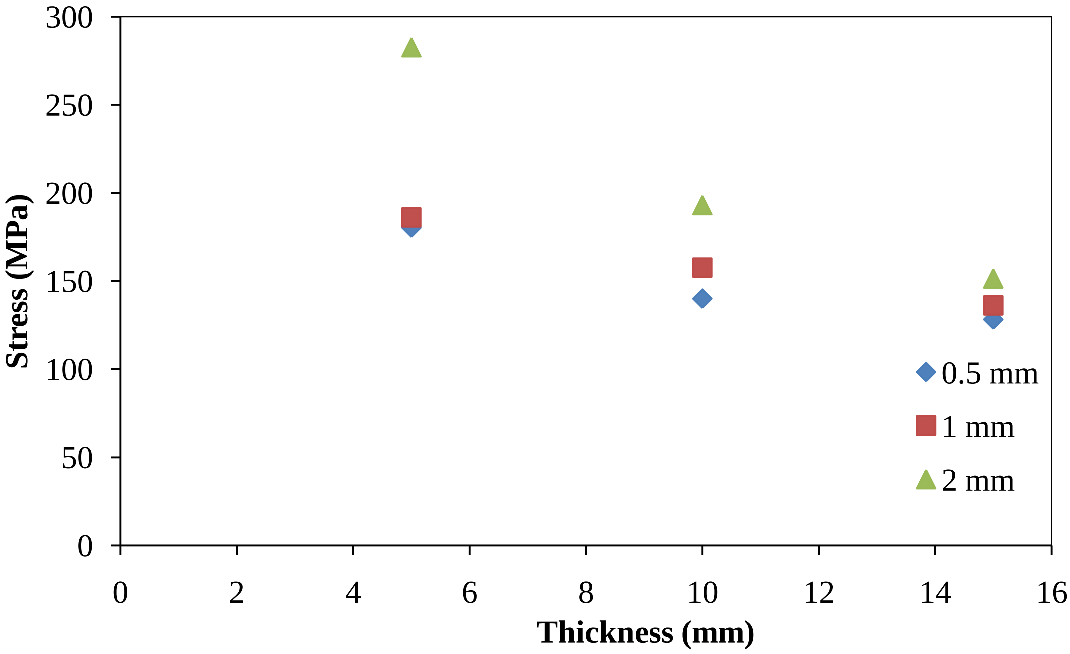


Figure 4.9: Graph Stress Vs Thickness (mm) with different notch depth

According to the (Mourad A.H .I, 2011), once the thickness exceeds the critical dimension, the value of stress becomes relatively constant, is a true material property which is called the plane-strain fracture toughness. The stress intensity represents the level of “stress” at the tip of the crack and the fracture toughness is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs.

4.4.3 Stress-Notch Depth

Figure 4.8 show the Stress –Notch depth graph. From graph, the value of the stress exerted is increase with increasing notch depth. The value of the stress is highest at 2 mm notch depth and lowest at 0.5 mm notch depth for each of the thickness .At 5 mm thickness the stress for 0.5 mm notch depth is 151.5 MPa, 1 mm is 186.1 MPa and at 2 mm is 282.8 MPa. For 10 mm thickness the force for 0.5 mm notch depth is 140.1 MPa, 10 mm is 157.7 MPa and at 15 mm is 193.2 MPa. And for 15 mm thickness the force for 0.5 mm notch depth is 134.3MPa, 1 mm is 136.3 MPa and at 2 mm is 151.5MPa. When notch depth is increase and thickness is decrease the stress exerted is increase for example at 2 mm notch depth and 5 mm thickness the stress is 282.8 MPa. While, when notch depth is decrease and thickness is increase the stress exerted is decrease for example at 0.5 mm notch depth and 15 mm thickness the stress exerted is 134.3 MPa. However, the stress exerted on the specimen will become constant at the critical dimension when the notch depth is decrease. From the graph, the stress exerted at 0.5 mm and 1 mm notch depth is slightly same and below 0.5 mm notch depth the stress is constant. Therefore the stress exerted on the specimen is increase when the notch depth is increase because the relation between the notch depths and stress is inversely proportional due to the area at the notch depth position. The stress exerted to the specimen need to be lower than stress intensity to initiate the crack and to achieve to maximum stress. It is occur due to decreasing the area at the testing point at the middle of the specimen due to the higher value of thickness and lower value of thickness will increase the cross section area at the center point of testing. At smaller notch depth the crack propagation consists of stable and unstable crack extension phases was occurred. The instability condition occurring after crack extension occurs. The lowest stress is needed to overcome the instability to initiate the crack until the stress reach to maximum. While at the largest value of notch depth the only spontaneous crack extension is possible and larger stress exerted is needed. This happen is due to the concentration of the plastic deformation in a small area along the notch depth. This occurs when the notch depth of a shallow single-edge notch is sufficiently small compared with the thickness. The concentration of the plastic deformation is large at the small notch depth and was effect the instability during cracking.

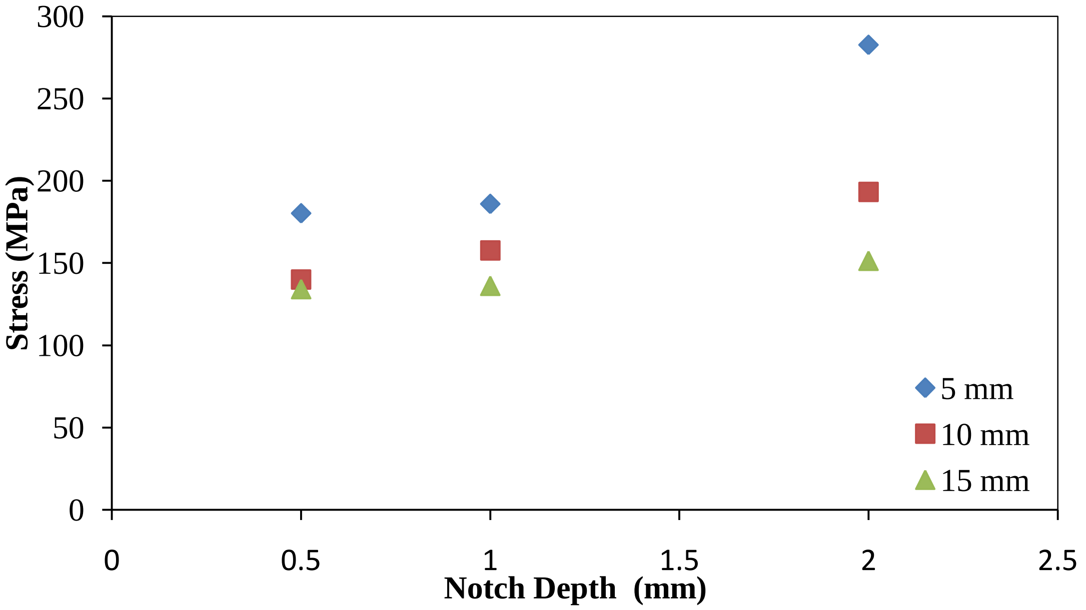


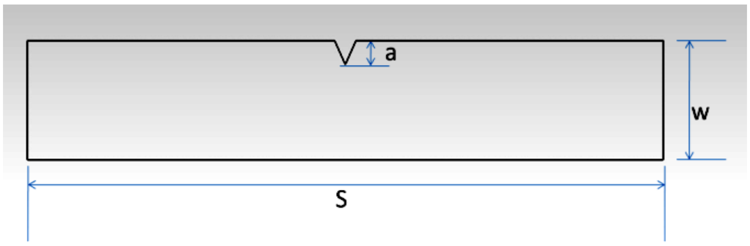
Figure 4.10: Graph Stress Vs Notch Radius (mm) with different thickness

According to the (Mourad A.H .I, 2011), once the notch depth exceeds the critical dimension, the value of stress becomes relatively constant, is a true material property which is called the plane-strain fracture toughness. The stress intensity represents the level of "stress" at the tip of the crack and the fracture toughness is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. For the notch depth the critical dimension was occurred when the thickness decrease. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs.

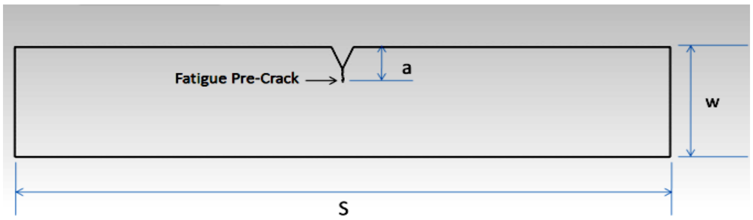
4.5 FRACTURE TOUGHNESS ANALYSIS

4.5.1 Calculation Theory of Fracture Toughness

For the fracture toughness calculation, the crack length is assumed from the notch depth without consider fatigue pre-crack as shown at figure 4.11:



(a)



(b)

Figure 4.11: Specimen Criteria: a) Without fatigue Pre-Crack, b) With Fatigue Pre-Crack

(H.Wang et al,2007) has evaluated the specimens perform three point bending test to get the fracture toughness. The toughness value was calculated according to the following formula and the result 4.4 shows in table:

$$f\left(\frac{c}{w}\right) = 2.9\left(\frac{c}{w}\right)^{1/2} - 4.6\left(\frac{c}{w}\right)^{3/2} + 21.8\left(\frac{c}{w}\right)^{5/2} - 37.6\left(\frac{c}{w}\right)^{7/2} + 38.7\left(\frac{c}{w}\right)^{9/2} \quad (4.1)$$

$$K_{IC} = \frac{F_c}{B}\,\frac{s}{w^{3/2}}\,f\left(\frac{c}{w}\right) \quad (4.2)$$

F_C : Critical load

B : Thickness

s : Supporting span

c : Notch Depth

w : Width

$f\,(c/W)$: Stress intensity shape factor.

Sample calculation of the fracture toughness:

i. For 0.5 mm notch radius

$$f\left(\frac{c}{w}\right) = 2.9\left(\frac{0.5}{10}\right)^{1/2} - 4.6\left(\frac{0.5}{10}\right)^{3/2} + 21.8\left(\frac{0.5}{10}\right)^{5/2} - 37.6\left(\frac{0.5}{10}\right)^{7/2} + 38.7\left(\frac{0.5}{10}\right)^{9/2}$$

$$= 0.61$$

$$K_{IC} = \frac{7.2\ kN}{0.005\ m}\,\frac{0.05\ m}{(0.01\ m)^{\frac{3}{2}}}\ (0.61)$$

= 43.78 Mpa√m

ii. For 1 mm notch radius

$$f\left(\frac{c}{w}\right) = 2.9\left(\frac{1}{10}\right)^{1/2} - 4.6\left(\frac{1}{10}\right)^{3/2} + 21.8\left(\frac{1}{10}\right)^{5/2} - 37.6\left(\frac{1}{10}\right)^{7/2} + 38.7\left(\frac{1}{10}\right)^{9/2}$$

= 0.83

$$K_{IC} = \frac{16.6\ kN}{0.01\ m}\,\frac{0.05\ m}{(0.01\ m)^{3/2}}\ (0.83)$$

= 69.0 Mpa√m

iii. For 2 mm notch radius

$$f\left(\frac{c}{w}\right) = 2.9\left(\frac{2}{10}\right)^{1/2} - 4.6\left(\frac{2}{10}\right)^{3/2} + 21.8\left(\frac{2}{10}\right)^{5/2} - 37.6\left(\frac{2}{10}\right)^{7/2} + 38.7\left(\frac{2}{10}\right)^{9/2}$$

$= 1.17$

$$K_{IC} = \frac{19.8\ kN}{0.015\ m}\ \frac{0.05\ m}{(0.01\ m)^{\frac{3}{2}}}\ (1.17)$$

= 77.29 Mpa√m

Table 4.4: Fracture Toughness Result

Parameter		Crack Length, a (mm)	Fracture Toughness, (Mpa√m)
Thickness (mm)	Notch Depth (mm)		
5	0.5	0.5	43.8
10			76.0
15			81.6
5	1	1	50.9
10			69.0
15			69.5
5	2	2	64.6
10			81.4
15			85.1

4.5.2 Fracture Toughness – Thickness

Figure 4.12 show that the relation between fracture toughness and thickness of the specimen. The value of the fracture toughness is increase with increase of the thickness (from 5mm to 10 mm) and at the thickness 15 mm above the value of the fracture toughness is become constant. At 5 mm thickness the fracture toughness at 0.5 mm notch depth is 43.8 MPa√m, at 1 mm is 50.9 MPa√m and at 2 mm is 64.6 MPa√m. For 10 mm thickness the force at 0.5 mm is 76 MPa√m, at 1 mm is 68.9 MPa√m and at 2 mm is 81.4 MPa√m. And for 15 mm thickness the force for 0.5 mm notch depth is 81.6 MPa√m, 1 mm is 69.5 MPa√m and at 2 mm is 85.1 MPa√m. When notch depth is decrease and thickness is increase the fracture toughness is increase for example at 0.5 mm notch depth and 15 mm thickness the fracture toughness is 85.1 kN. However, when notch depth is increase and thickness decrease the fracture toughness is decrease for example at 2 mm notch depth and 5 mm thickness the force obtain is 43.8 kN. When comparing the result from (M.O.Lai et.al,1984) the trend of the graph obtains is different. This is because the three point bending test is run without doing fatigue pre-cracking. Unstable condition will occurs when the test is running without doing pre-crack. Mean that, the three point bending test is not run smoothly and stable. The instability condition will affect the result of the test and the result obtain is wrong when comparing from the previous study (M. O. Lai et.al,1984).

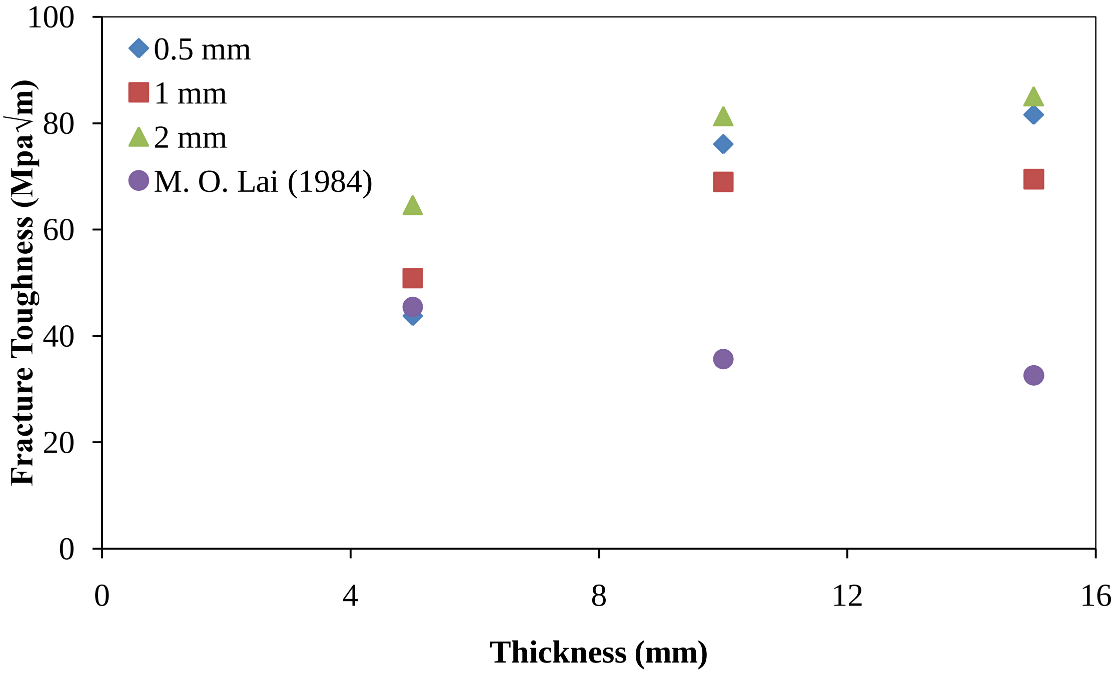


Figure 4.12: Graph Fracture Toughness Vs Thickness with different notch depth

In the previous study from (M. O. Lai et.al, 1984), these fracture features show that an increase in thickness will lead to a decrease in both the work per unit area for crack tip necking and the work per unit area for material separation. Therefore, fracture toughness K_{IC} decreases with an increase in thickness. It can also be explained by the influence of the stress triaxiality. Indeed, toughness is affected by the stress state. With increasing thickness, stress triaxiality will tend to increase at the crack tip, to accelerate the void growth rate, to decrease the fracture strain and crack tip necking degree, and thus to lead to a decrease of fracture toughness K_{IC}. This can justify results where the toughness is observed to decrease with increasing thickness even at small thicknesses. Once the thickness exceeds the critical dimension, the value of stress becomes relatively constant, is a true material property which is called the plane-strain fracture toughness. The stress intensity represents the level of “stress” at the tip of the crack and the fracture toughness is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs. As a conclusion, the thickness and notch depth are effected the fracture toughness on the specimen.

4.5.3 Fracture Toughness – Notch Depth

Figure 4.13 show that the fracture toughness versus notch depth graph. The relation between the fracture toughness and notch depth is proportional. This is because when notch depth decreases the fracture toughness is decrease and the fracture toughness will become constant when the force reaches critical dimenstion. At 5 mm thickness the fracture toughness at 0.5 mm notch depth is 43.8 MPa√m, at 1 mm is 50.9 MPa√m and at 2 mm is 64.6 mm. And for 10 mm thickness the fracture toughness at 0.5 mm notch depth is 76.0 MPa√m, at 1 mm notch depth is 69.0 MPa√m and at 2 mm notch depth is 81.4 MPa√m. For 15 mm thickness the fracture toughness for 0.5 mm notch depth is 81.6 MPa√m , for 1 mm notch depth is 69.5 MPa√m and for 2 mm notch depth is 85.1 MPa√m. The trend of the result is same by comparing to the M. O. LAI et.al, (1984) result. From the result obtain from the test and (M.O.LAI et.al, 1984) the fracture toughness will become constant when the thickness is decrease. According to the theory the curve is become relatively constant when the notch depth achieves the critical dimension, is a true material property which is called the plane-strain fracture toughness. The stress intensity represents the level of “stress” at the tip of the crack and the fracture toughness is the highest value of stress intensity that a material under very specific (plane-strain) conditions that a material can withstand without fracture. As the stress intensity factor reaches the K_{IC} value, unstable fracture occurs. The graph shows the value of fracture toughness at 1 0.5 mm and 1 mm is slightly same. Mean that, the fracture toughness was initiated to become constant.

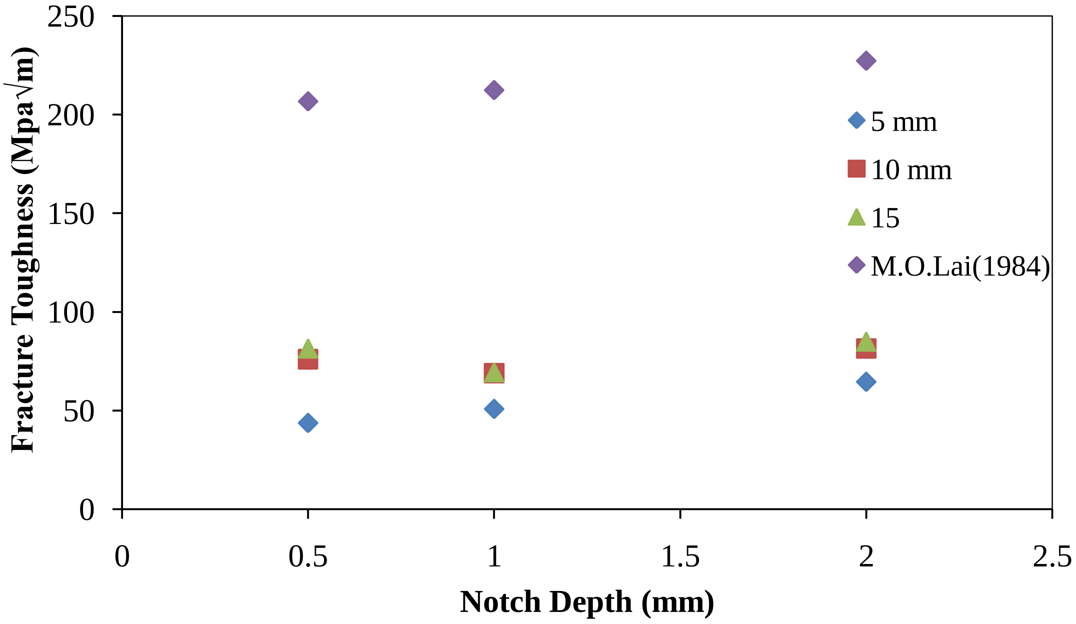


Figure 4.13: Graph Fracture Toughness Vs Notch Depth with different Thickness

In the previous study from (M. O. Lai et.al, 1984), the effect of notch depth on fracture toughness measurements shows that, there is a linear dependence between the notch depth and the fracture toughness, provided that the notch depth is less than some critical value. Below this critical value the measured value of the fracture toughness is sensibly constant. According to the Figure 4.13 the facture toughness value is become constant when the thickness at 0.5 mm and maintain constant when the thickness is decrease from the critical value (0.5 mm notch depth).

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

Through the data gain from the results, it can be conclude that thickness was effecting the fracture toughness for mild steel where increasing the thickness is increasing the fracture toughness proves by the pattern of result obtain. From the thickness fracture toughness test, the result obtain is different from (M.O.Lai et.al,1984) result according to the graph trend. Even though the result from both analytical and theoretical has a large difference, it still can be accepted since the analytical still results reach the plain strain fracture toughness when the thickness dimension reach the critical dimension. The different between analytical and experimental is due the experiential test was run without doing fatigue pre-crack. Without pre-crack the unstable condition was occurs during test that affected the result. According to the data gain from the results, it can be conclude that notch depth was effecting the fracture toughness for mild steel where decreasing the thickness is decreasing the fracture toughness proves by the pattern of result obtain From the notch depth fracture toughness test, the result obtain is same from (M.O.Lai et.al, 1984) test according to the graph trend. The result from both analytical and theatrical shows, when the notch of the specimen is decrease the fracture toughness is decrease until notch depths reach the critical dimension and the fracture toughness was constant. This result is strongly in agreement with the (M.O.Lai et.al, 1984). But, for the experiment, the results are disagreeing with the (M.O.Lai et.al, 1984) results since the experiment test was run without doing pre-crack and were caused the unstable condition. As an improvement for this experiment, the pre-crack is necessary for the fracture toughness test to reduce the unstable condition and the cracking process will run smoothly.

5.2 RECOMMENDATION

Here there are some recommendations that have been made in order to improve further results of this study.

(i) Testing fracture toughness for other material by applying this experiment method to compare the material fracture toughness and the material properties. Therefore, user will have a choice to choose the very effective, costly and toughness material in order to fabricate or built the components, machines and tools.

(ii) The experiment is test by applied different temperature of the specimen. Therefore, the material fracture toughness is analyzing in various condition in order design critical components.

(iii) Need to measured specimen geometry accurately in order to the get the accurate result.

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