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Effect Analysis of Post Heating Temperature Variation on Metallography and Bending Test of GMAW ASTM A53 Steel Weld Joint

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ABSTRACT

ASTM A53 steel is medium carbon steel with 0.3% carbon content and is often used for pipe manufacturing. The purpose of this study was to determine the effect of post heating temperature variation on bending and metallography test on weld joint of ASTM A53 steel using the GMAW process. The electrode used is ER-70S-6. Post heating temperature variations are 250°C, 300°C and 350°C. The bending test result showed that welding with 350°C postheating temperature produce the smallest open defect value. The microstructure result showed that welding with 350°C post heating temperature produce the smallest pearlite percentage in three areas observed.

Keywords: *A53 Steel, Gas Metal Arc Welding, Post Heating, Bending Test, Micro Test.*

1. INTRODUCTION

The rapid growth of scientific technology helps the development of maritime industries process. Back then, ship was only used as ocean-transportation facilities. Nowadays, there are many functions of ship such as carrying cargo, war facilities, and oil and gas exploration [1]. In manufacturing world, including maritime industry, welding is known to be one of the core processes. Welding is combination process between two different metals fusing into one metal because of the welding heat, either with or without pressure effect and with or without filler metal.

Based on the definition of Deutsches Institut für Normung (DIN), welding is a metallurgical bond in a metal or alloy metal connection that is carried out in a melted or liquid state. From this definition, it can be further explained that welding is the local connection of several metal rods using heat energy [2].

There are several methods in welding, including GMAW (Gas Metal Arc Welding) method, SMAW (Shielded Metal Arc Welding) method, FCAW (Flux Cored Arc Welding) method, and several other methods. In my final project, the welding method used is the GMAW (Gas Metal Arc Welding) method. In this research, the writer uses the GMAW (Gas Metal Arc Welding) welding method or Metal Inert Gas (MIG) where the electrode wires used are not encased and the supply properties are continuous. The weld area is protected from the atmosphere through gas produced from the welding tool [3]. The protective gas used is Argon gas, Helium or a mixture of both. To stabilize the arc sometimes O_2 gas between 2 to 5% or CO_2 between 5 to 20% were added [4].

Proper heat treatment is needed to increase the ductility and tightness of the welding results, one of the steps that can be taken is to warm up the material after the welding process (post-heating). Therefore, this final project study examines the results of the welding process of the Gas Metal Arc Welding (GMAW) method on corrosion resistance in the area of weld joints of medium carbon steel (ASTM A53) with post-heating treatment. Heating can be done at the time before or after welding. This heat treatment will affect the mechanical properties and microstructure of the material. It required the right heat temperature so that it can result in optimal conditions [5]. Heating can be done with various media such as torches, furnace machines, and others.

ASTM A53 steel is widely used in underwater pipeline construction. The problem that arises in welding pipeline connections is the amount of corrosion that occurs. This is because the material is placed on corrosive media which will certainly cause damage to the structure so that it will experience structural failure and affect the life of the pipe. One way to minimize the rate of corrosion is to do the pre weld heat treatment and post weld heat treatment on the welding results which aim to change the metallurgical arrangement formed on the welding results.

To improve the material mechanical properties, it will be given a post-weld heat treatment. The high temperature used in heat treatment will affect the mechanical properties and microstructure of the material. Therefore, it is necessary to research the effect of post-weld heat treatment temperature variations on hardness, tensile strength, and microstructure of the material [6]. The value of hardness, strength, and microstructure of the material will change when given heat treatment.

2. BASIC THEORY

2.1 GMAW Welding

Ausaid (2001) explains that Gas Metal Arc Welding (GMAW) is a welding process whose energy is obtained from electric arcs, where arc welding occurs between the surface of the workpiece with the tip of the electrode wire coming out of the nozzle together with the protective gas [7]. Meanwhile, according to AWS (2001), Gas Metal Arc Welding or commonly known as MIG is welding which involves the use of metal arcs and consumable electrodes with the addition of protective gas [8]. Welding with this method is generally operated semi-automatically. Along with the development of the construction industry that requires efficient, fast, and high-quality welding, it is not strange if the GMAW welding process is one of the widely used welding alternatives. In practice, to conduct welding with Gas Metal Arc Welding requires more complicated main equipment compared to manual arc welding equipment where power plants and welding cables are needed, the controlling of electrode wires, protective gas bottles as well as regulating and supplying protective gas supplies. The protective gas used is Argon gas, Helium or a mixture of both. To stabilize the arc sometimes O_2 gas between 2 to 5% or CO_2 between 5 to 20% were added [9].

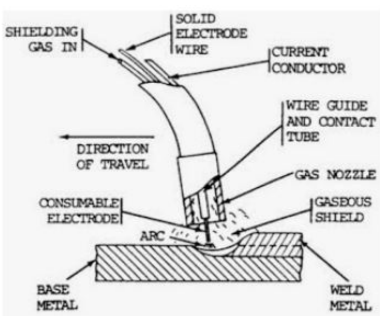

Figure 1. Gas Metal Arc Welding

2.2 Electrode

Electrodes are one of the basic equipment for arc welding which functions to drain electricity from an electric source to be able to melt the base metal. In metal electrodes, it consists of two parts, namely the filler metal and flux (the outer layer of the electrode). The electrode is also divided into two sides, the first side is metal that has been coated with flux and will meet directly with the parent metal (base metal), on the second side that is only metal without being fluxed and located in the clamp holder [10].

2.3 Postheating

Post weld heat treatment aims to improve the microstructure and the mechanical properties of the material. Two post welding heat treatment methods are by directly regulating the temperature while the welding is finished without waiting for it to cool to room temperature, and the other is by reheating the already cooled weld to a certain temperature, then re-cooling it at a certain cooling rate, by existing regulations. Reheating the weld in this PWHT can be done with an oxy torch, an electric heating element, and a heating kitchen, depending on the shape and volume of the workpiece.

2.4 Bending Test

Bending test is a test that is included in the destructive tests category or tests that are conducted by damaging a test material. This is done with the aim to determine the bending strength of the test material by pressing the test material with tools that have greater material strength compared to the test material. In this study, the bending test uses the standard in ASME Section IX.

2.5 Metallography Test

Metallographic test is a test conducted on the results of welding on the macro structure and micro structure. Macro structure observations are direct observations with naked eye to check for the presence or absence of defects in the pieces of material. The results obtained from the observation of macro structure are the length of the HAZ which is affected by the groove angle used. While the results obtained from observing the microstructure are phases (perlite and ferrite) contained in the material. The higher the value of the heat input, the pearlite phase will be more dominant, due to the fact that the pearlite phase makes the material to become more resilient. In contrary, it is found that the lower the value of the heat input, the the ferrite phase is dominant which makes the material to become softer.

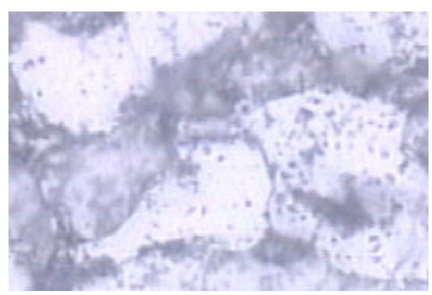
Figure 2. Micro Structure

3. RESULTS AND DISCUSSION

3.1 Welding Procedure

In this study, GMAW welding was used with the Welding Procedure Specification as follows:

- Material Spesification : ASTM A53
- Dimensions : 250 mm x 170 mm x 12 mm
- Joint Type : Butt Joint Single V– Groove
- Position : 1G

- Filler Metal Diameter : ER 70S-6 Ø 1.2mm
- Current : DCSP
- Number of Layer : 4 Layer
- Cleaning Method : Griding & Wire Brush
- Post Heating Temperature: 250ºC, 300ºC and 350º
- Current for 1st layer using 120 ampere, and for 2nd, 3rd and 4th layer using 160 ampere
- Voltage for 1st layer using 20 volt, and for 2nd, 3rd and 4th layer using 24 vol

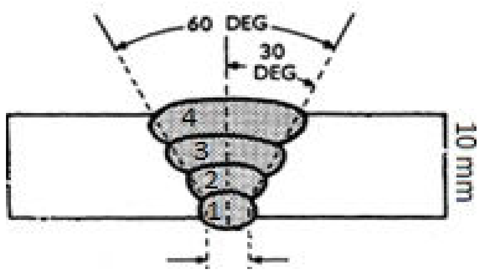

Figure 3. Welding Joint

3.2 Metallography Testing

Metallographic test in this study was done using microstructure and macrostructure test. The microstructure photo is carried out by 200x magnification using an electron microscope which aims to calculate the percentage of dark (pearlite) and white (ferrite) parts in the base metal, HAZ, and weld metal regions. In macrostructure, the photo is taken by using 3.5x magnification with DSLR camera in the base metal, HAZ, and weld metal regions.

3.2.1 Microstructure Test

In micro photographs, it was found that specimen with post heating temperature 350º have the highest percentage of pearlite. It is happened because the higher temperature of post heating can increase the percentage of pearlite characteristic on the material.

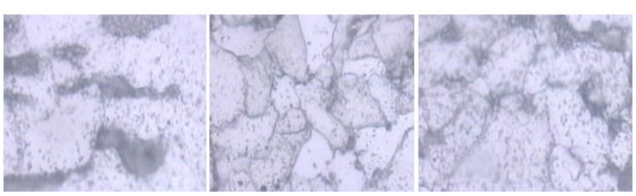
Figure 4. Microstructure of specimen with 250°C post heating temperature

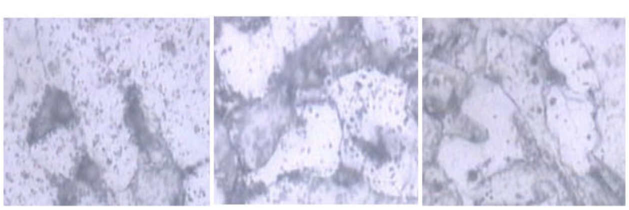
Figure 5. Microstructure of specimen with 300°C post heating temperature

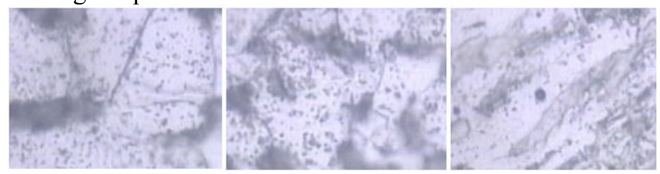
Figure 6. Microstructure of specimen with 350°C post heating temperature

For the results of analysis of the micro photographs of all seven specimens, see Table 1, and a graph of the comparison between ferrite and pearlite structures in all specimens can be seen in Figure 7.

Table 1. Micro Structure Percentage

Specimen	Base Metal		HAZ		Weld Metal	
	Pearlite	Ferrite	Pearlite	Ferrite	Pearlite	Ferrite
Postheating 250ºC	30%	70%	32%	68%	35%	65%
Postheating 300ºC	35%	65%	33%	65%	37%	63%
Postheating 350ºC	37%	63%	36%	64%	38%	62%

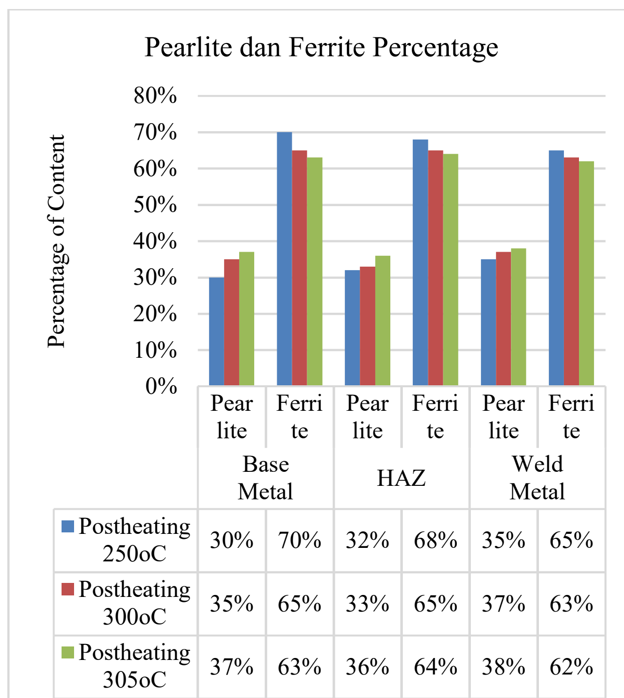

Figure 7. Comparation of the ferrite and pearlite percentage

3.2.2 Macrostructure Test

In micro photographs, the result of width in HAZ area relatively have the same result. Then it was found that specimen with post heating temperature of 350ºC have the widest HAZ area because the more heat you apply to the specimen could makes a wider HAZ.

Figure 8. Macrostructure of specimen with 250°C post heating temperature

Figure 9. Macrostructure of specimen with 300°C post heating temperature

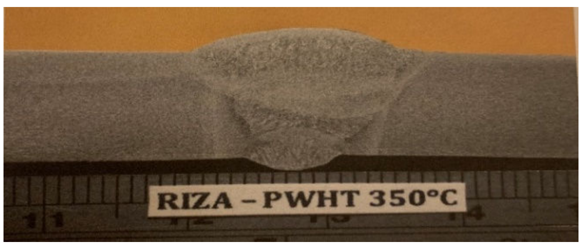

Figure 10. Macrostructure of specimen with 350°C post heating temperature

For the results of analysis of the macro photographs of all specimens, see Table 2, and a graph of the comparison of HAZ in all specimens can be seen in Figure 11.

Table 2. HAZ length variation

PWHT Variations	HAZ Length (cm)
250ºC	01.57
300ºC	1.66
350ºC	1.75

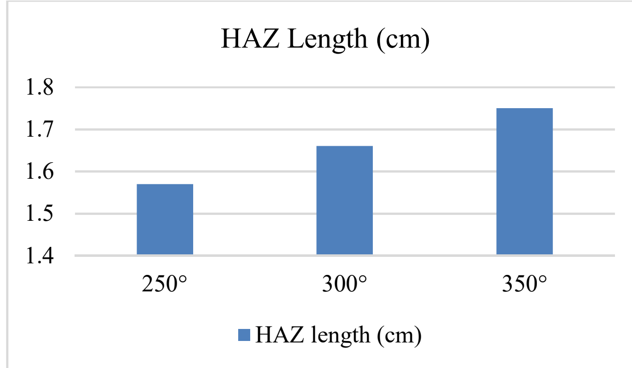

Figure 11. Comparison of HAZ wide

3.3 Bending Test

The standard that was used in this bending test is ASME Section IX, where the defects that occur in the welding material must not exceed 3 mm. This study used a curved angle of 180° and a diameter of 38 mm curved spines. Bending test that is conducted in this study was done on the *side bend* with specimen dimensions of 250 mm x 20 mm x 10 mm. This bending test is done 3 times on each specimen whose results can be seen in Table 3 and for detailed images of each specimen can be seen in Figure 11, and the bending test graph in Figure 12.

The bending test machine capacity is able to bend a material with the maximum force of 600 kN, while the bending occurs when the force reaches 250 kN. The components used to calculate the bending stress in this study are the maximum bending moment and linear resistance moment, where:

$$\sigma f = \frac{3xPxL}{2xbxd^2}$$

$$\sigma f = \frac{3\ x\ 250\ x\ 250}{2\ x\ 20\ x\ 10\ x10}$$

$$\sigma f = 46,875 \text{ kN/mm}$$

Table 3. The Result of Bending Test of 3 PWHT Variaties

PWHT Variations	Speciment	Bending Test Results	
		Open Defect (mm)	Acc/Rej
250°	1	0	Acc
	2	0,2	Acc
	3	0	Acc
300°	1	0	Acc
	2	0	Acc
	3	0,1	Acc
350°	1	0	Acc
	2	0	Acc
	3	0	Acc

Figure 12. Visual Pictures of The Result of Bending Test of 3 PWHT Variaties

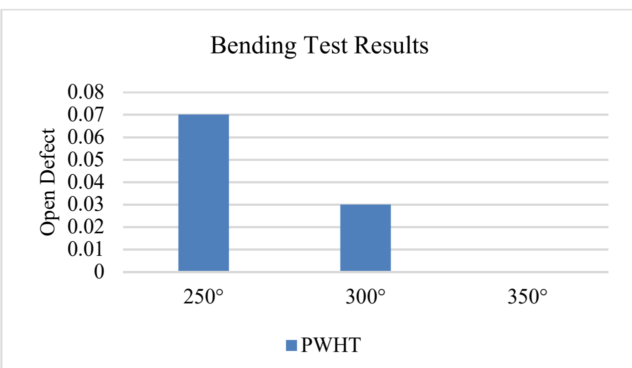

Figure 13. Graphic of The Mean of Open Defect of All Specimens

3.4 Correlation of Microstructure and Corrosion Rate Prediction Test

In this part, we will find the correlation between micro structure, macro structure and bending test. In the micro structure, welding specimen with a 350^oC postheating temperature have the highest percentage of pearlite structure in the base metal, HAZ and weld metal area than the other specimen with 37% on base metal, 36% on HAZ and 38% on weld metal.

In macrostructure test specimen with a 350^oC postheating temperature have the longest HAZ with 1,75 cm long. In the bending test, welding specimen with a 350^oC postheating temperature have the smallest open defect with 0 open defect value. A larger postheating temperature (350^oC) have highest percentage of pearlite, longest HAZ area, and smallest open defect value

4. CONCLUSION AND SUMMARY

From the analysis of preheating and postheating temperature variations against microstructure and corrosion rate prediction, we can get four points of conclusions, which are:

1. From the microstructure analysis, welding specimen with post heating temperature of 350^oC have the highest pearlite percentage on weld metal, HAZ and base metal than the other specimen. It is caused by the highest temperature of post heating, which increase the percentage of pearlite structure formed.
2. From the macrostructure analysis, welding specimen with post heating temperature of 350^oC have the widest HAZ area. It is caused by the highest temperature of post heating, which makes HAZ area to become wider.
3. Welding with postheating temperature of 350^oC has an open defect value of 0 mm. The greater the temperature of post heating, the smaller the value of the open defect in the bending test.
4. The correlation from the microstructure, macrostructure and bending test showed that the material with the highest pearlite percentage and the widest HAZ area, also has the lowest open defect value.

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