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Preheat and PWHT analysis of FCAW A573 grade 70 welds results of HT and NHT materials on hardness and microstructure

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Abstract

Material A573 Grade 70 is one type of material used to manufacture pressure vessel shells or walls. The thickness of the shell depends on the required pressure design for production. In a case study on pressure vessel shell manufacturing, a thickness of 36 mm was used near the manhole. Due to the connection between the shell and the manhole, the material A573 Grade 70 in the shell was subjected to heat influence. The shell near the manhole will be connected to the rest of the shell using the same material, A573 Grade 70. Consequently, it was necessary to analyse the heat treatment for this material. The heat treatments used to determine the microstructure and hardness value were Preheat and Post Weld Heat Treatment (PWHT). Both types of heat treatments were employed. The preheat temperatures varied at 120°C, 150°C, and 200°C for each joint undergoing PWHT at 650°C with a holding time of 60 minutes, as well as for joints without PWHT. The microstructure of variations with preheat and PWHT exhibited finer grains compared to variations without PWHT. The highest recorded hardness value among the variations with PWHT was 209.89 HVN in the weld metal for the 150°C preheat variation. The highest recorded hardness value among the variations without PWHT was 235.07 HVN in the weld metal for the 200°C preheat variation.

1. Introduction

The advancement of welding technology is crucial to accelerate production, such as welding using modern welding machine technology in the construction. Welding is the process of joining two or more materials, typically metals, using heat energy until the materials melt and fuse together, with or without pressure, and with or without additional filler material [1][2]. Welding techniques are among the most widely used because they offer several advantages, such as lighter machine structures made through welding processes and simpler manufacturing processes. The quality of welding results greatly depends on the skill of the welder and the operator of the welding machine. Flux Core Arc Welding is an automatic or semi-automatic welding process that uses tubular electrodes filled with flux to melt metal [3][4][5]. In FCAW welding, the protective agent used is flux or powder located in the core of the welding wire [6]. In addition to flux, FCAW employs a shielding gas to protect the molten metal during the welding process [7]. The use of additional shielding gas in FCAW welding ensures better quality welding results, thereby speeding up the fabrication process.

Heat treatment processes are used to alter the properties of metals by adjusting the temperature and time [8]. Preheating is a heat treatment process applied to the material to be welded. The preheating temperature is defined as the temperature of the base metal before welding begins [9][10], although in practice it can also be a specific temperature as desired. PWHT is a part of the heat treatment process aimed at relieving the residual stresses resulting from the welding process. This heating is performed to reach a specific temperature, with a holding time and cooling rate that have been designed to restore the original properties, to also discuss the mechanical strength of the material [11].

Preheat is a heat treatment applied to a material prior to welding. Preheating involves heating a material to the maximum preheat temperature specified by the material standard [12][13]. PWHT is a heat treatment applied to welded materials to reduce residual stresses resulting from the welding process [14][15]. This treatment is performed only after the welding process [16]. PWHT also has its own temperature according to the material specifications or standards used. The time for holding the material at temperature was also specified by the standards used. The cooling rate after the temperature is maintained can also affect the final outcome of the PWHT.

Hardness is the resistance of a material to compressive deformation [17]. Hardness testing was performed by pressing an indenter harder than the test material for several seconds, and the remaining impression was measured to determine hardness by dividing the pressing force by the area of the impression [18] [19]. Microscopic testing is a method used to analyze the type and microstructure of metals using a specialized metallographic microscope [20].

Haryadi's research on the " effect of pre- and post-heating on the GMAW process on the microstructure and tensile strength of AISI 1045 Carbon Steel" found that these treatments caused the weld metal and HAZ structure to become larger and elongated with a random orientation. This results in a higher tensile strength, with increases of 17.33% with Preheat, 2.72% with Post Heat, and 7.80% with both treatments [21]. Research by Bimantara et al. on the "Effect of Preheating on Rewelding ASTM A36 Steel Using the FCAW Process" found that preheating causes a minor, non-significant decrease in hardness and results in the formation of larger and denser grain sizes [22]. Shrestea studied the “effect of heat treatment on the microstructural hardness of Grade 91 steel and found that the hardness of the alloy decreased with increasing normalizing and tempering temperatures and times [23].

ASME BPVC Section VII Div.1 Appendix R for P-No. 1 materials (Groups 1, 2, and 3) states a preheat temperature of 175°F (79°C) for materials with a specified maximum carbon content over 0.30% and joint thickness over 1 inch (25 mm), and 50°F (10°C) for all other materials in this P-Number. Table UCS-56-1, explained for P-No. One materials, the heating rate above 800 °F (425°C) should not exceed 400 °F/h (222°C/h) divided by the maximum metal thickness in inches, capped at 400 °F/h (222°C/h), with temperature variation within 250 °F (140°C) over 15 feet (4.6 m). For tube-to-tube welding, the heating rate must be limited to 250 °F/h (140°C/h). Cooling above 800 °F (425°C) should be done in a closed furnace or cooling chamber at a rate not exceeding 500 °F/h (280°C/h) divided by the maximum metal thickness, capped at 500 °F/h (280°C/h), with temperature variation during cooling within 250 °F (140°C) over 15 feet (4.6 m). Vessels can be cooled in still air. For tube-to-tube sheet welding, the cooling rate above 800°F (425°C) must not exceed 250°F/hr (140°C/hr), unless post-weld heat treatment is in the austenitizing range [24].

In this issue, a study will be conducted on the hardness level that will occur in the material, where one side will undergo heat treatment (affected by the PWHT process) and one side will be a non-heat-treated material (not affected by PWHT). This scenario actually occurs on the shell material of a tank with a thickness of 36 mm that undergoes PWHT process, which will later be connected to another shell material that does not undergo any PWHT or heat treatment. In the shell-to-shell connection, a preheating process is conducted according to the specifications of the procedure used. PWHT treatment is performed to reduce the hardness value on the side of the material that has undergone previous welding (joint manhole to shell). If this PWHT treatment is not performed, there will be differences in hardness at the joint, as well as experiencing significant residual stresses at that joint.

The PWHT treatment on one side of the material is actually carried out owing to the connection of the manhole to one side of the material (shell), which will be connected to the other side of the material (shell) that does not undergo the same treatment. In the Welding Procedure Specification (WPS) for the connection of shell-to-shell materials, it is stated that the material must undergo preheating before the welding process. In this case, research is required on what happens and what differences occur in the resulting joints with different treatments by varying the preheating temperature of the material and comparing it with PWHT and non-PWHT in each variation. In this study a comparison will be made on the test results for each variation.

In this research, an analysis will be carried out of the welding results of A573 Grade 70 material with ER 81T1 K2 welding wire [25] which corresponds to the material used in the practicum, where the material undergoes different welding To obtain more data, a comparison will be made on the preheating temperature, namely preheating the material using a standard temperature of 150°C compared to temperatures 5% below it, which is 125°C, and 5% above it, which is 200°C. Hardness tests and micro etch tests will be conducted to determine the analysis results of the welding process. This study aimed to determine the effect of preheating on the FCAW welding of A573 Grade 70 material that underwent heat treatment and non-heat treatment on hardness values and microstructure, as well as the effect of preheating and PWHT on hardness values and microstructure. Thus, the fabrication process of the material can achieve good results; refer to the findings of this research.

2. Research Methods

2.1 Research Outline

This study employed an experimental method in which conclusions were obtained by conducting actual experiments with predetermined parameters.

Table 1. Parameter Specification

Electrode Diameter	Shielding Gas	Wire feed rate, in/mm (cm/min)	Arc Voltage (V)	CTWD in. (mm)	Deposition Rate, lbs/hr (kg/hr)
0.0045 in. (1.2mm)	75 Ar/ 25CO_2	174-300 (445-760)	21-25	½-1/4 (12-20)	3.3-5.8 (1.5-2.6)
		300-425 (760-1080)	24-28	5/8-7/8 (16-22)	5.8-8.1 (2.6-3.7)
		425-550 (1080-400)	27-30	¼-1 (20-25)	8.1-10.5 (3.7-4.8)
1/16 in. (1.6mm)	75 Ar/ 25CO_2	150-225 (380-570)	22-25	¾-1 (20-25)	5.4-8 (2.5-3.6)
		225-300 (570-760)	24-27	7/8-1 1/8 (22-29)	8-10.8 (3.8-4.9)
		300-375 (760-950)	26-31	1-1 ¼ (25-32)	10.8-12.2 (4.9-5.5)

This research uses FCAW equipment, including an Oxy-Acetylene Welding (OAW) machine for preheating, an FCAW welding machine, and ER 81T1 electrodes. The material was A573 Grade 70 plates, 36 mm thick, with a furnace for the PWHT process. Welding was performed on heat-treated and non-heat-treated materials with preheat variations of 125°C, 150°C, and 200°C, both with and without PWHT. Parameter specification is shown in Table 1.

2.2 Research Factor

This study used control and constant factors. The control factors, which can be adjusted according to the research objectives, include variations in welding between heat-treated and non-heat-treated materials at preheating temperatures of 125°C, 150°C, and 200°C, both with and without PWHT. The constant factors, which remain unchanged to avoid significantly affecting the research results, include the A 573 Grade 70 carbon steel material, voltage, welding speed, type and diameter of filler metal, type and flow rate of shielding gas, root face of 2-4 mm and grooves of 60° and 70°.

2.3 Tools and Materials

A573 Grade 70 material with dimensions of 150 × 300 × 36 mm, ER 81T1 K2 filler, and CO_2 shielding gas were used as the materials. A welding machine, furnace, hardness machine, measuring tools (ruler and thermogun), and auxiliary tools such as a grinder, cutting saw, semi-automatic flame cutting, marker, chipping hammer, steel brush, and camera were used as the equipment in this study.

2.4 Research Procedure

This experimental procedure was initiated by specimen preparation, including size adjustment, equipment setup, surface smoothing, and cleaning from impurities. One side of the specimen was placed in the furnace for heat treatment. The specimen was mounted on a workbench and welded to a side that was not preheated. The specimen shape was in accordance with Fig. 1. The diameter of the electrode wire in the wire feeder was measured. The FCAW welding machine was turned on and adjusted according to the specified factors. Shielding gas was prepared according to the flow rate. Preheating was performed on the specimen before welding at temperatures of 120°C, 150°C, 200°C with a holding time of 60 minutes, measured using a thermogun (for preheated specimens). The welding process used parameters of 150 – 200 A, 24 – 30 V, travel speed ± 12.5 mm/min, and heat input ± 1.73 – 1.8 kJ/mm. PWHT was performed on the specimen after welding at a temperature of 650ºC with a holding time of 60 minutes (for specimens that undergo PWHT). After welding was completed, the material was cut into test specimens with a length of 80 mm and a width of 30 mm, including the base metal, HAZ, and weld metal areas, according to the points in Fig. 2.

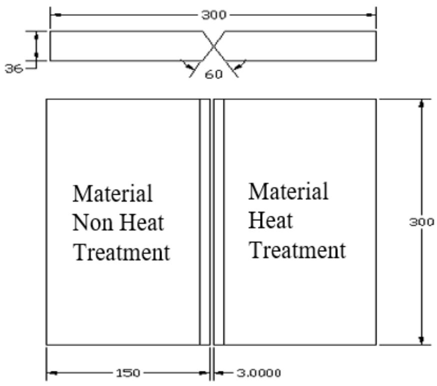


Fig. 1. Test Speciment

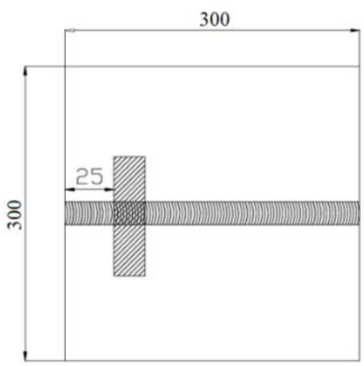


Fig. 2. Test Speciment Cutting

2.5 Specimen Test

Testing included hardness testing and metallography observation to examine the microstructure and hardness values in the Heat Affected Zone (HAZ), fusion line, and base metal. The points where hardness testing taken place was shown in Fig. 3.

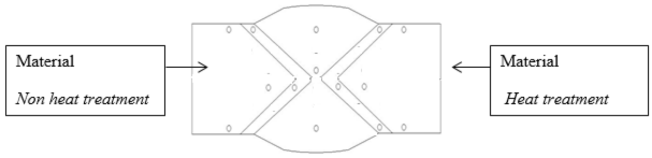


Fig. 3. Point of Hardness Test Taking Taken Place

3. Results and Discussions

3.1. Results of Preheat

Before the welding process, preheating was conducted on one side of the specimen at a temperature of 650°C with a holding time of 60 min. The material was preheated in the furnace with temperature 650°C for 60 minutes and was slow-cooled inside furnace until the temperature of 55°C, then unloaded. Preheat process of heat treatment is shown in Table 2 and the time record preheat process is shown in Table 3. Fig. 4 illustrates the heating and cooling processes of the specimen.

Table 2. Preheat Process of Heat Treatment

Description	Value
Loading Temperature	27ºC
Heating Rate	100ºC/hours
Holding Temperature	650ºC
Holding Time	60 minutes
Cooling Rate	60ºC/hours
Unloading Temperature	55ºC

Table 3. Time Record Preheat Process

Time	Temperature
0 - 60	27 - 650
60 - 120	650
120 - 1440	650 - 55

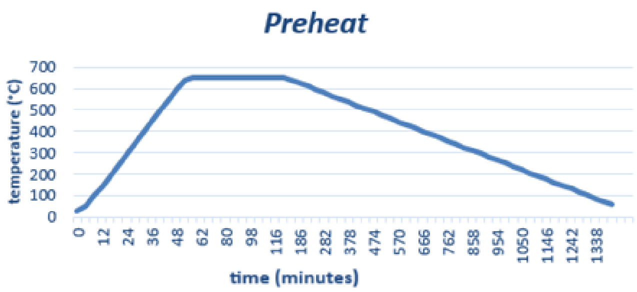


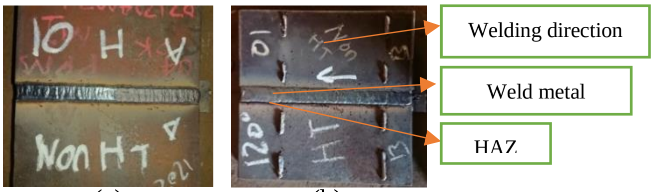
Fig. 4 Chart of Preheat Process

3.2 Welding Data

The welding process referred to the WPS with the welding process data. The reference code was ASME, and the P number of the material was P-NO.1. The thickness of the material was 36 mm with Heat Treatment (HT) and non-heat treatment (NHT), using FCAW welding and E81T1-K2 filler metal in the 3G welding position for the Butt Joint Double V Groove. The preheating temperatures were 120, 150, and 200°C with material code 1 for the PWHT specimens and material code 2 for the non-PWHT specimens. The actual current of the welding process is shown in Table 4. Welding specimens and terminology are shown in Fig.s 5-10.

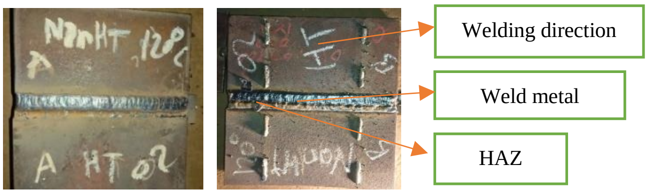
Table 4. The Actual Current of Welding Process

Layer	Current (A) of PWHT's Temperature					
	120°C		150°C		200°C	
	1	2	1	2	1	2
Root	175	165	177	179	179	176
Hot pass 1	178	176	188	187	184	187
Fill 1	185	179	188	187	184	187
Capping 1	210	190	212	218	223	213
Hot pass 2	168	178	189	186	184	179
Fill 2	174	188	189	186	194	194
Capping 2	215	222	232	223	204	217



(a) (b)

Fig. 5. (a) top view and (b) bottom view specimen with PWHT of 120°C (1).

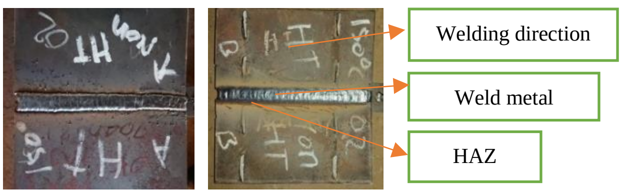


(a) (b)

Fig. 6. (a) top view and (b) bottom view specimen with PWHT of 120°C (2).

(a) (b)

Fig. 7. (a) top view and (b) bottom view specimen with PWHT 150°C (1).

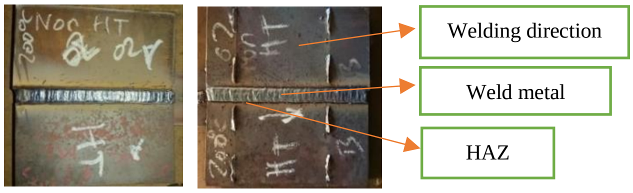


(a) (b)

Fig. 8. (a) top view and (b) bottom view specimen with PWHT of 150°C (2).

(a) (b)

Fig. 9. (a) top view and (b) bottom view specimen with PWHT of 200°C (1).



(a) (b)

Fig. 10. (a) top view and (b) bottom view specimen with PWHT of 200°C (2).

3.3 Results of Post Weld Heat Treatment

The PWHT was performed after the welding process at temperature of 650ºC with holding 60 minutes as shown in Table 5-6. Fig. 11 illustrates the heating and cooling processes for the specimens. This process involved heating to 650°C and holding for 60 min, followed by slow cooling for one day inside the furnace with a gradual decrease in temperature. The specimens were A573 Grade 70 with dimensions of 150 x 300 x 36 mm, which was welded by FCAW process with ER 81T1 K2 filler metal and CO_2 shielding gas, and the various currents and heat treatments.

Table 5. PWHT Process

Description	Value
Loading Temperature	27ºC
Heating Rate	100ºC/hours
Holding Temperature	650ºC
Holding Time	60 minutes
Cooling Rate	60ºC/hours
Unloading Temperature	55ºC

Tabel 6. Time Record PWHT Process of Specimens

Time (Minute)	Temperature (˚C)
0 - 60	27 - 650
60 - 120	650
120 - 1440	650 - 55

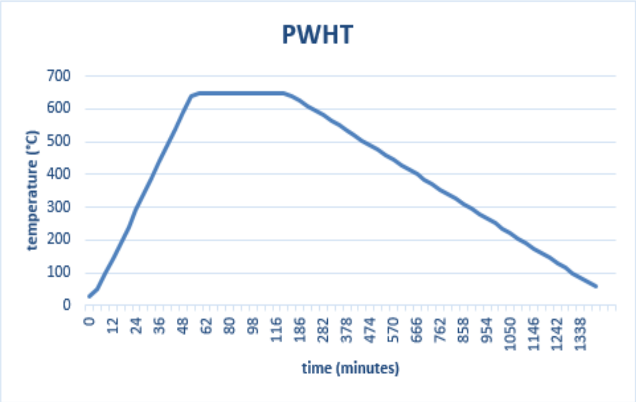


Fig. 11. Chart of PWHT Process

3.4 Results and Analysis of Microstructure

Microstructure testing was conducted to determine the microstructure's changes which occurred after varying preheat conditions in each specimen and between PWHT and Non-PWHT. The microstructure testing employed an optical microscope with magnifications of 200X and 500X. The microstructure image capture points were taken at the mid-point of the material thickness. Before conducting microstructure testing, specimens were etched using a 2% Nital solution which composition of 2 ml HNO_3 + 98 ml alcohol. In this study, microstructure testing was performed on the base metal, HAZ, fusion line, and weld metal. The micro testing results relatively showed bright ferrite and dark perlite, indicating a change in mechanical properties which was indicated by the dark pearlite and the increase of hardness. The locations of the microstructure were captured could show in the Fig. 12.

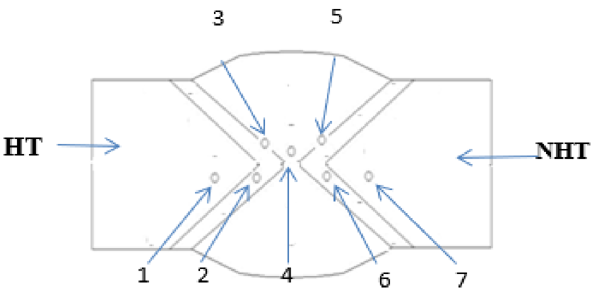


Fig. 12. Location of Microstructure Testing

a. Microstructure of Base Metal with Heat Treatment Non PWHT

Fig. 13, this study utilized A573 Grade 70 material where heat treatment was applied to one side of the base metal prior to welding, at a temperature of 650°C with a holding time of 60 minutes. The microstructure was obtained in this material consists of bright ferrite and relatively dark pearlite.

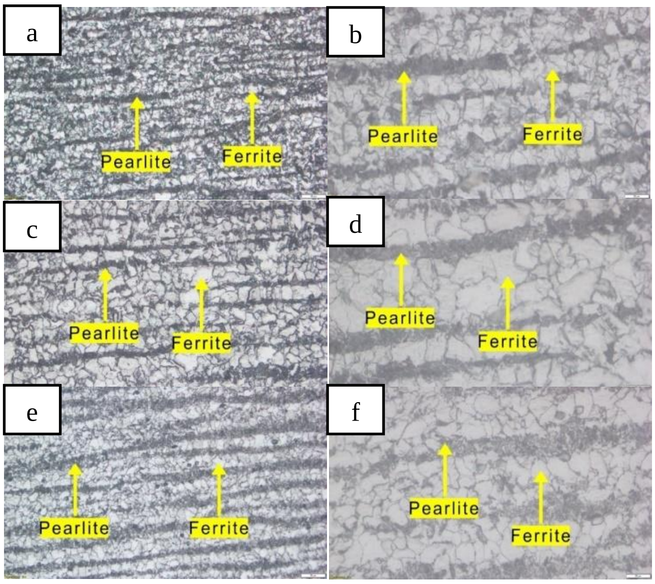


Fig. 13. Microstructure of Base Metal with Heat Treatment of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); 200°C (2) Magnification of 200x (e) and 500x (f).

b. Microstructure Base Metal with Non Heat Treatment and Non PWHT

Fig. 14, this study employed A573 Grade 70 material, where no heat treatment was applied to one side of the base metal. The microstructure obtained in this material consisted of bright ferrite and relatively dark pearlite.

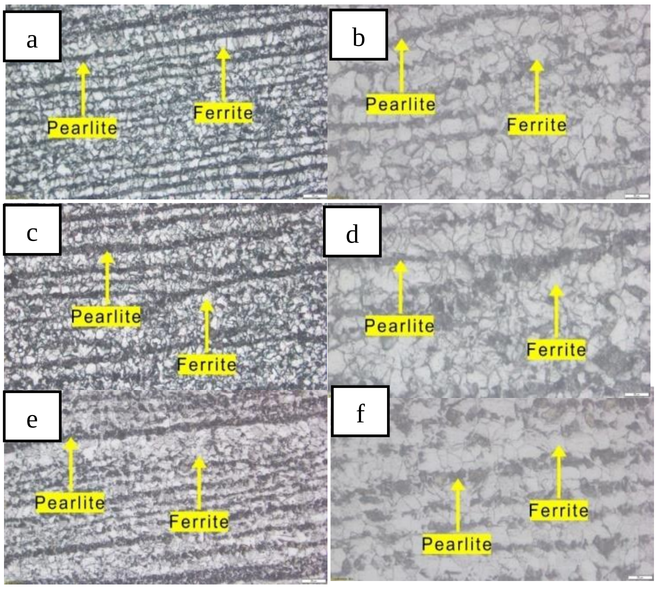


Fig. 14. Microstructure of Base Metal with Non Heat Treatment of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x (e) and 500x (f).

c. Microstructure Test of Base Metal with Heat Treatment and PWHT

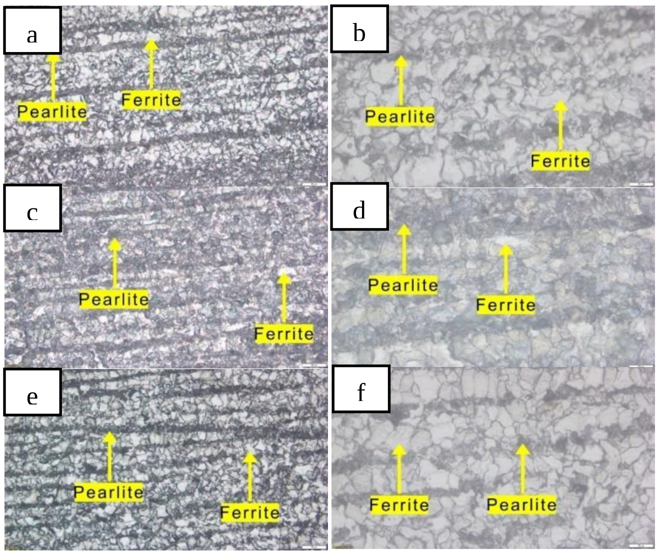


Fig. 15. Microstructure of Base Metal with Heat Treatment and PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150°C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x (e) and 500x (f)

Fig. 15 shows the A573 Grade 70 material that underwent heat treatment before and after welding at 650°C with a holding time of 60 min. The microstructure of this material consists of bright ferrite and dark pearlite.

d. Microstructure Test of Base Metal with Non Heat Treatment and PWHT

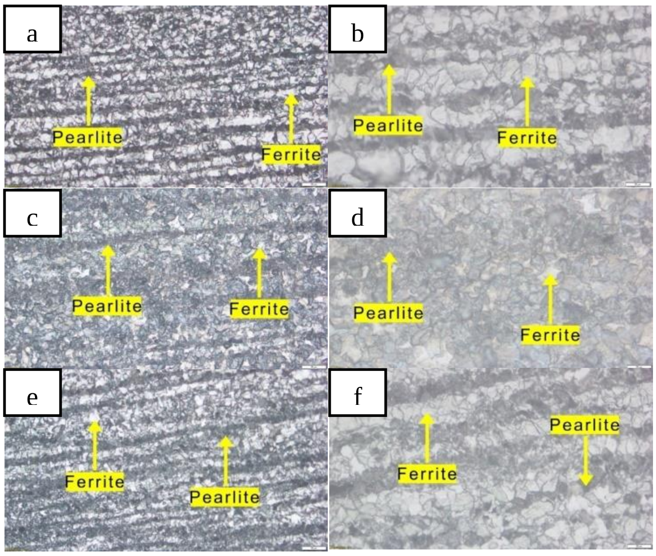


Fig. 16. Microstructure of Base Metal with Non Heat Treatment and PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150 °C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x (e) and 500x (f).

Fig. 16, this study utilized A573 Grade 70 material, in which no heat treatment was applied to one side of the base metal, but PWHT was performed after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite.

e. Microstructure of HAZ with Heat Treatment and Non PWHT

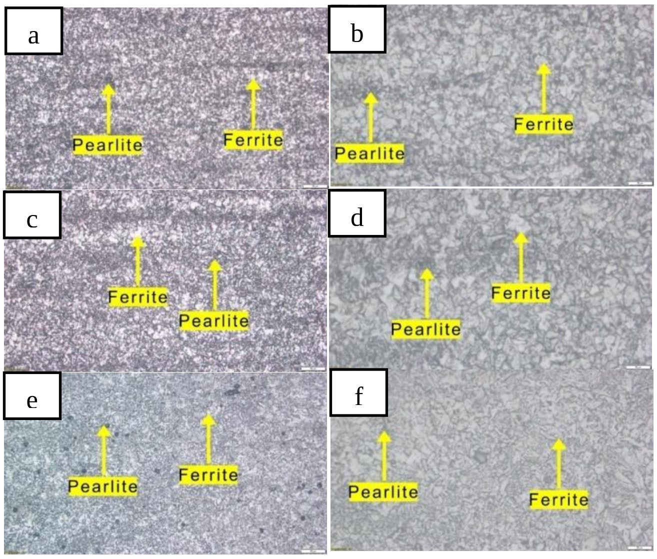


Fig. 17. Microstructure of HAZ with Heat Treatment of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x(e) and 500x (f)

Fig. 17, this study utilized A573 Grade 70 material, in which the HAZ was located on the side of the base metal that received heat treatment before the welding process at a temperature of 650°C with a holding time of 60 minutes. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the HAZ was finer compared to the base metal.

f. Microstructure of HAZ with Non Heat Treatment and Non PWHT

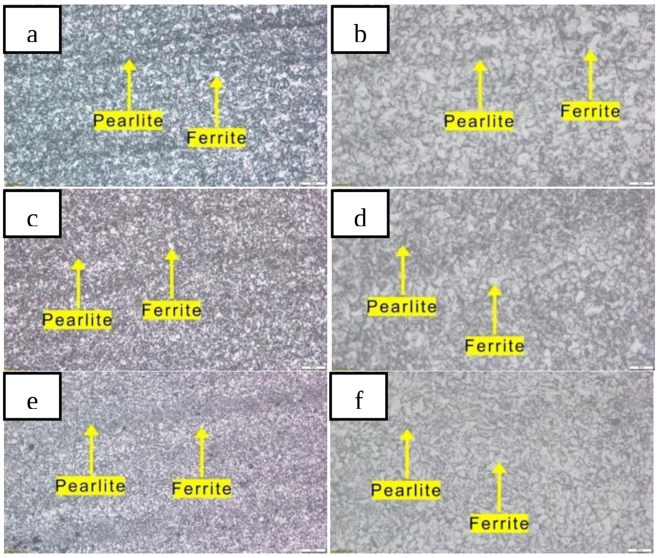


Fig. 18. Microstructure of HAZ with Non Heat Treatment of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x (e) and 500x (f).

Fig. 18, this study utilized A573 Grade 70 material, where the HAZ was located on the base metal that did not undergo heat treatment. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the HAZ was finer compared to the base metal.

g. Microstructure of HAZ with Heat Treatment and PWHT

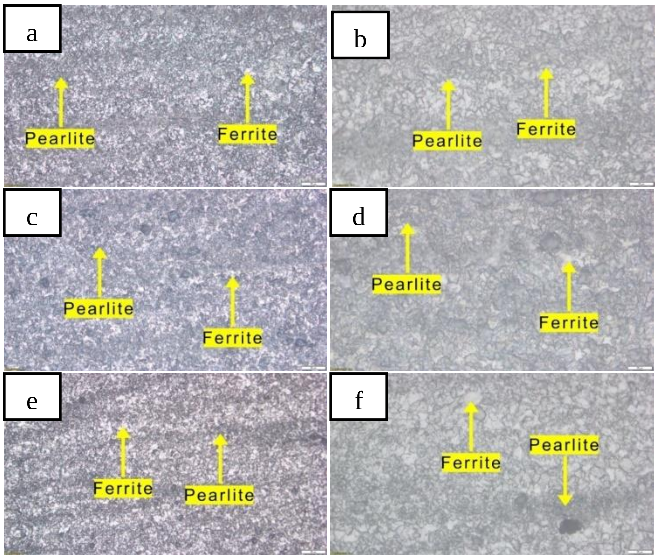


Fig. 19. Microstructure of HAZ with Heat Treatment and PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150°C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x (e) and 500x (f)

Fig. 19, this study utilized A573 Grade 70 material where the HAZ was located on the side of the base metal that received heat treatment before the welding process at a temperature of 650°C with a holding time of 60 minutes. Additionally, PWHT was conducted on this base metal after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the HAZ was finer compared to the base metal.

h. Microstructure of HAZ with Non Heat Treatment and PWHT

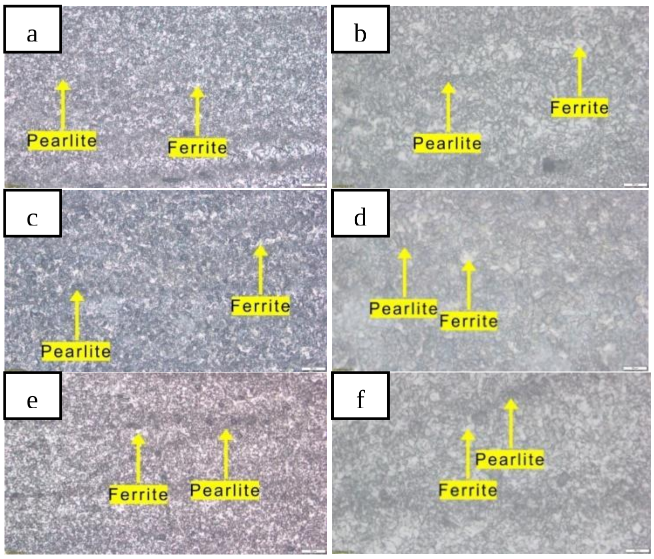


Fig. 20. Microstructure of HAZ with Non Heat Treatment at Welding Current of 120 A (1) Magnification of 200x (a) and 500x (b); Welding Current of 150 A (1) Magnification of 200x (c) and 500x (d); and Welding Current of 200 A (1) Magnification of 200x (e) and 500x (f)

Fig. 20, this study utilized A573 Grade 70 material, where the HAZ was located on the base metal that did not undergo heat treatment, but underwent PWHT after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the HAZ was finer compared to the base metal.

i. Microstructure of Fusion Line with Heat Treatment and Non PWHT

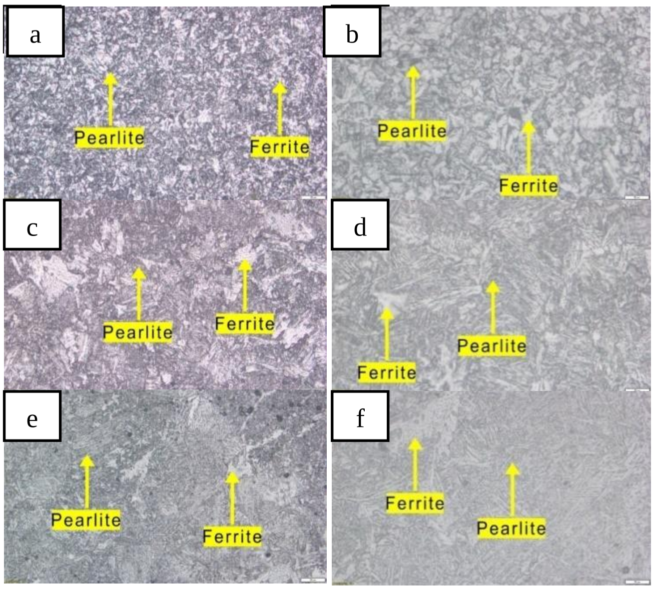


Fig. 21. Microstructure of Fusion Line with Heat Treatment of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x (e) and 500x (f)

Fig. 21, this study utilized A573 Grade 70 material which the fusion line is located on the base metal side that underwent heat treatment before the welding process at a temperature of 650°C with a holding time of 60 minutes. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. In the fusion line, the microstructure mostly exhibited grain boundary ferrite, with acicular ferrite surrounding it.

j. Microstructure of Fusion Line with Non Heat Treatment and Non PWHT

Fig. 22, this study utilized A573 Grade 70 material which the fusion line is located on the base metal side that did not undergo heat treatment. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. In the fusion line, the microstructure mostly exhibits grain boundary ferrite, with acicular ferrite surrounding it.

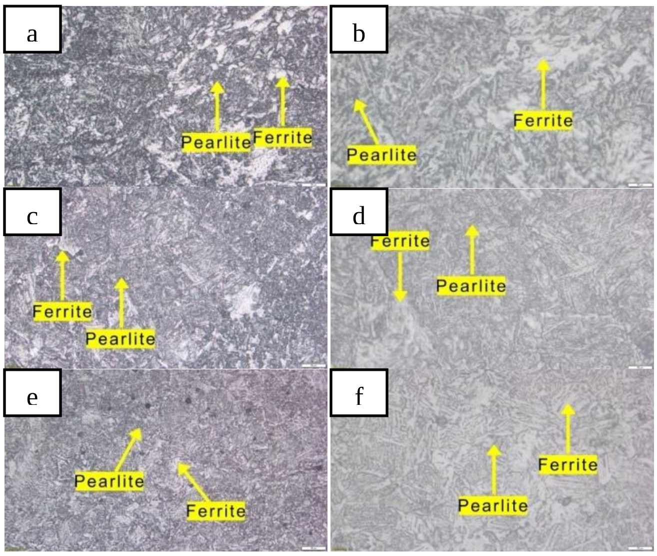


Fig. 22. Microstructure of Fusion Line with Non Heat Treatment and PWHT of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x (e) and 500x (f)

k. Microstructure of Fusion Line with Heat Treatment and PWHT

Fig. 23, this study utilized A573 Grade 70 material which the fusion line was located on the base metal side that underwent heat treatment before the welding process at a temperature of 650°C with a holding time of 60 minutes. Additionally, PWHT was conducted on this base metal after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. In the fusion line, the microstructure mostly exhibits grain boundary ferrite, with acicular ferrite surrounding it.

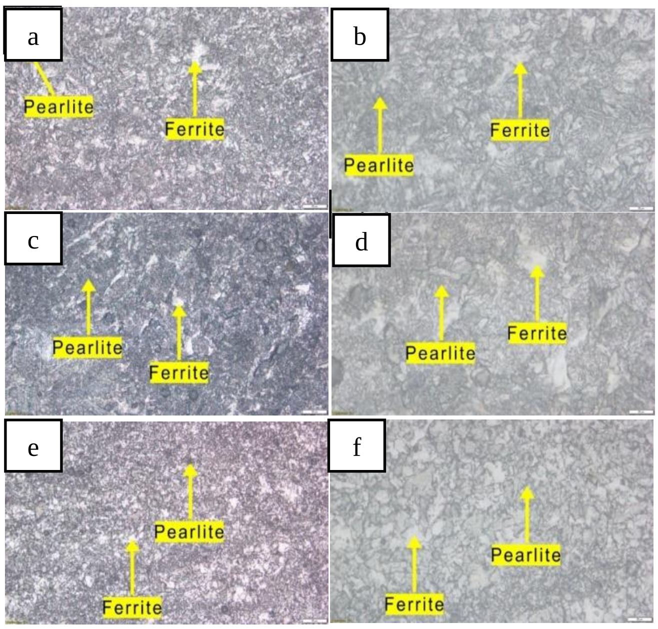


Fig. 23. Microstructure of Fusion Line with Heat Treatment and PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150°C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x (e) and 500x (f)

l. Microstructure of Fusion Line with Non Heat Treatment and PWHT

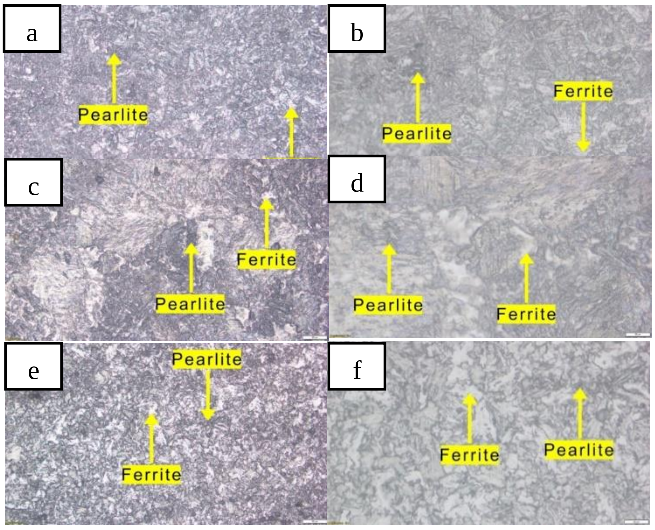


Fig. 24. Microstructure of Fusion Line with Non Heat Treatment and PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150°C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x(e) and 500x (f)

Fig. 24, this study utilized A573 Grade 70 material, in which the fusion line was located on the base metal side that did not undergo heat treatment, but PWHT was conducted after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. In the fusion line, the microstructure mostly exhibits grain boundary ferrite, with acicular ferrite surrounding it.

m. Microstructure of Weld Metal with Non PWHT

Fig. 25, this study utilized A573 Grade 70 material which the image capture was conducted on the weld metal. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the

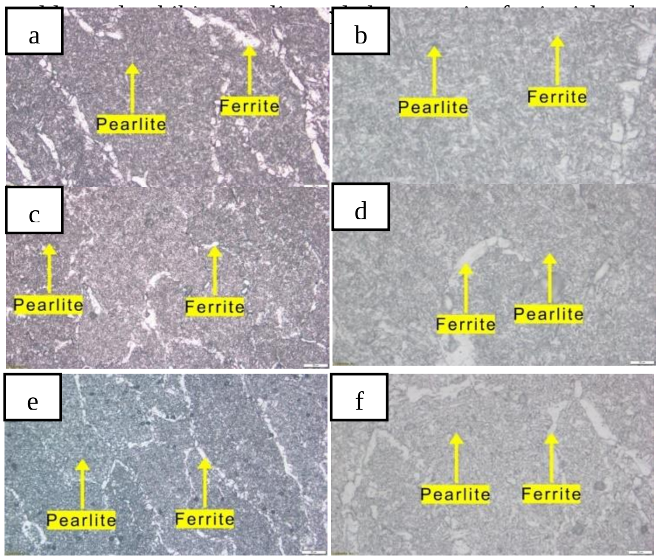


Fig. 25. Microstructure of Weld Metal with Heat Treatment and Non PWHT of 120°C (2) Magnification of 200x (a) and 500x (b); 150°C (2) Magnification of 200x (c) and 500x (d); and 200°C (2) Magnification of 200x (e) and 500x (f)

n. Microstructure of Weld Metal with PWHT

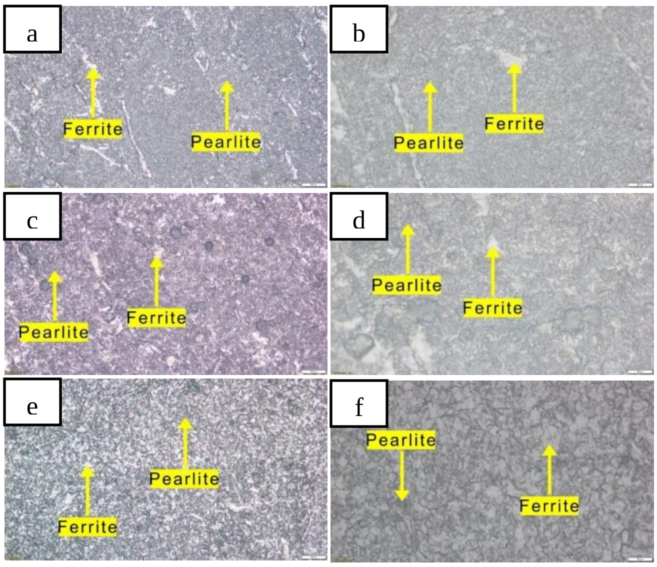


Fig. 26. Microstructure of Weld Metal with PWHT of 120°C (1) Magnification of 200x (a) and 500x (b); 150°C (1) Magnification of 200x (c) and 500x (d); and 200°C (1) Magnification of 200x (e) and 500x (f)

Fig. 26, this study utilized A573 Grade 70 material which the image capture is conducted on the weld metal. This weld metal undergoes PWHT after welding. The microstructure obtained in this material consists of bright ferrite and relatively dark pearlite. The microstructure in the weld metal experiences fine pearlite and also contains ferrite islands.

3.5 Results and Analysis of Hardness Test

This hardness test was used to compare the hardness results that occur after various preheat temperature variations with PWHT and non-PWHT processes. Using a diamond pyramid indenter, with an automatic hardness machine, and a load of 10 kgf applied, the results will be in HVN units. The hardness test points could show in Fig. 27.

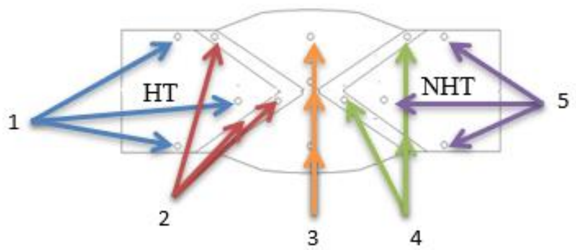


Fig. 27. Location of Hardness Testing

Taking point for hardness test

1. Base metal HT
2. HAZ HT
3. Weld Metal
4. HAZ NHT
5. Base metal NHT

Before conducting the test, there were several fundamentals to determine whether the test results were appropriate or not, namely, the test results of specimens that did not receive any treatment or base specimens could show in Table 7.

Table 7. Hardness Value Before Variation

Area	Hardness Value (HVN)
Base metal	160
	162
	157
HAZ	161
	163
	167
Weld Metal	214
	219
	210

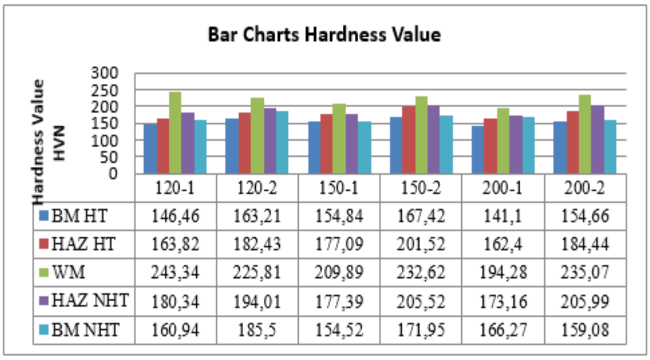


Fig. 28. Diagram of The Average of Hardness Results for All Specimens

From all the experimental heat treatment, it could show that the hardness values in the base metal area differ between the base metal which received preheat and the base metal which did not receive preheat due to the different changing of grain size. In the HAZ area, the hardness tends to decrease in the HAZ area that underwent preheat before welding and received PWHT after welding. Similarly, the hardness value of the weld metal decreased due to the PWHT process. If correlated with the phases which found in the microstructure, it could be inferred that the hardness increased with the dominance of the pearlite phase. From this analysis, it could be said that the hardness value could be increased due to the pearlite phase was more dominant than the ferrite phase. The order of phases becoming more brittle were ferrite, perlite, bainite, and martensite.

4. Conclusions

Based on the analysis of the welding material A573 Grade 70 with PWHT at 650°C and holding time of 60 minutes and without PWHT with preheat variations of 120°C, 150°C, and 200°C, that microstructure of ferrite and pearlite phases were obtained by heat treatment of preheat without PWHT. The variations of PWHT do not significantly affect the hardness of the Heat Affected Zone (HAZ) or weld metal. The highest hardness was obtained from the preheat variation of 150°C with PWHT at 209.89 HVN in the weld metal. The highest hardness from the preheat variation of 200°C without PWHT was 235.07 HVN in the weld metal.

References

[1] Muhammad Taufik, “Jurnal Pendidikan Teknik Mesin Undiksha Shell Powder,” *Pendidik. Tek. Mesin*, vol. 10, no. 1, pp. 55–62, 2022.

[2] J. Awali, F. Rudiyanto, S. Thesalonicha, M. P. D. Lubis, R. A. Tanjung, and Y. Triana, “Analisis Variasi Arus Pengelasan Kombinasi SMAW-FCAW dengan Kampuh Double V-Groove terhadap Kekerasan dan Struktur Mikro Dissimilar Material JIS G3101-SS400 dan ASTM A36,” *J. Rekayasa Mesin*, vol. 12, no. 2, pp. 421–432, 2021, doi: 10.21776/ub.jrm.2021.012.02.19.

[3] V. Krestanto and T. H. Ningsih, “Pengaruh Variasi Arus Pengelasan FCAW Baja ASTM A36 Terhadap Kekerasan,” *J. JTM*, vol. 12, no. 01, pp. 7–12, 2023, [Online]. Available: https://ejournal.unesa.ac.id/index.php/jtm-unesa/article/view/57127/44935

[4] W. L. Dhanistha, H. Pratikno, S. D. P. Maharani, Suntoyo, Silvianita, and D. Satrio, “Comparative Analysis of Welding Mechanical Properties FCAW Welding Joint of A36 and A53,” *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1198, no. 1, 2023, doi: 10.1088/1755-1315/1198/1/012035.

[5] M. Y. Pratama, U. Budiarto, and S. Jokosisworo, “Analisa Perbandingan Kekuatan Tarik, Tekuk, dan Mikrografi Pada Sambungan Las Baja SS 400 Akibat Pengelasan FCAW (Flux- Cored Arc Welding) dengan Variasi Jenis Kampuh dan Posisi Pengelasan,” *Tek. Perkapalan*, vol. 7, no. 2, pp. 152–160, 2019, [Online]. Available: https://ejournal3.undip.ac.id/index.php/naval/article/download/24216/22496

[6] N. K. A-immah, N. Syahroni, and Y. S. Hadiwidodo, “Analisis Pengaruh Variasi Flow Rate Gas Pelindung Pada Pengelasan FCAW-G Terhadap Struktur Mikro Dan Kekuatan Mekanik Sambungan Material Grade A,” *J. Tek. ITS*, vol. 7, no. 2, 2019, doi: 10.12962/j23373539.v7i2.33035.

[7] M. I. R. Yuniarto, H. Pratikno, and D. M. Chamelia, “Analisis Pengaruh Variasi Heat Input Pengelasan FCAW pada Sambungan Baja BKI Grade A terhadap Sifat Mekanik,” *J. Tek. ITS*, vol. 8, no. 2, 2020, doi: 10.12962/j23373539.v8i2.47184.

[8] U. Hasdiana, *Fabrication and Welding Engineering*, vol. 11, no. 1. 2018. [Online]. Available: http://link.springer.com/10.1007/978-3-319-59379-1%0Ahttp://dx.doi.org/10.1016/B978-0-12-420070-8.00002-7%0Ahttp://dx.doi.org/10.1016/j.ab.2015.03.024%0Ahttps://doi.org/10.1080/07352689.2018.1441103%0Ahttp://www.chile.bmw-motorrad.cl/sync/showroom/lam/es/

[9] A. W. Society, *Welding Handbook Ninth Edition MATERIALS AND APPLICATIONS, PART 2 American Welding Society*, vol. 5.

[10] D. Y. Akbar, Wartono, and D. R. Hartana, “Pengaruh Temperatur Preheat Terhadap Sifat Mekanis Las Smaw Pada Baja Karbon,” *Cendekia Mek.*, vol. 01, no. 01, pp. 47–56, 2020.

[11] G. D. Haryadi, R. Ismail, and M. Haira, “Pengaruh Post Weld Heat Treatment (Pwht) dengan Pemanas Induksi Terhadap Sifat Mekanik dan Struktur Mikro Sambungan Las Shield Metal Arc Welding (Smaw) pada Pipa API 5l X52,” *Rotasi*, vol. 19, no. 3, p. 117, 2017, doi: 10.14710/rotasi.19.3.117-124.

[12] O. Dharmawan, “Pengaruh Variasi Suhu Preheat Terhadap Kekuatan Tarik Dan Lebar Haz Pada Material a36 Dengan Menggunakan Metode Las Gtaw,” *nstitut Teknol. Sepuluh Nopember.*, pp. 1–85, 2019.

[13] A. Rifaldi, A. U. Ryadin, and A. R. Hakim, “Pengaruh Suhu Preheating Terhadap Kekuatan Tarik Dan Kekerasan Pelat Baja Astm a36 Pada Pengelasan Shielded Metal Arc Welding (Smaw),” *Sigma Tek.*, vol. 4, no. 1, pp. 81–90, 2021, doi: 10.33373/sigmateknika.v4i1.3216.

[14] H. Adhyawantara, N. Y. Nugroho, T. Perkapalan, U. Hang, and T. Surabaya, “Vol . 4 No . 2 Februari 2023 PENGARUH HOLDING TIME PADA BAJA ST 40 DENGAN PENGELASAN FCAW,” vol. 4, no. 2, pp. 86–91, 2023, [Online]. Available: https://www.ejurnal.universitaskarimun.ac.id/index.php/jalasena/article/download/869/598

[15] S. T. Mesin, F. Teknik, U. N. Surabaya, J. T. Mesin, F. Teknik, and U. N. Surabaya, “PENGARUH VARIASI MEDIA PENDINGIN DALAM PROSES PWHT PENGELASAN SMAW UNTUK MATERIAL BAJA SS400 TERHADAP NILAI KEKERASAN DAN KEKUATAN TARIK Canggih Wahyunanta Novi Sukma Drastiawati Abstrak,” 2020.

[16] E. Nuraliansyah, “Pengaruh Proses Preheat Dan Postheat Pada Pengelasan Gas Metal Arc Welding (Gmaw) Baja Aisi 1045,” *Gorontalo J. Infrastruct. Sci. Eng.*, vol. 5, no. 2, pp. 59–72, 2022.

[17] A. I. Junaidi, “Analisa Pengujian Kekerasan Material Baja Karbonrendah Dan BesiMenggunakan Metode Uji Brinnel,” *Jitekh*, vol. 7, no. 2, pp. 57–61, 2019.

[18] I. Irwana, “Pembuatan Dan Analisa Kekerasan Dan Struktur Mikro Logam Paduan Aluminium Dengan Aditif 6 Fe - 1 Ni (%Berat),” *Banten Univ. Pamulang*, p. 167, 2018.

[19] M. M. Munir, *Modul praktik DT-NDT Politeknik Perkapalan Negeri Surabaya*. 2019. [Online]. Available: https://id.scribd.com/document/450719079/MODUL-PRAKTEK-JOB-SHEET-DT-NDT-pdf

[20] A. AHMADIN, “Pengujian Kekerasan Dan Struktur Mikro Plat Baja Karbon Rendah Setelah Proses Pemanasan Dengan Suhu 8000c Di Quenching Bio Solar,” *Maj. Tek. Simes*, vol. 15, no. 2, p. 8, 2021, doi: 10.32663/simes.v15i2.2063.

[21] M. S. Haryadi, *Pengaruh pre dan post heating pada proses gas metal arc welding (gmaw) terhadap struktur mikro dan kekuatan tarik baja karbon aisi 1045*. 2016.

[22] B. H. Pangaribowo and W. H. A. Putra, “Studi Pengaruh Pemanasan Awal pada Pengelasan Ulang Baja ASTM A36 akibat Reparasi terhadap Sifat Mekanis menggunakan Proses Las FCAW,” *J. Tek. ITS*, vol. 7, no. 2, 2019, doi: 10.12962/j23373539.v7i2.32392.

[23] T. Shrestha, S. F. Alsagabi, I. Charit, G. P. Potirniche, and M. V. Glazoff, “Effect of heat treatment on microstructure and hardness of grade 91 steel,” *Metals (Basel).*, vol. 5, no. 1, pp. 131–149, 2015, doi: 10.3390/met5010131.

[24] The American Society of Mechanical Engineers, “BPVC SECTION VIII Rules for Construction of Pressure Vessels Division 1 2023,” 2023, [Online]. Available: https://www.asme.org/codes-standards/find-codes-standards/bpvc-viii-1-bpvc-section-viii-rules-construction-pressure-vessels-division-1/2023/print-book

[25] ESAB, “Welding filler metal,” 2016.