Improved Procedure to Prevent Hydrogen Induced Cracking for Welding Offshore Structures

by

Myra Azwinna Binti Sapian

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Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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(MECHANICAL ENGINEERING)

Approved by,

_____

Assoc. Prof. Dr. Razali Hamzah

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MYRA AZWINNA BINTI SAPIAN

ABSTRACT

The objectives of the study are to study the causes of failure due to hydrogen induced cracking and its method of prevention and improve the current offshore welding procedure thus reduces the occurrence of hydrogen induced cracking in offshore repair works. The project covered the condition and prevention methods of hydrogen induced cracking based on literature review and also some experimental works done as part of the study.

In fabricating an offshore structure, multiple assemblies are joined together to get the final product. The materials used to assemble these assemblies are made from carbon steel and they are joined together by weld. In 1980's research shows that 7% of failures in petroleum and gas industry are caused by weld defects. Therefore, the entire welding process played a vital role as far as the quality and integrity of the end product. The steel manufacturing industry has offered and developed improved steel strength properties to enhance resistance towards damage caused by hydrogen. A reliable and cost effective maintenance and repairworks for offshore structure are also required to promote long term product integrity. Thus, effective welding processes and procedures for repairworks that could reduce the risk of hydrogen induced cracking could be employed in the future.

Some of the methodology for this project is to get hold of the problem definition which covers the problem statement of the project, background of study and setting the specific objectives. Researched and literature review regarding the project through resources such as engineering handbooks and journals were done. Methodologies done thorough out this project were material preparation, surface preparation, exposing the sample to hydrogen evolution by impressed current cathodic protection, testing on surface by using liquid penetrant inspection and also visual inspection by using optical microscope. From the results gained, the study concluded that hydrogen induced cracking tended to happen more when the sample was being overprotected by cathodic protection. When impressed current applied were very high, it would result a very high hydrogen evolution. Hence, the probability of hydrogen induced cracking to occur would therefore increase.

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Finally, I dedicate this work to my parents for their moral support, encouragement and understanding until the completion of this study.

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LIST OF ABBREVIATION

HIC = Hydrogen Induced Cracking

HAZ = Heat Affected Zone

H_2 = Hydrogen

Fe = Iron

WPS = Welding Procedure Specification

AWS = American Welding Society

PTS = PETRONAS Technical Standard

API = American Petroleum Institute

ASME = American Society of Mechanical Engineers

ASTM = American Society for Testing and Materials

SMAW = Shielded Metal Arc Welding

NDT = Non Destructive Testing

VI = Visual Inspection

MPI = Magnetic Particle Inspection

UT = Ultrasonic Testing

RT = Radiography Testing

SEM = Scanning Electron Microscope

CE% = Percentage of Carbon Equivalent

CHAPTER 1: INTRODUCTION

1.1 Background of Study

The search for oil and gas leads to the discovery of deep water reservoirs with high pressure and high temperature. Therefore, the structures are being exposed to a wide range of offshore environment. In order to maintain a cost effective project, a good material choice, corrosion control and welding procedure to sustain the quality before and after the structures have been brought offshore are important. Implementations of these measures are becoming more important as it will affect on the safety, environmental and also economic of the project. As we know, welding is the best method to be used for metal fastening. Many new methods, applications and systems have been developed over the years. However, over a time period, the joint weldment of the structures tends to develop blister and/or cracks caused by exposure to hydrogen. This type of crack is controlled by the absorption of hydrogen into the metal lattice [1]. Hydrogen induced cracking (HIC) and hydrogen pressure cracking are the terms used to describe cracking for this type of offshore structures.

1.2 Problem Statement

Most of the main assemblies of these offshore structures are being done by using welding process. After welding work is conducted, hydrogen induced cracking can easily occur if there is lack in proper handling of pre-heating, proper procedure and post-heating. If there is a possibility of restructuring the welding repair work procedure to reduce the occurrence of hydrogen induced cracking, then the impact will be reduction in maintenance costs of the offshore structures.

1.3 Objective and Scope of Study

Objectives:

a. To study the causes of failure due to hydrogen induced cracking.
b. To study method of prevention of hydrogen induced cracking.
c. To make improvement to the current welding repair work procedure for onshore and offshore to prevent hydrogen induced cracking.

Scopes of Study:

a. Gather information about offshore welding defects and its causes.
b. Search for options to reduce weld failures caused by hydrogen induced cracking.
c. Propose a modification in repair welding procedure for offshore welding repair work.
d. Test and analyze the modified procedure for repair works on samples in laboratory by simulating the environment and condition of offshore Malaysia.
e. Propose an option for the new welding repair work procedure that can prevent hydrogen induced cracking.

CHAPTER 2: LITERATURE REVIEW

2.1 Hydrogen Induced Cracking (HIC)

A hydrogen induced crack is a brittle internal crack that occurs after the metal has completely solidified. One of the hydrogen cold-cracking characteristic is its delayed nature, that is, crack initiation and especially propagation may take place several hours, or sometimes even days or weeks, after welding has been completed [3]. The crack paths can either be transgranular or intergranular paths [1]. This type of crack can occur in both the weldment and also in the heat-affected zone (HAZ) of the welded joints [1, 2].

Cracks that occur at the weldment are most commonly observed occurring around ambient temperature. This happens due to hydrogen is introduced to the molten pool through moisture. Other reason for cracks to occur is hydrogen containing compounds in fluxes or on the surface of the filler metal and the parent metal. The molten pool and the solidified bead will then become a reservoir of dissolved hydrogen [2].

For cracks that occur in the HAZ, the hydrogen from the molten pool will then diffuses from the weld bead to the adjacent region of the HAZ which has been heated sufficiently to form austenite. As the microstructure hardens, the austenite transforms and further diffuses the hydrogen. Hydrogen that retained in this region adjacent to the weld bead can also cause cracking [2].

2.1.1 Factors Causing HIC

Most welding books frequently mention on these three factors such as presence of hydrogen, microstructure and tensile stresses acting on the welded joint. Hence, these three factors will be paid more attention to in our further discussion.

The explanation for those three factors is [1, 4, 5]:

a. Presence of hydrogen.

   The presence of hydrogen content must be sufficiently high. Hydrogen can be absorbed during melting, welding, galvanizing, pickling, controlled atmosphere annealing, or while the component is in service. This happens due to the breakdown of water (atmospheric moisture) or oil or from hydrogen molecule itself. If the amount of hydrogen trapped is high, this will promote HIC to occur.

b. Microstructure.

   It is affected by chemical composition of the parent metal itself and the weldment cooling rate. Metals with high carbon content and alloy steels are most likely to experience cold cracking.

c. Tensile stresses acting on the welded joint.

   This involves joint restraint, stress concentrator, and weld metal yield strength. Hydrogen will accumulates in the areas of maximum tensile stress concentration during welding. It is basically the area where the penetration bead joints the parent metal. For a multipass welding, hydrogen is very unlikely to diffuse away from this zone. Therefore, the possibility of HIC to occur will be higher.

2.1.2 Mechanism of HIC

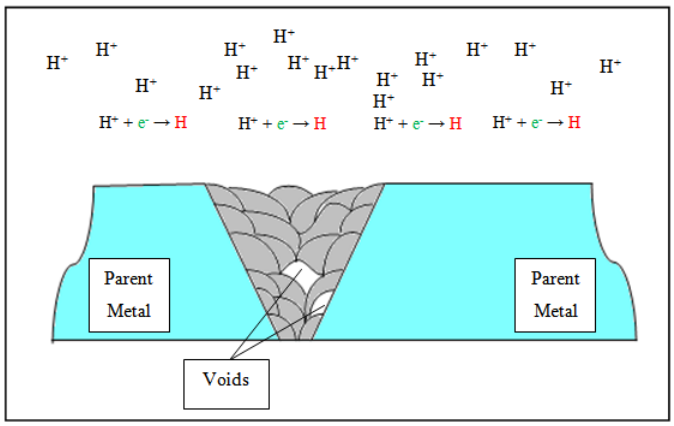


Figure 2.1: Hydrogen Reaction

Figure 2.1 shows the hydrogen reaction involved in crack growth. The process initiated during the incubation period which is when hydrogen atoms that diffuse over interstitial lattice sites.

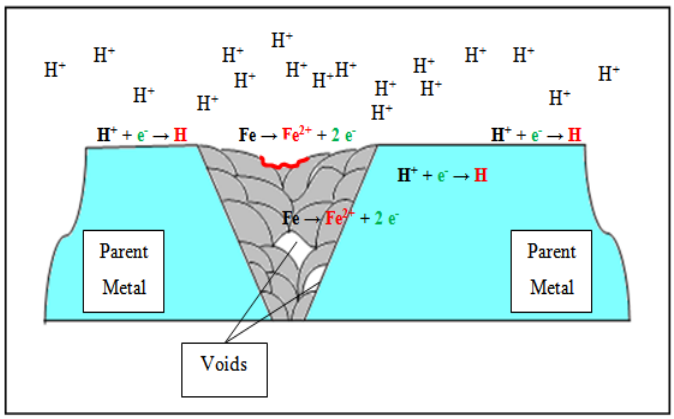


Figure 2.2: Ferrite Reaction

Figure 2.2 shows the ferrite reaction involved in crack growth. This reaction takes place at a convenient location such as an inclusion interface. The formation of a hydrogen molecule from two hydrogen atoms results in a local increase in pressure [6]. Two types of reaction can be observed which are:-

$$Fe \rightarrow Fe^{2+} + 2e^{-} \qquad \text{---------- (2.1)}$$

$$2H^{+} + 2e^{-} \rightarrow H_2 \qquad \text{---------- (2.2)}$$

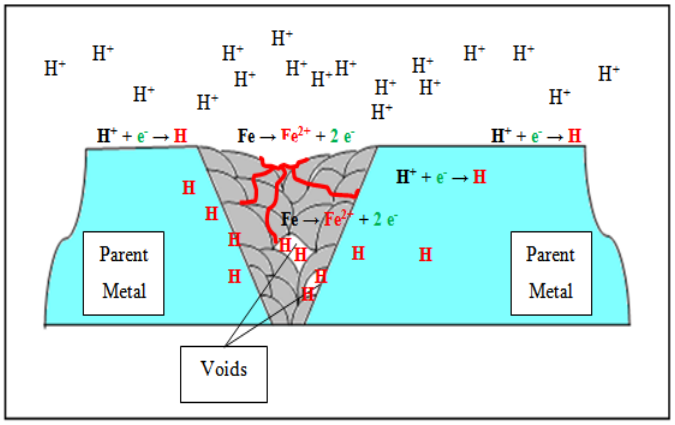


Figure 2.3: Weldment Starts to Corrode & Hydrogen Accumulates in Inclusion

Figure 2.3 shows that as more and more molecules form at a given site, the pressure increases to the point where, if the site is near the surface, a blister may form [6].

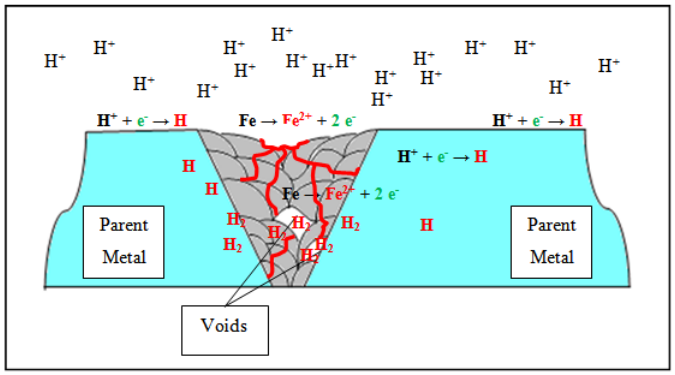


Figure 2.4: Crack Growth

Figure 2.4 shows that if the site is remote from the surface, the formation and growth of crack may take place. If there is a number of such cracks form, they can link up and greatly reduce the fracture resistance [6].

2.2 Welding Procedure Specification (WPS)

A WPS is a document that describes how welding is to be carried out in production. It outlines all of the parameters required to perform the welding operation and is recommended for all welding operations for many application codes and standards. WPS provides sufficient details such as welding process or processes and the base materials to be used, the joint design and geometry, gases and flow rates, welding position and includes all of the process conditions and variables to enable any competent person to apply the information and produce a weld of acceptable quality.

The amount of detail and the level of controls specified on a WPS depend on the application and criticality of the joint to be welded. If it is used in conjunction with approved welding procedures, then the ranges of thicknesses, diameters, welding current, materials, joint types etc. stated should be in accordance with the approval ranges permitted by the welding procedure. However, careful consideration should be given to the ranges specified in order to ensure that they are achievable, as the ranges given by welding procedure standards do not always represent good welding practice [16, 17].

Each manufacturer or contractor must qualify the WPS by welding test coupons (samples) and by testing the coupons in accordance with the code. Testing such as tensile test, root bends and face bands will be made on the test coupons as required by the code. A different WPS is required for each change in an essentials variable [19].

2.2.1 Essential Variables in WPS

Typical Items That Should Be Recorded On W.P.S:-

a. Base metal thickness
b. Base metal strength or composition
c. Filler metal strength and composition or AWS classification number
d. Preheat temperature
e. Interpass heating

f. Post-heat temperature
g. Joint geometry
h. Welding process
i. Welding technique
j. Welding position
k. Shielding gas
l. Deletion of backing material in single pass welded butt joints
m. A change from uphill to downhill or from downhill to uphill welding.

2.2.2 WPS – FSP-HLE-17-49

Table 2.1 (on page 9) shows the parameters of WPS FSP-HLE-17-49 (Appendix I) that is being used by PCSB for the fabrication of its platforms. The WPS is developed based on AWS D1.1 2004 code and PTS 20.104 ’98 standard. Both code and standard will aid the manufacturers in producing a safe and reliable welding operation.

Table 2.1: Parameters of WPS FSP-HLE-17-49

1.	Procedure number	FSP-HLE-17-49
2.	Base metal thickness	Plate: 3mm to 65mm Diameter: DN 600mm & over
3.	Base metal strength/composition	A 516 Gr. 70
4.	Filler metal strength & composition	Root: E 7016 Cap: E 7018
5.	Preheat / interpass temperature	Min: 10°C Max: 300°C
6.	Post-heat temperature	Not required
7.	Joint geometry	Single Vee, 60° to 70°
8.	Welding process	SMAW
9.	Welding Technique	Max run width: 12mm (manual), 16mm (auto & semi auto)
10.	Welding position	1G & 2G
11.	Shielding gas	None

2.3 Shielded Metal Arc Welding (SMAW)

Shielded Metal Arc Welding (SMAW) or Stick welding is a process which melts and joins metals by heating them with an arc between a coated metal electrode and the workpiece [12, 13]. Because of the versatility of the process and the simplicity of its equipment and operation, shielded metal arc welding is one of the world's most popular welding processes. It is a dependable process that can weld any steel in any position. This type of welding is commonly used in maintenance and repair work [14].

2.3.1 Process Principle

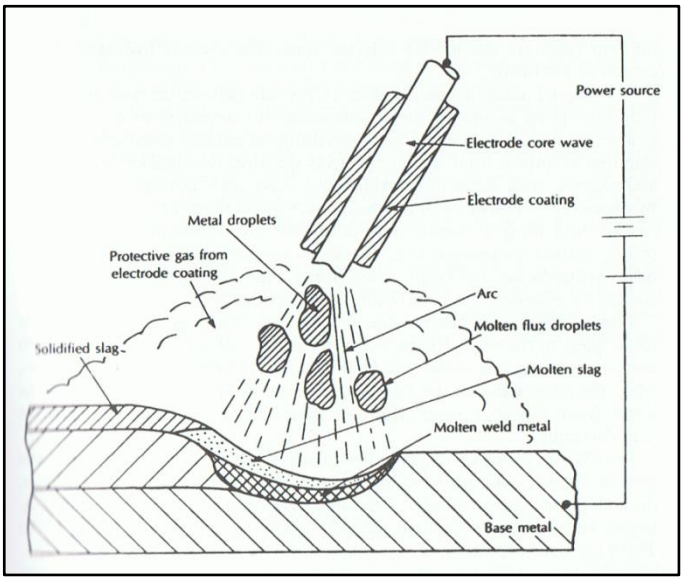
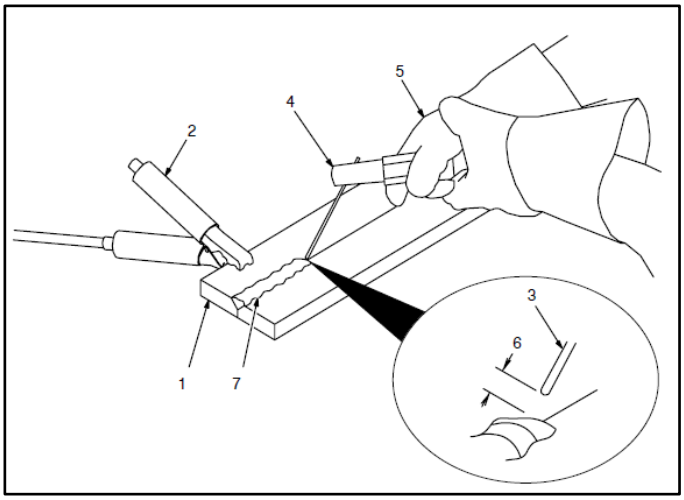


Figure 2.5: Schematic of SMAW process

Figure 2.5 shows the metal coalescence is produced by the heat from an electric arc that is maintained between the tip of a flux-coated electrode and the surface of the base metal being welded. The flux coat of the electrode assists in creating the arc and provides the shielding gas and slag covering to protect the weld from contamination [13]. A core wire conducts the electric current from a constant current power supply to the arc and provides most of the filler metal to the joint [12].

2.3.2 Typical Set-Up and Procedure



1. Workpiece
2. Work clamp
3. Electrode
4. Insulated Electrode Holder
5. Electrode Holder Position
6. Arc Length
7. Slag

Figure 2.6: Typical SMAW Set-Up [13]

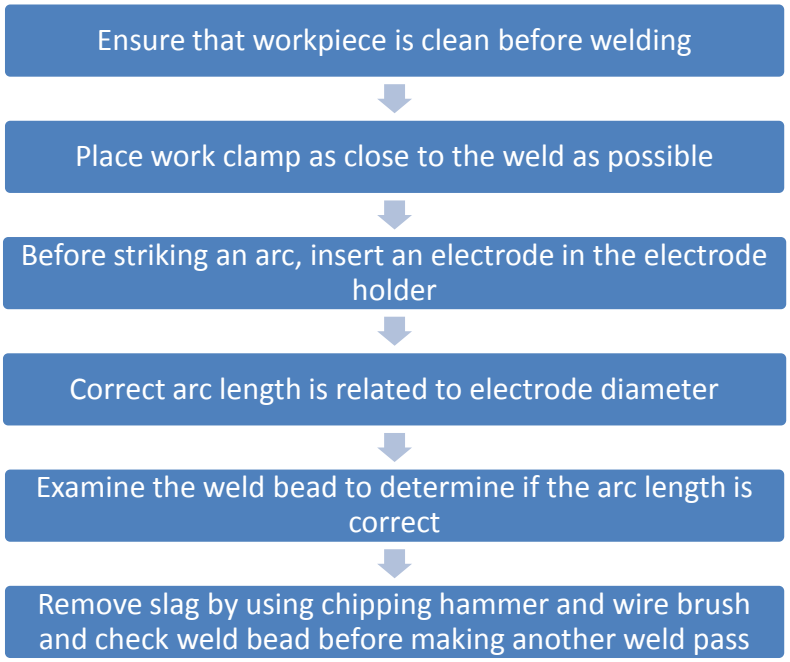


Figure 2.7: Typical Procedure for SMAW

Figure 2.6 above shows the typical set-up for SMAW while figure 2.7 above shows the typical procedure for SMAW [13] based on the Guidelines for Shielded Metal Arc Welding (Appendix II).

2.3.3 Electrodes

For SMAW, the electrodes have a solid metal wire core and a thick flux covering them. These electrodes can be identified by their wire diameter and by a series of letters and numbers. Covered electrodes serve many purposes in addition to adding filler metal to the molten weld pool.

By absorbing the moisture from the air, the effectiveness of most electrodes will decrease. This will cause the electrodes to become damp thus introducing hydrogen into the weld. Cracking and brittleness will have more tendencies to occur. Many welding procedures require that electrodes to be thoroughly dried beforehand.

The time it takes for an electrode to pick-up moisture depends on the type of the electrode itself and will vary from 30 minutes to 4 hours. Therefore, welders will only take enough electrodes from the oven to last for this moisture-pickup time period. Extra care of the electrodes must be taken to prevent breaking of the flux coating.

Flux of the electrode serves an important purpose during the welding operation. Some of the flux covering will change to neutral gas or reducing gas (CO or H_2). They prevent oxygen in the air from combining with the molten metal. Its special ingredients work to remove impurities that are floated on top of the molten pool from the molten metal. As it cools, the flux will form a coating material over the weld called slag. The slag will prevent the air from contacting the hot metal.

The electrodes used in the WPS referred are E7016 and E7018. These electrodes are use to weld carbon and low alloy steel. Both electrodes are used for arc welding and have a minimum tensile strength as welded of 72,000 psi (496MPa). However, additional elongation may allow the tensile strength of some of these to go down to 70,000 psi (483MPa).

2.3.4 Base Metal (A516 grade 70)

A516 grade 70 is a high strength steel that is usually used for fabricating pressure vessels. The chemical composition of A516 grade 70 is as Table 2.2 below:-

Table 2.2: Chemical Composition for A 516 Grade 70

	C max			Si	Mn	P, S Max
Thickness, mm	≤12.7	12. to 50.0	50.0 to 100.0			
A516 grade 70	0.27	0.28	0.30	0.15 to 0.40	0.85 to 1.20	0.035

$$CE\% = \%C + \left(\frac{\%Mn+\%Si}{6}\right) + \left(\frac{\%Cr+\%Mo+\%V}{5}\right) + \left(\frac{\%Cu+\%Ni}{15}\right) \text{ ----- (2.3)}$$

By using equation 2.3 above;

$$CE\% = 0.28 + \left(\frac{0.95 + 0.28}{6}\right) = 0.485 > 0.45$$

Therefore, the material used is prone to weld cracking and preheat temperature range between 100 to 400°C and low hydrogen electrodes are required [20].

2.3.5 Advantages & Disadvantages

Advantages:

a. It can be used for welding most structural and alloy steels. These include low carbon or mild steels; low-alloy, heat treatable steels and high-alloy steels such as stainless steels.
b. It can be used for joining common nickel alloys, copper and aluminum alloys.
c. It can be used in all positions - flat, vertical, horizontal, or overhead.

d. It only requires the simplest equipment.

Disadvantages:

a. Inferior to GMAW if one compares the cost of the time and materials needed to deposit the weld metal. SMAW deposits the weld metal more slowly than GMAW.
b. Slag removal, unused electrode stubs, and spatter add a lot to the cost of SMAW. It accounts for about 44 percent of the consumed electrodes.
c. The entrapment of slag in the form of inclusions which may have to be removed.

As we know, the steel grade that is used for structures are A36, but due to limitation of material, material A516 Grade 70 is used during the study.

Table 2.3: Chemical Composition for A 36 [24]

	Plate*				
	Up thru 3/4	Over 3/4 thru 1-1/2	Over 1-1/2 thru 2-1/2	Over 2-1/2 thru 4	Over 4
Carbon	0.25	0.25	0.26	0.27	0.29
Manganese	--	.80/1.20	.85/1.20	.85/1.20	.85/1.20
Phosphorus	0.04	0.04	0.04	0.04	0.04
Sulphur	0.05	0.05	0.05	0.05	0.05
Silicon	.40 max	.40 max	.15/.40	.15/.40	.15/.40
Copper min % when copper steel is specified	0.20	0.20	0.20	0.20	0.20

By using equation 2.3 above,

$$CE\% = 0.25 + \left(\frac{1.0 + 0.35}{6}\right) = 0.475 > 0.45$$

The A516 Grade 70 steel can steel be used because it will have similar properties as A36.

2.4 Hydrogen Evolution

An electrode reaction in which hydrogen gas is produced at the cathode of an electrolytic cell by the reduction of hydrogen ions or the reduction of the water molecules of an aqueous solution.

The equations of these reactions in aqueous solution are:-

$$2\ H^+ + 2\ e^- \leftrightarrow H_2 \qquad \text{---------- (2.4)}$$

$$2\ H_2O + 2\ e^- \leftrightarrow H_2 + 2\ OH^- \qquad \text{---------- (2.5)}$$

Cathodic hydrogen evolution is one of the common electrochemical reactions. It is the principle reaction in electrolytic hydrogen production, the auxiliary reaction in the production of many substances forming at the anode such as chlorine and side reaction in much cathodic process [21]. The strong hydrogen evolution occurring on the cathode may reduce some of the oxides, and the strong bubble evolution removes the scales mechanically.

2.5 Non Destructive Testing (NDT)

Non Destructive Testing (NDT), Non Destructive Evaluation (NDE) and Non Destructive Inspection (NDI) are the terms used to represent the techniques that are based on the application of physical principles engaged for the purpose of determining the characteristics of material, components or system and for detecting and assessing the harmful flaws without impairing of material, components or system [7].

These methods of testing play important roles to gather information not only for the finished product but also during various stages of manufacturing and to determine the condition of the structure and estimating its remaining useful life even though no NDT techniques can guarantee that all flaws will be detected. The type of testing that is going to be used depends on the type of a structure and its conditions. [7, 8]

In selecting a NDT method for evaluation of a specific type of defect, it should be kept in mind that NDT methods may complement each other and therefore several

NDT methods may be capable of performing the same task. It is important to keep in mind that the objective of an effective testing program is to detect defects as specified by the design based on fit-for-purpose [10]. Therefore, the selection of one method over another is based on the following parameters:

a. Type and origin of defect.
b. Material manufacturing process.
c. Accessibility of the component to perform NDT.
d. Type of equipment available.
e. Time and cost that is available.

As hydrogen induced cracks are often very fine and may be sub-surface, they can be difficult to detect. Internal cracks require ultrasonic or radiographic examination techniques. Ultrasonic examination is preferred, as radiography is restricted to detecting relatively wide cracks that are parallel to the beam. As the formation of cracks may be delayed for many hours after the completion of welding, the delay time before inspection, according to the relevant fabrication code, should be observed [4].

There are more NDT techniques that are available to be used but only techniques that are suitable in this project will be discussed further.

2.5.1 Liquid Penetrant Inspection (LPI)

This type of testing utilizes the natural accumulation of a fluid around a discontinuity to create a recognizable indication of a crack or other surface opening defect. Capillary action attracts the fluid to the defect as compared to its surrounding. In order to locate the area of excess fluid (defect region), the background area must be contrast enough thus leading to distinct detection of the defect on the surface.

Basic procedure for this type of testing is basically by applying a penetrant to the surface of the sample and given time to soak into surface breaking cracks and cavities that are open to the surface. The surplus penetrant is then removed from the surface. Developer is then applied to the same surface and the penetrant which enter cavities are then made visible.

Figure 2.8 below describes the flow of liquid penetrant testing for a surface.

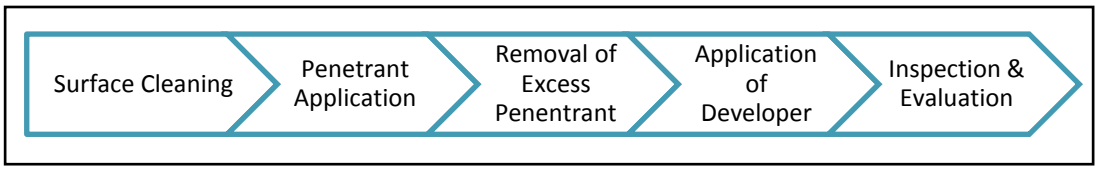


Figure 2.8: Flow Diagram of LPI

Table 2.2 below describes the two types of penetrant that are usually used in a liquid penetrant test.

Table 2.4: Types of Penetrant and its Description

Types of Penetrant	Description
Dye penetrant	a. Gives a colored indication, usually red, on a white background. b. 3 versions – solvent-clean, water wash, post-emulsifier.
Fluorescent penetrant	a. Needs a source of ultraviolet (UV-A) lights for viewing. b. 2 versions – water washable, post-emulsifier.

This method is commonly used to detect:

a. Cracks of any orientation.
b. Porosity.
c. Pin hole.
d. Voids.
e. Various types of welding defects, etc.

2.5.2 Visual Inspection (VI)

The human eye is the most powerful tool for VI. The sensitivity of the eye varies with different wavelengths of lights. Therefore, a proper lighting condition is needed and each personnel are only permitted to two hours of working on continuous basis to avoid errors due to decrease in visual reliability and unfairness [7].

It is also beneficial and recommended for personnel to use optical aid to magnify defects that hardly can be seen with naked eyes and to permit visual checks for the areas that are not accessible to the unaided eyes. Optical aids that are commonly used are:

a. Microscope.
b. Endoscope.
c. Flexible fiber-optic borescope.
d. Mirror on stem.
e. Hand magnifying glass.
f. Inspection glass.

2.5.3 Ultrasonic Testing (UT)

Ultrasonic testing can be done on most materials, metallic or non-metallic to detect surface and sub-surface defects such as laps, seams, voids, and cracks and can be accurately evaluated from one side.

This method of testing utilizes high frequency of acoustic waves generated by piezoelectric transducer. The resultant acoustic wavelengths in the sample are of the order of one to tenth millimeters. A highly directional sound beam is transmitted to the sample by a probe through a suitable lubricant such as grease or oil like material. These acoustic waves propagate effectively through most structural materials, but are being dissipated or reflected by inhomogeneities or discontinuities. This methods will provides quantitative information regarding the thickness of the sample, depth of an indicated defect, size of the defect, etc.

There are three types of sound waves that usually used during the testing. The types of sound waves are:

a. Longitudinal waves.
b. Transverse or shear waves.
c. Surface of Rayleigh waves.

This type of testing can detect the following defects:

a. Surface breaking and hidden cracks in any orientation.
b. Intergranular cracks.
c. Porosity.
d. Creep.
e. Hydrogen embrittlement, etc.

A probe is used to transmit the ultrasonic wave to the surface of the material with the aid of suitable lubricant such as grease or oil like material. The signal move through the metal and then will be reflected back towards the probe from any flaws or discontinuities. The probe will later send the signal to the oscilloscope and will be reflected on the screen of the oscilloscope [9].

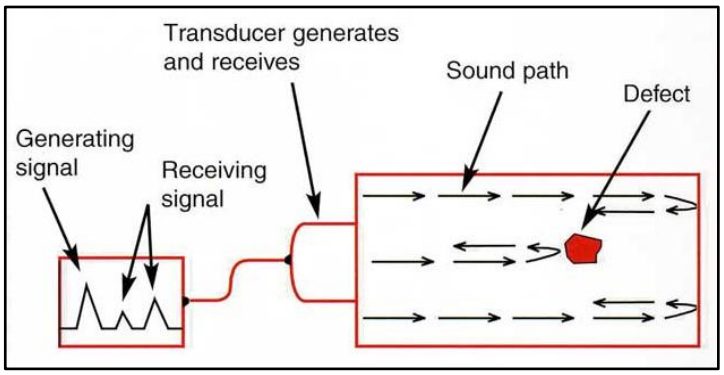


Figure 2.9: Typical Set-up for Taking Ultrasonic Test on a Surface

Figure 3.3 shows a basic typical set-up for taking ultrasonic test on a surface.

2.5.3 Radiography Testing (RT)

Radiography testing is one of the common types of NDT that is widely used to detect defects such as porosity and voids. X-rays and gamma-rays are electromagnetic radiation that are travelling in straight line and are progressively absorbed as they pass through the material. They will effect a photographic so that, if a source of X-rays is placed on one side of a sample and a sheet of photographic film or the other. When there is cavity or defect, the intensity of the image of the processed film will be different. Variations in the darkness of the image may be interpreted to provide information concerning the internal structure of the material [9].

Moreover, the samples that are to be used for the testing do not require initial preparation on the surface. On the other hand, the equipment for this method is expensive thus can only be handled by skilled personnel with requiring major safety protection.

RT is selected to detect and size the following types of defect:

a. Cracks (parallel to the radiation beam).
b. Porosity.
c. Volumetric defects such as slag inclusion and voids.
d. Blockages or deposits inside the pipelines or pressure vessels.
e. Thickness, etc.

An appropriate source of X-ray or Gamma-ray with the mean of switching this on and off for a predetermined exposure time and a photographic film. The film needs to be the same size with the sample and held in a light-tight holder with a thin front in order to protect it from light but also allowing it to be exposed to the electromagnetic radiation of X-ray or Gamma-ray.

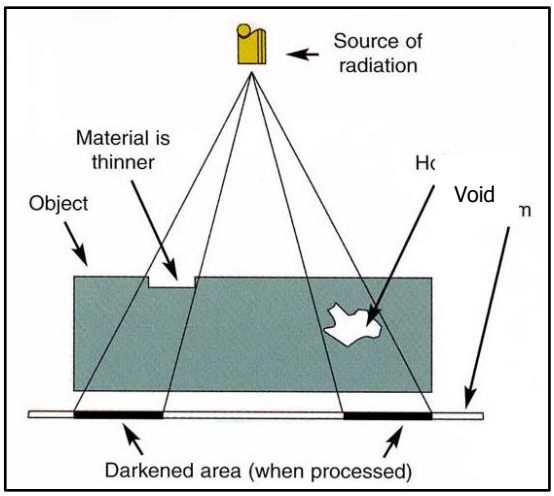


Figure 2.10: Typical Set-up for Taking Radiographs of a Surface.

The film must be developed, wash and let to be dry so the result can be examined. Nowadays, automatic film processor is also available but the cost of the machine is quite high. To read the film effectively, it must be placed on a proper illuminated screen.

CHAPTER 3: METHODOLOGY

3.1 Project Flow Chart

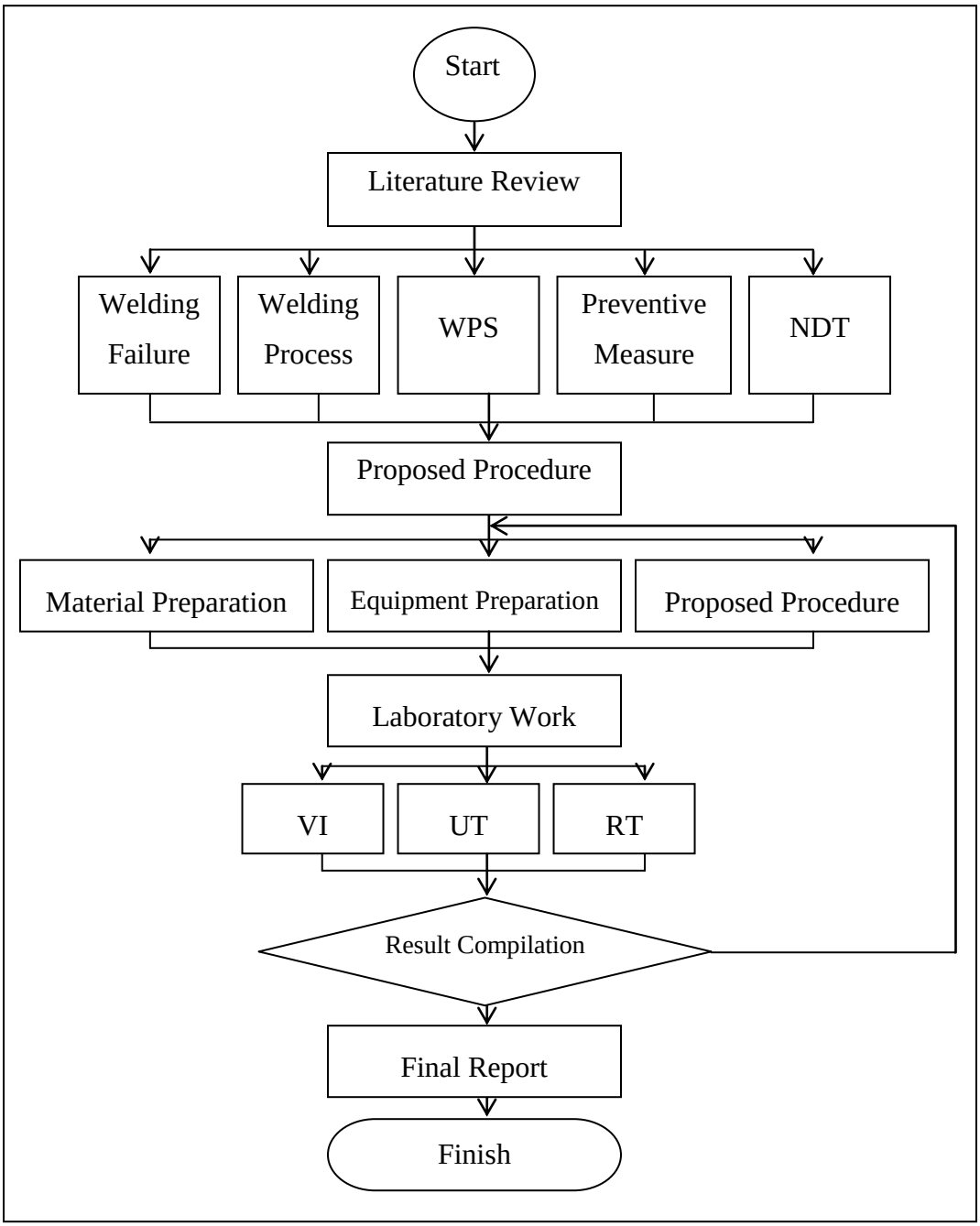


Figure 3.1: Methodology Flow Chart

Figure 3.1 above shows the methodology used in completing my research. The tests mention includes the specimens' exposure in similar to offshore environment with different welding process and technique.

3.2 Project Activities

The project begins with a project definition and background study. The project focuses on the improved procedure for preventing hydrogen induced cracking for offshore repair works. Some literature review has been done throughout the first semester in order to gather as much information and learn of the basic principles of the welding repair works. Besides that, the basic design of various types of welding procedures is also studied based on the guidelines of various standards (PTS, API, ASME, ASTM, etc.). Through the study of hydrogen induced cracking and the welding procedure, author discovered a parameter to study on, in order to improve the procedure for preventing hydrogen induced cracking for offshore repair works. The welding procedure specification for the design offshore repair works is studied and reviewed for self understanding.

3.3 Milestones

The Gantt chart in Appendix V explains the milestone of this project for the second part. The target of the project during the first semester, which is research and case study have been achieved. Further findings and studies on the method of preventions of hydrogen induced cracking are to be implemented throughout the final semester. As a closure to this project, the results or discovery will be in terms of laboratory experiment data.

3.4 Tools and Equipment Required

a. Welding equipment.
b. Offshore structure steel.
c. Salt Spray Chamber.
d. Equipment for testing.

3.5 Material Preparation

A sample of size 8in x 6in x 1in is being cut into few smaller samples, using horizontal band saw. The reasons of cutting the sample into smaller sizes are, easier for grinding and polishing smaller samples and thus easier to observe the microstructure later on.

Figure 3.2: 10” Horizontal Band Saw

Every precaution such as wearing Personal Protective Equipments (PPE) which consists of full covered shoes, gloves and goggle, are taken while dealing with the cutting process.

3.5.1 Expose to Hydrogen Evolution

After the sample is being cut into 3 smaller pieces, each of the small sample is being drilled a hole on top of it and threading is being made inside the hole. A screw will be inserted to the threaded hole and a wire copper will be tied to the screw in order to complete the circuit. All the surfaces of the samples are cleaned with the cleaner and brushed with copper brush to remove any dirt, debris, grease or any other contaminations.

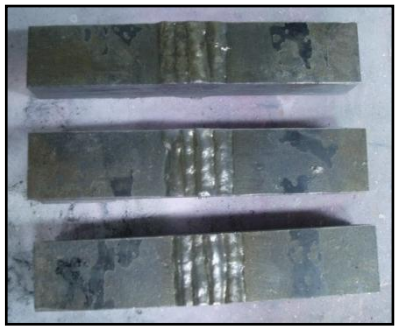


Figure 3.3: The Three Samples

3.5.2 Surface & Microstructure Observation

The material is cut into a small piece that covers all three sections which are the parent metal, HAZ and also the weld bead. One of the surfaces is then grinded and polished until the surface becomes shiny. In order to make the surface good enough to be observed under microscope, it has first to be grinded with grinder having wet silicon carbide with smaller grit number and then subsequently increased to higher grit number.

Figure 3.3: The Grit Number

Then, the grinded sample is polished using the polisher which have a diamond film of 6µ for several minutes. After that, the surface is further polished with diamond film of 1µ until the desired finishing is obtained. Later, the sample is then etched with

Nital 2 etchant, to optically enhance its microstructure such as grain size and phase features. Nital 2 etchant which consist of 100ml Ethanol together with 2ml nitric acid were used to polished surface for 45 seconds.

Figure 3.4: The Polished Sample

3.6 Checking Initial Condition

The samples that will be exposed to hydrogen evolution is first been checked by using liquid penetrant testing (PT) and magnetic particle testing (MT).

3.6.1 Liquid Penetrant Testing (PT)

The surface of the samples that is going to be checked is being cleaned with a special cleaner and brushed with a wire brush. The surface is then sprayed with the liquid penetrant and was being left to penetrate into any cracks or pits for about 20 to 30 minutes. After that, the excessive penetrant was removed with clean cloth and cleaner. The developer liquid is then sprayed onto the surface that has been cleaned. Surface of the samples is then inspected for any discontinuities or defects. The surface is cleaned thoroughly after the inspection.

Figure 3.5: The Cleaner, Liquid Penetrant and Developer Used

3.6.2 Magnetic Particle Inspection

The surface of the samples is being cleaned with a cleaner furnished with the magnetic particle kit. In order to get a more visible result, developer is then sprayed onto the surface and let to dry. After a few minutes, the sample is magnetized by using magnetic probe and black liquid magnetic particle is sprayed onto the magnetized surface.

Figure 3.6: The Magnetic Particle Test Kit Used

3.7 Exposing To Hydrogen Environment

3.7.1 Preparing the Salt Solution

In order to prepare 3% of NaCl solution, 30 grams of NaCl is mixed with 1litre of deionized water. The solution is then stirred with a stirrer for a few minutes to ensure that all the salt have diluted in the water uniformly.

3.7.2 Preparing the Experiment Setup

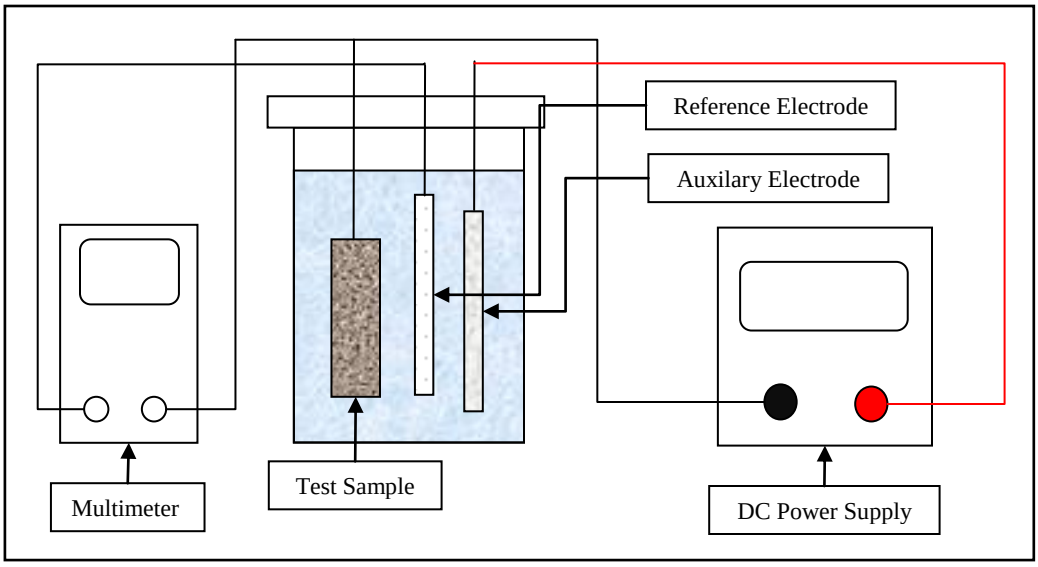


Figure 3.7: Schematic Diagram for Experimental Setup

A schematic diagram of the setup for the experiments is shown in Figure 3.7. The test assembly consists of one-liter glass cell, a DC power supply, and a digital multimeter. The reference electrode used is a saturated calomel electrode (SCE) and the auxiliary electrode is a silver/silver chloride. The experiments were conducted for duration up to 96 hours in order to observe the effect of hydrogen evolution to the weldment.

3.7.3 Experimental Procedure

During the experiment, constant current was supplied to the circuit (600mA, 700mA, 800mA).

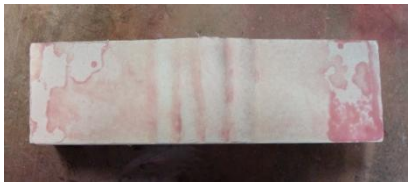
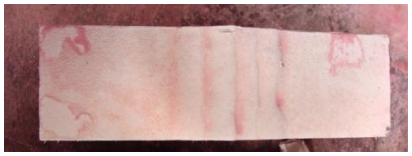
1. Prepare l liter of 3% NaCl solution.
2. Insert the test sample, auxiliary electrode and reference electrode into the glass cell.
3. Make sure all the connections of the circuit are in the correct order.
4. The DC power supply is switched on and amount of the current impressed is set to be 600mA.
5. The reading of the voltage for each setup is monitored every 24 hours for 96 hours.
6. Repeat the procedures for other settings (700mA and 800mA).

CHAPTER 4: RESULTS & DISCUSSION

4.1 Liquid Penetration Testing

Due to the equipment limitation, only the results for liquid penetration inspection and optical microscope can be shown in this report.

Table 4.1: LPI of Test Samples Before and After Hydrogen Evolution

Current Impressed, mA	Before Experiment	After Experiment
600		
700		
800		

(Sample size: 80mm x 30mm x 25mm)

From the figure above we cannot see the cracking on the samples. This is probably due to reasons such as hydrogen induced cracking is a type of delay cracking which requires a long exposure time and also requires the right environment which is the offshore environment. Author could not get hold of other types of testing such as UT and RT, which can observe the inner microstructure of the samples specifically and thus becomes one of the reasons the cracking could not be seen.

The samples that have been exposed to impressed current cathodic protection at 600mA and 800mA are cut by using EDM wire cut machine in order to examine the inner surface of the samples.

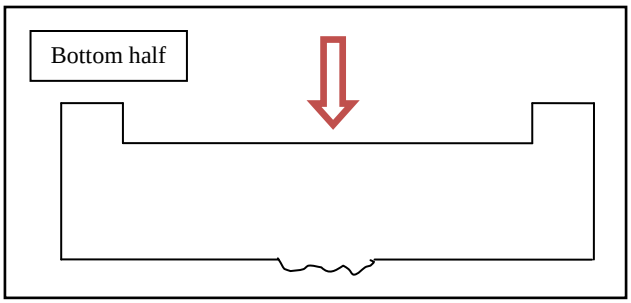
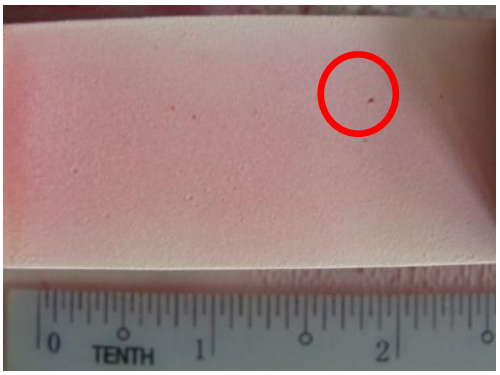
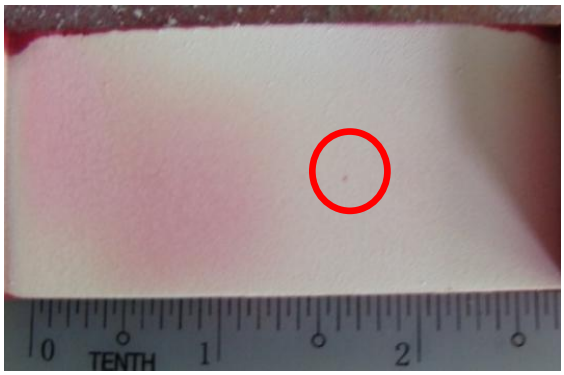


Figure 4.1: Schematic Diagram of Inner Surface that Undergone LPI

Table 4.2: Inner Surface that Undergone LPI

Current Impressed, mA	View 1	View 2
600		
800		

From the table above, some red marks on the surface due to the cracks that have been developed during the experimental procedure. For impressed current of 600mA, the crack occurs at the HAZ area of the sample. For Impressed current of 800mA, the red mark is observed to be at the weld bead of the sample.

4.2 Optical Microscope

Optical microscope is used to get a better understanding on HIC. The other surface that has been cut by using EDM Wire Cut machine such as the surface shown in Figure 4.2 is examined.

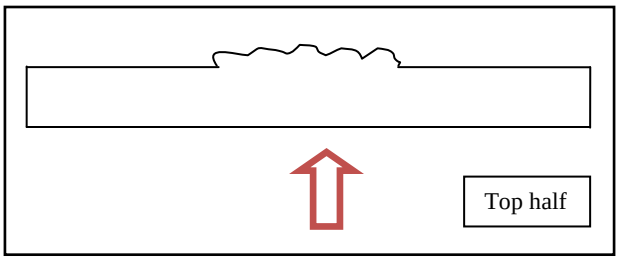


Figure 4.2: Schematic Diagram of Surface that Undergone VI

a. Before Experiment (Magnification: x50)

Shown in Table4.3 below are the results of the visual inspection by using optical microscope with magnification of x50. There are three sections of the sample that are shown below, which are the parent metal, HAZ section and also the weld bead section.

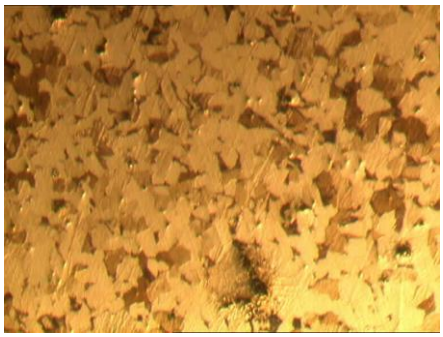
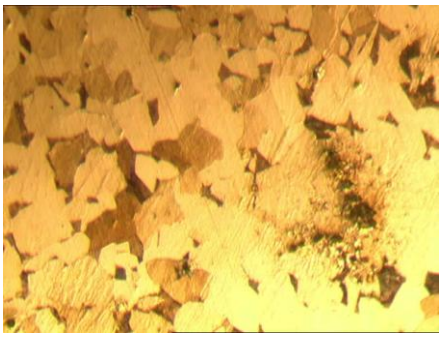
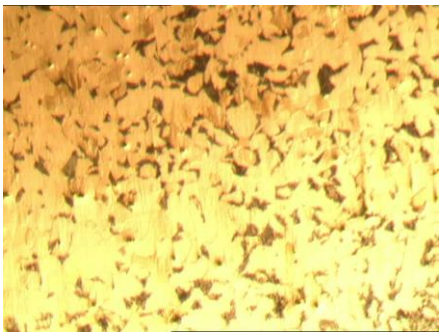
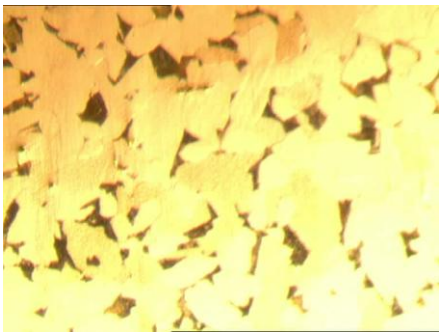
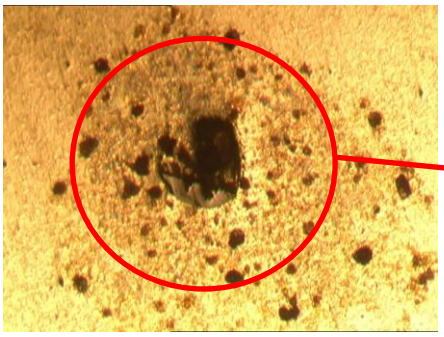
As we can see, the grain size for the three sections is different. The parent metal has bigger grain size than HAZ and weld bead sections. This is due to the post heat treatment undergone by these sections during fabrication operation.

Table 4.3: Surface of the Sample with Magnification: x50

Parent Metal	
HAZ	
Weld Bead	

b. After Experiment (Impressed Current = 600mA)

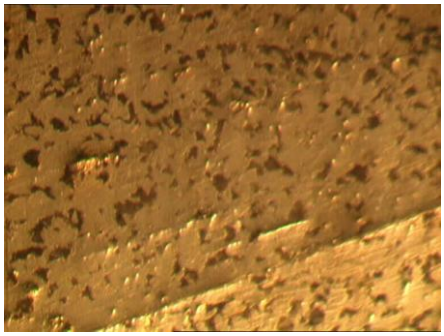
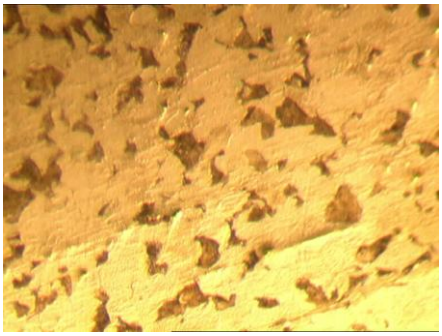
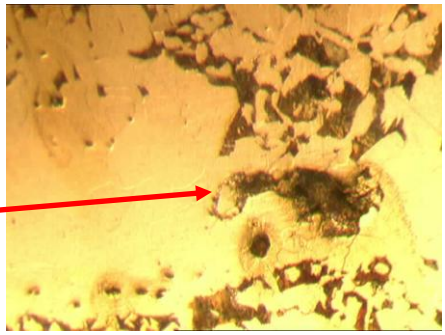
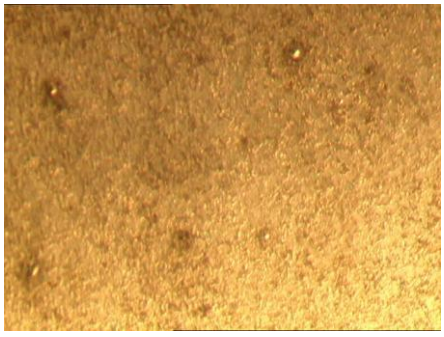
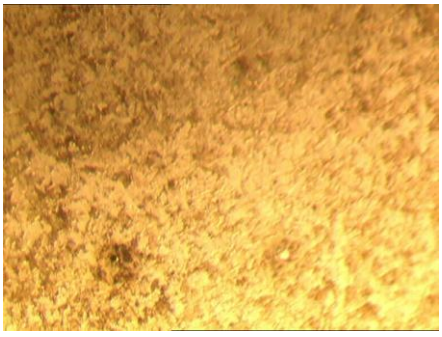
Table 4.4: Surface of the Sample with Magnification: x50 & x100 After Experiment for 600mA Impressed Current

	Magnification: X50	Magnification: X100
Parent Metal		
HAZ		
Weld Bead (blister)		

From table 4.4, there are also three sections of the sample that are shown in the table above. Blister can be observed at the weld bead section of the sample that has undergone impressed current cathodic protection of 600mA. The blister is more visible by using the magnification of X100.

c. After Experiment (Impressed Current = 800mA)

Table 4.5: Surface of the Sample with Magnification: x50 & x100 After Experiment for 800mA Impressed Current

	Magnification: X50	Magnification: X100
Parent Metal		
HAZ (blister)		
Weld Bead		

From table 4.5 above, we can observe the microstructure from three different sections; parent metal, HAZ, and weld bead. As for the sample that has been provided impressed current value of 800mA, the blister can be easily observed at the HAZ section. By using the magnification of x100, the blister can be more specifically observed.

4.3 Hydrogen Evolution Data

Table 4.6: Voltage Reading for Impressed Current = 600mA

reading	day 1, mV	day 2, mV	day3, mV	day4, mV
1	-1774	-1699	-1895	-1760
2	-1728	-1697	-1876	-1688
3	-1710	-1677	-1876	-1684
4	-1705	-1670	-1885	-1685
5	-1703	-1657	-1880	-1684
6	-1700	-1650	-1878	-1687
average	-1720.00	-1675.00	-1881.67	-1698.00

Table 4.7: Voltage Reading for Impressed Current = 700mA

reading	day 1, mV	day 2, mV	day3, mV	day4, mV
1	-1862	-1717	-1649	-1722
2	-1825	-1675	-1637	-1685
3	-1843	-1660	-1639	-1668
4	-1848	-1653	-1640	-1658
5	-1850	-1650	-1638	-1648
6	-1845	-1648	-1646	-1640
average	-1845.50	-1667.17	-1641.50	-1670.17

Table 4.8: Voltage Reading for Impressed Current = 800mA

reading	day 1, mV	day 2, mV	day3, mV	day4, mV
1	-2052	-1757	-1888	-2025
2	-2050	-1751	-1887	-2006
3	-2049	-1747	-1890	-2002
4	-2050	-1746	-1888	-1996
5	-2045	-1752	-1889	-1993
6	-2047	-1755	-1890	-1990
average	-2048.83	-1751.33	-1888.67	-2002.00

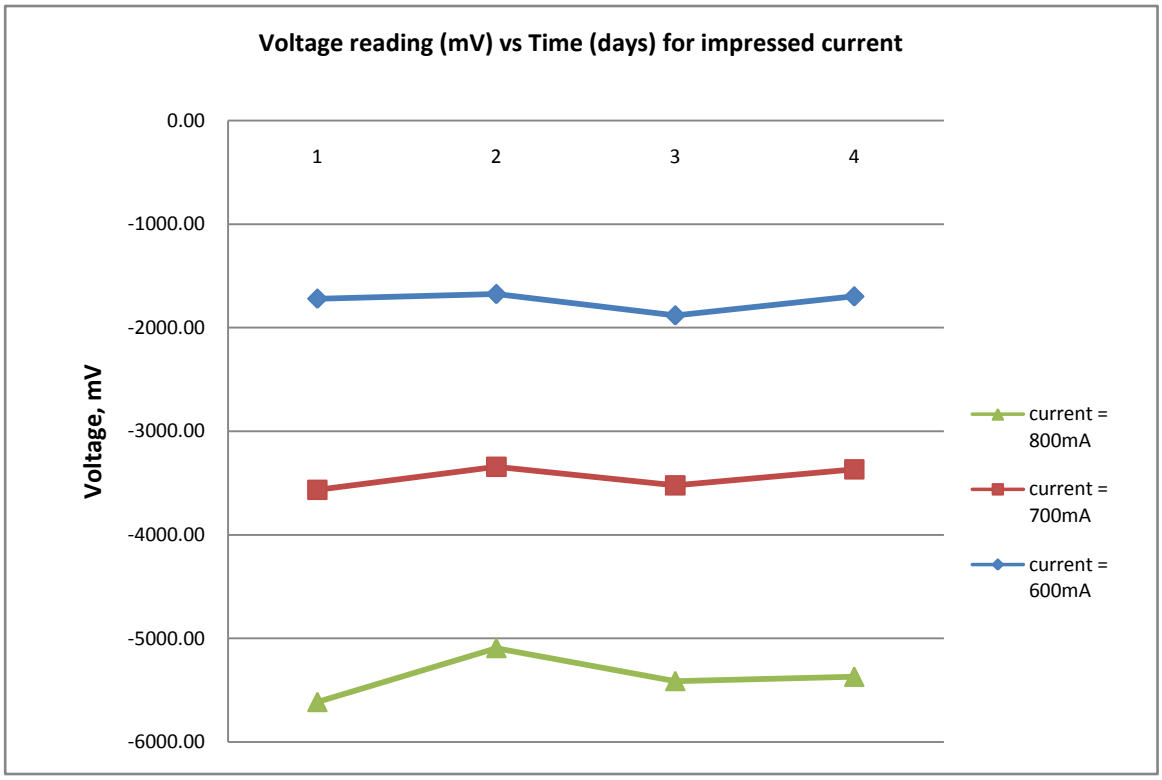


Figure 4.3: Voltage reading (mV) vs Time (days) for Impressed Current

The graph above is plotted based on the data from tables 4.6, 4.7 and 4.8 t have been gathered during the experiment of impressed current cathodic protection.

From the experiment, increase in the voltage value will result in the increase of hydrogen evolving. From the understanding, voltage amount of -750 mV relatively will protect a metal cathodically from being corroded in an environment. But due to higher voltage produced during the experiment (-1600 to -2100mV), excessive hydrogen might cause hydrogen induced cracking to occur.

CHAPTER 5 : CONCLUSION & RECOMMENDATION

5.1 Conclusion

The initial stage of this project in doing research and study on previous literature had given a better understanding on the causes of failure due to hydrogen induced cracking. The method of HIC, hydrogen induced cracking also has been studied throughout this project.

Based from the research and experimental work, it is found that:-

a. The causes of failure due to hydrogen induced cracking were because of the absorption of hydrogen into the metal lattice during manufacturing of the material, welding of the structure or even while the structure in operation. HIC was normally internal crack that has characteristic of delayed in nature, that was, crack initiation and especially propagation might take place several hours, or sometimes even days or weeks, after welding had completed and commonly occurred around ambient temperature. The tendencies of occurrence are relatively to be high when excessive cathodic protection was applied onto a structure if the impressed current was not monitored from time to time to prevent over protection.
b. In order to prevent HIC from occurring during welding, several methods suggested namely:-
    i. Methods that can be used to prevent HIC:-
        - Provide longer annealing time for the steel so that the trapped hydrogen can be removed.
        - Reduce the electrodes hydrogen content with proper baking and handling requirement.
    ii. Suggestions in order to improve current welding work procedure:-

- Use hydrogen free material which has undergone specific heat treatment such as longer annealing time at 100-650°C under vacuum conditions. Thus, metals of hydrogen inclusions can be get rid of.
- Remove the slag produced before the next weld is laid and on the last weldment before its being inspect or paint.
- Bake the electrode at 121°C (250°F) prior to usage. They are only allowed to be out from the oven for maximum four hours in order to prevent excessive hydrogen being absorbed. If it has been out for over 4 hours, the electrodes have to be baked again at 260°C to 371°C (500°F to 700°F) for 1 hours. Before the electrodes are being used, they will have to be stored at 120°C (250°F) until they are used but not for longer than 72 hours.
- Control the current during the welding operation in order to control the stability of the arc and heat produced. By doing this, it prevents load voltage from decreasing as the welding current increases.

5.2 Recommendations

The limitation in this project that restricted the study was the limitation of doing microstructure observation of the inner part of the sample with more suitable testing method. Thus if this project were to be further studied, it was recommended that they use such methods as Ultrasonic Testing and Radiography Testing.

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LIST OF APPENDICES

Appendix I: WPS – FSP-HLE-17-49

Appendix II: Guidelines for Shielded Metal Arc Welding

Appendix III: Carigali Standard Procedure (CSP -16) rev 01

Appendix IV: Project Gantt Chart

No.	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Project Work Continue	■	■	■							MID-SEMESTER BREAK							
2	Submission of Progress Report 1				●													
3	Project Work Continue					■	■	■										
4	Submission of Progress Report 2								●									
5	Project work continue & Seminar (compulsory)									■								
6	Poster Exhibition											●						
7	Submission of Dissertation (Soft Bound)														●			
8	Oral Presentation															■	■	
9	Submission of Project Dissertation (Hard Bound)																	●

● Suggested Milestone
■ Process

Appendix V: Characteristics of E7016 & E7018 Electrodes

Characteristics of E7016 & E7018 Electrodes [14]

Electrode	Coating Type	Welding Position	Current Type	Penetration	Deposition Rate	Bead Appearance	Spatter	Slag Removal	Minimum Tensile Strength (p.s.i)	Yield Point (p.s.i)	Minimum Elongation in 2" (%)
E7016	Low hydrogen potassium	All positions	DCEP, a.c	Mild to medium	Good rate	Smooth and convex	Slight	Very easy	70,000	60,000	22
E7018	Iron powder low hydrogen	All positions	DCEP, a.c	Mild	High rate	Smooth and flat to convex	Slight	Very easy	72,000	60,000	22

Appendix VI: Current Range for E7016 & E7018 Electrodes

Current Range for E7016 & E7018 Electrodes [14]

	Current Range (A)	
	Electrode Type	
Electrode diameter (in.)	E7016	E7018
1/16 5/64 3/32	65 - 110	70 – 100
1/8 5/32 3/16	100 – 150 140 – 200 180 – 255	115 – 165 150 – 220 200 – 275
7/32 1/4 5/16	240 – 320 300 – 390 375 - 475	260 – 340 315 – 400 375 - 470