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STUDY ON FRACTURE IN LOW CARBON STEEL USING BEND SPECIMEN WITH AND WITHOUT CARBURIZING

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"I declare that this report is the result of my own effort except for quotations and extracts which is mentioned as reference"

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Date: March 27, 2008

DEDICATION

For my loved ones

AKNOWLEDGEMENT

My deepest appreciation goes to my supervisor, Mr. Omar Bapokutty for his guidance and moral support through out the completion of my final year project. I also want to dedicate my gratitude to all lecturers and technicians that have assisted me in order to complete my specimen preparation and experiments. To all my friends whom have aided me in this project, thank you for being there when I needed help to complete my task.

ABSTRACT

Surface hardening such as solid carburizing is well known in the engineering field and the basis of this action is to extend the life span of machines and other metal structures in order to cope with economic demand. The reason for this project is to study the fracture in Low Carbon Steel using bend specimen with and without carburizing. The experiment involves three point bending and flexural test. In flexural testing, the value of maximum load is obtain and brought forward to the next testing which is the three point bend. The significance of three point bending test is to determine the fracture toughness of the carburized and un-carburized specimens. Formula implemented to gain the fracture toughness is referred from the book of ASTM E399 Guide Book, published in 2004 which is designed for Bend Specimens.

ABSTRAK

Pengerasan Permukaan seperti Pengkarbonan Pejal adalah amat dikenali dalam bidang kejuruteraan dan tujuan utama proses ini adalah untuk memanjangkan hayat mesin dan struktur yang diperbuat daripada logam. Projek ini bertujuan untuk menyelidik retakan pada Besi Berkarbon Rendah dengan menggunakan specimen lentur yang telah melalui proses Pengkarbonan Pejal dan juga yang belum melalui proses pengkarbonan pejal. Experimen ini mambabitkan Tiga Titik Lenturan dan Ujian Lenturan. Tujuan pengaplikasian ujian lenturan adalah untuk mendapatkan nilai beban maksima yang akan digunapakai dalam ujian tiga titik lenturan. Kepentingan ujian tiga titik lenturen adalah untuk mementukan ketegaran retakan untuk specimen yang telah melalui pengkarbonan dan yang belum melalui pengkarbonan. Fomula yang digunapakai untuk mencari ketegaran retakan dirujuk pada buku panduan ASTM E399 yang dicetak pada tahun 2004 dan direka khas untuk specimen lenturan.

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NOMENCLATURE

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

P_Q = Load maximum kN

S = Span in cm

B = Base in cm

W = Width in cm

$\left(\frac{a}{w}\right)$ = Crack Length over Width

$f\left(\frac{a}{w}\right)$ = Dimension less parameter or function depend on crack and specimen size

K = Stress intensity factor

Y = dimensionless factor (1.00)

σ = Yield Strength

π = Pai value of 3.142

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Surface engineering techniques is blooming due to the inclining request to improve additional surface properties for structural materials. Yet there are flaws in every human creations and surface engineering will in the end succumb to structural properties such as fracture. Fracture is the state of being broken (Ruse, 1997) and such a setback will exist to be an endemic which moves parallel along side man-made structures. There are different types of metals in the world and they are grouped into several types according to the percentage of substance that it consists of. Some on the types are Low Carbon Steel or also called ad Mild Steel, High Carbon Steel, Stainless Steel etc. Man-made creation such as metal will fail due to wear or other factors and this project stresses on the study on fracture in Low Carbon Steel using Bend Specimen with and without Carburizing.

1.2 PROBLEM STATEMENT

Studies on the impact of Carburizing towards metal surfaces had mainly focused on properties such as corrosive and wear of metal material such as low carbon steel. In spite of all the emphasizing on corrosion and wear, many have failed to focus on a vital matter such as fracture on metals. Cracks and fracture can occur on any shapes and form of metal such as straight, circle and bended. In fact, fracture is one of the reasons for the failure of technological invention in today's modern world. Catastrophic failures in major airlines crashes, sunken vessels and explosion of space shuttles are also contributed by fracture of materials (Anderson, 1994). Hence, Fracture mechanics slowly develops with the main intention to do analysis on more sophisticated models of material behavior. In coherent, research on fracture in low carbon steel using with and without carburizing bend specimen is implemented.

1.3 OBJECTIVE

The main objective of this project is to investigate fracture behavior and its mechanism in low carbon steel (AISI 1020) using a bend specimen with and without carburizing. Other objectives are:

1) The carburizing method used in this project is solid carburizing where Wilcarbo powder is involved in the surface hardening process and conducted at the temperature of 850°C.
2) Other intentions involved in this final year project are designing experiments and conducting it to Low Carbon steel Specimens. These experiments includes Flexural testing with the purpose if gaining the maximum load that the material can withhold and 3-point bending test which is significant to obtain the fracture toughness.
3) Finally, the result between uncarburized and carburized low carbon steel will be analyzed and compared by using properties such as fracture toughness as well as its nature of crack and fracture.

1.4 SCOPE

Materials prepared for this investigation are low carbon steel and there are ten specimens all together. These specimens are prepared by using machines such as Bend Saw, CNC milling Machine and EDM Wirecut Machine. Five specimens undergo solid carburizing which is done in a prepared furnace and another five will be left un-carburized. Two specimens are involved in Flexural test which consist of one from Carburized specimen and another as Un-Carburized. Three point bending experiment will be conducted on six out of ten bend specimen by using INSTRON 8802 Digital Control. Another four are set to be back ups in case there are any complications occurred during the testing. Upon completion, specimens are evaluated under microscopes to analyze cracks and grain structure.

1.5 OVERVIEW

Current development of surface engineering techniques involves carburizing which is mainly known as Surface Hardening. Prior studies have noted that such event causes changes in properties which will lead to fatigue and failure. Investigation and studies are done vastly on cases such as corrosion and ware. Little was it known about the effect of fracture mechanism towards a material until disastrous accidents or failure happens. Fracture will disturb material properties of any metal such as alloy or stainless steel. This report will focus on the fracture behavior of low carbon steel (AISI 1020) using a bend specimen with and without pack carburizing. The evaluation on fracture properties are based on crack initiation and small crack growth behavior in the fracture surface and this case will also be compare between carburized and un-carburized material. Explicit comparisons are based on the fracture toughness between the surface hardened material and the specimens without any treatment process.

CHAPTER 2

LITERATURE RIVIEW

2.1 METHOD

The method used to obtain information for this final year project is archival collection. Facts, data and information as well as knowledge pertaining study on fracture in low carbon steel (AISI 1020) using bend specimen with and without carburizing were taken from internet, reference books and journals.

2.2 TERMINOLOGY

There are several terms that are vital to generate better understanding towards this report. Those important terms are Fracture, Fracture Toughness, Notch, Low Carbon Steel, Three Point Bending and Carburizing.

2.2.1 FRACTURE

Fracture is the state of being broken and further meaning is brought from Oxford dictionary where fracture is an instance of braking or being broken. According to Broberg K. Bertam (1999), “A crack may be defined as a material separation by opening or sliding, with the separation distance substantially smaller than the separation extent-the crack length”. Fracture however, thought as an event where increased loading abruptly causes accelerated growth of pre-existing cracks. The fracture properties are discussed on the basis of crack initiation and small crack growth behavior and fracture surface analysis. William F. Smith (2003) mentioned in his study that the fracture of a metal starts at a place where the stress concentration is the highest, which may be at the top of a sharp crack. Thus, specimens in this project are having purposely initiated cracked in order to obtain precise and explicit results.

2.2.1.1 FRACTURE TOUGHNESS

The resistance to fracture of a material is known as its fracture toughness (Pisarski, 2004). The facture toughness of a material usually depends on the orientation and direction of propagation of the crack in relationship to the anisotropy of the material, which depends, in turn on the principal direction of mechanical working of grain flow. The system enables the classification of course of crack plane at any time possible provided that it is still in the system (ASTM, 2004). Fracture surface analysis is carried out using Scanning Electron Microscope (SEM).

Figure 2.0 exhibits the observations of crack propagation via infrared in a sheet of steel of 50mm width. Images for six time instances during six seconds: each color corresponding to 2 degree Celsius. The infrared observation shows the initial reaction region when a crack occurs. Cracks will gradually expand due to increasing force and the infrared region will widen parallel until a certain yield to the crack growth.

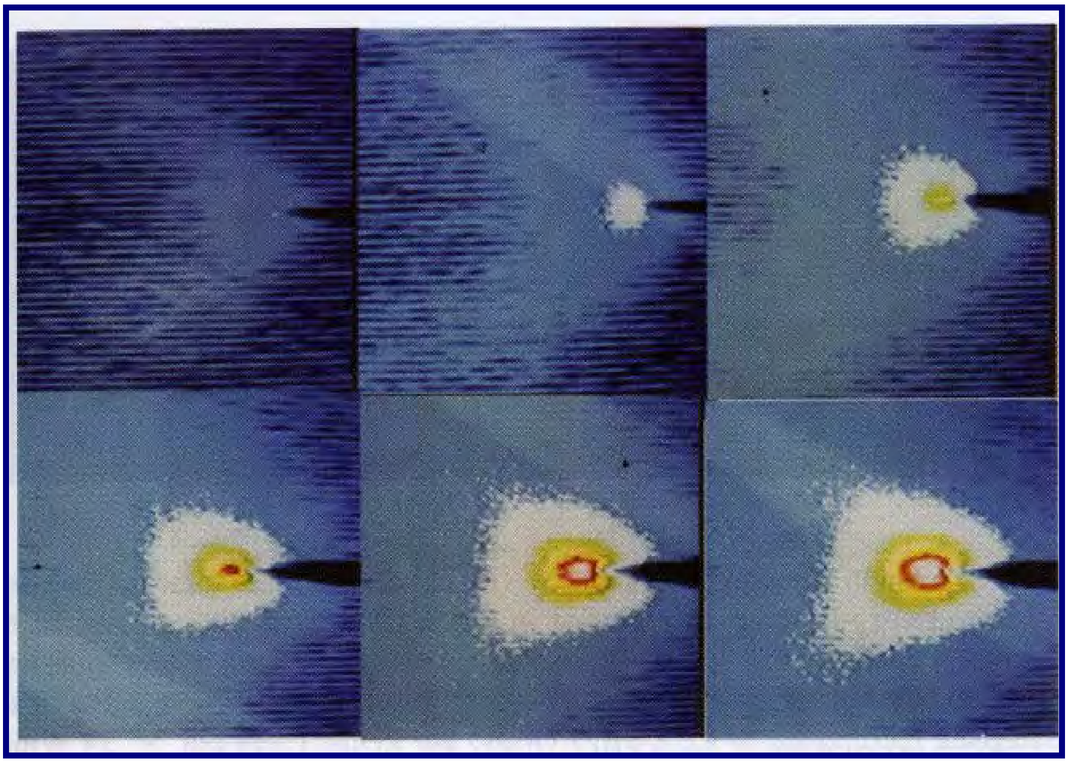

Figure 2.0 Crack Observation

(Source: Bui, Ehrlacher and Nguyen, 1979)

Fracture mechanics testing techniques are usually applied on testing of metal material which contains sharp crack in relation to the environment factors. Generally, the testing on Early Age Cracking (EAC) is using constant load or also known as constant deflection specimens. This is a procedure where load used on the material are either directly applied dead weight or by using pulley to increase the dead weight load (Corrosionsource.com, 2002).In the study of Low Carbon Steel using Bend Specimen with and without carburizing on the other hand uses fracture toughness test which is related to the surface hardened material. The test design for this project is the fracture toughness test in order to obtain the fracture toughness of the materials and to observe failure behavior of the materials subjected to the cyclic load.

A fracture toughness test measures the resistance of a material to crack extension where this test may yield either a single value of fracture toughness or a resistance curve. Through this process, toughness parameter such as Stress Intensity Factor (K), J-Integral (J) or Crack Tip Opening Displacement (CTOD) is plotted against crack extension. A particular toughness significance is basically enough to note that a test fails by cleavage because this fracture mechanism is typically unstable.

K, can be considered as a stress-based estimate of fracture toughness. It is derived from a function which depends on the applied force at failure. K depends on geometry of the flaw depth, together with a geometric function, which is given in test standards.

CTOD or δ(crack-tip opening displacement) can be considered as a strain-based estimate of fracture toughness. However, it can be separated into elastic and plastic components. The elastic part of CTOD is derived from the stress intensity factor, K. In some standards, the plastic component of CTOD is obtained by assuming that the specimen rotates about a plastic hinge. The plastic component is derived from the crack mouth opening displacement (measured using a clip gauge). The position of the plastic hinge is given in test standards for each specimen type. Alternative methods exist for estimating CTOD, which make no assumption regarding the position of the plastic hinge. These require the determination of J from which CTOD is derived. CTOD values determined from formulations assuming a plastic hinge may differ from those determined from J.

J (the J-integral) is an energy-based estimate of fracture toughness. It can be separated into elastic and plastic components. As with CTOD, the elastic component is based on K, while the plastic component is derived from the plastic area under the force-displacement curve (Pisarski, 2004).

Another approach to evaluate fracture is through linear elastic fracture mechanics (LEFM) where the stress intensity factor, K_I describes the elastic crack tips stress field when a material is loaded perpendicular to a crack plane. The stress intensity at the tip of the crack can be calculated using standard equations as given in the book of guideline, ASTM (2004) which states $K_I = Y\sigma (\pi a)^{1/2}$. In order to analyze the relationship between crack growths rate versus stress intensity K_I, dead weight-loaded specimen are used and the experiment will emphasize on the crack length. As the force increases, the crack will grow and as it reached the critical length, fast fracture will occur and it is vital that the load at fracture to be identified. The resistance of this material to fracture may be characterized by the stress intensity at fracture, K_{IC}, which is also known as the fracture toughness. Fracture to occur when $K_I = K_{IC}$ (UTeM, 2007).

Fracture toughness of a material and the manner in which the crack grows depends on strength and thickness of the specimen. For thickness independent fracture toughness, the linear elastic fracture mechanics is applied. There are many types of fracture toughness testing that includes Testing of Compact Specimens, Testing of The Arc-Shaped Tension Specimen and the Testing of Disk- Shaped Specimen. This project implements the Testing of Bend Specimen.

For the Testing of Compact Specimens, the standard compact specimen is a single edge-notched and fatigue cracked plate loaded in tension. There are two holes at both sides of the notch which will be used for clevis and also to be loaded through pins. The size of these holes depends on the critical tolerances and suggested proportions (ASTM, 2004)

Besides Testing of Compact Specimens, there is also Testing of The Arc-Shaped Tension Specimen. It has a single edge-notched and fatigue cracked ring segment loaded in tension. This type of fracture testing intends to measure the fracture toughness so that the normal to the crack plane is the circumferential direction and the direction of the crack propagation is in the radial direction. The inner radius and outer radius, r_1 and r_2 are usually not specified to enable the preparation of the arc specimen from any cylindrical geometry.

Testing of Disk-Shaped Specimen is one of types in fracture toughness testing provided that the specimen shape is a disk. The standard Disk-Shaped compact Specimen is a single edge-notched and fatigue cracks disk segment loaded in tension.

For this final year project, the test implemented is the Testing of Bend Specimen. The Standard bend specimen is a single edge-notched and fatigue cracked beam loaded in three-point bending with a support span, S, nominally equal to four times the width, W.

All these different testing methods will result different average width (*f*), width (*W*), Crack Length (*a*) and thickness (*B*) depending to the shapes of specimens. In order to obtain the value of Fracture Toughness (K_Q), the formula adapted is

$$K_Q = \left[\frac{(P.S)}{\left(B.W^{3/2}\right)} \right] . f\left(\frac{a}{w}\right)$$

The value of $f\left(\frac{a}{w}\right)$ are specified in the table provided by ASTM Standard guide book and the table varies according to each type of fracture toughness testing.

Complications that might occur during this experiment is the crack growth tend to increase along with the value of K as the crack proceeds and thus, crack opening displacement has to be at a rapid rate. Sometimes the period required to run a decreasing K test is very long and to avoid such issue is to use a rising load test whereby the fracture mechanics specimen is subjected to an increasing load provided that the crack open displacement is monitored.

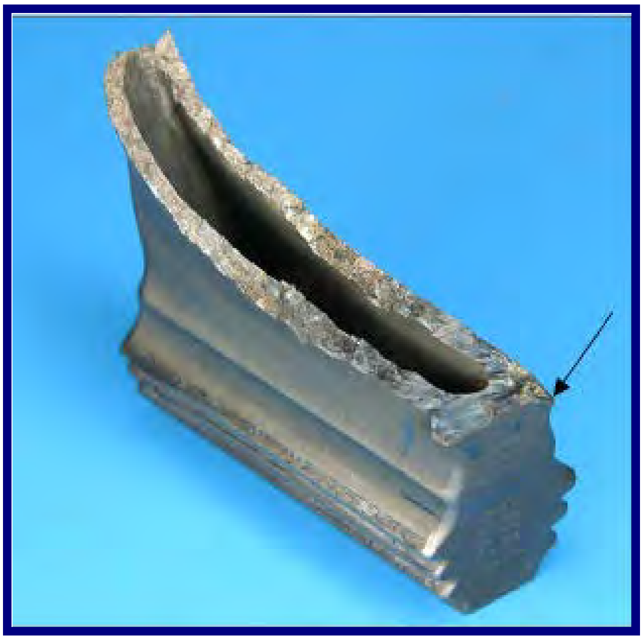

Figure 2.1 Fractured Blade of an Aircraft

(Source: Australian Transport Safety Bureau, 2006)

Figure 2.1 shows a fractured blade of Boeing Co 747-338, VH-EBU which caused on of the planes engine to be shut down due to excessive vibration. On 22 October 2004, this plane was on its way from Honolulu, U.S to Sydney, Australia and had problems during it was airborne. This project that emphasize on fracture is important for safety purposes especially those that are involved in the technical industries.