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Investigation of Corrosion Rate for Different Type of Welding Joints using Shielded Metal Arc Welding (SMAW)

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Abstract. Corrosion is the deterioration of a metal as a result of chemical reactions between metal and its surrounding. Different type of metal and environmental condition, particularly gasses that are in contact with the metal, determine the rate of corrosion. Different type of welding joints can be factors that contribute to the corrosion problems since different type of welding joint normally exposed to the corrosion and erosion agents like salt, air, water, material composition, dissolved oxygen content in the fluid, pH and fluid's velocity characteristics. Research was carried out in order to investigate the corrosion rate on mild steel at 3 different types of welding joint which are butt joint, lap joint and edge joint after immersed in Sodium Chloride (NaCl), Hydrochloric acid (HCl), distilled water and natural sea water for 30 to 50 days. The mild steel was joined using Shielded Metal Arc Welding. For each of the welding joint the parameters were fixed which are current, voltage and speed of travel. Immersion and hardness test were conducted to distinguish the corrosion rate. Results shown butt joint suffered the highest corrosion rate than lap joint and edge joint and morphology transformation differences occur during the corrosion process.

1. Introduction

Metal joining is a controlled process that is widely employed to fuse similar/dissimilar metals. Among the several metal joining techniques, welding is one of the most widely used for a variety of applications. Metallurgical, physical, and chemical changes caused by welding processes severely affect the corrosion resistance of welds [1]. SMAW occupies the most important position in the group of fusion welding processes, and due to its flexibility and cost effectiveness, it is an indispensable technology for the construction of steel-framed buildings, ship building, motor vehicle manufacture, power plants and other industries. Since the SMAW method is so versatile; it is the most suitable method to work in many situations [2]. Mild steel is the most commonly used steel for welding on account of relatively low and good material and mechanical properties that are suitable for many applications particularly in severe condition such as extreme weather, greenhouse effect, external massive loads and corrosive marine environment. [3] Unfortunately, the corrosion was crucial for the industries that used metal and using material such mild steel and add-ed to the welding process make the situation worst. Mild steel is among the metal that has lowest corrosion resistance and weld joint that was affected by corrosion changes the microstructures thus decrease the strength of the joining [4]. To make it worst, most of the structure and the welding joints were expose to the environment which contain the corrosion agent such as water, oxygen and other impurities thus accelerate the



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corrosion. When corrosion occurs, the weld joint will suffer critical damage as the behaviour of the corrosion itself which deteriorates the affected metals. Furthermore, when the corrosion attacks, the hardness of the welding joints will be affected and weaken the microstructure due to corrosion. For critical applications like in construction field and automotive industries, knowledge related to welding corrosion must be considered. Localized and general corrosion reduces lifetime significantly and may cause failures [5]. The weld area just took a small area as compared to the base metal in welded joints. Thus, a selective weld attack will take place. Metal composition and microstructure alteration resulting from the heat cycle will affect the corrosion behaviour for the welded joint. Moreover, temperature gradient, microstructure variation, grain structure and chemical composition can create local electrochemical potential variations thus leading to corrosion [6]. The corrosion behaviour at three adjacent regions in welded metal which were weld metal, heat affected zone and base metal is complex due to the heterogeneous microstructure over the welding zone [7]. Different welding joints may have different rate of corrosion. This study focused on 3 types of welding joints which were butt joint, lap joint and edge joint.

2. Experimental Procedure

2.1. Sample Preparation

The material used for this research was mild steel. The sample was cut into 200 mm length x 100mm width x 6mm thick. Before welding process, the surface of the mild steel was cleaned using metal grinder to clean the existing corrosion. The joining that performed in this study were butt joint, lap joint, and edge joint. All joint was done by using Shielded Metal Arc Welding (SMAW). Table 1 shows the parameter of welding process.

Table 1. Parameters of Shielded Metal Arc Welding (SMAW)

Parameters		Unit
Diameter of Rod		3.2 mm
Voltage		21-25 V
Current	Flat	90-100 (A)
	Vertical	80-95 (A)

2.2. Immersion Test

Corrosion rate was determined through immersion test when weight before and after was taken. The specimen was soaked on the sodium chloride 3.0M NaCl, hydrochloric acid (HCl) natural sea water and distilled water with a different timeline of 10 days, 30 days and 50 days. Corrosion rate was calculated with the formula:

$$\text{Corrosion Rate (mm /y)} = \frac{w}{A} \frac{T}{365}$$

w=Weight loss (gram)

A= Total area of exposure (cm²)

T = Exposure time in hours g/mm²/yr. = gram per square mm per year (corrosion rate units)

2.3. Hardness Test

Hardness test was conducted in order to see the hardness of the base metals, weld metals and heat affected zone (HAZ) area. The Vickers hardness test was used to measure the degree of hardness due to the material used as the sample.



Figure 1. Vickers hardness tester

2.4. Microstructure Test

This microstructure test was conducted to see the behaviour of the microstructure after the corrosion process. This is because, the corrosion also affects the microstructure between the base metals and weld metals. There are four preliminary steps need to be done to have the good image of the microstructure which are cutting, grinding, polishing and etching. Then the samples were soaked in the Nital solution which consists of 2% nitric acid and 98% alcohol. Lastly, the samples were observed under the Olympus BX 41 M microscope.

3. Result and Discussion

3.1. Immersion Test

Based on the result of immersion test, all the sample shows the deduction in weight. The weight of the samples was reduced with the time immersed. As the samples immersed in the solutions, there were a layer of corrosion developed on each sample, but this phenomenon not occurred in Hydrochloric acid (HCl) solution. The layer was known as insoluble graphitic layer of corrosion product left behind in the process. By figuring the graph of immersion, the corrosion rate directly proportional to the weight loss. Between all the solutions used, acidic solution recorded the highest losses.

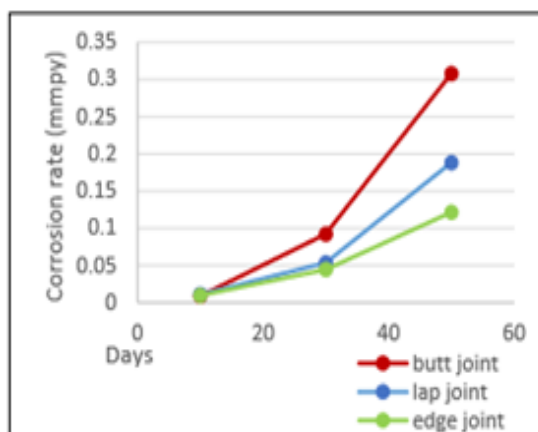


Figure 2. Corrosion rate in natural sea water

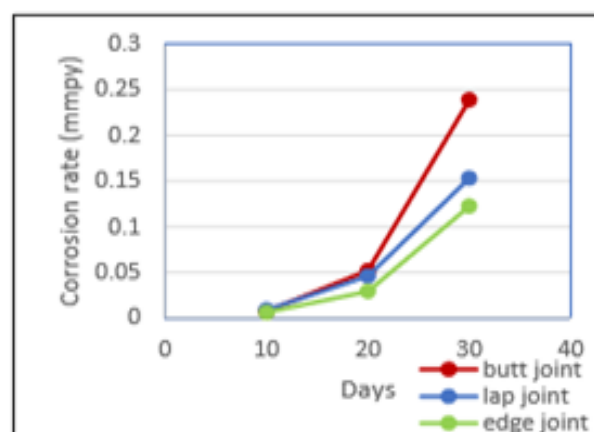


Figure 3. Corrosion rate in sodium chloride (NaCl)

Based on Figure 2 and Figure 3, natural sea water and Sodium Chloride (NaCl) has the corrosion agent which was salt, but the corrosion only occur and damaging the outer appearance of the sample only. The pH concentration was the one factor of decreased in corrosion rates of the specimens in the salt and alkali environment. The other factor may due to the increasing exposure time toward the electrochemical behaviour of SMAW process. Previous study shows that corrosion attack becomes slower due to alkaline environment. Higher the rate of alkalinity, the slower the chemical reaction of materials [8]. Corrosion was occurring due to reaction material and its surrounding. The chemical reaction between oxygen and water make the loss of electron. There are many factors that influencing

corrosion of weld section such as incomplete weld penetration, improper choice of filler metal etc. [9]. Longer time taken of immersion donated to the increasing of weight loss. Metals in seawater corrode by releasing metal ions into the water around them. Different environment, acid and salt environment with increasing exposure time effect due to electrochemical behaviour. The weight will loss due the corrosion.

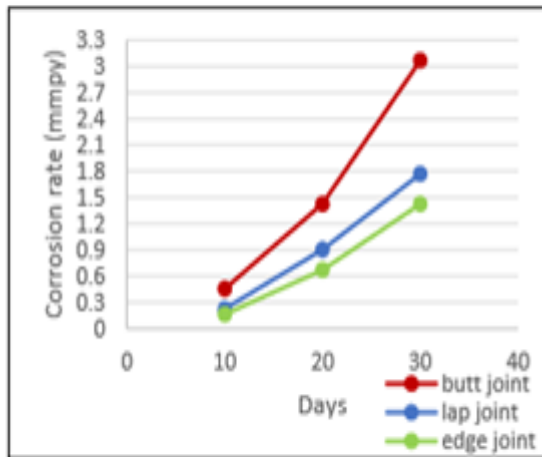


Figure 4. Corrosion rate in hydrochloric acid (HCl)

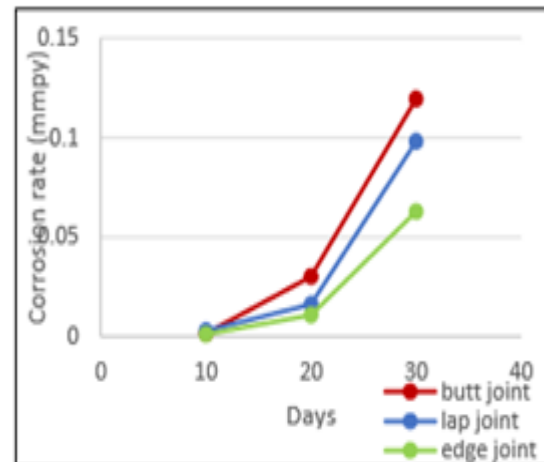
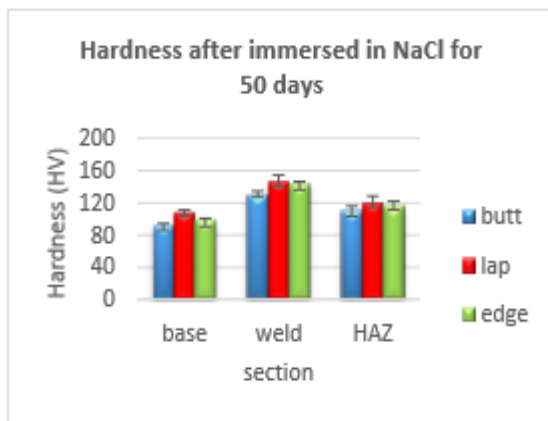
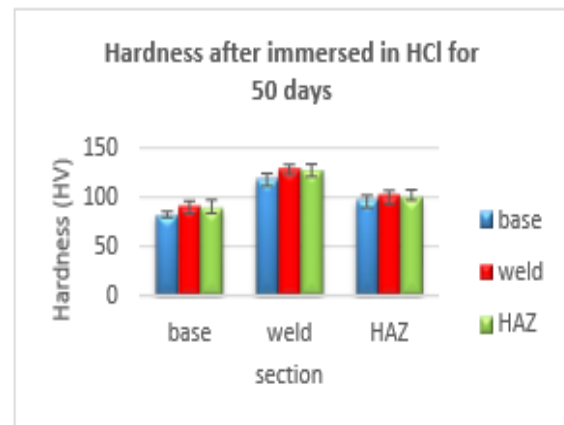


Figure 5. Corrosion rate in distilled water

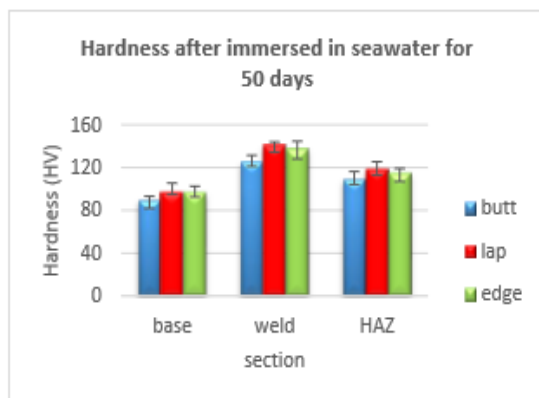
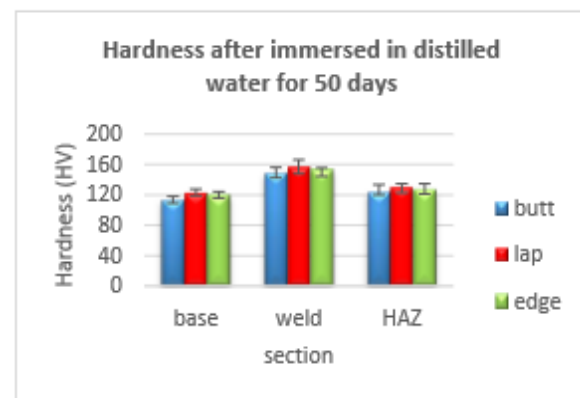
The deduction of the weight loss caused by HCL was showed in Figure 4. Hydrochloric Acid (HCl) has the properties of deterioration of metals and non-metals. So once the samples were immersed in acidic solution, the acid will attack not only the physical appearance of the sample but also inside the sample itself. That the reason why the corrosion rate for mild steel immersed in acidic solution has the highest corrosion rate. While in Figure 5 the sample was immersed in distilled water. The rate of corrosion is the lowest among other solution since pH for distilled water is 7 which does not have ion or other calcium in the solution. Among those three types of joints that being immersed, butt joint recorded the highest percentage of weight losses. This due to the fabrication of the butt joint itself which the welding process was fast. Butt joint also severe the highest deterioration in Hydro-chloric acid (HCl) solution whereas lap and edge joint also deteriorate but the value is low.

3.2. Hardness Test

The hardness value was observed at three different spot which were base metals, weld metals and heat affected zone (HAZ). All the samples were immersed in natural seawater, Sodium Chloride (NaCl), Hydrochloric Acid (HCl) and distilled water for 50 days. Based on the graph the highest value of hardness recorded was lap joint. Whereas the lowest hardness value recorded was butt joint.

**Figure 6.** Sample immersed in NaCl**Figure 7.** Sample immersed in HCl

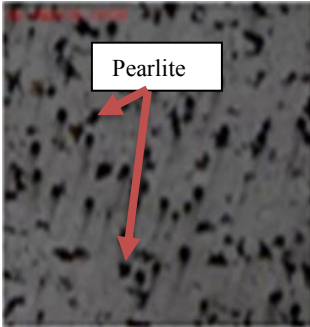
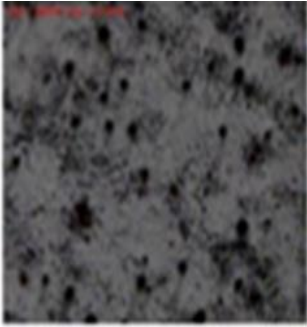
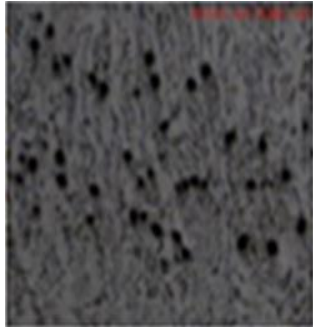
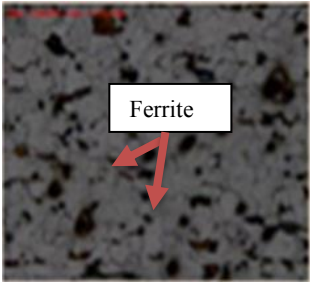

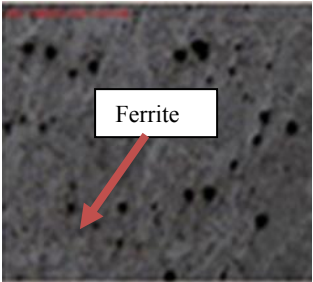
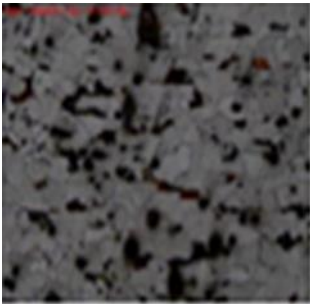
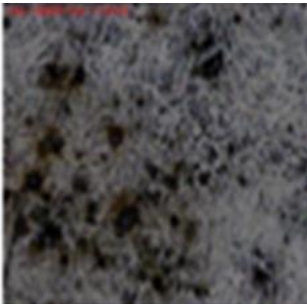
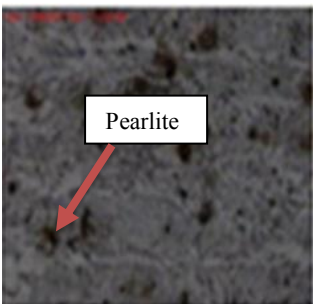
Based on the data tabulated in Figure 6, Figure 7, Figure 8 and Figure 9 the sample which immersed in Hydrochloric acid (HCl) shows the highest deduction in the value of hardness, followed by natural sea water, Sodium Chloride (NaCl) and distilled water. Acidic solution such as Hydrochloric acid (HCl) has the properties of deteriorate metals thus the sample in acidic solution were suffered of metals deteriorate. This lead to the highest deduction of the hardness of the sample in Hydrochloric acid solution.

**Figure 8.** Sample immersed in natural sea water**Figure 9.** Sample immersed in distilled water

3.3. Microstructure Test

The microstructure of the welded sample was observed at three different sections which are at the base metals, weld metals and heat affected zone (HAZ). After exposed to the environment for 3 months, corrosion not only attacks on the surface of the sample but also in the inner part of the metal. That the reason why the strength of a metals decreasing when corrosion takes place. Corrosion start to attack on the perlite area which then continue to deteriorate metals from inside. Table 2 shows that typical microstructure of base metal is composed of ferrite and small regions of pearlite (α -Fe + Fe₃C) at grain boundaries edges and corners. At Heat Affected Zone (HAZ) the Widmannstetter ferrite, and some colonies of pearlite were found. It is known that solid-state phase transformations, such as grain growth, recrystallization, phase transitions, annealing, and tempering, all occur in the HAZ of steel welds

Table 2. Microstructure for different type of joint

Type of Joint	Base Metal	HAZ	Weld Metal
Butt Joint			
Lap Joint			
Edge Joint			

However, the microstructure of weld metal is totally different from the other zones. Due to rapid cooling it causes microstructural inhomogeneity. This zone contains mainly ferrite and some colonies of pearlite. The microstructure that evolved in the weld is heterogeneous due to the rapid cooling process and chemical reaction that evolve during the process [10].

Figure 6,7,8 and 9 shows that the hardness of weld metal is the highest mainly due to the strain induced hardening followed by HAZ and base metal. It can be clearly observed from Table 2 that the grain size for base metal was coarse as compared to weld metal and HAZ. That the reason why it being affected by corrosion in large scale. Most of carbon is dissolved in martensite and austenite phases, but there are still few carbides existing in the featherlike bainite [11]. Corrosion will start attack on the soft area (coarse grain) and as the time passed it will become more aggressive and attacked until the whole phase of the bainite [12].

4.0 Conclusion

Butt joint loss higher weight during the immersion test followed by lap joint. Meanwhile edge joint had the least loss weight and corrosion rate. Another contribution to the corrosion rate was the pH concentration between acidic, salt and alkali environment. The exposure time leads to the process of rusting metal from the chemical reaction oxygen and water make the loss of electrons. Moreover, the hardness of butt joint also the lowest. As observed under microscope, the grain structure for weld metal was the finest thus the maximum hardness values are situated in the area of weld metal and HAZ which indicates its specificity. It should be emphasized that obtained results could be applied for

improving the possibility of constructional methods applied by engineers. Hence the next investigation area should be searching for the link between the material and structural design processes.

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