UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INVESTIGATION ON THE EFFECT OF HEAT TREATMENT ON FRACTURE TOUGHNESS OF PRESURE VESSEL STEEL

This report submitted in accordance with the requirement of the Universiti Teknikal Malaysia Melaka (Utem) for the Bachelor Degree of Manufacturing Engineering (Engineering Materials) with Honours.

by

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process) with Honors. The member of the supervisory committee is as follow:

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ABSTRACT

Structural failure by fracture toughness in pressure vessel steel A516 Grade 70 of low carbon steel can have severe consequences in term of heat treatment. Fracture toughness K_{IC} test is used to examine the toughness of each specimen after heat treatment process done. In this research, the most common type of this term is discussed and analyzed. The types of heat treatments that have been done like tempering on 400^{o}C, quenching in water, normalizing and full annealing. The structural after heat treatment exposed to change the mechanical properties to this material. Resulting from these changes affected the fracture toughness K_{IC} value. The methodologies were used such as Scanning Electron Machine and Axioscope Zeiss Optical Microscope to examine the microstructure by 50x magnification. Vickers Hardness and Tensile Test also were used to observe the mechanical properties of each specimen. Fracture toughness K_{IC} value is obtained by using Instron Machine. As result, K_{IC} graph show that tempering heat treatment make specimen tougher, hard and high strength compare to full annealing, normalizing and base metal. But, this specimen has low ductile and brittle.

ABSTRAK

Kegagalan tanki keluli pada bahan A516 kelas 70 metal yang mempunyai karbon yang rendah dapat dikesan daripada proses rawatan haba. Semua sampel yang telah mengalami proses rawatan haba akan diuji untuk menentukan kekuatan bahan tersebut daripada retak menggunakan ujian K_{IC}. Dalam kajian yang telah dijalankan, terdapat beberapa jenis rawatan haba yang telah dibuat ke atas bahan A516 kelas 70 seperti, pembajaan pada suhu 400 darjah celcius, sepuh lindap kejut menggunakan air, penormalan dan juga penyepuhlindapan didalam relau. Hasil daripada rawatan haba ini telah merubah struktur sampel dan juga sifat mekanikal. Seterusnya ini akan memberi kesan terhadap perbezaan nilai kekuatan retakan $K_{IC.}$ Mesin Imbasan Elektron dan Optik Mikroskop telah digunakan untuk melihat struktur dalaman pada sampel. Nilai pembesaran yang digunakan untuk semua sampel adalah 50x0.70. Mesin Instron pula digunakan untuk mendapatkan nilai kekuatan sampel yang hendak diuji daripada retak. Ujian kekerasan dan juga ujian ketegangan turut dijalankan untuk mengenalpasti sifat mekanikal yang terdapat pada sampel ini. Graf K_{IC} telah menunjukkan bahawa rawatan haba pembajaan telah menjadikan sampel lebih kuat dan k eras berbanding yang lain. Namun begitu, rawatan jenis ini membuatkan sampel lemah dari segi kelikatan dan rapuh apabila mencapai pada satu tahap

DEDICATION

I dedicate this report especially to UTeM, to my supervisor, to my parents and my family. Never forget to my friends and to all people that help and support me during my completion of this report.

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LIST OF ABBREVIATIONS AND SYMBOLS

ASTM	-	American Society for Testing and Materials
Al	-	Aluminium
AISI	-	American iron and steel institute
AC	-	Alternating current
BCC	-	Body centred cubic
BCT	-	Body centred tetragonal
BM	-	Base metal
CTOD	-	Crack-tip opening displacement
CGHAZ	-	Coarse-grained heat affected zone
C	-	Composition
CGB	-	Coarse-grained bainitic
CCT	-	Centre-cracked tension
Cr	-	Chromium
EDM	-	Electric discharge machining
EPFM	-	Elastic-plastic fracture mechanics
FCG		Fatigue crack growth
FCC	-	Face centred cubic
FGB	-	Fine-grained bainitic
FGHAZ	-	Fine-grained heat affected zone
GDS	-	Glow Discharge Spectrometry
HAZ	-	Heat affected zone
ICR	-	Inter-critical region
K	-	Critical stress
K_1	-	Stress intensity factor
K_C	-	Maximum fracture toughness
K_{IC}	-	Fracture toughness
LEFM	-	Linear elastic fracture mechanics
LPG	-	Liquefied petroleum gas
Mo	-	Molybdenum
Mn	-	Magneseum

MPa	-	Mega pascal
Psig	-	Pound-force per square inch gauge
PWHT	-	Post weld heat treatment
SENT	-	Single edge notch tension
SENB	-	Single edge notch bend
SS	-	Stainless steel
Si	-	Silicon
Ti	-	Titanium
UNS	-	United Standard
WM	-	Weld metal
Zr	-	Zirconium
da/dN	-	Crack growth rate per cycle of loading
σ_x	-	Longitudinal stress
σ_y	-	Transverse stress
σ_m	-	Maximum stress
r	-	Radius
E	-	Young`s Modulus
$a*$	-	Effective crack length
r_p	-	Circular plastic zone of radius
θ	-	Angular coordinate
τ_{xy}	-	Torque stress
f	-	Residual stress
G	-	Energy release rate
γ_s	-	Specific surface energy
t	-	Thickness
a	-	Width and Length
γ_p	-	Work of plastic deformation
σ	-	Applied stress
a	-	Crack length
σ_{ys}	-	Elastic-plastic boundary

CHAPTER 1

INTRODUCTION

In this century, the world is more advanced together with turn of their rolling. These phenomena show that the industry is increasing and alert for new-technologies. Industries have now growing up caused of high demands on the quality of engineering technology. An either obvious of one example am requesting on the use of pressure vessels steel as autoclaves, boiler and others. This existed in all sector industry to generate one product having quality and durable. Pressure vessels are one device that it’s very synonyms for high temperatures. This is very sensitive area so all factor fabrication of pressure vessels is not in consideration because it`s impact involve deaths and priceless property damage. Therefore, these books publish to investigate the fracture toughness of pressure vessel steel and relation on microstructure

1.1 Problem Statement

The main topic of this research is about to investigate on the effect of heat treatment on fracture toughness of pressure vessels steel. This research carried out base on still equivalent has been problem rose in pressure vessels steel.

Cracking of internal surface in pressure vessels is very synonym happened but until now to avoid this failure it`s still undergoing. Cracks will occur at welds and in the HAZ of the weld and the crack will affect both parallel and transverse to the weld. Cracking has occurred just after welding and as well as during the intended service life. In particular, tensile residual stresses near the weld area may cause brittle fracture, stress raisers, fatigue failure and stress corrosion cracking when exposed to corrosive environments at certain temperature ranges [Challenger, N.V. 1995].

Semi-skilled or weaknesses during welding process is one of the critical failures in pressure vessels. This problem such as brittle cracking in the heat-affected zone (HAZ), often result from the use of steels containing excessive amounts of residual elements that increase hardens ability and susceptibility to cracking. Steel sometimes produced inadvertently when low-carbon steel is made in a furnace normally used to make high-alloy steel. The refractory lining of the furnace may impart sufficient residual chromium and other alloying elements to a heat of low-carbon steel that problems occur when components made from that heat are joined using standard welding procedures. Therefore, complete control of composition is of the almost importance when welding is involved [Powel, G.W. 2002].

1.2 Objective

The overall objective of these researches is as follow;

i) To investigate the effect of heat treatment on fracture toughness of pressure vessel steel
ii) To identify the fracture toughness on different microstructure.

1.3 Scope of the Project

The aimed of this research is to investigate the effect of heat treatment on fracture toughness of pressure vessels steel for two different materials. The material that used is from ASTM A516 Grade 70. Referring on ASTM standard, the properties of this material is low-carbon. As mention in chapter 2 on literature review, the carbon content of low-carbon steel is less 0.25% carbon. To ensure this research done with their objective and scope, a few methods of heat treatment and also testing hardness are used. On the heat treatment process this research used austenizing, annealing normalizing, quenching and tempering. This research also covers the determination of fracture toughness steel under predominantly linear-elastic fracture mechanic, elastic-plastic fracture mechanic plane-strain conditions using fatigue pre-cracked, Crack Tip Opening Displacement (CTOD) and K_{IC}. The details of test apparatus, specimen configuration, and experimental procedure are given based on ASTM standard E 399-90.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction of Pressure Vessel

Vessels tanks, and pipelines that carry, store, or receive fluids are called pressure vessels. A pressure vessel is defined as a container with a pressure differential between inside and outside. The inside pressure is usually higher than the outside, except for some isolated situations. The fluid inside the vessel may undergo a change in state as in the case of steam boilers, or may combine with other have a combination of high pressures together with high temperatures, and in some cases flammable fluids or highly radio active material. Because of such hazards it is imperative that the design be such that no leakage can occur. In addition these vessels have to be designed carefully to cope with the operating temperature and pressure. It should be borne in mind that the rupture of pressure vessels has a potential to cause extensive physical injury and property damage. Plant safety and integrity are of fundamental concern in pressure vessel design and these of course depend on the adequacy of design codes.

In other words of pressure vessel steel is a closed container designed to hold gases or liquids at a pressure different from the ambient pressure. The end caps fitted to the cylindrical body are called heads. The rules for pressure vessel are contained in the American Society of Mechanical Engineers Boiler and Pressure Vessel Code [Harvey, J.F. 1985]. Pressure vessels are used in a variety of applications. These include the industry and the private sector. For examples of pressure vessels are; autoclaves, storage tanks or oil refineries.

Large pressure vessels were invented during the industrial revolution, particularly in England for making steam engines [Harvey, J.F. 1985]. Design and testing standards came about after some large explosions lead to loss off life and a system of certification and testing mutations.

Pressure vessels as components of a complete plant are designed to meet various requirements as determined by the designers and analysis responsible for the overall design. The first step in the designed procedure is to select the necessary relevant information, establishing in this way a body of design requirements. Once the design requirements have been established, suitable materials are selected and the specified design code will give an allowable design or nominal stress that is used to dimension the main pressure vessel thickness.

Generally, almost any material with good tensile properties that is chemically stable in the chosen application can be employed. Many pressure vessels are made of steel. To manufacture a spherical pressure vessel, forged parts would have to be welded together. Some mechanical properties of steel are increased by forging, but welding can sometimes reduce these desirable properties. In case of welding, in order to make the pressure vessel meet international safety standards, carefully selected steel with a high impact resistance and corrosion resistant material should also be used.

2.2 Structural and Material Considerations

The continued and prolonged use of pressure vessels for power generation, nuclear or chemical reactions, industrial processing, and storage requires them to withstand severe conditions of pressure, temperature, and other environments. Such environmental conditions include corrosion, neutron irradiation, hydrogen embrittlement, and so on. Pressure vessels are required to operate at a high temperature range from as high as 600^{o}C to as low as -20^{o}C, with design pressures as high as 140 MPa. Some vessels are designed to carry noncorrosive fluids; while others are designed to withstand harsh corrosive and highly radioactive environments. The type of service, whether steady or cyclic, may also vary considerably. For each set of operating parameters, the pressure vessels material may be required to have certain properties. For example, operation at very low temperatures would require the use of materials with high notch toughness, while operation at high temperatures would require the use of materials with high creep strength.

Apart from the mechanical properties, considerations on manufacturability, commercial availability, as well as cost, has to be accounted for in the selection process. From researcher the materials that are used in pressure vessel construction are:

a) Steels
i) Nonferrous materials such as aluminum and copper
ii) Specialty metals such as titanium and zirconium
iii) Nonmetallic materials, such as, plastic, composites and concrete
iv) Metallic and nonmetallic protective coatings

b) The mechanical properties that generally are of interest are:
i) Yield strength
ii) Ultimate strength
iii) Reduction of area (a measure of ductility)
iv) Fracture toughness
v) Resistance to corrosion

2.3 Pressure Vessel Steel

For this research, the types of material that used as follow the ASTM standard requirement. The material that will be used in this research is A516 Grade 70 or ASME SA 516 (low-carbon steel)

2.3.1 ASTM A516 Grade 70 or ASME SA516

The grade of this material is one of the most popular steel grades in market. It is primarily intended for use in welded pressure vessels where notch toughness is important. It comes in four grades 55, 60, 65 & 70. These grades cover a range of tensile strengths from 55 - 90 MPa and this versatility explains much of the specification popularity. For material tested were an ASTM A516 grade 70 hot-rolled steel of ferritic-perlitic structure is one of our most popular steels. The ASME standard composition is as follows (dependent on grade).

Referring the ASTM standard, table below shows the lists of chemical composition and mechanical property requirements for these grades. Most of the steel are given no heat treatment after hot rolling and thus develop their mechanical properties as a result of control of composition and grain size (through deoxidation practice). In some case, for example A515 and A516, plates greater than 50mm thickness are normalized. Although only moderate in yield and tensile strength, these kinds of steels have the proper combination of strength, ductility, toughness and weldability to perform satisfactorily in structural applications. The carbon content is rarely over 0.25% (to increase it above this level may reduce toughness and weldability) and will rarely be blow 0.15% for reasons of strength [Henkle, D. *et al* 2002]

Table 2.1: Composition range and limits for ASTM A 516 Grade 70

ASTM GRADE	Type / Grade	UNS Designation	Heat Composition Ranges and Limits, % (a)				
			C	Mn	P	S	Si
A 516	Grade 70	K 02700	0.31	0.85-1.20	0.035	0.04	0.15-0.30

Table 2.2: Mechanical properties and their application of structural steel

ASTM GRADE	USE	YIELD STRENGTH, MPa	TENSILE STRENGTH, MPa	ELONGATION IN 50mm, %
A 516 / 70	Pressure vessels, low temperature	310	520	26