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Analysis of The Effect of Post Weld Heat Treatment (PWHT) on The Hardness and Corrosion Rate of SMAW Welded Joints on AISI 304 Plates

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ABSTRACT

Post-welding heat treatment (PWHT) is a heat treatment of steel that has undergone welding. The purpose of doing PWHT is to improve the properties of the material itself. Such as uniforming the microstructure, reducing residual stresses, and improving corrosion resistance. In this study the authors conducted a shielded arc welding (SMAW) welding experiment on an AISI 304 steel plate which had a thickness of 8 mm, a width of 150 mm, and a length of 200 mm. AISI 304 is a type of austenitic stainless steel. The type of seam used is the v seam with an angle of 60˚ and a root face of 2 mm. As for the welding process, it was carried out in the 1G position, using an E308S-15 electrode with a diameter of 2 mm, and a current of 60 A. From the welding carried out on the AISI 304 plate, then cuts were made to divide the steel into 10 specimens, with a width of 10 mm, a thickness of 8 mm, and 60 mm long. PWHT was carried out with temperature variations of 1100˚C, 900˚C and 700˚C for 15 minutes, and cooled using water as the medium. Conclusions that can be drawn from this research, among others; (1) From the PWHT process carried out at temperatures of 1100˚C, 900˚C and 700˚C. Temperature of 1100˚C can reduce carbide deposition in the weld metal, HAZ and base metal areas, (2) The highest level of hardness occurs in the weld metal area without PWHT of 111.7 HRB, while the lowest hardness level occurs in the HAZ area with PWHT of 1100˚C as big as 95.6 HRB. (3) The highest corrosion rate occurred at PWHT 700˚C of 0.429 mm/y, while the lowest corrosion rate occurred at PWHT 1100˚C of 0.073 mm/y.

Keywords: PWHT (Post Welding Heat Treatment), AISI 304, chromium carbide

1. Introduction

AISI 304 is an austenitic rust steel containing around 18% chromium elements. The various types of stainless steel, the austenitic type is the most weldable, this is due to the presence of a small amount of carbon [1], namely around 0.08%. The low carbon content in steel can increase the elongation, strength, impact value and weldability of steel [2].

There are three main factors that need to be considered in welding stainless steel [3], namely (1) corrosion resistance in the weld and heat affected zone, (2) residual stress which can cause distortion, weld cracking, or rupture, and (3) types of martensite and ferritic, mechanical properties in the weld metal, and heat affected zones. According to him, the welding process that is most widely used to weld stainless steel is the SMAW (Shielded Metal Arc Welding) welding process. This type of welding is widely used, from small-scale businesses such as welding workshops to large industries such as mining, construction and transportation. Because welding is considered flexible or you could say there are no limitations in use in various positions and conditions, and operational costs are not expensive. However, austenitic stainless steel is susceptible to chromium carbide deposition due to exposure to high temperatures and according to him the welding process is the most common cause of chromium carbide deposition on austenitic stainless steel [4].

The deposition of Chromium Carbide (Cr_3C_2) on austenitic stainless steel can cause the stainless steel to become more sensitive to corrosion attack.

Chromium carbide precipitation can be avoided, with three methods, (1) postweld annealing, (2) limiting the carbon content, and (3) stabilizing the carbon content [5]. Therefore, the author tries to apply postweld annealing to SMAW welded joints on AISI 304 plates, taking into account the three aspects above, which need to be considered when welding stainless steel. The aim to be achieved from this research is to determine the effect of PWHT application on changes in hardness values, corrosion rate and microstructure of AISI 304 plates which have been carried out by the SMAW welding process [6].

2. Methodology of Research

This research is experimental research conducted in the material testing laboratory at Merdeka University, Malang. This research began with a literature study, then material preparation, the SMAW welding process followed by the heat treatment process [7]. After that, metallographic testing and hardness testing were carried out using the Rockwell method. Next, corrosion testing was carried out using a sulfuric acid solution. After data collection, the data is processed and analyzed using descriptive analysis [8].

Figure 1. AISI 304

1. *Material preparation*

The material used in this research is austenitic stainless steel type AISI 304 with a length of 200 mm, width 150 mm and thickness 8 mm.

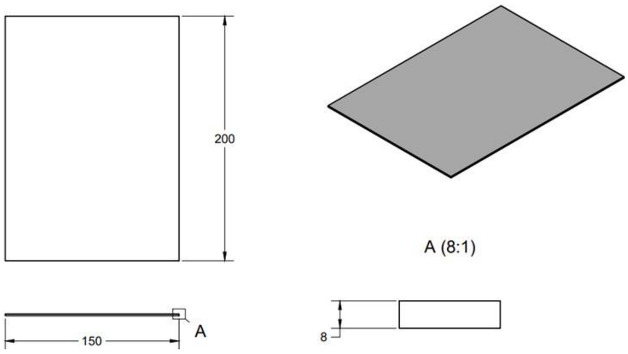

Figure 2. Material dimensions (AISI 304)

Then the material is tested for composition to confirm the elements contained in the specimen. The results obtained from composition testing are as follows:

Table 1. Chemical composition of AISI 304

Materials	Chemical composition (%wt)				
AISI 304	**C**	**Si**	**Al**	**Cu**	**V**
	0.0107	0.2857	0.0163	0.0317	0.0857
	P	**Sn**	**Cr**	**Nb**	**Co**
	0.0039	0.0034	19	0.0104	0.2471
	N	**Ti**	**Mn**	**Mo**	**Ni**
	0.0342	0.0051	1.1925	0.0041	7.4103

Source: PT. IspatIndo, Sidoarjo

2. *SMAW welding process*

The welding process begins by making a V cap, with a bevel of 60°C and a root face of 2 mm on the specimen. Then carry out the welding process using the SMAW process, using electrodes E308S-15, Current 60 A, and position 1G (flat position).

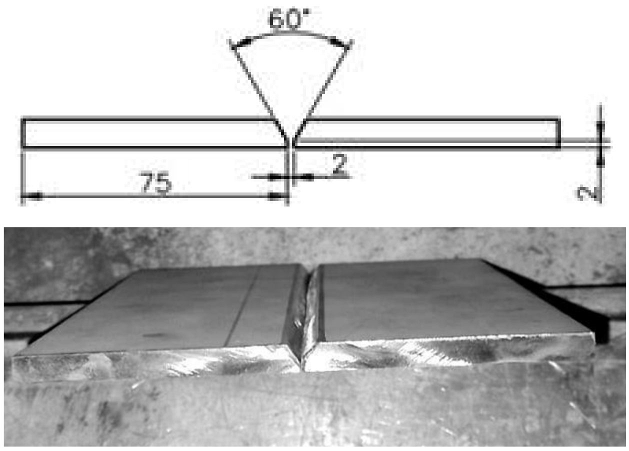

Figure 3. V cap dimensions

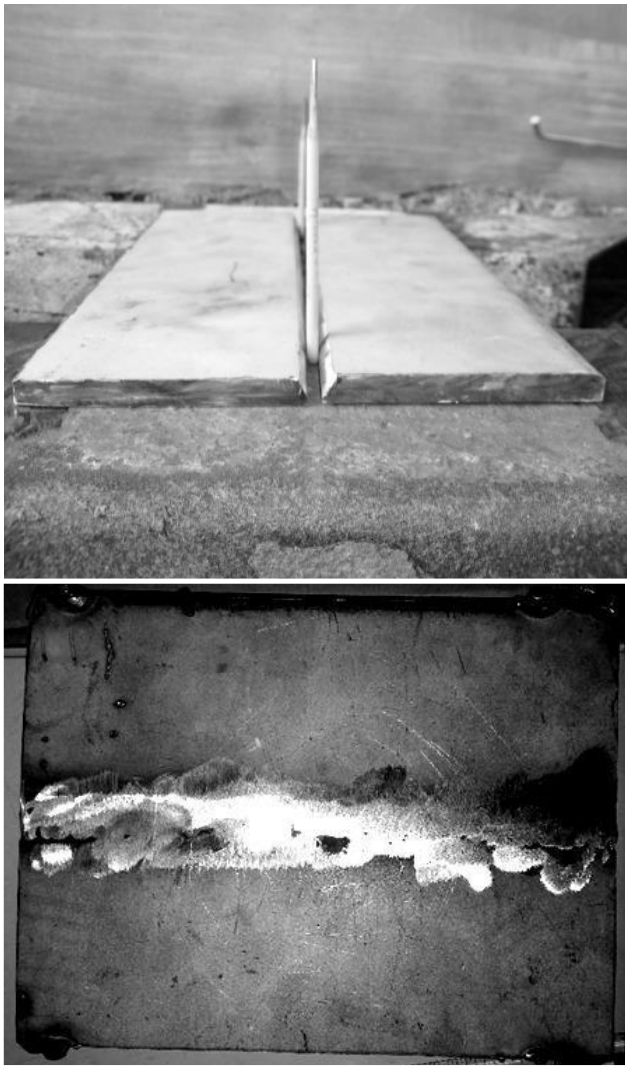

Figure 4. Position and result of welding

3. PWHT process

The PWHT process in this research was carried out at CV. Bumi Buana Citra with the procedures used in the PWHT process, are as follows:

a. Specimen Preparation, the specimens used in the PWHT process are 60 mm long, 10 mm wide and 8 mm thick, totaling 10 specimens.

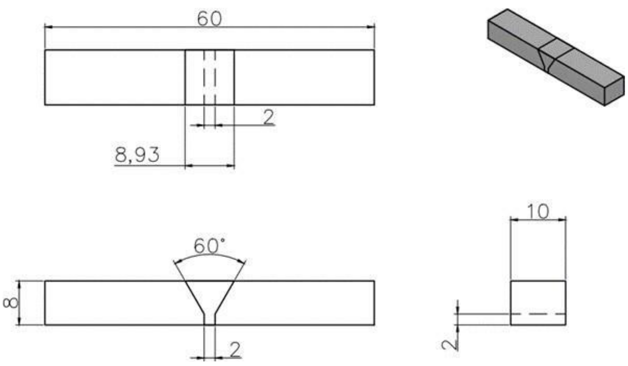

Figure 5. Technical drawing of specimen samples

b. Specimen creation is carried out by cutting the welding specimen, with cutting coordinates 30 mm to the right and to the left of the center point of the weld metal.

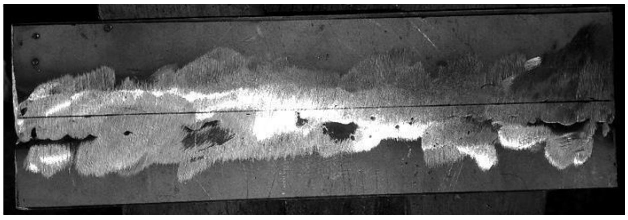

Figure 6. Result of cutting the specimen

c. Polish the specimen, then divide it into 10 with a width of 10 mm and a length of 60 mm.

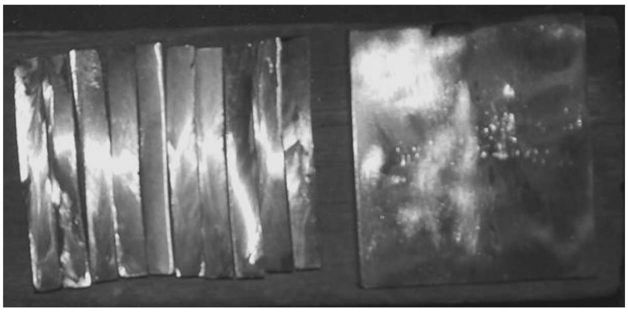

Figure 7. Specimen for PWHT

d. The specimen was heated at various temperatures of 700˚C, 900˚C, and 1100˚C for 15 minutes, and cooled using water.

4. Metallographic testing

The testing process was carried out by taking 4 specimens as samples, then sanding one of the specimen surfaces in stages on a grid of 200, 500, 800, 1000, 2000, and 3000. Then polished with Autosol and a hand grinder whose rotation speed had been adjusted. After that, etching is carried out using aqua regia solution and cleaned with soapy water, then alcohol. Then observations were made on the etched metal surface using a metal optical microscope to see the microstructure formed as a result of the welding and PWHT processes.

Figure 8. Specimen for metallographic testing

5. Hardness testing

Hardness testing was carried out using the Rockwell Hardness Tester method with B scale by taking 4 samples from specimens that had undergone microstructure testing. Hardness testing is carried out at 5 (five) points in 3 (three) areas per specimen, namely the base metal, heat affected zone (HAZ), and weld metal.

6. Corrosion rate testing

Corrosion rate testing was carried out by immersing the specimen in 500 ml of 98% H_2SO_4 solution for 10 days.

Figure 9. Immersion of Specimens in H_2SO_4

7. Tools and materials

The tools and materials used in this research are as follows:

a. 900 W welding machine type 120 e
b. Electrode E 308S-15
c. Heating furnace
d. Optical microscope
e. Rockwell hard test machine
f. H_2SO_4 98%
g. Hand grinding
h. Grinding stones cut, sharpen and polish
i. Pliers
j. Hammer
k. Grid sandpaper 200, 500, 800, 1000, 2000, and 3000.

8. Variables of research

a. The dependent parameters of this research are the PWHT (Post Weld Heat Treatment) process with heating temperatures of 700, 900, 1100. With a holding time of 15 minutes and quenching using water media on the level of hardness, corrosion rate and microstructure of SMAW welded joints on AISI 304 Plate .
b. The independent parameters of this research are the level of hardness, microstructure and corrosion rate resulting from the PWHT (Post Weld Heat Treatment) process with heating temperatures of 700, 900, 1100. With a holding time of 15 minutes and quench using water media.

3. Result and Discussion

1. Microstructure test results

The results obtained from microstructure testing in this research can be seen in the following image.

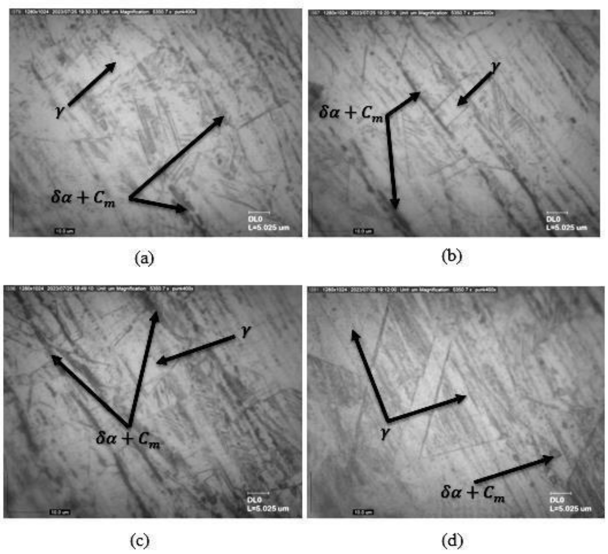

Figure 10. Microstructure in the Parent Metal Region (a) Without PWHT, (b) PWHT 700˚C, (c) PWHT 900˚C, (d) PWHT 1100˚C.

In the picture above you can see the differences in microstructure in each metal area between stainless steel welds without PWHT, and with PWHT at temperatures of 700˚C, 900˚C and 1100˚C. The symbol (δα) in figures 10 and 11 represents the ferrite-delta phase where there is carbide precipitation (Cm). The deposition of carbide (chromium caride) on ferrite-delta is called the sigma phase, where the sigma phase is an brittle phase that occurs due to insufficient heating to dissolve the alloy elements (C, Cr, Mo,) in austenite (γ) so that these elements form new compounds called carbides [9]. The sigma phase can increase the hardness of stainless steel, but will be more susceptible to corrosion [5]. So it can be concluded that, the deposition of carbides formed on steel will increase its hardness, while its corrosion resistance will decrease due to reduced chromium in austenite (γ) [10].

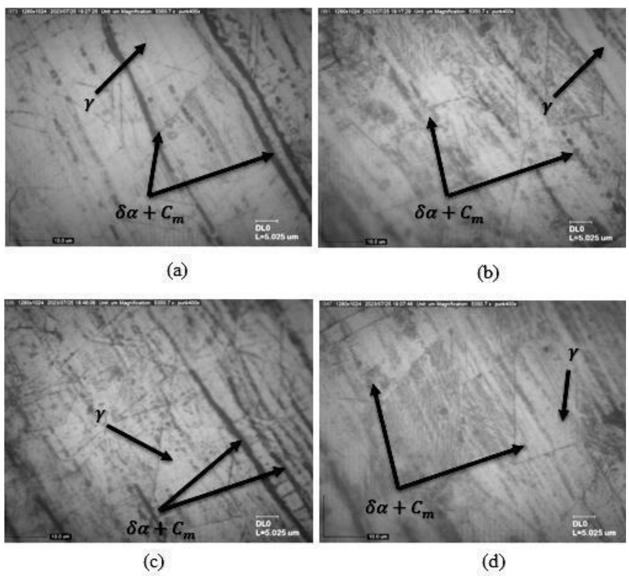

Figure 11. Microstructure in the HAZ Region (a) Without PWHT, (b) PWHT 700˚C, (c) PWHT 900˚C, (d) PWHT 1100˚C.

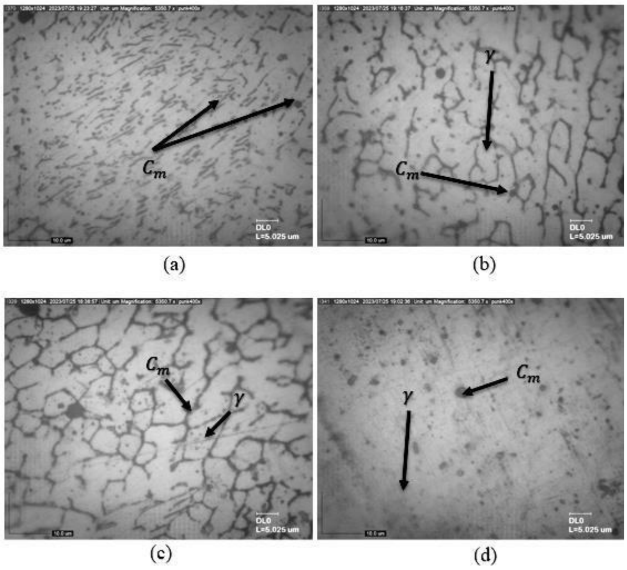

Figure 12. Microstructure in the Weld Metal Area (a) Without PWHT, (b) PWHT 700˚C, (c) PWHT 900˚C, (d) PWHT 1100˚C.

In Figures 10, 11 and 12 it can be seen that PWHT at a temperature of 1100˚C can reduce the level of chromium deposition, whereas in the welding process without PWHT and with PWHT at temperatures of 700˚C and 900˚C carbide deposition is still clearly visible. So it can be concluded that the PWHT process at a temperature of 1100˚C can reduce the level of brittleness due to the deposition of carbides formed, while the hardness value will be smaller compared to the three processes [11].

2. Hardness testing result

The results obtained from the hardness testing carried out in this research are as follows.

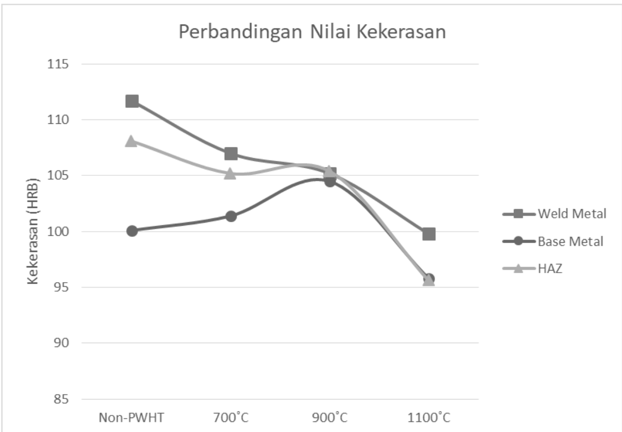

Figure 13. Comparison chart of hardness and PWHT process

Table 2. Hardness testing result

No	PWHT	Testing Area	Averages (HRB)
1	Non PWHT	Base	100.1
		HAZ	108.1
		Weld	111.7
2	700˚C	Base	101.4
		HAZ	105.2
		Weld	107
3	900˚C	Base	104.5
		HAZ	105.4
		Weld	105.2
4	1100˚C	Base	95.8
		HAZ	95.6
		Weld	99.8

In Figure 13 it can be seen that in welding without PWHT the largest hardness value occurs in the weld metal area at 111.7 HRB. At PWHT 700˚C the greatest hardness value occurs in the weld metal area at 107 HRB. At PWHT 900˚C the largest hardness value occurs in the HAZ (Heat Affected Zone) area of 105.4 HRB. At PWHT 1100˚C the greatest hardness value occurs in the weld metal at

99.8 HRB [12]. So it can be concluded that these areas have the potential for brittleness or cracking if subjected to a load. The hardness value is obtained from the level of deposition of chromium carbide which is formed as a result of the welding and PWHT processes carried out.

3. Corrosion testing result

The results obtained from the corrosion rate tests carried out are as follows:

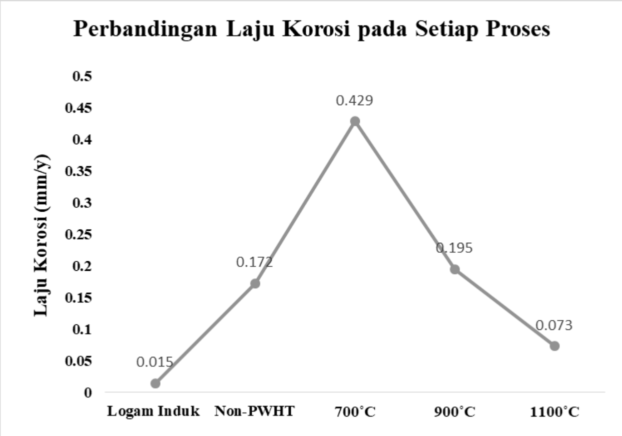

Figure 14. Corrosion rate comparison chart

In Figure 14 it can be seen that the greatest corrosion rate occurs at PWHT with a temperature of 700˚C, namely 0.429 mm/y. This can occur because this temperature is the temperature range for deposition of chromium carbide which can cause stainless steel to be susceptible to corrosion. As explained by Joshep R. Davies (1998), chromium carbide precipitation can occur when austenitic stainless steel is heated for a period of time in the range of approximately 425°C to 870°C. Meanwhile, at PWHT 1100˚C the corrosion rate decreases to 0.073 mm/y, indicating that there is an increase in corrosion resistance of 42% of the corrosion resistance due to welding carried out, this can happen because this temperature is the recommended temperature to avoid carbide deposition which can cause stainless steel is susceptible to corrosion. As explained by Joseph. R. Davies (1998), That the annealing temperature must exceed the medium range to avoid sensitization due to carbide precipitation along grain boundaries, namely above 1040°C [10].

4. Conclusion

Based on the discussion, it can be concluded that the SMAW welding process that uses an E308S-15 electrode, a current of 60 A, and a horizontal position (1G) can cause carbide deposition in the HAZ area, weld metal, and base metal. Based on the PWHT process carried out at temperatures of 700˚C, 900˚C and 1100˚C. a temperature of 1100˚C can reduce carbide deposition in the HAZ area, weld metal and base metal. The highest level of hardness occurred in the weld metal area without PWHT at 111.7 HRB, while the lowest level of hardness occurred in the HAZ area with PWHT 1100˚C at 95.6 HRB. The largest corrosion rate occurred at PWHT 700˚C at 0.429 mm/y, while the lowest corrosion rate occurred at PWHT 1100˚C at 0.073 mm/y.

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