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PREHEATING TEMPERATURE EFFECT ON FLUX-CORED ARC WELDING (FCAW) IN 3G POSITION ON STEEL PLATE TOWARDS TENSILE STRENGTH AND HARDNESS

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ABSTRACT

Every process, whether planning, testing, or production, must meet established standards and be conducted professionally. Professionalism means that processes are carried out correctly, from procedures and implementation to analysis and decision-making or conclusions. This prevents undesirable outcomes and ultimately ensures the sustainability of the company or its operations. This research was conducted to fulfill the professionalism standards in studying the effect of preheating temperature on welding results, especially on the mechanical properties of the weld, in this case, the tensile strength and hardness of LR Grade (AH36) steel plate welds. This research used the Flux-Cored Arc Welding (FCAW) process with variations in preheating temperature: without preheating, 100°C, and 200°C. The tensile test results showed that the specimen without preheating had the highest tensile strength of 530.28 MPa. Among the preheated specimens, the specimen with preheating at 200°C had the highest average tensile strength of 518.79 MPa. Therefore, it can be concluded that increasing the preheating temperature of the material decreases its tensile strength. Hardness observations showed that higher preheating temperatures caused a decrease in the hardness of the base metal and the Heat-Affected Zone (HAZ), while the hardness of the weld metal increased. Based on these two parameters, it can be concluded that preheating is not optimal for flux-cored arc welding (FCAW) with LR Grade (AH36) material.

Keywords: Flux-cored arc welding, LR grade, preheating, professionalism, ship plate, sustainability

Introduction

Every process, from planning, testing to production, must meet established standards and be executed professionally. Professionalism means that processes are executed correctly, from procedures and implementation to analysis and decision-making or conclusions. This prevents undesirable outcomes and ultimately ensures the sustainability of the company and its operations. This also applies to the shipping industry. In the shipping industry, one of the most frequently performed processes is welding, particularly in the steel ship industry. The welding method widely used to meet this need is Flux-Cored Arc Welding (FCAW). FCAW is known as a welding process that offers high speed, deep penetration, and can be applied to various welding positions and metal types. This process also allows welding to be performed in open environments, as some types of FCAW wire can provide internal shielding gas (self-shielded) [1][2].

One important factor in the welding process is the preheating temperature. Preheating is the process of heating the material before welding, intending to reduce the temperature difference between the weld area and the surrounding area [3]. This helps to prevent cracking due to rapid cooling and reduces residual stress that can affect the mechanical strength of the weld joint [4].

In carbon steel welding, especially for steels with medium to high carbon content, preheating is highly recommended as it can prevent the formation of hard and brittle martensite in the heat-affected zone (HAZ). If the preheating temperature is not properly considered, hydrogen cracking may occur, leading to structural failure of the welded joint [5]. Therefore, this study focuses on analyzing the effect of preheating temperature on the tensile strength and hardness of carbon steel weld joints using the FCAW method.

Several previous studies have shown that preheating affects the mechanical properties of weld joints. Increasing the preheating temperature can reduce the cooling rate after welding, resulting in a finer microstructure and toughness of the weld joint [6]. Furthermore, a study found that excessively high preheating temperatures can lead to excessive grain growth, potentially reducing the tensile strength of the weld joint [7]. Therefore, it is important to determine the optimal preheating temperature to achieve the best mechanical properties.

Since ship hull structures must be able to withstand dynamic loads, seawater corrosion, and pressure from waves and cargo, uncontrolled mechanical properties such as tensile strength and toughness in weld joints can lead to cracking or even structural failure during ship operation. Thus, preheating serves as a crucial preventive measure to ensure the integrity of weld joints in ship hull construction.

In the industry, the selection of preheating temperature often refers to established standards such as the AWS D1.1 Structural Welding Code, which recommends a temperature range based on the type of material and plate thickness. However, in practice, the preheating temperature is also influenced by other factors such as the type of electrode used, the cooling method, and environmental conditions during the welding process [8][9].

This study aims to evaluate the effect of varying preheating temperatures on the mechanical properties of carbon steel weld joints, particularly in terms of tensile strength and hardness. The temperature variations used in this study are no preheating, 100°C, and 200°C. Tensile testing is conducted to determine the extent to which the mechanical strength of the weld joint can withstand tensile forces, while hardness testing is performed to evaluate changes in mechanical properties in the weld and HAZ areas. The results of this study are expected to contribute to the field of welding, particularly in determining optimal preheating parameters to improve the quality of carbon steel weld joints. Additionally, this research may serve as a reference for the manufacturing and construction industries in implementing more effective and efficient welding techniques.

Methodology

a. Research Detail

The steps of the research are to analyze the effect of variations in preheating temperature on the tensile strength of carbon steel welded joints using the FCAW method. Moreover, it analyzes the effect of preheating temperature variations on hardness in the weld area and HAZ. Then, determining the optimal use of preheating or not to obtain the best combination of tensile strength and hardness in carbon steel welded joints.

b. Data Identification

Previous research on the welding process of carbon steel plates of the LR GRADE AH36 type, selecting the appropriate welding parameters is crucial to ensure the quality and strength of the weld joints, particularly in terms of tensile strength and hardness. One critical parameter that must be considered is the preheating temperature, or the initial heating of the material before welding. Preheating is known to affect the cooling rate and heat distribution in the weld area and its surroundings, which directly influences the mechanical properties of the weld.

However, the effect of varying preheating temperatures on the tensile strength of LR GRADE AH36 plates welded using the FCAW method has not been fully understood. Further research is needed to comprehend how changes in preheating temperature—such as no preheating, 100°C, and 200°C—affect the weld joint's resistance to tensile forces.

c. Data Collection

Data collection in this study was carried out experimentally in a laboratory to evaluate the effect of varying preheating temperatures on the tensile strength and hardness of welds produced using the

FCAW method on LR GRADE AH36 carbon steel plates with a 3G (vertical up) welding position. The initial step involved material preparation, including cutting the steel plates into standardized test specimens, followed by surface cleaning to remove contaminants such as oil, rust, or dust that could affect weld quality. The specimens were then grouped based on preheating temperature variations: no preheating (as the control), preheating at 100°C, and preheating at 200°C. Preheating was applied evenly to the welding area using a heating device until the desired temperature was reached, with temperature control monitored using thermocouples and infrared thermometers to ensure consistency [10].

The welding process was conducted using the FCAW method, with welding parameters such as current, voltage, welding speed, and filler wire type kept constant for all specimens to ensure that preheating temperature was the only independent variable. After welding and sufficient cooling, the specimens were cut to prepare samples for tensile and hardness testing [11].

Tensile testing was performed using a Universal Testing Machine (UTM) in accordance with the AWS D1.1 standard, where each specimen was pulled until fracture to obtain the maximum tensile strength value (Ultimate Tensile Strength/UTS). Meanwhile, hardness testing was conducted using the Vickers Hardness Test method, also based on AWS D1.1 standards. Hardness was measured at three key locations: the weld metal (WM), the heat-affected zone (HAZ), and the base metal (BM), to observe how different preheating temperatures affected the hardness distribution across the weld area.

All data obtained from the testing were carefully recorded, both manually and using supporting software. Additionally, every step of the testing process was documented with photographs and technical notes to ensure traceability of data. The collected data were then analyzed quantitatively to identify trends and changes, and to compare the results across the different preheating temperature conditions, ultimately concluding their effects on the mechanical properties of the welded joints.

d. Data Analysis

The data analysis will be conducted based on the results of tensile strength and hardness tests from each specimen welded with different preheating temperatures, namely without preheating, at 100°C, and at 200°C. The purpose of this analysis is to evaluate the extent to which preheating temperature influences the mechanical properties of welded joints on LR GRADE AH36 carbon steel plates welded using the Flux-Cored Arc Welding (FCAW) method in the 3G (vertical up) position [4][5].

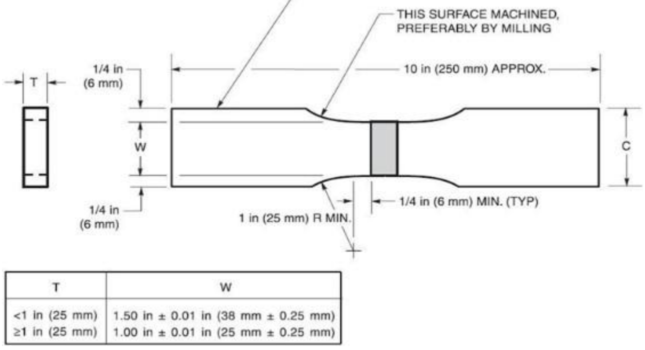
e. The Effect of Preheating Temperature on the Tensile Strength of Welded Joints

Preheating temperature in the welding process plays an important role in determining the quality of the weld joint, particularly its tensile strength. Tensile strength is one of the main mechanical parameters used to assess a material's resistance to tensile forces until fracture occurs. In welded joints, tensile strength is influenced by the microstructure formed during the process, which is significantly affected by thermal parameters such as preheating temperature.

f. Tensile Test

Each material has different properties (flexibility, hardness, toughness, etc.). To determine the mechanical properties of a material, testing is required—tensile testing is one of the most commonly performed tests. This test is used to determine the strength level of a material and to identify its characteristics [12].

A tensile testing machine operates by pulling the specimen axially, from both ends, until the specimen undergoes plastic deformation and eventually breaks. During the pulling process, a change in length occurs at the center of the specimen, and a measuring device accurately records this elongation relative to the applied load. From this data, several key parameters are calculated, such as the UTS, yield strength, modulus of elasticity (Young's modulus), and total elongation.



T	W
<1 in (25 mm)	1.50 in ± 0.01 in (38 mm ± 0.25 mm)
≥1 in (25 mm)	1.00 in ± 0.01 in (25 mm ± 0.25 mm)

Figure 1. Examples of Tensile Test

g. Hardness Test

The hardness test aims to determine a material's resistance to plastic deformation caused by external loads. A commonly used method for testing the hardness of shipbuilding steel is the Vickers hardness test (HV), which is suitable for materials with small thicknesses and smoother surfaces.

The Vickers method involves pressing a diamond indenter, shaped like a pyramid with a square base and an angle of 136 degrees between opposite faces, into the surface of the test material or specimen. This indentation process creates a mark or impression on the material's surface. The hardness value is determined by measuring the average diagonal length of the indentation using a microscope.

One of the main reasons for conducting a hardness test on welded joints is to avoid the potential formation of martensitic structures, especially in medium- to high-carbon steels. Martensite is a very hard but brittle structure, prone to cracking, particularly under cold conditions or when hydrogen is absorbed into the weld metal. If the measured hardness value in the HAZ exceeds the standard limit (e.g., above 350 HV for carbon steels), the joint is considered at high risk of hydrogen-induced cracking (HIC) and typically must be repaired or subjected to Post-Weld Heat Treatment (PWHT) to reduce its hardness.

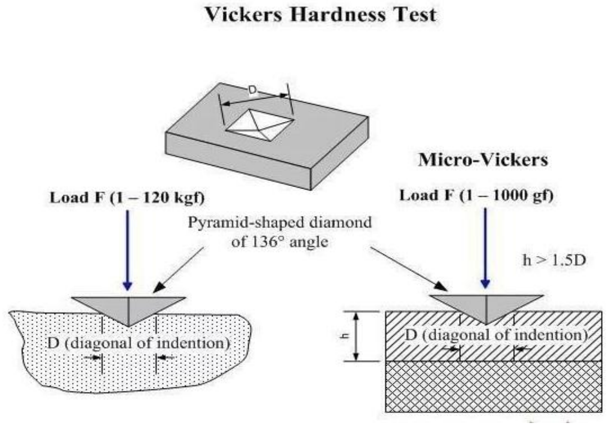


Figure 2. Examples of Hardness Test

Result and Discussion

a. Welding Procedure Specification (WPS)

The welding process was carried out at PT PAL INDONESIA. The testing of the welded specimens was conducted at the Material Testing Laboratory of PT PAL INDONESIA. Welding was performed on LR GRADE (AH36) steel plates with the following specifications: length 300 mm, width 300 mm (2 plates), and thickness 11 mm. A bevel was made on one side of the plate before welding. The welding process followed the parameters specified in the WPS applicable at PT PAL INDONESIA.

The WPS is a qualified written document prepared as a guideline for welding operators during the welding process to ensure compliance with all required standards and codes. WPS is a mandatory standard that must be met and is a prerequisite in the welding process used in the operation of industrial tools or machines that involve welding. The WPS must be prepared before performing any welding operations. It is also implemented in the welding of various industrial equipment or machinery, such as heat exchangers, pressure vessels, and other equipment that involves welding applications.

b. WPS on Plates without Preheating.

Based on the WPS that was prepared before the welding process, the LR GRADE (AH36) plate material without preheating consists of three welding layers, with a ceramic backing applied beforehand. The ceramic backing functions as a support to improve weld penetration and to produce a neater and stronger weld. Each welding layer is described as follows:

The first layer is the root weld, which serves as the base welding on the material. In this stage, the electrode used is AWS A5.20 type with a diameter of 1.2 millimeters. The current applied during the root weld is 17 Amperes, and the voltage is 26.8 Volts. From the recorded time for one root weld pass, it took 3.45 minutes, resulting in a welding travel speed of 87 mm/min. The polarity type used DCEM.

The second layer is the filling weld, which serves to fill the joint in the material. In this stage, the electrode used is AWS A5.20 type with a diameter of 1.2 millimeters. The current used during the weld is 17 Amperes, and the voltage is 26.8 Volts. Based on the recorded time for one pass of the filling weld, it took 1.26 minutes, resulting in a welding travel speed of 238 mm/min. The polarity type used is DCEM.

The third layer is the weld cap area. In this stage, the electrode used is AWS A5.20 type with a diameter of 1.2 millimeters. The current used during the weld is 17 Amperes, and the voltage is 26.8 Volts. Based on the recorded time for one pass

Table 1. WPS without preheating

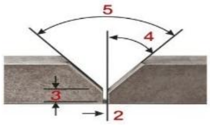
WELDING PROCEDURE							
Weld Layer (s)	Process	Filler Metal		Current		Volt Range (V)	Travel Speed Range (mm/min)
		Class	Diameter (mm)	Type of Polarity	Amp. Range (A)		
1st	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	60 – 90
2nd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 – 140
3rd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 – 140
 Joint Detail							

Table 2. WPS preheating 100^{0}C

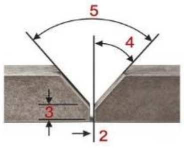
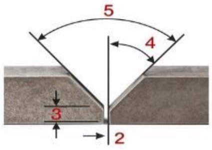
WELDING PROCEDURE							
Weld Layer (s)	Process	Filler Metal		Current		Volt Range (V)	Travel Speed Range (mm/min)
		Class	Diameter (mm)	Type of Polarity	Amp. Range (A)		
1st	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	60 - 90
2nd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 - 140
3rd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 - 140
 Joint Detail							

Table 3. WPS preheating 200^{0}C

WELDING PROCEDURE							
Weld Layer (s)	Process	Filler Metal		Current		Volt Range (V)	Travel Speed Range (mm/min)
		Class	Diameter (mm)	Type of Polarity	Amp. Range (A)		
1st	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	60 - 90
2nd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 - 140
3rd	FCAW	AWS A5.20	1,2	DCEM	15-19	25-28	80 - 140
 Joint Detail							

of the cap weld, it took 2.6 minutes, resulting in a welding travel speed of 115.3 mm/min. The polarity type used is DCEM.

c. WPS for Plate Welding with Preheating at 100°C

Based on the Welding Procedure Specification (WPS) data prepared before the welding process, the LR GRADE (AH36) plate material undergoes a preheating process consisting of three welding layers. Each welding layer is explained as follows.

The first layer is the root weld on the material. In this stage, the electrode used is AWS A5.20 type with a diameter of 1.2 millimeters. The current used for the root weld is 17 Amperes, and the voltage is 26.8 Volts. Based on the recorded time for one pass of the root weld, it took 4.02 minutes, resulting in a welding travel speed of 74.6 mm/min. The type of polarity used (DCEM).

The second layer is the filling weld on the material. In this stage, the electrode used is also AWS A5.20 type with a diameter of 1.2 millimeters. The current used remains 17 Amperes, and the voltage is 26.8 Volts. The recorded time for one pass of the filling weld is 2 minutes, resulting in a welding travel speed of 150 mm/min. The type of polarity used (DCEM).

The third layer is the weld cap area. In this stage, the electrode used is the AWS A5.20 type with a diameter of 1.2 millimeters. The current used for the cap weld is 17 Amperes, and the voltage is 26.8 Volts. The recorded time for one pass of the cap weld is 2.43 minutes, resulting in a welding travel speed of 123 mm/min. The type of polarity used is DCEM.

d. WPS for Plate Welding with Preheating at 200⁰C

Based on the WPS data prepared before the welding process, the LR GRADE (AH36) plate material undergoes a preheating process consisting of three welding layers. Each welding layer is explained as follows.

The first layer is the base welding on the material (root weld). In this stage, the electrode used is of AWS A5.20 type with a diameter of 1.2 millimeters. The current used in the root weld is 17 Amperes, and the voltage is 26.8 Volts. From the recorded time for one pass of the root weld, it took 4.02 minutes, resulting in a welding travel speed of 74.6 mm/min. The polarity type used is DCEM.

The second layer is the filling weld on the material. In this stage, the electrode used is also of AWS A5.20 type with a diameter of 1.2 millimeters. The current used is 17 Amperes, and the voltage is 26.8 Volts. The recorded time for one pass of the filling weld is 2 minutes, resulting in a welding travel speed of 150 mm/min. The polarity type used is DCEM.

The third layer is the weld cap area (cap). In this stage, the electrode used is of AWS A5.20 type with a diameter of 1.2 millimeters. The current used in the cap weld is 17 Amperes, and the voltage is 26.8 Volts. The recorded time for one pass of the cap weld is 2.43 minutes, resulting in a welding travel speed of 123 mm/min. The polarity type used is DCEM.

e. Visual Test

Visual inspection was carried out as an initial stage in the series of tests to assess the quality of the weld joint. This test aims to identify the presence of surface defects directly without damaging the specimen. In this study, the visual inspection was conducted after the welding process was completed and the weld metal had fully cooled. The examination was performed using bright lighting, a magnifying glass, and a weld gauge to evaluate the geometric dimensions of the weld cross-section.

The visual observation results on all specimens indicated no significant surface defects. The surface of the weld metal appeared smooth and uniform, with a consistent and neat weld bead appearance, and showed good fusion between the weld metal and the base metal. No cracks, open porosity (blow holes), undercut, overlap, slag inclusion, or excessive spatter were found on the weld surface.

Overall, the visual inspection results support the success of the welding parameters designed in this procedure and provide a strong basis to proceed to the next stage of destructive testing. The absence of visual defects also strengthens the assumption that the weld joint has good structural integrity, is fit for use, and meets the visual standard criteria based on AWS D1.1 and ISO 5817 level B (stringent).

f. Test Visual Objectives

Visual testing (VT) is the most basic non-destructive testing (NDT) method used to evaluate the surface condition of welded joints. Its purpose is to ensure that the weld is free from any visible defects and meets established quality standards before further testing is conducted.

g. Observation result

After a thorough inspection of all test specimens at varying preheating temperatures, no visual defects were found. The following are the general findings of the visual inspection:

1. Uniform weld path, no deviations in direction or shape.
2. Smooth weld surface and free of slag, spatter, or contamination.
3. No open porosity.
4. No undercuts or overlaps.
5. No microcracks at the root or weld surface.
6. No arc strikes observed outside the weld zone.

Figure 2. Welding results without preheating

Figure 3. Welding results initial heating 100^0C

Figure 4. Welding results initial heating 200^0C

h. Mechanical Testing

Mechanical testing is a series of tests conducted on materials to determine their mechanical properties, such as strength, hardness, toughness, and ductility. The main objective of this testing is to ensure that the material (including weld joints) can withstand loads and forces during service without failure. The superior properties of a material can be matched to its intended application. There is a tendency for some mechanical properties to be inversely related, meaning that optimizing certain properties often comes at the expense of others. Therefore, selecting a suitable material and applying the right treatment becomes essential to optimize these properties according to the specific requirements.

Mechanical testing is a critical part of weld quality assessment because it provides a quantitative understanding of the material's strength and resistance to applied loads. In the context of welding, mechanical tests are used to evaluate whether the weld results meet technical specifications and quality standards, particularly in terms of tensile strength and hardness of the joint. These tests not only measure the joint's resistance to external forces but also reflect the microstructural condition and the success of fusion between metals. In this study, two main types of mechanical tests were carried out: tensile testing and hardness testing, both of which aim to evaluate the welding results using the FCAW method on steel plates in the 3G position.

i. Tensile Strength Test

Tensile testing is carried out to determine the extent to which a welded joint can withstand axial tensile forces before failure or fracture occurs. This test serves as a primary indicator of the success of the welding process, as it reveals the strength of fusion between the weld metal and the base metal, as well as the microstructural condition along the weld zone. In this study, tensile tests were performed on specimens welded using the FCAW method in the 3G position on steel plates, both with and without the application of preheating.

The experimental device used for tensile testing must have strong grips and high stiffness. The tensile test is conducted in accordance with a specific standard. In this final project, the tensile testing refers to the AWS D1.1 standard. The test specimens were prepared based on AWS D1.1–09 specifications, with dimensions of 300 mm in length, 38 mm in width, and 11 mm in thickness, with a minimum radius of 60 mm.

The results of the tensile test are presented in the form of a graph. The graph shows the yield stress and maximum stress of the material being tested. The graph also identifies the fracture zones that occurred during the specimen testing. The

Table 4. Non-preheating tensile test calculation results

Test Piece Code	Visual	A0 (WxT) mm^2	p.yield (kgf)	P.max (kgf)	Yield Strength (MPa)	Tensile Strength (MPa)	L0 (mm)	L1 (mm)	E (%)	Breaking
Non	Good	(25,3x11) 278,3	11.000	15.050	387,55	530,28	50	67	34	Base metal

Table 5. Calculation results of tensile preheat 100^{0}C

Test Piece Code	Visual	A0 (WxT) mm^2	p.yield (kgf)	P.max (kgf)	Yield Strength (MPa)	Tensile Strength (MPa)	L0 (mm)	L1 (mm)	E (%)	Breaking
100	good	(25x11) 275	10.850	14.550	386,86	518,79	50	64	28	Weld Metal

Table 6. Calculation results of tensile preheat 200^{0}C

Test Piece Code	Visual	A0 (WxT) mm^2	p.yield (kgf)	P.max (kgf)	Yield Strength (MPa)	Tensile Strength (MPa)	L0 (mm)	L1 (mm)	E (%)	Breaking
100	good	(25,4x11) 279,4	10.450	14.525	366,75	509,76	50	68	36	Base metal

following describes the results of each test and the tensile test calculations for each specimen.

Table 7. Minimum results of tensile test calculation

Mechanic Properties	Minimum Value LR AH36
Yield Strength (YS)	≥ 355 MPa
Tensile Strength (UTS)	490 Mpa
Elongation ($L_0 = 5.65\sqrt{A}$)	≥ 21%

From the tensile test data based on calculations in Tables 4.4 to 4.6, it is found that preheating treatment affects the tensile strength of LR Grade (AH36) steel. The results of this thesis research showed that specimens given 200^{0}C preheating treatment had the lowest tensile strength of 509.76 MPa, and one of the test materials experienced fracture in the base metal. specimens with 100^{0}C preheating had a tensile strength value of 518.79 MPa. specimens without preheating had the highest average tensile strength of 530.041 MPa.

From the specimen without preheating to the one treated with a preheating temperature of 200°C, the tensile strength decreased progressively. This decline in tensile strength was directly proportional to the increasing preheating temperature. The reduction is attributed to the influence of higher preheating temperatures, which lead to less effective penetration during the welding process, thereby resulting in poor fusion between the base metal and weld metal.

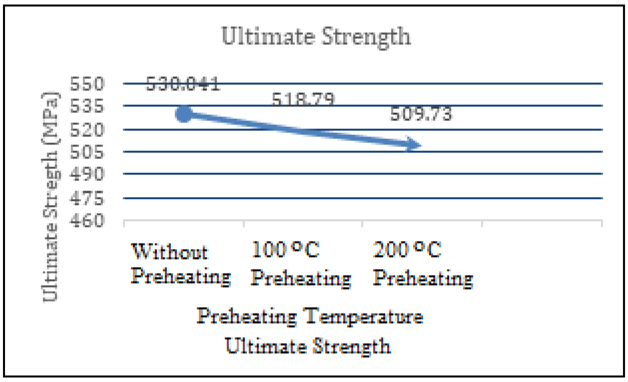


Figure 5. Ultimate Strength Specimen Graph

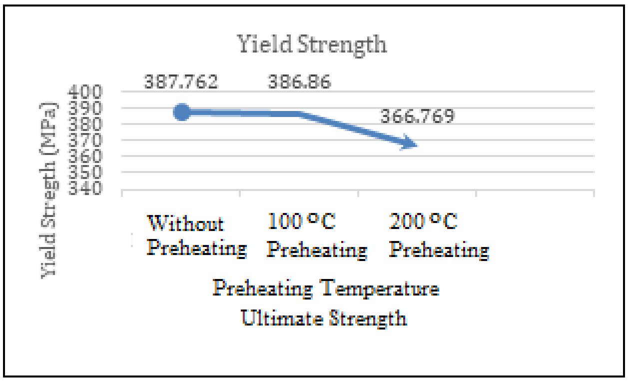


Figure 6. Yield Strength Specimen Graph

Table 8. Hardness test results data of specimens without preheating

Location	Vickers Hardness								
	Weld metal			HAZ			Base Metal		
	1	2	3	1	2	3	1	2	3
200^0 C	201,21	203,32	205,47	182,64	183,82	186,64	184,61	179,92	182,64
Average	203,33			184,36			182,40		

Table 9. Hardness test results data of specimens preheated to 100^0C

Location	Vickers Hardness								
	Weld metal			HAZ			Base Metal		
	1	2	3	1	2	3	1	2	3
100^0 C	201,21	200,57	204,42	185,44	200,89	187,56	187,24	184,61	189,14
Average	202,06			191,29			187,87		

Table 10. Hardness test results data of specimens preheated to 200^0C

Location	Vickers Hardness								
	Weld metal			HAZ			Base Metal		
	1	2	3	1	2	3	1	2	3
Without preheat	179,92	182,32	181,51	181,78	201,89	193,08	187,28	198,79	198,25
Average	181,25			192,25			194,77		

j. Vickrs Hardness Test

In this study, the hardness test was performed using the Vickers Microhardness method, which was chosen due to its accuracy in measuring narrow regions and its ability to detect even small variations in hardness. The testing instrument used was a microhardness tester with a load of 1 kilogram (HV1) and a dwell time of 10–15 seconds. The test was carried out on FCAW weld specimens in the 3G position, both with and without preheating treatment.

Before testing, the specimens were cross-sectioned perpendicular to the welding direction and polished until the surface was smooth and even.

The data in Table 8 shows the results of specimen hardness tests without preheating temperature in the base metal, HAZ, and weld metal areas. Each area was sampled at three pressure points so that each specimen was tested nine times. From the test results above, the average nominal value for the weld metal was 181.25 VHN, HAZ 192.25 VHN, and base metal 194.77 VHN. The lowest hardness value was due to rapid cooling,

which resulted in a softer weld metal. Meanwhile, in the HAZ and Base Metal areas, the hardness was high because the HAZ area experienced very rapid cooling (quenching). This rapid cooling can cause martensite transformation in carbon or alloy steel, resulting in a hard but brittle structure.

The data in Table 9 is the result of the hardness test of specimens that were given a preheating temperature treatment of 100°C in the areas of base metal, HAZ, and weld metal. Each area was sampled at three points, so each specimen underwent nine indentation tests.

From the test results above, the average nominal values were obtained as follows: weld metal 202.06 VHN, HAZ 191.29 VHN, and base metal 187.87 VHN. In the weld metal area, the value increased due to the slower cooling, which prevented the formation of soft structures. Meanwhile, in the HAZ and base metal areas, the value decreased due to the increase in the initial temperature of the metal before the welding process. As a result, after welding, the metal did not cool directly from high temperature to room temperature, and the cooling occurred more slowly. This prevented the formation of martensite (a hard structure). Instead, ferrite and pearlite, which are softer, were formed.

The data in Table 10 is the result of the hardness test of welded specimens without preheating temperature treatment, in the areas of weld metal, HAZ, and base metal. Each area was sampled at three points, so each specimen underwent nine indentation tests.

From the test results above, the average nominal values were obtained as follows: weld metal 203.33 VHN, HAZ 184.36 VHN, and base metal 182.40 VHN. In this treatment, the base metal and HAZ areas had the lowest hardness values, while the weld metal had the highest hardness value. This was caused by the tempering effect on the base metal and the slow cooling that caused the HAZ to form a soft structure.

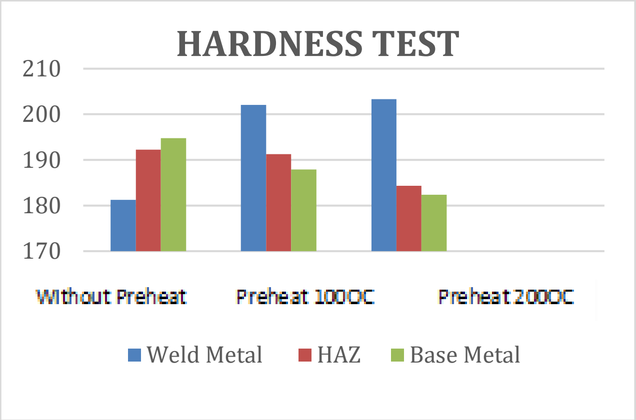


Figure 7. Hardness test results

From the graph above, it can be concluded that preheating treatment affects the mechanical properties of the material, especially the hardness properties. The material experiences an increase in hardness value in the weld metal due to the influence of the heat received by the specimen during the preheating process, which causes the higher temperature, the harder the specimen is treated. Meanwhile, in the base metal and HAZ areas, the higher the preheating temperature given, the lower the hardness value of the metal. This is because at low preheat or without preheat, rapid cooling can form a very hard but brittle martensite or bainite structure. High preheats, the HAZ zone experiences the formation of large and soft grains, resulting in a decreased hardness value. Then, in the base metal zone, the greater the preheat, some of the heat spreads to the base metal, causing a mild "tempering" effect near the HAZ. This effect makes the base metal softer and less tense.

Conclusion

From the results of the previous discussion, the following conclusions can be drawn:

1. The result of the mechanical test, specifically the tensile strength, showed that the specimen without preheating had the highest average tensile strength value of 530.28 MPa, while the specimen with preheating at a temperature of 200^{0}C had the lowest average tensile strength value of 518.79 MPa. Therefore, it can be concluded that the higher the preheating temperature applied to the material, the lower its tensile strength becomes.
2. The hardness test results showed that the specimen with the highest hardness values in the base metal and Heat Affected Zone (HAZ) areas was the one without preheating. Conversely, the specimen with the lowest hardness in the weld metal area was also the one that did not undergo preheating. Thus, it can be concluded that preheating treatment affects the hardness values in the welded area, where preheating tends to reduce hardness in the base metal and HAZ areas, but can increase hardness in the weld metal area.
3. From the series of tests carried out and the data processing conducted, it can be determined that the application of preheating temperature is less optimal for FCAW (Flux-Cored Arc Welding) on LR Grade (AH36) ship steel plate.

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