STUDY ON FRACTURE TOUGHNESS IN LOW CARBON STEEL USING COMPACT SPECIMENS WITH AND WITHOUT CARBURIZING

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‘Saya akui bahawa telah membaca
karya ini dan pada pandangan saya / kami karya ini
adalah memadai dari segi skop dan kualiti untuk tujuan penganugerahan
Ijazah Sarjana Muda Kejuruteraan Mekanikal (Rekabentuk dan Innovasi)’

Tandatangan :…………………………
Nama Penyelia : En. Omar bin Bapokutty
Tarikh :………………………...

"Saya akui laporan ini adalah hasil kerja saya sendiri kecuali ringkasan dan petikan yang tiap-tiap satunya saya telah jelaskan sumbernya"

Tandatangan : …………………………..
Nama Penulis : Khairul Idzham Bin Hasni
Tarikh : 27th March 2008

To my beloved family,

thank you for your support and encouragement that you have given in my life.

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I would like to express an immense gratitude to the God Al-Mighty Allah s.w.t and the true idol of ours, Rasulullah s.a.w. who gave me the will to pursue this report until it finished, the courage to hold on to my thoughts, and the astuteness to think wisely whenever I need it the most. I also want to dedicate a special appreciation to my parents whose always stand by my side and keep encouraging me until the end of whatever I am doing.

Special thanks to my respected lecturers Mr. Omar bin Bapokutty for his ideas and agreeable of making this report as something can be touched and observed physically, not just being expressed by speeches. His guidance, experiences and method of teaching were really useful for me in the future and I definitely think that it will somehow affect my opinion in a very positive way, indeed.

I also want to say thanks to all my friends for their helps and opinions because all of it was functional to me in many kind of way. Hopefully this report is a piece of written work that meets the criterion and worth to be observed by others because somehow, the endeavor to finish this task was something I wish it to be worth my effort.

ABSTRAK

Kajian mengenai keliatan patah dalam keluli berkarbon rendah ini bertujuan untuk menganalisis keliatan patah dalam dua keadaan; keadaan asal dan tanpa penyusukkarbonan. Selain itu, kajian ini juga bertujuan untuk membuat perbandingan mengenai kesan keliatan patah dalam dua keadaan ini. Keluli karbon jenis AISI 1020 digunakan dalam kajian ini. Spesimen jenis *Compact Tension (CT)* spesimen akan digunakan dengan mengikut piawaian ASTM E399. Sepuluh spesimen akan disediakan melalui proses pembuatan tertentu dan lima daripadanya akan melalui proses penyusukkarbonan. Ujian-ujian yang akan dilakukan terdiri daripada tiga jenis bermula dengan Ujian Ketegangan untuk mendapatkan daya maksimum dan juga kekuatan alah. Ujian Pra-Retakan Lesu akan dilakukan selepas Ujian Ketegangan untuk menyediakan spesimen dengan mulaan retak antara 2mm ke 2.5mm. Ujian Keliatan Patah adalah ujian terakhir untuk melengkapkan kajian ini. *Universal testing Machine;* Instron 8802 akan digunakan untuk menjalankan ketiga-tiga kajian. Keputusan antara kedua-dua keadaan ini akan dibandingkan melalui kaedah analitikal untuk mencapai objektif kaian ini.

ABSTRACT

Study on Fracture Toughness in Low Carbon Steel carries the objectives to analyze the effect on fracture toughness on Low Carbon Steel in two conditions; with and without carburizing. Other than that is to compare the effect on fracture toughness between carburizing and without carburizing. Carbon Steel type AISI 1020 is the selected material for this study. Compact Tension (CT) specimen is the type of specimen used for this study with standard constraint followed by ASTM E399. Ten specimens will be prepared through manufacturing processes and five of will be carburized using pack carburizing process. There are three types of testing methods will be conducted starts with Tensile Test to get the maximum load and yield strength for both conditions. Fatigue Pre-Cracking Test will be conducted after Tensile Test to prepare the specimens with pre-crack in the range of 2mm to 2.5mm. Next, Fracture Toughness Test is the last method to carry out to complete the finding of the study. Universal Testing Machine; Instron 8802 will be used to conduct all testing methods. The results between both conditions will be compared in analitical method in order to achieve the desired target of this study.

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a = Crack Length, mm

B = Specimen Thickness, mm

E' = Effective Young’s Modulus, Pa (psi)

K_I = Stress Intensity Factor, MPa.m$^{1/2}$

K_{IC} = Plane-Strain Fracture Toughness, MPa.m$^{1/2}$

$K_{IC}(t)$ = Rapid Load Plane-Strain Fracture Toughness, MPa.m$^{1/2}$

K_Q = Fracture Toughness, MPa.m$^{1/2}$

P = Specific Load, klbf (kN)

P_{max} = Maximum load that specimen able to sustain, klbf (kN)

R_{SC} = Specimen Strength Ratio

T_x = Temperature of Rapid Load Toughness Test, K

t = Loading Time, ms

V_m = Crack Mouth Opening Displacement, mm
υ = Poisson Ratio

σ_F = Fracture Stress, MPa

σ_{YD} = Dynamic Yield Strength, MPa

σ_{YS} = Yield Strength, MPa

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CHAPTER I

INTRODUCTION

1.1 An Overview on Analysis

This thesis systematically investigates the effect on fracture toughness of Low Carbon Steel with and without carburizing. In order to run the analysis and from the previous research done, Carbon Steel; type AISI 1020) is the most suitable material that can be used for the testing to get the result. By using compact specimen followed with ASTM standard, testing will be conducted in two conditions; with and without carburization. Using ASTM E399 as a guide, Plane Strain Fracture Toughness experiment using compact specimen will be carried out in order to obtain the necessary information for the analysis.

In materials science, fracture toughness is a property which describes the ability of a material containing a crack to resist fracture, and is one of the most important properties of any material for virtually all design applications. It is denoted as K_{1c}.The subscript '1c' denotes mode 1 (crack opening; ordinary strain), since the material can be made thick enough to resist shear (mode 2) or tear (mode 3). Fracture toughness is a quantitative way of expressing a material's resistance to brittle fracture when a crack is present. If a material has a large value of fracture toughness it will probably undergo ductile fracture. Brittle fracture is very characteristic of materials with a low fracture toughness value.

Fracture occurs when the metal experiences stress that exceeds its yield strength. Fractures occur as two different types, ductile fracture and brittle fracture. Brittle fracture occurs when the metal doesn’t yield before it breaks. Instead of the sheets of atoms in the metal sliding over each other as occurs in deformation, when stressed, the sheets of atoms pull completely apart. This type of fracture most often occurs in metals that are extremely hard. Brittle fracture almost always occurs at low temperatures. Ductile fracture is the most common type of fracture in metal. Unlike what occurs in a brittle fracture, the metal yields before it breaks in a ductile fracture. The peak stress a metal can withstand before it breaks is called tensile strength. Ductile fracture is caused by the stress exerted on the metal actually work hardening the metal as it yields, cracks from fatigue develop, and then these cracks propagate very rapidly through the metal until complete failure occurs

1.2 Objective and Approach

The main objectives of this analysis are:

I. To analyze the effect on fracture toughness on Low Carbon Steel in two condition; (1) with carburizing and (2) without carburizing.
II. To compare the effect on fracture toughness between carburizing and without carburizing.

The fracture toughness testing procedures specified in ASTM Standard No. E399 will be used. Ten compact specimens of nominal thickness 25mm will be tested. Each sample contains a notch, or 'machined crack'. At the tip of the notch a true crack has been produced by repeatedly loading (fatiguing) the specimen.

1.3 Scope of Analysis

In this analysis, there are three major scopes needs to be considered in order to achieve the objectives of analysis.

Specimen preparation is the first step of analysis. There will be 10 specimen needs to be prepared for this analysis. Dimensions and tolerances of the specimen will be followed by ASTM Standard for compact specimen dimension. Material that will be used for this analysis is AISI 1020 carbon steel that is the most suitable specification of low carbon steel.

Carburizing process of the specimen will be conducted before the testing. Only five (5) specimens will be carburized for testing while another five (5) specimens will be used without carburizing. The method of carburizing will be conducted using pack carburization method.

Testing method will be conducted using ASTM Standard Test Method for Plain-Strain Fracture Toughness. Testing will be conducted in two different conditions; (1) without carburizing, and (2) with carburizing. Then the result on both conditions is to be analyzed to compare between both conditions.

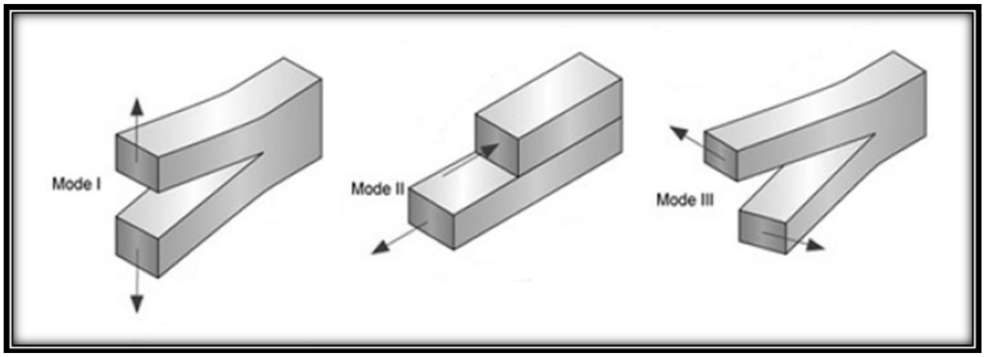
CHAPTER II

LITERATURE REVIEW

2.1 Overview on Fracture Toughness

Fracture toughness is an indication of the amount of stress required to propagate a preexisting 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. (*from NDT Resource Center, 2001*)

A parameter called the stress-intensity factor (K) is used to determine the fracture toughness of most materials. A Roman numeral subscript indicates the mode of fracture and the three modes of fracture are illustrated in Figure 2.1. Mode I fracture is the condition in which the crack plane is normal to the direction of largest tensile loading that is indicates testing in which a tensile stress causes the crack to open. This is the most commonly encountered mode and, therefore, for the remainder of the material will be consider as K_I (refer Figure 2.1). *(from R.J Sanford, 2003)*



Mode-I	Stress intensity factor, K_{Ic} is the most often used engineering design parameter.
Mode-II	Opening or tensile mode where the crack surfaces move directly apart.
Mode-III	Tearing and anti-plane shear mode where the crack surfaces move relative to one another and parallel to the leading edge of the crack.

Figure 2.1: Load types for Modes of Fracture

(Source: R.J Sanford, 2003)

Table 2.1: Typical Fracture-Toughness Values for Selected Engineering Alloys

(Source: R.W. Herzberg, 1989)

Material	K_{IC}		**σ** ***yield strength***	
	$MPa\sqrt{m}$	$ksi\sqrt{in.}$	MPa	ksi
Aluminium alloys;				
2024-T851	26.4	24	455	66
7075-T651	24.2	22	495	72
7178-T651	23.1	21	570	83
Titanium alloy;				
Ti-6A1-4V	55	50	1035	150
Alloy steels;				
4340 (low alloy steel)	60.4	55	1515	220
17-7pH(precipitation hardening)	76.9	70	1435	208
350 maraging steel	55	50	1550	225

Fracture toughness values of material are most useful in mechanical design when working with materials of limited toughness or ductility such as high-strength aluminum, steel and titanium alloys. Table 2.1 lists K_{IC} values for some of these alloys. Material that show little plastic deformation before fracture have relatively low fracture toughness, K_{IC} values and tend to be more brittle, whereas those with higher K_{IC} values are more ductile. Fracture toughness values can be used in mechanical design to predict the allowable flaw size in alloys with limited ductility acted upon by specific stresses. *(from R.W. Herzberg, 1989)*

2.1.1 Toughness

The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed *toughness*. The emphasis of this definition should be placed on the ability to absorb energy before fracture. Recall that ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. Therefore, one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called “material toughness” and it has units of energy per volume. Material toughness equates to a slow absorption of energy by the material.