UNIVERSITI TEKNIKAL MALAYSIA MELAKA

STUDY THE EFFECT OF HIGH TEMPERATURE CYCLE EXPOSURE TO EVALUATION ON EMBRITTLEMENT OF WELDED PRESSURE VESSEL STEEL

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

By

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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This thesis submitted to the senate of UTeM and has been accepted as partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Manufacturing Process). The members of the supervisory committee are as follow:

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DECLARATION

I hereby, declared this thesis entitled "Study the Effect of high Temperature Cycle Exposure to Evaluation on Embrittlement of Pressure Vessel Steel" is the results of my own research except as cited in references

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ABSTRACT

The research of the effect of high temperature cycle exposure to evaluation on embrittlement of welded pressure vessel steel has been developed purposely in order to study the effect of embrittlement behavior of pressure vessel steel after expose to elevated temperature. The temper embrittlement has been usually observed in pressure vessel steel that serving at high temperature, due to the segregation of trace elements at the grain boundaries and/or carbide interface. This impurity elements segregation will cause deterioration hardness of the steel based on the theory. These pressure vessel steel have a potential for temper embrittlement. Therefore, the research and observation in the mechanical properties of tempered welded area are very important in order to support on-going steel development for services temperature and also useful to avoid the embrittlement during the services. The pressure vessel steel (ASTM A516) have been chosen to be used as the type of specimens in this research. The welded area of pressure vessel steel is on service temperature of pressure vessel (450℃) at different exposure time. The welded area for all specimens after exposure was characterized by microstructure observation, EDS, and hardness measurement. Based on these results, evaluation on embrittlement is discussed in order to determine the approximate effect of high cycle temperature to embrittlment behavior. Experimental results revealed that temper embrittlement hardly affect the hardness value for welded area and the microstructure characteristics of pressure vessel steel are significantly changed.

ABSTRAK

Kajian tentang kesan pendedahan suhu tinggi kepada penaksiran sifat kerapuhan bagi kimpalan pengandang yang diperbuat daripada besi telah di jalankan bagi tujuan untuk mengkaji kesan terhadap sifat kerapuhan pengandang selepas terdedah kepada penigkatan suhu. Pada kebiasaannya, sifat kerapuhan ini selalunya diperhatikan hadir dalam pengandang besi yang beroperasi dalam suhu yang tinggi,; dimana fonomena ini berlaku di sebabkan oleh pengasingan unsur-unsur pada butiran sempadan. Berdasarkan kepada teori, pengasingan unsur-unsur kotoran atau cemaran ini akan mengakibatkan kemusnahan serta kerapuhan besi. Oleh yang demikian, kajian dan pemerhatian keatas ciri-ciri mekanikal kawasan kimpalan adalah sangat penting bagi memastikan pengandang mampu beroperasi pada suhu operasi dan untuk mengelakkan daripada berlakunya kerapuhan ketika pengandang sedang beroperasi. Jenis besi pengandang yang telah di gunakan sebagai spesimen dalam kajian ini adalah ASTM A516. Bagi melengkapkan kajian ini, kaedah yang dijalankan adalah dengan melakukan pendedahan spesimen kepada peningkatan suhu sekitar 450℃ terhadap setiap spesimen yang mempunyai kawasan kimpalan. Sifat-sifat mekanikal bagi kawasan kimpalan (kesemua spesimen) selepas melalui proses peningkatan kekerasan dianalisis melalui pemerhatian mikrostrukturnya, ujian pengesahan unsure-unsur serta ujian takat kekerasan yang dilakukan pada suhu bilik. Berdasarkan keputusan ujian-ujian yang telah dijalankn, hasil analysis di bincangkan bagi tujuan mengenal pasti kesan pendedahan suhu yang tinggi terhadap sifat kerapuhan pengandang. Keputusan kajian jelas menunjukkan bahawa pendedahan pengandang kepada suhu yang tinggi sangat mempengaruhi keputusan ujian kekerasan bagi setiap zone kimpalan dan sifat-sifat mikrostruktur besi pengandang tersebut turut berubah dengan nyata sekali.

DEDICATION

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LIST OF ABBREVIATIONS, SYMBOLS, SPECIALIZED NOMENCLATURE

%	-	Percentage
ASTM	-	American Society for Testing and Materials
AISI	-	The American Iron and Steel Institute
HR	-	Rockwell hardness number
^{0}C	-	Degrees Celsius
DBTT	-	Ductile to Brittle Transition
HAZ	-	Heat Affected Zone
BM	-	Base Metal
WM	-	Weld Metal
Cr	-	Chromium
Mo	-	Molybdenum
SEM	-	Scanning Electron Microscope
BCC	-	Body-center cubic
FCC	-	Faced-centered cubic
Fe_3C	-	Carbide
CCT	-	Continuous Cooling Transformation
EDX	-	Energy-dispersive X-Ray spectroscopy
TTT	-	Time Temperature Transformation
SEM	-	Scanning Electron Microscope
C	-	Carbon
wt%	-	Weight percentage
Cl	-	Chlorine
Al	-	Aluminium
Si	-	Silicon
Fe	-	Ferum
α	-	Alfa

γ	-	Gamma
Lab	-	Laboratory
FKP	-	Faculty of Manufacturing Engineering
max	-	Maximum
µ	-	Micron
Mpa	-	Mega Paschal
in	-	Inch
mm	-	Millimeter
cm	-	Sentimeter
SAW	-	Submerged Arc welding
PWHT	-	Post Weld Heat Treatment
UE	-	Unembrittlement
LE	-	Light Embrittlement
ME	-	Medium Embrittlement
HE	-	Heavy Embrittlement
EDS	-	Energy Dispersive X-ray Spectroscopy

CHAPTER 1
INTRODUCTION

1.1 Research Background

Towards developing the weld consumables for tempered martensite steels, evaluation on embrittlement is importance in order to prevent catastrophic failure of structure, often originating from brittle fracture of welded joint for engineering system that are operating at high temperature cycle (650 ℃ - 1100℃) that involve contact of metallic with combustion product gases, such as gas turbines, steam generator, and numerous petrochemical process vessel. Based on that, this research is developing in order to study the effect of high temperature cycle exposure to evaluation on embrittlement of welded pressure vessel steel.

The composition element and structure on base metal are quite different compared to heat affected zone (HAZ) of welded. This is because of the distribution of molybdenum within the alloy parent plate and in the weld heat affected zone. Heavy partition of molybdenum to carbide phases in the metal would result temper embrittlement, as molybdenum retard the segregation of embrittling tramp element to grain boundaries. Therefore, the research and observation in the mechanical properties of tempered welded area are very important in order to support on-going steel development for services temperature > 620℃ and also useful to avoid the embrittlement during the services.

Overall part of this study was a consideration of the effect of time tempering on the welded zone (base metal and HAZ area) in a submerged-arc welding. For this purpose, the medium carbon steel (ASTM A516) is used in this research. The 2.25Cr-1Mo steel has much advantage for both ambient and high temperature steel. The potential uses of this steel are in the electrical power generation plants and petrochemical industries. These pressure vessel steel have a potential for temper embrittlement that lead to toughness degradation and a reduction of a critical flaw size for brittle fracture.

A survey of literature shows the composition to be controlling parameter for temper embrittlement, in-particular the presence of impurity elements such as P and the presence of elements such as Mo which effect of impurity segregation. Much information is available to describe embrittlement phenomenon for Cr-Mo steels. This research also describe the mechanism of temper embrittlement and microstructure characteristic which allows the structural integrity of potential embrittled vessels for the purpose of remaining life assessment and plant life extension

To determine the properties of the steel after tempering process, several tests like Vickers Hardness, EDS analysis and microstructure observation will be done for all samples that tempering at elevated temperature according to ASTM references.

1.2 Problem Statement

Temperature embrittlement is a phenomenon where ductile metal become brittle due to high temperature exposure. This exposure temperature will also affect the hardness of the welded pressure vessel area. Therefore, it is important in order to evaluate embrittlement of material which all of this data could be use for further research to define the fracture of welded pressure vessel steel.

1.3 Objectives of Project

The purpose of this project is:

i) To study the effect of high temperature cycle exposure to evaluation on embrittlement of welded pressure vessel steel.

ii) To determine the effect of precipitation elements on microstructure development and hardness of based metal and heat affected zone (HAZ) of welded pressure vessel steel.

1.4 Scope of Project

This study will focus on the effect of high temperature cycle exposure to evaluation on embrittlement of welded pressure vessel steel. This project will include the literature review on the phase transformation in steel, temper embrittlement, the preparation and procedure of heat treatment at elevated temperature, mechanical testing by using hardness measurement and microstructure observation. The microstructure for each specimen will be observed under the Optical Microscope. While the composition of element in welded area (base metal and HAZ) after tempering will be observed using EDS analysis.

1.5 Hypotheses

The tempering process with different exposure time will cause the significant reduction of the hardness of the steel, due to the segregation of trace elements at the grain boundaries and/or carbide interface. The microstructure is also different between Heat affected zones (HAZ), and base metal (BM) when expose at elevated high temperature.

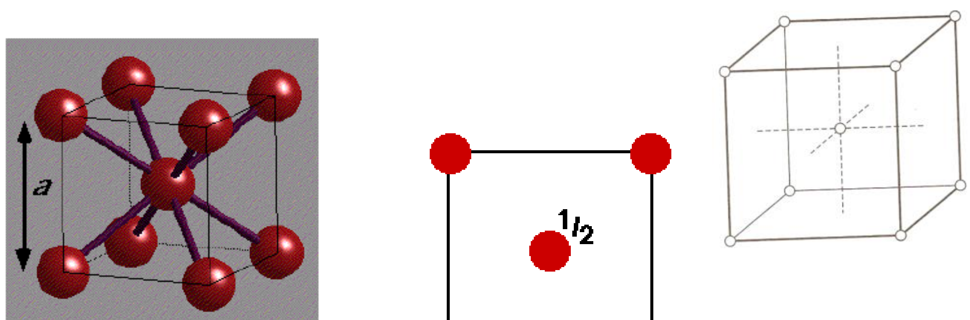
CHAPTER 2

LITERATURE REVIEW

2.1 Metallurgy

2.1.1 Body-Centered Cubic Crystals

Body-centered cubic (BCC) structure can be defined as an atom that lies at each corner of the cube and one in the center. In body –centered cubic structures, each of corner atoms are touch the central atom but the corner atoms do not touch each other, Figure 2.1, [14]. This is one of the common and simplest shapes found in the crystal and minerals. For the other metal with the BCC structure at room temperature include chromium, iron, molybdenum, and vanadium.



(c)

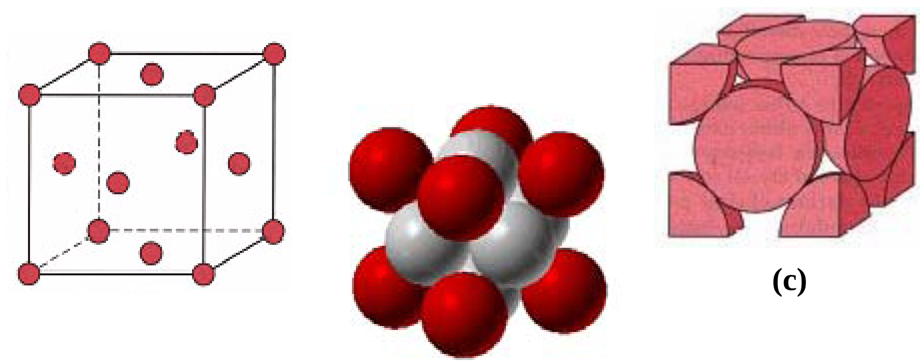
(a) (b)

Figure 2.1: The structure of a body-centered cubic metal: **(a)** the full solid sphere model, **(b)** the point model shows the location of the atom centered, **(c)** The positions of the centers of the atoms in one unit cell of the BCC [14]

Figure 2.1 **(c)** shows that nine atoms associate with each cell but some atoms are shared among several cells [11]. Each corner atom in body-centered cubic is shared by eight cells. Since the coordination number is less for BCC than FCC, so also is the atomic packing factor for BCC is lower (0.68 versus 0.74) [15].

2.1.2 Faced-Centered Cubic Crystal

Atom that are located at each of the corner and on the centered of all the faces of cubic unit cell can be defined as face-centered cubic structure (FCC), Figure 2.2, [16].



(c)

(a)

(b)

Figure 2.2: The structure of a faced-centered cubic unit cell: **(a)** the point model show the atoms location, **(b)** the full solid sphere that shown all 14 atoms associated with unit cells, **(c)** the partial solid sphere model shows the fraction of each atom contained within this unit cell. [16]

Metal that has the FCC structure at room temperature are include aluminum, calcium, copper, gold, and lead, nickel, platinum and silver. By referring Figure 2.2, this structure has an atom at each corner plus an additional atom at the center at each face. Since each face is shared by two unit cells, there are four atoms per FCC cell and each atom in the FCC structure has 12 nearest neighbors.