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Effect of Preheating Process and V Groove Type on the Tensile and Metallography Test of ASTM A53 with A36 Weld Joint Using FCAW Method

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ABSTRACT

Steel is a metal material that is often used in the maritime industry due to its availability and weldability. ASTM A53 steel is a low carbon steel commonly used for piping applications. ASTM A36 steel is a low carbon steel commonly used for offshore buildings. This study aims to determine the influence of preheat temperature and V groove type on bend resistance of A53 and A36 weld joint using FCAW (Flux Cored Arc Welding) method. The preheat temperature used are 100°C and 150°C with groove type variations used were single V groove and double V groove. The type of protective gas used is 100% CO_2. The results of tensile strength test showed that in the welding process in this study, specimen with preheat temperature of 150°C and double V-Groove shape has the strongest tensile strength, with HAZ width of 3.91 mm, ferrite phase percentage of 58.08%, and pearlite phase percentage of 41.92%.

Keywords : *A36 steel, A53 steel, Preheating, V Groove, , Flux Cored Arc Welding*.

1. INTRODUCTION

As the age progresses, welding continues to be used until today. In the maritime industry, welding process is very important because many constructions require technology to connect steel as building materials. Welding is also used in the fabrication of aircraft, automotive, shipping and piping applications [1]. Therefore, welding is the core stage in fabrication [2].

Welding is the process of connecting several metal rods using heat energy [3]. ASTM A53 and A36 steels are often used for welding as they are basic materials and easy to weld. The advantage in using those material is that it has good properties and strength against corrosion [4].

There are several known arc welding methods, including: GMAW (Gas Metal Arc Welding), FCAW (Flux Cored Arc Welding), SMAW (Shield Metal Arc Welding), and so on. In this research, the welding method used is FCAW (Flux Cored Arc Welding), because it is able to provide several advantages such as: welding can be done semi-automatically, has a high reliability and can be operated comfortably. When using FCAW method, the composition of the protective gas is considered as the most important thing due to its function to protect the melting of metal fillers in the groove from environmental factors [5]. The shape of the groove also affects the mechanical and metallographic properties of the welded joint[6].

Therefore, the study will discuss how to bend weld joint with FCAW method on ASTM A53 steel plate with ASTM A36. This study will analyze the influence of preheating process and V groove type against the welded joints of ASTM A53 steel plate with ASTM A36.

2. MATERIALS AND METHODS

This section will discuss a series of steps carried out in the whole process of this study. Literature studies should be done first in accordance with codes and standards, then the appropriate Welding Procedure Specification (WPS) can be made. WPS design needs to be discussed with welder. After preparing materials and equipment, the welding can be done according to the intended procedure. After the welding procedure is complete, the specimen is prepared to be tested for its mechanical properties. The tests carried out are tensile test, bending test, and metallographic test.

2.1 Flux Cored Arc Welding (FCAW)

FCAW (Flux Cored Arc Welding) is a type of electric arc welding comes from electrodes and from the outside. The protective gas derived from the electrode is a flux found in the electrode nucleus [7]. The purpose of using protective gases is to stabilize the arc flame and protect the metal fluid from air contamination. There are several factors that affect the welding result, including: the composition and flow rate of protective gases, the type of electrodes, the shape of the groove, the rate of feeding, voltage, current, and so on [9]. The basic system on FCAW welding is shown in Figure 1.

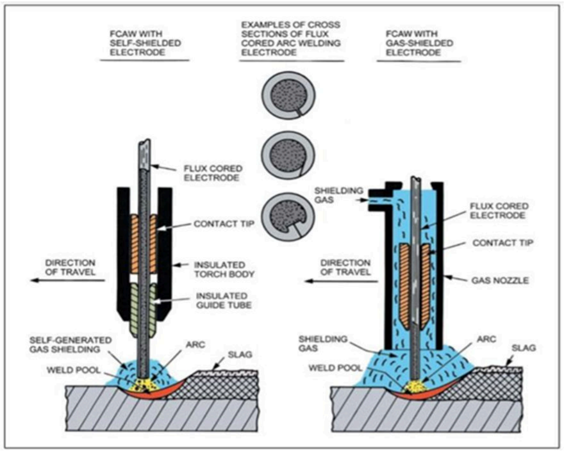

Figure 1. FCAW Basic System [10]

2.2 Preheating

The preheating is the harvesting of some or all part of the metal to be welded [11]. This heating aims to reduce the temperature difference that arises [12]. In addition, early heating can slow the cooling rate and reduce weld distortion and defects [13][14]. The initial heating temperature for low carbon content of 0.2 % - 0.3% is 90°C to 150°C [15].

2.3 Welding Groove

Welding Groove is the size of the space filled with welding filler metal. It aims to accommodate filler metal so that more surface area is attached to the work object and improve the quality of welding. If the weld is thicker, more acicular ferrite will be formed [16]. There are several things to note while determining the type of welding groove: the thickness of work objects, types of work objects, desired strength, and welding position.

2.4 Tensile Test

Tensile test is a test using force or tensile stress on the material that aims to know the strength of the material being tested. In this study, the stress used is the external actual stress, which the tensile test is carried out by means of continuous withdrawal of tensile forces. This is done so that the material experiences a long increase and experience fatigue which then the material will fail. Materials that experienced plastic deformation can fail when the generated stress exceed the material yield strength [17].

2.5 Metallography Test

Metallography is the study of the microstructure characteristic of metal and their alloy. It also analyze the property of metal and their alloy, which consists of macrostructure and microstructure test. Macrostructure test is a material testing process with naked eye to observe the morphology of the weld, including the measurement of the HAZ width and the presence of defect in the weld due to the deformation process, heat treatment process, and composition differences. The weld result can be seen properly as illustrated in Figure 2.

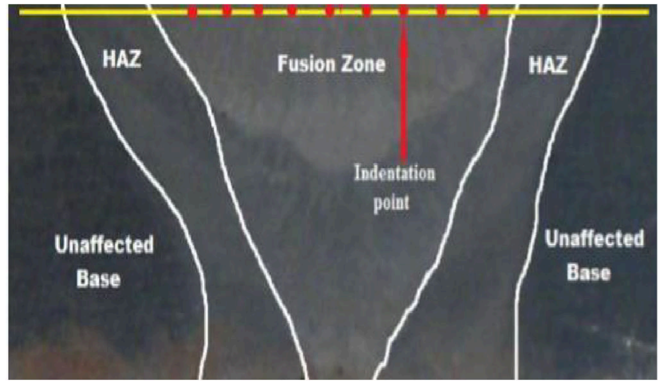

Figure 2. Illustration of Weld Area [18]

While micro-testing is a test of the structure of materials using a microscope. This test is carried out to find out the shape and changes of micro-structures due to phase changes. It should be also note that in medium carbon steel welding metals there are not only ferrite and pearlite grains, but widmanstatten ferrite, acicular ferrite, polygonal ferrite, and bainite, can also be found [19].

3. RESULT AND DISCUSSION

3.1 Welding Procedure

In this study, welding was done using Welding Procedure Spesification as follows:

- Material : ASTM A53 and ASTM A36
- Dimension : 200 mm x 150 mm x 15 mm
- Joint Type : Butt Joint
- Groove Type : Single and Double V Groove
- Groove Angle : 60°
- Number of Layer : 4 and 6 Layers
- Welding Position : 1G
- Single V Volume : 278.400 mm^3
- Double V Volume : 139.200 mm^3
- Preheat Temperature : 100°C and 150°C
- AWS No. (Class) : AWS ER71-T
- Filler Metal (Dia.) : Ø 1.2 mm
- Current : DCEP
- Cleaning Method : Griding
- Shielding Gas : 100% CO_2
- Gas Flow Rate : 15L/min - 20L/min

The use of preheat temperatures of 100°C and 150°C is carried out in both type of groove using pure CO-protective gas. Illustration of groove specimens can be seen in Figure 3 and Figure 4.

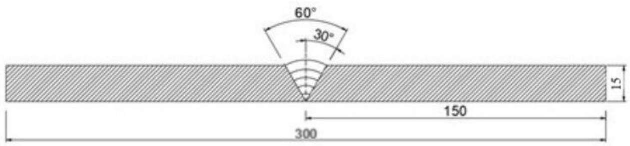

Figure 3. Single V– Groove Joint Specification

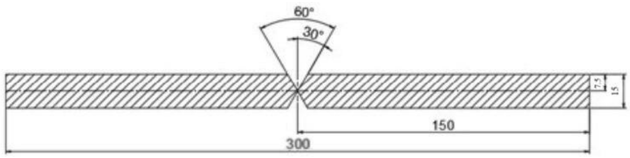

Figure 4. Double V– Groove Joint Specification

3.2 Tensile Test Result

The purpose of this test is to obtain the yield and ultimate tensile strength value of the welding test specimen that has passed the radiography test. In addition, this test is also useful to know the elastic and plastic limits of the test specimen. The standard used in this test is ASME Section IX, where the welding specimen is declared to pass the tensile test when the ultimate strength on the metal weld exceeds the specified tensile minimum on the base metal itself and breaks (break point) on the base metal. To get valid and accurate test results for each specimen is carried out three times. In this study using different materials namely A53 and A36 steel, minimum specified tensile material of A53 steel is smaller than A36 steel so that breaking point is on the base metal steel A53. For details of the test results of the six test specimens can be seen in Table 1, with the visual results of the test object contained in Figure 5, while for the graph of the test results are contained in Figure 6.

Table 1. Specimen Tensile Test Result

Specimen	Specimen Spesification			F Yield	F Ultimate	Tensile Test Result			Averange	
	Width	Thickness	Area			Yield Strength	Ultimate Strength	Breaking	Yield Strength	Ultimate Strength
	(mm)	(mm)	(mm)	kN	kN	(MPa)	(MPa)		(Mpa)	(MPa)
0A-1	17,5	13	227,5	60,29	80,36	265,01099	353,230769	*Base Metal*		
0A-2	17,5	13	227,5	60,5	80,15	265,93407	352,307692	*Base Metal*		
0A-3	17,5	13	227,5	60,77	80,52	267,12088	353,934066	*Base Metal*	266,021978	353,158
0B-1	17,5	13	227,5	67,44	86,27	296,43956	379,208791	*Base Metal*		
0B-2	17,5	13	227,5	67,7	86,66	297,58242	380,923077	*Base Metal*		
0B-3	17,5	13	227,5	67,73	86,8	297,71429	381,538462	*Base Metal*	297,245421	380,557
1A-1	17,5	13	227,5	82,55	91,21	362,85714	400,923077	*Base Metal*		
1A-2	17,5	13	227,5	82,74	91,15	363,69231	400,659341	*Base Metal*		
1A-3	17,5	13	227,5	82,9	91,67	364,3956	402,945055	*Base Metal*	363,648352	401,509
1B-1	17,5	13	227,5	88,48	96,44	388,92308	423,912088	*Base Metal*		
1B-2	17,5	13	227,5	88,36	96,29	388,3956	423,252747	*Base Metal*		
1B-3	17,5	13	227,5	88,72	96,51	389,97802	424,21978	*Base Metal*	389,098901	423,795
2A-1	17,5	13	227,5	94,38	105,38	414,85714	463,208791	*Base Metal*		
2A-2	17,5	13	227,5	94,71	105,56	416,30769	464	*Base Metal*		
2A-3	17,5	13	227,5	94,92	105,81	417,23077	465,098901	*Base Metal*	416,131868	464,103
2B-1	17,5	13	227,5	96,12	110,37	422,50549	485,142857	*Base Metal*		
2B-2	17,5	13	227,5	96,73	110,68	425,18681	486,505495	*Base Metal*		
2B-3	17,5	13	227,5	96,88	110,82	425,84615	487,120879	*Base Metal*	424,512821	486,256

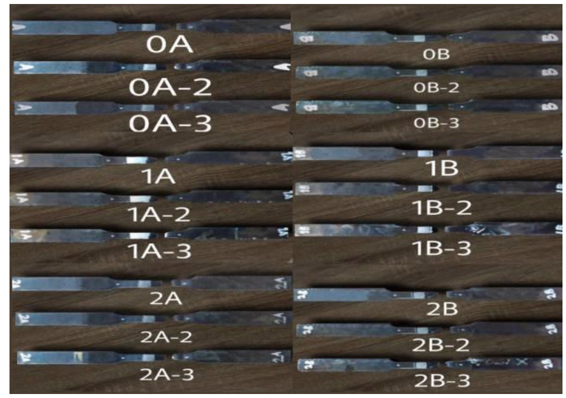

Figure 5. Tensile Test Result

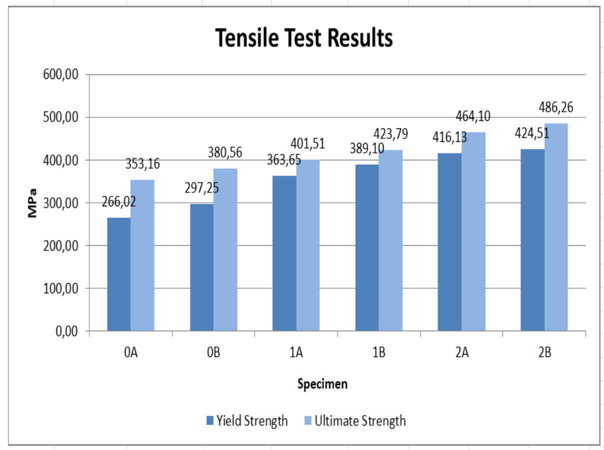

Figure 6. Graph of Tensile Test Result on Each Specimen

Specimen tensile test results based on ASME Section IX with single V Groove and Double V Groove form were declared to pass the tensile test criteria, and it was obtained that FCAW welding specimens with preheat temperature of 150°C and Double V Groove type had the highest average tensile strength value of 503.643 MPa. This is because the specimen undergoes a faster cooling process. When viewed from the influence of its groove form, the Double V-Groove holds less weld pool volume than the Single V-Groove, so the cooling process on the Double V-Groove is relatively faster and provides greater tensile strength.

3.3 Metallography Test

Metallographic testing consists of photo observation of macro structures and photos of micro structures. Macro photo observations of structures use DSLR cameras with a magnification of 7x to capture the base metal area, HAZ, and weld metal. The purpose of the macro structure photo is to measure the width of the HAZ area and to find out the defects in the weld macro. While the micro structure photos are done using 100x and 400x magnification on a microscope used to calculate the percentage of dark parts (pearlite) and white parts (ferrite) in the base metal area, HAZ, and weld metal.

In the macro photo observations, the widest HAZ area was produced in specimen 2A with the form of Single V Groove groove and preheat temperature of 150°C, obtained the width of haz area of 5.10 mm. then decrease sequentially on specimens 2B, and 1A. The decline continued at 1B, 0A and 0B. So 0B as a specimen with the smallest HAZ width, with a width of 1.97 mm. From the data, it is concluded that the greater the preheat temperature, the greater the HAZ area formed. The width of HAZ is summarized in Table 2, while the macro photo results on the six specimens can be seen in Figure 7, and the HAZ width comparison graph on the six specimens can be seen in Figure 8.

Table 3. HAZ Width of Each Specimen

Specimen	Description	HAZ (mm)
0A	*Single* V without Preheat	2,38
0B	*Double* V without Preheat	1,97
1A	*Single* V and 100°C	3,40
1B	*Double* V and 100°C	2,86
2A	*Single* V and 150°C	5,10
2B	*Double* V and 150°C	3,91

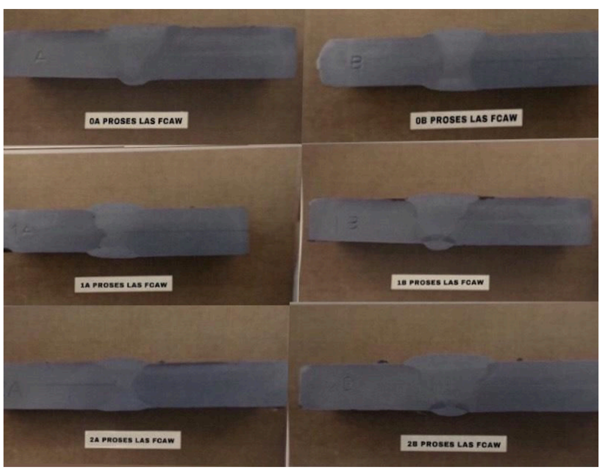

Figure 7. Macrostructure of six specimen

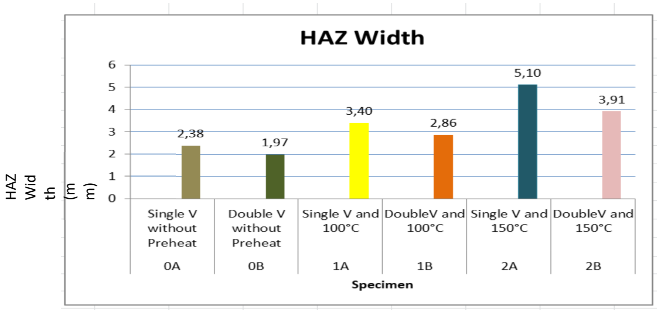

Figure 8. HAZ Width Area

On the macro structure, no welding defects were found on the entire specimen. In the results of micro-photo observations, it was found that the preheat temperature is directly proportional to the decrease in ferrite composition and the increase in pearlite composition. From this study, it was found that the percentage of ferrite at the lowest average was found in the same form as the largest preheat temperature, namely in specimen 2B with double V Groove shape and 150°C preheat temperature had the lowest average percentage of ferrite structure when compared to other specimens of 58.08% and pearlite 41.92%. Whereas based on its preheat temperature, the average ferrite percentage in Figure 15 tends to be less on specimens with Double V-Groove. Therefore, it can be concluded that, Double V-Groove groove has a weld that is more resilient, especially in specimen 2B because it has the fewest ferrite phases compared to other specimens. This is due to the large volume of weld metal that fills the groove, it is known that single V-Groove groove requires more filler metal than Double V-Groove, so that the heat can spread into a wider area and the cooling process becomes longer. Micro-photos of all test specimens can be seen in Figure 9 to Figure 14.

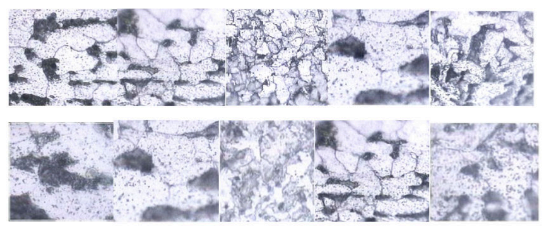

Figure 9. Microstructure Result of 0A Specimen

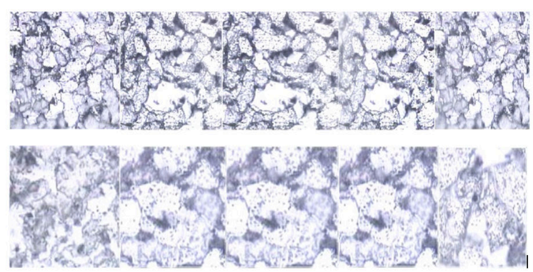

Figure 10. Microstructure Result of 0B Specimen

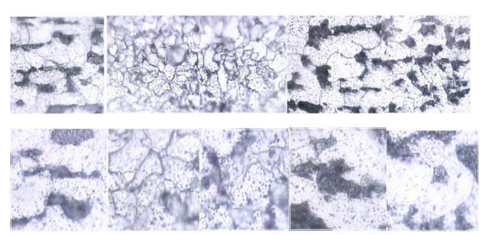

Figure 11. Microstructure Result of 1A Specimen

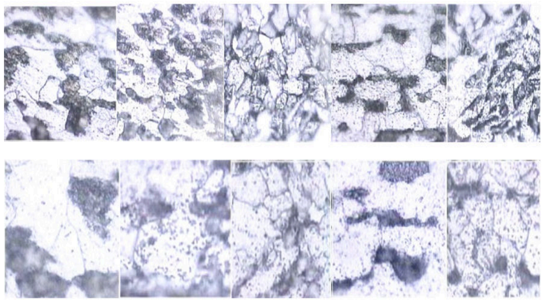

Figure 12. Microstructure Result of 1B Specimen

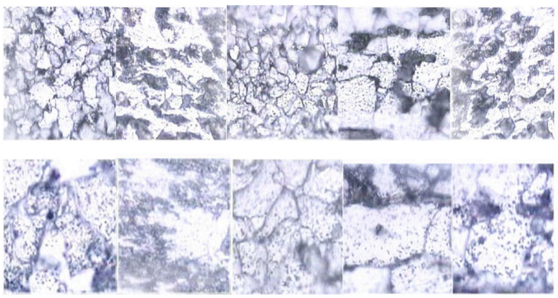

Figure 13 Microstructure Result of 2A Specimen

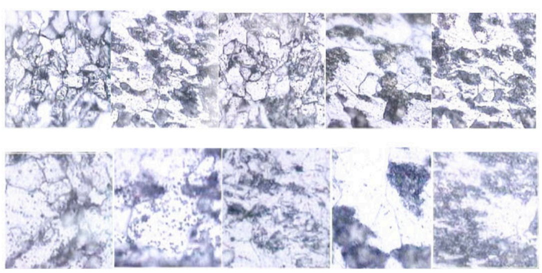

Figure 14. Microstructure Result of 3F Specimen

For the analysis of micro-photographs of all specimens can be seen in Table 4, and the graph of the comparison between ferrite and pearlite structures in the six specimens can be seen in Figure 15.

Table 4. The Result of Microstructure Test

Specimen	Description	%									
		A53		HAZ A53		*Weld Metal*		A36		HAZ A36	
		Ferrite	*Pearlite*	*Ferrite*	*Pearlite*	*Ferrite*	*Pearlite*	*Ferrite*	*Pearlite*	*Ferrite*	*Pearlite*
0A	*Single* V without*Preheat*	69,7	30,3	58	42	70,1	29,9	69,2	30,8	59,6	40,4
0B	*Double* V without*Preheat*	65,8	34,2	56,2	43,8	62,5	37,5	67,8	32,2	56,3	43,7
1A	*Single* V and 100°C	65	35	57,2	42,8	62,7	37,3	67,4	32,6	55,9	44,1
1B	*Double* V and 100°C	65	35,7	54,2	45,8	60,9	39,1	65,9	34,1	55,2	44,8
2A	*Single* V and 150°C	64,1	35,9	53,7	46,3	60,9	39,1	66,2	33,8	53,7	46,3
2B	*Double* V and 150°C	62,4	37,6	52,5	47,5	56,6	43,4	64,4	35,6	54,5	45,5

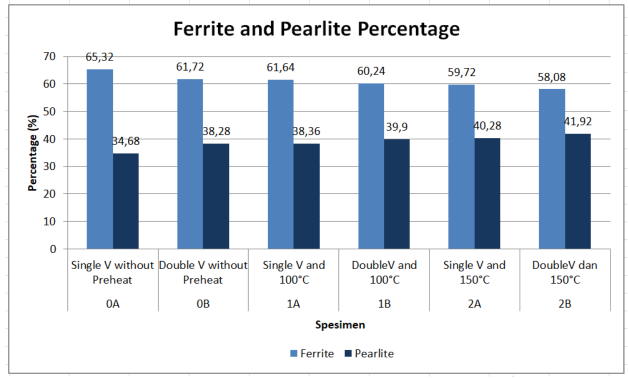

Figure 15. Graph of Average *Ferrite* and *Pearlite*

3.4 The Correlation between Tensile Test and Metallography Test

Based on tensile testing and macro-micro observations that have been done, it can be seen that variations of the form of groove and preheat temperature used in welding greatly influence the welding results that are in specimens with Double V-Groove groove and preheat temperature of 150°C, it appears that the material has the highest ultimate strength value compared to the welding process with the same type of groove and other preheat temperatures, with ferrite phases that are directly proportional to the width of HAZ. Similarly, when viewed on specimens with the same preheat temperature and with different groove types, the ultimate strength value is obtained in specimens with Single V-Groove groove compared to Double V-Groove. In macro-micro structure testing, HAZ area width was obtained much longer with ferrite structure that formed more on Single V-Groove groove than Double V-Groove. The larger the ferrite structure that is formed, the more easily broken the material becomes when tested for tensile.

Therefore, in both tests it can be seen that the amount of preheat temperature and the use of the different type of groove during the welding process affects the result of material connections, where the greater the preheat temperature used in the same type of groove will increase its tensile strength. Just like at the time of testing, materials with preheat temperatures combined with double V-Groove could result in greater average ultimate strength. This result carries on to the macro-micro photo results, HAZ areas are formed shorter and ferrite formed less. Double V Groove shape can accelerate the cooling process so that it narrows the HAZ area, and can reduce the percentage of ferrite structure.

4. CONCLUSION

From the results of the research related to the influence of variations in the preheating process, with temperature variatons of 100°C and 150°C and groove type variations of Single V-Groove and Double V-Groove groove against FCAW welding of A53 steel materials with A36 steel. Three points are elaborated as follows:

1. In the test results of welding tensile test with preheating temperature of 150°C and double V groove groove shape has the largest yield strength and ultimate strength compared to other specimens, with a value of 42.51 MPa and 486.26 MPa, respectively. The higher the preheat temperature used, the greater the tensile test parameter will be.
2. In the observation of welding metallography with preheat temperature of 150°C and single V groove type has the largest HAZ width among other specimens, with a value of 5.1 mm. While the largest pearlite phase percentage is found in specimens with preheat temperature of 150°C and double V groove with the value of 37.6% on base metal and 47.5% on HAZ of the ASTM A53 steel, 43.4% in weld metal, 35.6% on base metal and 45.5% on HAZ of the ASTM A36 steel.
3. The higher the preheat temperature used in welding the thick groove shape, the more tensile strength, the wider the HAZ will be. This is due to the close association with the selection of the type of groove. The less weld metal volume fills, the faster the connection cooling process. It also applies to the contrary.

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