INVESTIGATION OF CORROSION EFFECTS ON GALVANIZED STEEL-ALUMINIUM WELD JOINT

NUR AKMAR BINTI ABDUL ARIFF

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UNIVERSITI MALAYSIA PAHANG

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ABSTRACT

Dissimilar material joining is crucial because it has many advantages but corrosion is become a barrier to this type of joining. The main purpose of this project is to investigate the corrosion effects on galvanized steel-aluminium weld joint by observing its microstructure and to study the optimum parameters that will improve the corrosion behavior of the weld joint. The project scopes are dissimilar welding of galvanized steel-aluminium sheets by using automatic MIG welding; investigate the weld quality, defects and specimen's microstructure before and after corrosion and lastly investigate the hardness of the weldment. The galvanized steel and aluminium are joined by using varied parameters of voltage and current. Then, the samples had undergone some process for microstructure observation and corrosion test. The polarization test had applied to study the corrosion behavior. The corrosion rate was determined by using Tafel analysis that generated by IVMAN software. The hardness of the weldment is investigated before and after corrosion. The result obtained showed that pitting corrosion take places in almost all sample because of porosity defects during welding process. Besides, the Vickers hardness test showed that there are changes for hardness value after corrosion test. The microstructure showed that sample no. 4 has finer grain structure in fusion zone compared to other sample and has the highest hardness value before and after corrosion. In addition, the corrosion rate is different for all samples and sample no. 4 showed that it has more corrosion resistance. In the nutshell, the heat input used during welding process will have different affect to microstructure and hardness of the weldment. In order to improve this project, the porosity defects which always occur during welding process can be reduced by using low thickness of electrode and used different aqueous solution for corrosion test.

ABSTRAK

Penyambungan dua jenis bahan yang berlainan amat penting kerana ia mempunyai banyak kelebihan tetapi pengaratan menjadi satu penghalang kepada proses ini. Tujuan utama projek ini ialah untuk menyiasat kesan pengaratn kepada penyambungan besi bergalvani-aluminium dengan memerhatikan mikrostruktur dan untuk mengkaji parameter yang sesuai untuk meningkatkan lagi sifat karat pada bahagian penyambungan. Skop projek ini ialah penyambungan besi bergalvani-aluminium dengan mengunakan mesin MIG automatic, menyiasat kualiti penyambungan, kecacatan dan mikrostruktur sampel sebelum dan selepas karat. Besi bergalvani dan aluminium dikimpal dengan mengunankan nilai voltan dan arus yang berlainan. Kemudian, sample menjalani beberapa proses untuk pemerhatian mikrostrktur dan ujian karat. Ujian pengutuban dijalankan untuk mengkaji sifat pengaratan. Nilai kadar pengaratan ditentuakn dengan menggunakan analisis Tafel melalui perisian IVMAN. Kekerasan pada bahagian penyambungan disiasat sebelum dan selepas pengaratan. Keputusan yang diperoleh menunjukan lubang pengaratn pada hamper semua sampel disebabkan oleh keporossan semasa proses kimpalan. Selain itu, ujiak kekerasan Vickers menunukukan terdapat perubahan pada nilai kekerasan selepas proses pengaratan. Mikrostruktur menunjukkan sample no. 4 mempuntai struktur butiran yang lebih halus pada bahagian penyambungan berbanding dengan sampel lain dan ia mempunyai nilai kekerasan yang paling tinggi sebelum dan selepas proses pengaratan. Tambahan pula, kadar pengaratan berlainan untuk semua sampel dan sampel no. 4 menunjukan ia mempunyai rintangan yang baik kepada pengaratan. Kesimpulannya, haba input yang digunakan semasa proses kimpalan mempunyai pengaruh yang berlainan keada mikrostruktur dan kekerasan pada bahagian penyambungan. Bagi meningkatkan lagi projek ini, keporosan yang berlaku semasa proses kimpalan boleh dikurangkan dengan menggunakan ketebalan elektrod yang rendah dan menggunakan larutan yang berbeza untuk ujian pengaratan.

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CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Welding is a process of joining two or more metal parts permanently at their contacting surfaces by using various welding method that use heat or pressure. There are many ways in order to join the materials, which are fusion welding and solid state welding. But, some of the welding processes are use heat only. Welding is important because it provides a permanent joint and the welded components become single part. Normally, metals from the same material are being combined together. But, nowadays metal from dissimilar material weld joining has become concern issue due to the demand for lower cost, enhanced mechanical and thermal properties and reduced weight.

Even so, the process yields unwanted disadvantages on the specimen, such as stress corrosion cracking in the fusion boundary region of the weld joint. Since, there are many advantages can get from this type of welding process, it is important to know that whether it has effect to the strength, hardness and other mechanical properties. The applications of this type of materials are in shipping sector, piping industries and car manufacturing.

This project used aluminium and galvanized steel. Therefore both materials has tendency to corrode in the environment. Corrosion is the deterioration of materials by chemical interaction with its environment. When the metal is corroded, it will lead to loss of mechanical strength and structural failure or breakdown. There are two type of corrosion which aqueous corrosion and gaseous corrosion. Since this project will use natural seawater, therefore it is known as aqueous corrosion.

Most corrosion processes involves at least two electrochemical reactions which is anodic and cathodic reaction. Potential difference results when the electrically connected anode and cathode are separated by a physical distance in a conductive media. Anode caused the metal surface to become positively charged. This positive ion can be called as cation that attracts negative ion or anion found in electrolyte to form new compound. This new compound no longer has its origin metal characteristic but it will take a new form such as rust. The reduction process allows metal at cathode area to retain its metallic characteristic. A common oxidation reaction in corrosion is the oxidation of neutral irons atoms to positively charged iron ions:

$$Fe \longrightarrow Fe^{+2} + 2e^{-}$$

The electron lost usually end up on a nonmetallic atom forming a negatively charged nonmetallic ion.

$$4H^{+} + O_2 + 4e^{-} \longrightarrow 2H_2O \quad \text{or} \quad 2H^{+} + 2e^{-} \longrightarrow H_2$$

This reduction process occurred at cathode which positive current enters the electrode from electrolyte.

Corrosion is something that everyone hopes to avoid but it is something that we must learn to deal with. It has big impact on the material. Moreover it also gives impact to the economy. An example of corrosion damages with shared responsibilities was the sewer explosion that killed over 200 people in Guadalajara, Mexico, in April 1992. Damage costs were estimated at 75 million U.S. dollars. Other example is the structural failure on 28 April 1988, of a 19-year-old Boeing 737, operated by Aloha airlines, was a defining event in creating awareness of aging aircraft in the public domain. Moreover, corrosion also causes plant shutdowns, waste of valuable resources, loss or contamination of product, reduction in efficiency, costly maintenance and expensive overdesign.

This project investigates the corrosion effect on galvanized steel to aluminium weld joints by observing its microstructure. The method will be used to study the corrosion effects is polarization test. The mechanical properties such as Vickers hardness before and after corrosion will be observed.

1.2 PROBLEM STATEMENT

The joining of aluminium to steel by fusion welding is difficult because of the formation of brittle interface phases which can change the mechanical properties of the materials used. Nowadays, there has been a growing requirement of welded structures made with dissimilar metals in order to reduce weights and save energy. But, corrosion had become a barrier in order to make this dissimilar material achieve the objective. Corrosion is a serious problem for all engineering sector nowadays. One of the main concerns in dissimilar weld joint is the corrosion rate of the welded area since this type of materials have good potential in engineering industries. It is important to know the corrosion effects to the dissimilar metals joining so that it can achieve the objective to reduce cost because corrosion has high maintenance cost to repair it. Therefore more investigation is needed to carry out in order to obtain better understanding on welded area corrosion behavior.

1.3 OBJECTIVES

The objectives of this project are

i. To investigate the corrosion effects on galvanized steel-aluminium weld joint by observing its microstructure
ii. To study the optimum parameters that will improve the corrosion behavior of the weld joint.

1.4 PROJECT SCOPES

The scopes of this project are

i. Dissimilar welding of galvanized steel with aluminium sheets by using automatic metal inert gas (MIG) welding.
ii. Investigate the weld quality and defects before and after corrosion.
iii. Investigate the specimen's microstructure before and after corrosion.
iv. Investigate the mechanical properties such as hardness of the welded joint.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is a reviewed from existing work related to this final year project about weld zones, type of welding will be used, tailor welded blank, material, filler metal and corrosion. There are some previous studies that also investigated about corrosion using dissimilar material.

2.2 WELD AREA

Typical fusion weld joint in which filler metal has been added consists of four zone such as fusion zone, weld interface zone, heat-affected zone and unaffected zone that shown in Figure 2.1.

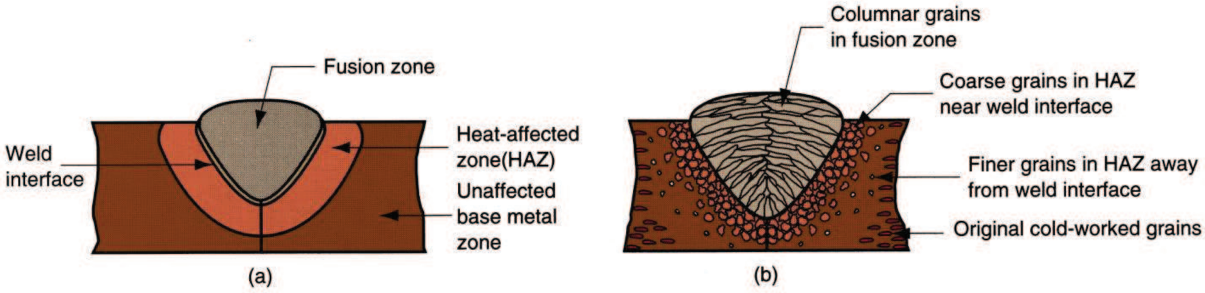

Figure 2.1: Welded area

Source: Fundamentals of Modern Manufacturing Third Edition, 2007

2.2.1 Fusion Zone

It is a zone where the metals melted and the base metal and filler metal united to produce a zone with a composition that is most usually different from the base metal. This difference can cause galvanic corrosion. Besides, this zone offers a microscopic galvanic effect due to microstructural separation resulting from solidification. It is also has a thin region next to the fusion line known as unmixed region. Unmixed region happened when the base metal is melted and then quickly solidified to produce a composition similar to the base metal (Olson et al., 1993).

2.2.2 Weld Interface Zone

It is also known as partially melted zone where there are interfaces between melted part and unmelted part. It is usually one or two grains into the heat-affected zone connected to the fusion line (Olson et al., 1993).

2.2.3 Heat-Affected Zone

Every position in this region experiences a unique thermal experience during welding. Thus, each position has its own microstructural features and corrosion tendency (Olson et al., 1993).

2.2.4 Unaffected Base Metal Zone

This zone experienced temperatures below melting point, but high enough to cause microstructural changes in the solid metal. The chemical composition same as base metal, but this region has been heat treated so that its properties and structure have been altered. Effect on mechanical properties in HAZ is usually negative, and it is here that welding failures often occur (Olson et al., 1993).

2.3 TYPE OF WELDING PROCESS

Nowadays, there are many ways to joint metals, consisting of fusion welding and solid state welding. This project will focus on fusion welding and it is a joining process that uses fusion of the base metal and filler metal to make the weld. The three major types of fusion welding processes are as follows:

Table 2.1: Types of fusion welding

TYPES OF FUSION WELDING	DESCRIPTION
Gas welding	Oxyacetylene welding (OAW): used gas combined with oxygen to produce the flame
Arc welding	Shielded metal arc welding (SMAW): process that melts and joins metals by heating them with an arc established between a sticklike covered electrode and the metals

Table 2.1: Continued

TYPES OF FUSION WELDING	DESCRIPTION
	Gas–tungsten arc welding (GTAW): process that melts and joins metals by heating them with an arc established between a nonconsumable tungsten electrode and the metals.
	Plasma arc welding (PAW): process that melts and joins metals by heating them with a constricted arc establish between a tungsten electrode and the metals.
	Gas–metal arc welding (MIG): process that melts and joins metals by heating them with an arc established between a continuously fed filler wire electrode and the metals.
	Flux-cored arc welding (FCAW): similar with GMAW but used wire consisting of a steel electrode tube surrounding a powder fill material.
	Submerged arc welding (SAW): process that melts and joins metals by heating them with an arc established between a consumable wire electrode and the metals, with the arc being shielded by a molten slag and granular flux.
	Electroslag welding (ESW): process that melts and joins metals by heating them with a pool of molten slag held between the metals and continuously feeding a filler wire electrode into it.
High-energy beam welding	Laser beam welding (LBW): process that melts and joins metals by heating them with a laser beam.

Source: Welding Metallurgy, 2003

2.3.1 Metal Inert Gas (MIG) Welding

The welding process chosen is gas metal arc welding (GMAW) or metal inert gas (MIG) welding because of this process comparatively easier applicability and better economy (Lakshminarayanan et al., 2009). MIG welding is widely used because it can produce welds with good appearance and quality. Figure 2.2 below shows the basic equipment used in MIG welding.Shielding of the arc and the molten weld pool is usually obtained by using inert gas such as argon and helium is known as MIG welding process. In the MIG welding process, the arc and the weld are protected from atmospheric contamination by a gas shield. Besides, an electric potential is established between the electrode and workpiece will cause a current flow which produce thermal energy in the partially ionized inert gas (Moreira et al., 2007).

The welding process must fulfill these three conditions:-

i. The weld face and root should be flat without any superfluous material on it and without side cracking
ii. Weld strength cannot be lower than of parent metal
iii. Formability of welded joint should be better or equal than that of the parent metal (Tusek et al., 2001).

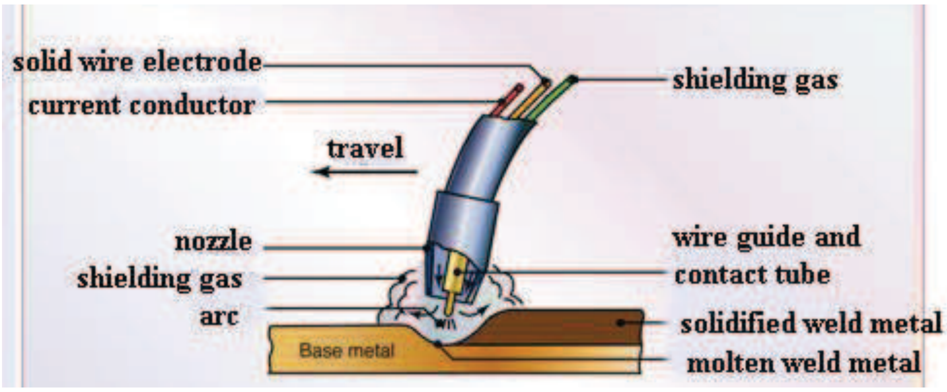

Figure 2.2: Schematic illustration of the MIG welding process

Source: Fundamentals of Modern Manufacturing Third Edition, 2007

A constant current AC power source with a continuous high frequency is used with water or air-cooled MIG torch and an externally supplied inert shielding gas. The used of AC process because it can provide a degree of cleaning of the material surface during the electrode positive cycle although it is not a replacement for appropriate cleaning of the base material. This welding process will give the welder very good control.

A good indication that the electrode diameter is suitable for the welding current is by observing the ball diameter and the ease with which it forms. The electrode which has too small diameter for the welding current will shape an excessively large ball but too large an electrode will not shape a good ball at all. Besides, it is important to make sure the workpiece and the filler rod is clean. If the rod has been exposed to air for a long time, we must clean it by pulling in the rod through a 'Scotchbrite' type of abrasive pad or through stainless steel to remove the oxide layer. This welding process can weld thicker material but it well require many more weld passes and cause high heat input, leading in distortion and will decrease the mechanical properties of the base material (Sivashanmugam et al., 2010).

2.3.2 Advantages of MIG Welding

By using this welding process, it can be very clean when using an inert shielding gas. This gas will protect the arc so that there is very little loss of alloying elements. The main advantage between MIG over TIG is the much higher deposition rate which allows thicker material to be welded at higher welding speeds. Moreover, this type of welding also can weld thin material. Large metal deposition rates are easy to obtain with the large-diameter filler wires when used high welding current (Kou, 2003). MIG welding is versatile and can be used with a wide variety of metals and alloys.

2.4 Tailor Welded Blank (TWB)

Nowadays, manufacturers more focused on cost reduction, enhanced mechanical and thermal properties and weight reduction. In order to achieve this objective, multiple materials are being combined in many products. One of the method used in order to achieve the objectives is tailor welded blank (TWB), which consists of two or more sheets that have been welded together in a single plane. TWB have semi-products of multiple shapes, thicknesses and materials which can be welded together (Figure 2.3).

Examples of A to D showed TWB by using different shapes such as from differently cut sheet metal. They are also from different materials, thicknesses or may be one of the materials coated with another metal while others are not. The other examples are example E showed two sheet metals from different thicknesses and examples F to H are from different material which are welded together (Tusek et al., 2001).

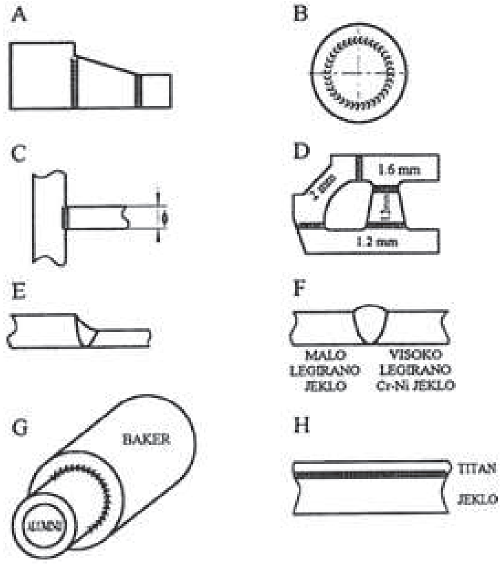

Figure 2.3: Examples of tailored blanks and profiles

Source: Welding of Tailored Blanks of Different Materials, 2001

Fusion welding with consumable method can be used for welding tailored welding blanks are used for special cases for example when welding different material and the filler material can replace for their different properties as well as create a uniform joint with good durability and strength (Tusek et al., 2001).

The application of TWB has become popular method in the automotive industry. These blanks are stamped to produce body panels. The advantages by using this technique are can reduce weight, decreased the part count, streamlining the assembly process and can cut the cost by using singular as replacement of multiple blanks. By applying this technique to aluminium, it offers important potential further weight reduction for future automobiles industry (Shakeri et al., 2002).

The progress of TWB has increased in practice and it is being introduced in all the fields of use of metal materials. The amount of working operations, waste andenergy consumption can be reduced by using this technique and at the same time physical-chemical requirements are easier to achieve (Tusek et al., 2001).

2.5 MATERIAL

2.5.1 Aluminium

Aluminium welding has its own problem due to the properties of aluminium. Aluminium has high thermal conductivity, high chemical reactivity with oxygen, and high hydrogen solubility at high temperature. This properties can affect the welded joint because the present of defects on the weld bead. Aluminium alloys used in aerospace, automobile industries, railway vehicles, bridges, and high speed ships because it has light weight, higher strength to weight ratio and good corrosion resistance (Lakshminarayanan et al., 2009).

Aluminium alloys can be used replace the fiber-reinforced plastics (FRP) for use as ship materials in order to reduce the ship weight and results in increasing the speed and improve the safety. However, aluminium alloys are a good corrosion resistance but serious accident and economic loss can increase due to chloride ion contained in seawater (Kim et al., 2010). The high-strength aluminium alloy usually shows poor weldability mostly because of solidification problem. This problem will affect the mechanical properties of welded parts (Yazdipour et al., 2011).

The aluminium chosen is AA6061 aluminium alloy because it is suitable to study the corrosion effects. The digit 6 is refers to magnesium and silicon as the major alloys. The second digit showed the purity of thee aluminium and the digit 0 showed no control. This aluminium alloy is the most widely used medium strength aluminium and has wide acceptance in the fabrication of light weight structure (Lakshminarayan et al., 2009). The aluminium rich matrix adjacent to $MgSi_2$ intermetallic precipitates or silicon-rich-phases in aluminium-silicon-magnesium alloys has been shown to be easily influenced to corrosion in NaCl solutions. There is an observation that showed coarse intermetallic particles containing aluminium, silicon and magnesium act as nucleation sites for pit formation. This formation has effect on the fatigue life of 6061 aluminium (Mutombo and Toit, 2011).

2.5.2 Galvanized Steel

Galvanized steel also known as zinc coated steel. Zinc coatings are used to improve aqueous corrosion of steel by using two methods. First method is barrier protection, which the zinc coating will separate the steel from the corrosion environment. The zinc coating will be the first to corrode before the corrosive environment reaches the steel. Then the second method is galvanic protection, which means zinc is less noble at ambient condition and it will corrode to protect steel substrate (Marder, 2000).

The galvanized steel chosen is ASTM A653 – Z90 because it is suitable to study the corrosion behavior since the zinc coating act as barrier protection to steel. The ASTM specification which is A653 showed the coating composition is consists of zinc. Besides, it is the most commonly used type of coated steel sheet in manufacturing and construction. Then, Z90 showed the coating weight of zinc on the surface of steel sheet. It has 90 g/m^2 for both sides of steel. There is an observation that the zinc vapour and oxides generated during welding process will produce pore and gas void in the welded joint and resulting in cracking (Rozalski and Gawrysiuk, 2008). From the previous research showed that the formation of gas cavities because of vaporization of zinc and methods for reduction the blowholes were developed in order to improve the welding quality (Matsui and Oikawa, 1998).

2.5.3 Weldability Galvanized Steel-Aluminium

In the next few years, the aim of automotive industry is to decrease fuel consumption in order to meet new anti-pollution standards. This is why there are several investigations about the use of high strength steel and light alloys (Sierra et al., 2008).

Thus, the joining process of aluminium to steel by fusion welding methods is widely studied. The process is quiet challenging because of the formation of brittle interface phase which can deteriorate the mechanical properties of the joints. However, if the thickness of the layer is less than 10µm, the joint will be mechanically sound. The existence of a zinc coating will increase wettability of the aluminium to steel substrate (Zhang et al., 2007). It can also enhance the wetting of filler metal onto the steel surface and prevent the formation of Fe-Al intermetallic compounds (IMC). Therefore, the aluminium and galvanized steel is weldability since the melting point between both materials is not too much. However, zinc often vaporized with the increasing of heat input and resulted in pores in the weld (Dong et al., 2010).

2.6 FILLER METAL

Filler metal is a metal that will be added in order to make a welded joint. It is become a part of finished weld. Normally, the dissimilar filler metal having a lower melting point and similar or lower strength than the base metal. High silicon and magnesium content aluminium alloys are easy to weld because low sensitivity to crack. Actually, 6XXX series alloys are very sensitive to crack if the composition of fusion zone is same with base metal composition. The filler metal will be chosen is 5356 filler metal. It is because for aluminium 6061, the fusion zone should have at least 70 % alloy 5356 filler metal. This type of filler metal produce very ductile welds. It is also high corrosion resistance when used with base alloys which have same magnesium content. In addition it provides highest as-welded strength, possible to the smallest fillet welds and more economical (Mandal, 2001).

Filler metal composition is determined by

i. Weldability of the parent metal,
ii. Minimum mechanical properties of the weld metal,
iii. Corrosion resistance,
iv. Anodic coating requirement (Mandal, 2001).

The parts of the parent metal including filler material, if it is used, are melted in fusion welding technique. Both will be mixed when melting during welding processes and it will create a weld or joint or in other words seam. The primary purpose of filler material is to fill in the weld groove as well as create a welded joint. If different types of parent metals are used, a suitable filler material will replace for their different properties and cannot be welded together without it. If the fusion welding techniques do not use a filler material, this technique cannot be used to join metals and alloys which are dissolved or completely dissolve in one another (Tusek et al., 2001).

2.7 CORROSION

Corrosion mostly defined as electrochemical reaction between the materials with its environment that cause a change to material and its properties. The most common type of corrosion that usually found is uniform corrosion. There are two major area are usually concerned in the corrosion of metals. The first area is where the metal is exposed to a liquid electrolyte such as water and can be called as aqueous corrosion. Corrosion in aqueous solution is an electrochemical process where the corroding metal is an electrode that has contact with electrolyte. The process will only take place on the metal surface. Then the second area is where the corrosion takes place in gaseous environment and can be called as oxidation. This type of corrosion is gaseous corrosion. Sometimes these two areas can be referred as wet corrosion and dry corrosion (Cramer and Covino, 2003).

The main use of seawater is for cooling purpose but it is also used for firefighting and oilfield water injection. Besides, it also not takes a longer time to investigate the corrosion effect by using this corrosion substance. The important properties of seawater are

i. High salt concentration mainly sodium chloride
ii. High electrical conductivity
iii. Relative high and constant pH
iv. Solubility for gases which oxygen and carbon dioxide are important in the context of corrosion (Roberge, 1999).

2.7.1 Forms of Weld Corrosion

The weld area can experience all type of corrosion, but it is easily influenced by variations in microstructure and composition. The forms of weld corrosion below are type of corrosion that might be revealed on the weld joint.

i. Galvanic corrosion

This type of corrosion occurs when two dissimilar metals are in physical or electrical contact in aqueous electrolyte. The filler metal which having different composition with base metal may produce electrochemical potential differences resulting some weldment areas become more active. For example, the junction of water main where a copper pipe meets a steel pipe where various components immersed in water is made of different alloys. It is easily to investigate since it occurs when a metal is in contact with its environment (Olson et al., 1993). The form of galvanic corrosion is shown in Figure 2.4. The conditions that will need in order the galvanic corrosion to be occurred were showed below

i. Metal must be far apart on the galvanic series
ii. The metals must be in electrical contact
iii. The metal junction must be bridged by an electrolyte

Figure 2.4: Galvanic Corrosion

Source: Handbook of Corrosion Engineering, 1999

The galvanic action in seawater is long range and spreads uniformly across the entire surface area of metallic structure because of high conductivity in seawater. This action is much stronger in seawater compared to freshwater. For example, the corrosion rate of an anodic metal such as zinc or steel is larger by a factor of 5-12 times than in the uncoupled condition (Uhlig, 2011). Metals and alloys with more positive potentials in the galvanic series such as platinum are called noble metals and active metals are metals with more negative potential such as magnesium. The less noble metal will be at anode and suffers accelerated attack whereas the cathode is more noble metals will protect by the galvanic current (Cafferty, 2010).

ii. Pitting

It is form of localized attack caused by a breakdown in the thin passive oxide film that usually protects material to be corroded. Once a pit has formed, it will act as an anode supported by relatively large cathodic regions. Pitting potential occurs when the combination of material and solution achieves a potential that exceeds a critical value. Although weld metal has higher probability of being localized attack because of the separation of micro in the dendritic structure, but nowadays the filler metals have better pitting resistance. However, pitting may still occur in unmixed zone even used proper filler metal (Olson et al., 1993). Aluminium and its alloys are showing good sense to chloride environment, and it will cause localized attack such as pitting corrosion (Shakeri et al., 2002).The pitting corrosion is shown in Figure 2.5

Figure 2.5: Pitting corrosion

Source: Handbook of Corrosion Engineering, 1999