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Analysis of the Effect of PWHT on the Corrosion Test of API 5L X65 Material in Submerged Arc Welding

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Abstract

This research discusses the method of making distribution pipes using the Submerged Arc Welding (SAW) welding process, especially for pipes with spiral connections. The material used is API 5L X65. SAW pipes with spiral joints are more commonly used for low-pressure piping systems. However, in certain cases, the production of SAW pipes for Sour Service distribution requires special treatment. Sour Service pipes have a high level of corrosion and residual stress, so Post Weld Heat Treatment (PWHT) is required to prevent Hydrogen Induced Cracking (HIC). HIC occurs due to the absorption and accumulation of hydrogen gas in the metal, causing the formation and growth of cracks, which is also influenced by residual stress. PWHT is applied to reduce residual stress to reduce the risk of corrosion. PWHT is a process to change the structure of the weld metal by heating the metal at a certain temperature and time. This research shows that variations in PWHT temperature produce an average residual stress that is not much different with less difference than 2%, In corrosion testing with the HIC method shows crack evidence but is still satisfactory NACE MR0175 criteria for pipe PWHT temperature variation conditions.

Keywords: *API 5L X65, Hydrogen Induced Cracking, PWHT, Residual Stress, SAW*

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INTRODUCTION

PT. X is a company that produces pipes with various specifications located in East Java. This company focuses on and has experience in making pipes, from making pipes for construction to making pipes for oil and gas. The types of pipes produced are spiral pipes and HFW (High Frequency Welding) pipes. One method of making distribution pipes is to use the Submerged Arc Welding (SAW) welding process. SAW is an automatic welding process that uses external filler material (wire electrodes) as a connection to a plate that has been rolled and has a cylindrical shape. SAW pipes with spiral joints are produced at higher rates compared to SAW pipes with longitudinal joints. In general, spiral pipes are usually only used for low-pressure piping systems such as water so they do not require special treatment such as PWHT. However, in the case that occurred at PT. X where there is a production of SAW pipes that will be used for the distribution of Sour Service, where the Sour Service distribution pipe has a high level of corrosion so that the need for heat treatment or post weld heat treatment to prevent residual tension, causing corrosion and material failure.

Pipes produced using the SAW welding method are carried out using automatic machines run by machine operators by procedures created by local engineers. So, the SAW welding method has a high level of efficiency and the resulting pipe has a very low defect rate. The manufacturing/forming process using the SAW welding method usually consists of several steps as depicted in Figure 1 below. With the rotation of the roller, the strip will gradually change shape into a circle. Submerged Arc Welding (SAW) is a type of electric arc welding where the welding process involves heating and melting the workpiece and filler metal or electrode by an electric arc that is between the parent metal and the electrode (filler metal). SAW welding uses a flux that looks like sand to protect the filler metal that melts during the welding process from contamination from the outside air, thereby producing good welds [2].

In general, spiral pipes are usually only used for low-pressure piping systems such as water so they do not require special treatment such as PWHT [3]. However, in the case that occurred at PT. Indal Steel Pipe is where SAW pipes are produced which will be used for Sour Service distribution, where Sour Service distribution pipes have a high level of

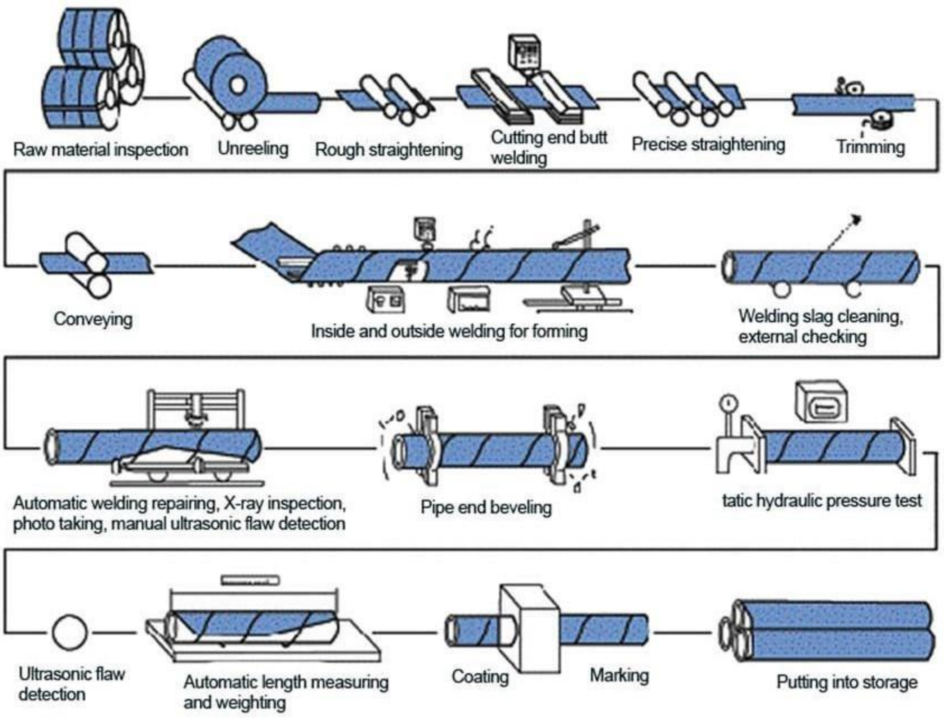


Figure 1. SAW Pipe Manufacturing Process [1]

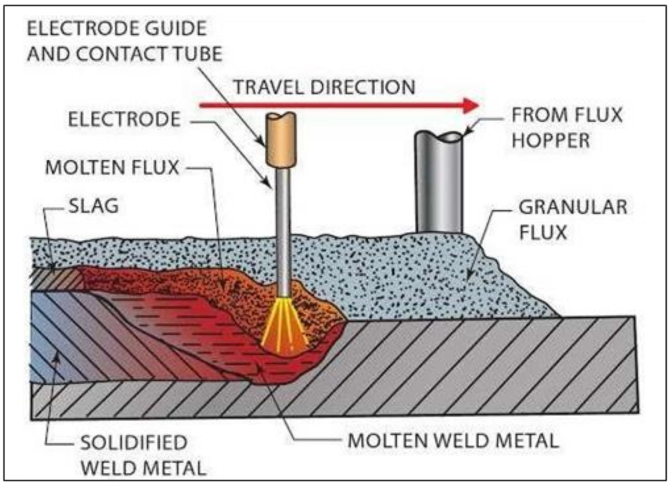


Figure 2. SAW Welding Process [4]

corrosion so that post-weld heat treatment or Post Weld Heat Treatment is required to prevent SSCC or Sulfide Stress Corrosion Cracking.

During welding, a material (especially carbon steel) will experience changes in its microstructure due to the heating and cooling process. This is a change in structure that becomes inhomogeneous and causes residual stress in the post-welding material. The impact of this residual stress will make the material harder, but its toughness is small. This is certainly an unexpected trait. Therefore, the material must be returned to its original properties by heating it to a certain temperature and holding time [5].

Post-weld heat treatment (PWHT) is a heat treatment process carried out on the welding results of a component. This heating is carried out until it reaches a temperature below the transformation temperature with a controlled heating rate and is also held at that temperature for a certain time and then a controlled cooling rate. The main purpose of post-weld heat treatment is to eliminate residual stresses that occur in the welding results.

Figure 3 shows that in general for carbon steel, the austenitizing temperature is 30-50°C above the critical temperature A3 for hypoeutectoid steel and 30-50°C above the critical temperature A1.

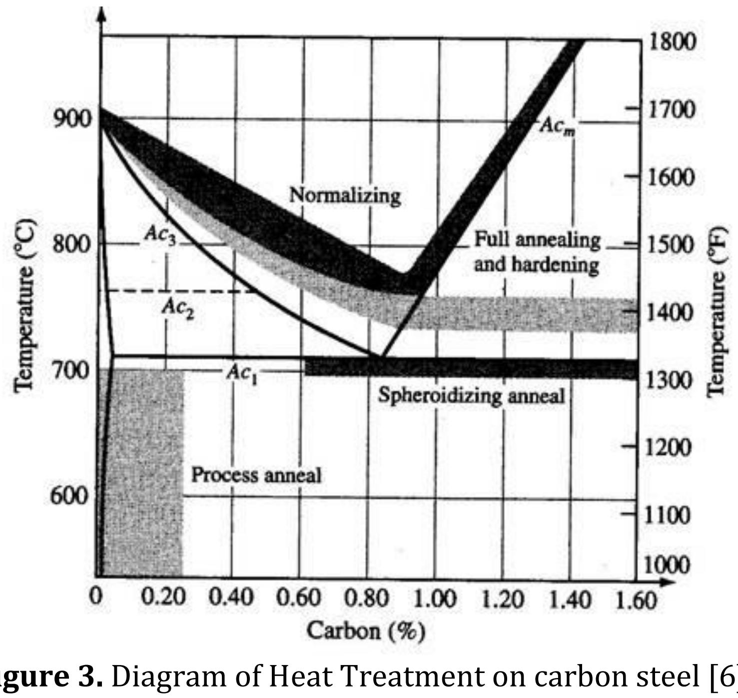


Figure 3. Diagram of Heat Treatment on carbon steel [6]

On PWHT machines in the field, the welding results are reheated at temperature A3, which is a temperature above 800°C. The pipe that comes out of the HFW welding machine will be heated three times, namely T1, T2, and T3 at the same welding speed. Then the temperature of the weld metal is measured using a pyrometer to ensure the actual temperature of the material reaches temperature A3. At 60 meters the pipe that has undergone PWHT is cooled to room temperature using the quenching method within 6 minutes of the PWHT process. PWHT (post-welding heat treatment) is a process for changing the structure of the weld metal by heating the metal for a specified time and temperature to obtain certain mechanical properties. In this case, the PWHT carried out aims to reduce residual stress. PWHT also aims to increase sensitivity in the HAZ area to reduce the risk of cracks due to corrosion due to acidic fluids.

Hydrogen-induced cracking (HIC) occurs due to the absorption and accumulation of hydrogen gas in the metal, leading to the formation of and growth of micro cracks. Corrosive media containing hydrogen thus, causes the accumulation of hydrogen in the metal which forms bubbles and cracks. The residual stress in the pipe needs to be considered because it causes strains corresponding to changes in lattice spacing, the emergence of distortion, cracking, and the low ability to accept stress from outside. The longitudinal residual stress distribution explains the crack formation on the inside of the pipe wall. Tensile residual stresses contribute to the development of cracks in welded joints on linear sections of the main gas pipeline [7]. The causes of HIC the simultaneous influence of residual stresses need to be overcome by using post-welding heat treatment or PWHT. Based on research conducted by Rapiansyah Putra regarding the effect of PWHT on the mechanical properties and microstructure of SMAW welding on carbon steel, it is explained that the grain structure in the welding process with PWHT treatment the results are more uniform, the PWHT process can increase toughness and reduce material hardness [8]. In addition, other research states that the proposed PWHT method can achieve the optimal effect of hot treatment and can produce small tensile or even compressive stresses on the inner surface of the weld, which can reduce problems by HIC based on the effect of temperature [9]. Based on this, the author conducted research on the analysis of the effect of PWHT on the corrosion test of API 5l X65 material in submerged arc welding.

Therefore, it is necessary to find the right parameters to make PWHT suitable for acceptance criteria and prevent corrosion due to residual stress. This study aims to investigate and establish the effect of the PWHT process in SAW welding of X65 material on residual stress and HIC.

METHODS AND ANALYSIS

This research began by conducting a literature study which included studying and collecting relevant reference sources as a reference in conducting research. Field studies are carried out to obtain information or real data in the field, such as during the SAW pipe production process. The result of direct observation is to get a direct picture of the process when heating the pipe using heat induction and the process of cooling the pipe after heating. So that it can provide more accurate results and avoid research errors and facts can be expressed as a realization of existing theories. The next stage is to prepare tools and materials before carrying out the experimental process.

Material and Preparation

The material used in this research is API 5L X65. The Submerged Arc Welding welding process is carried out automatically, controlled by the SAW machine operator, and supervised by the supervisor and QC/QA. The first stage of the welding process is preparing the API 5L L450MO PSL 2 carbon steel material. The SAW machine is run at a

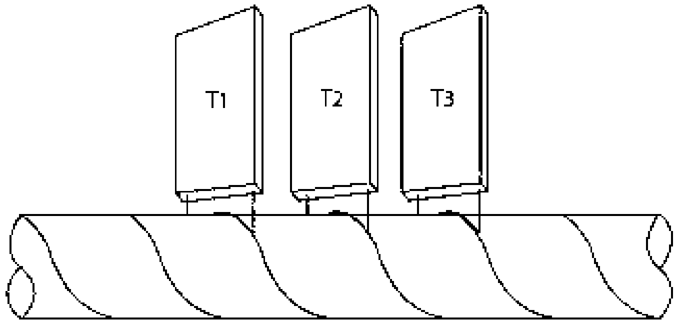


Figure 4. PWHT Machine Design on SAW Machines

Table 1. PWHT Temperature Variations

No	PWHT1 (°C)	PWHT2 (°C)	PWHT3 (°C)
1	850	950	1000
2	900	1000	1050
3	950	1050	1100

speed of 0.4 - 1.0 m/min. The material that has passed through the SAW machine will be heated to a temperature of 850°C - 1100°C. The current and voltage are 600 A – 900 A and 25 V – 40 V respectively. The power used to run the SAW machine is 470 kW – 485 kW [10].

After the pipe undergoes the SAW welding process, then the pipe undergoes a heat treatment process after welding or PWHT. The aim of PWHT is, among other things, to improve mechanical properties and reduce residual stress in pipes after the high-temperature welding process. The parameters that will be used for the PWHT process are shown in Table 1:

In its implementation, PWHT was carried out three times as shown in Figure 4 with the overall length from the start point to the finish point being 6500 mm for 39 s with a welding speed of 100,007 mm/s. The temperature of the weld metal will be measured using a pyrometer to determine the actual temperature value of the weld metal after going through PWHT as a reference for PWHT temperature variations. The distance from the inductor to the pipe for the PWHT process is 10 mm, this is done to ensure that the PWHT covers the entire weld metal area, HAZ area, and base metal.

The Test Specimen

After the SAW and PWHT welding processes are complete, the next process is taking samples for test specimens. The specimen is subjected to a residual stress test. The following are the steps to calculate the residual stress in the pipe: Cut 3 pipes to the width specified in the MPS from one pipe. Then marking is carried out on the test areas at 0° (weld metal), 90°, and 180°. Initial measurements (circums, thickness, and distance between points). Next, make cuts in each area tested at 0°, 90° and 180°. marked with a circle as in Figure 5 then take measurements after sawing (distance between point and circle).

The next test is the HIC (Hydrogen Induced Cracking) Test which is carried out based on NACE TM0284 [12]. This test is a test material resistant to acidic environments. In this HIC testing, the specimens used are API 5L X65 pipe material welded joint specimens. Steps in carrying out HIC testing include the first stage is immersing the specimen in vessels administered chemical solutions based on NACE TM017. In a container that already contains the above liquid The minimum pH requirements for the initial and final solutions must be recorded with the condition that pH = 2.7 ± 0.1. During testing, pH solution is not more than 4.0. The material was soaked for 96 hours later clea-

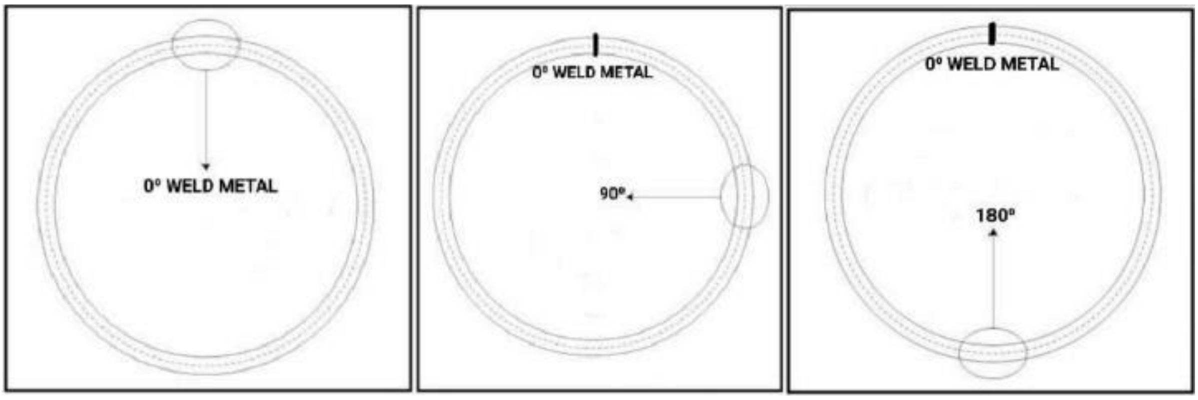


Figure 5. Cutting Pipe Specimens Residual Stress Testing [11]

ned with water, wiped with acetone, and air dried. During testing, specimens are checked periodically in the test vessel whenever possible.

After getting some measurement data, we can enter it into a formula. The formula is as follows: [11]

$$\sigma_h = \left[\frac{E.t}{1-v^2}\right]\left[\frac{1}{D_i} - \frac{1}{\left(\frac{x}{\pi}+D_i\right)}\right] \quad (1)$$

With E is modulus of elasticity (200000 MPa) [11], t is test ring thickness (mm), v is poisson ratio of carbon steel (0.3), Di is initial OD of test ring (mm), and x is clear opening (mm)

RESULTS AND DISCUSSIONS

When presenting and discussing results, give in depth analysis, not only reporting the results. Before testing, the API 5L X65 material was subjected to a PWHT process with temperatures as shown in Figure 6 below.

Next, the pipe that has gone through the PWHT machine will go through cooling by quenching method with water. With cooling rate Quenching temperature is shown in Figure 7 the cooling (quenching) diagram shows that pipes with temperature parameters PWHT1, PWHT2, and PWHT3 enter the quenching machine at temperatures of 170˚C, 198˚C, and 235˚C.

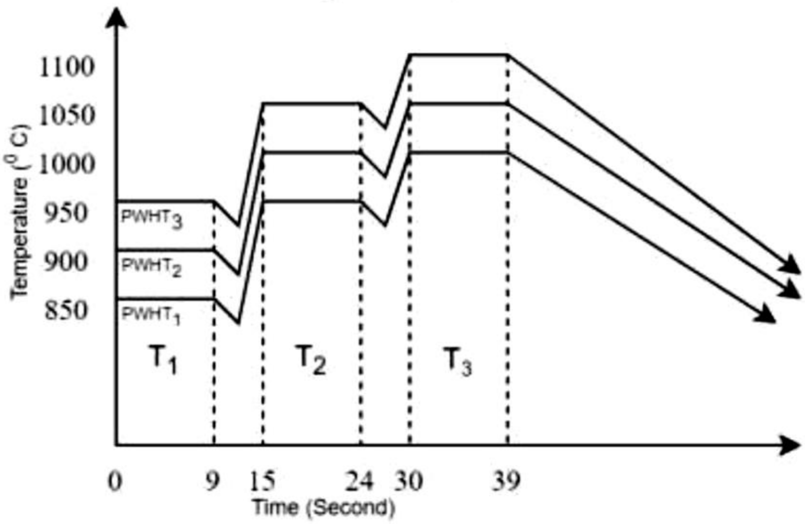


Figure 6. PWHT Temperature Diagram

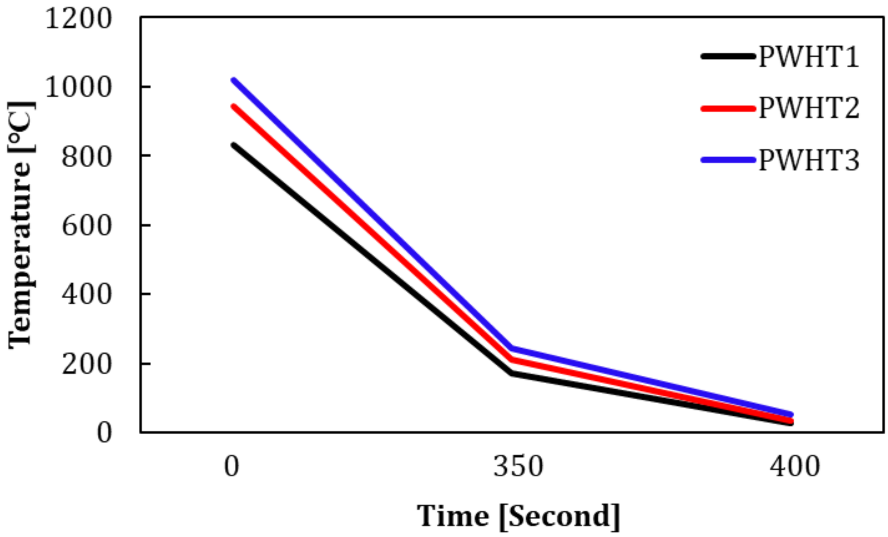


Figure 7. Cooling Diagram

Table 2. Residual Stress Test Results

No	Treatment	Residual Stress (% SMYS)			ΣAvg Residual Stress (% SMYS)
		0°	90°	180°	
1	PWHT1	13.92	20.30	25.08	19.76
2	PWHT2	14.11	20.47	25.85	20.14
3	PWHT3	14.75	20.86	26.22	20.61

In Figure 7 the cooling (quenching) diagram shows that pipes enter the quenching machine at 350 seconds after the pipe leaves the PWHT machine and the pipe exits the quenching machine at 400 seconds after leaving the PWHT machine. So, the temperature parameters PWHT1, PWHT2, and PWHT3 are 1.89˚C/s, 2.12˚C/s, and 2.18˚C/s respectively.

The next process after the material has been welded and PWHT is residual stress testing. Residual stress testing is a procedure used to measure the stress remaining in a material after the heating or welding process. This residual stress can affect material properties, such as corrosion resistance and fatigue lives. The residual stress testing method in this research is the splitting method. The splitting method, also known as the "crack compliance method" or "slitting method," is a technique used to measure residual stresses in materials. This method involves creating cracks or incisions in the material and measuring changes in strain or displacement resulting from the release of residual stress [13].

The residual stress value can be determined by using the equation in the calculation formula explained above. The results and average of residual stress testing in this study can be seen in Table 2. The results of stress testing are numerical and have units of % SMYS. It can be seen from the difference between PWHT and residual stress, the average value of stress for PWHT 1 is 19.76, for PWHT 2 it is 20.14, while for PWHT 3 it is 20.61. In PWHT 1 the average value of the remaining voltage is considered to be the lowest compared to the other PWHT treatment variables. However, there is the highest average residual stress value in PWHT 3, namely 20.14.

The residual stress value for each pipe does not vary enough and the difference between each pipe is not much so the difference in PWHT temperature in the pipe does not affect the residual stress value. However, there is a significant increase because after

Table 3. Microscope Test Results

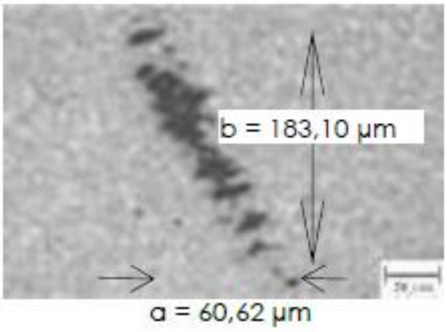
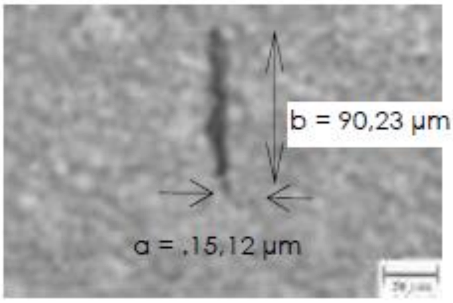
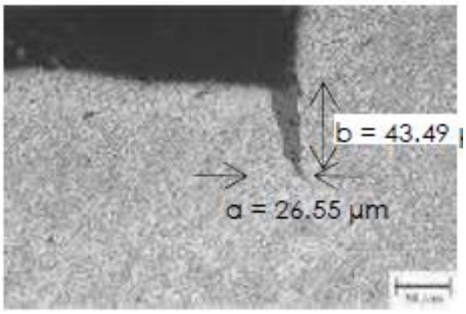
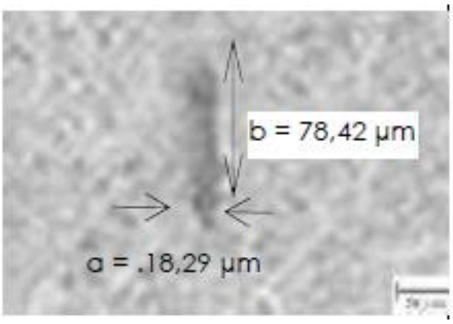
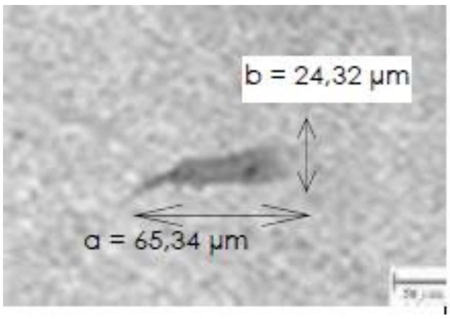
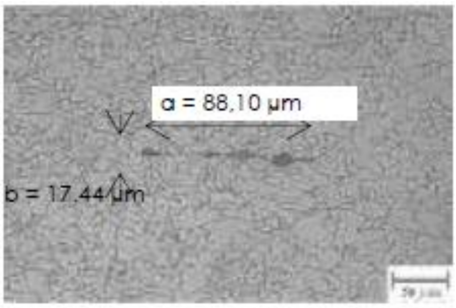
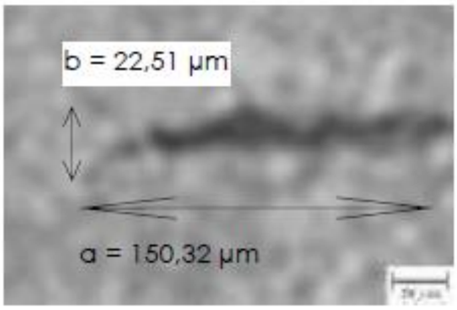
Description	Result Microscope Test
PWHT 1	  
PWHT 2	 
PWHT 3	 

Table 4. Crack Ratio Vulnerability Results

Sections	Crack Ratio (%)		
	PWHT 1	PWHT 2	PWHT 3
Crack Sensitivity Ratio (CSR)	0,0023	0,0012	0,0007
Crack Length Ratio (CLR)	0,0065	0,0053	0,0020
Crack Thickness Ratio (CTR)	0,015	0,010	0,003

Figure 8. HIC visual examination results

PWHT, volumetric changes increase due to grain growth, which causes an increase in the magnitude of the longitudinal residual stress [14].

In this study, the Hydrogen Induced Cracking test simulation was carried out test simulation to determine the corrosion resistance of each pipe variable with different PWHT temperatures. Corrosion testing was conducted on all three variable specimens using a three-electrode cell. In this test, this corrosion test uses a solution of 50 g sodium chloride, 5 g glacial acetic acid, and 945 g distilled water as the corrosive media. in the container that already contains the above liquid, the minimum requirement for the purity of hydrogen sulfide (H2S) purity is 99.5% with a specified temperature of 24˚C ± 3˚C for 96 hours.

After the specimens have been soaked for 96 hours, the first step is visual testing. From this test, there were no visible indications on the specimen in the section. This is because the surface profile is still very rough and difficult to observe as seen in Figure 8. Based on this, further investigation is needed with a microscope, and the following results were obtained.

After that, variations in crack evidence were obtained from the three specimens above There will measurements of length, thickness, and crack sensitivity will be analyzed in the HIC test, the measurement results are in Table 3. Crack sensitivity ratio, Crack length ratio, and Crack Thickness ratio will be measured based on NACE TM0284 [12] so that the crack ratio obtained is as follows as in Table 4. From the table and image of the crack evidence above, the results can be seen corrosion test simulation where it is shown that the PWHT 3 specimen has the best crack sensitivity ratio (CSR) is 0.0007%. Whereas specimen PWHT1 had the worst crack sensitivity ratio (CSR) with a ratio of 0.0023%. The corrosion resistance of the PWHT3 specimen is better than the PWHT 1 specimen due to differences in temperature administration treatment. Crack evidence that has a size of <0.5 mm is considered a single crack [15].

The proposed PWHT method can achieve the optimal effect of treatment hot and can produce small tensile or even compressive stresses on the inner surface of the weld, which can reduce problems by HIC based on the effect of temperature [9]. PWHT on each weld metal specimen and the base metal will increase corrosion resistance. Compared with the condition after welded, PWHT can improve SSC resistance of metal welds, but cannot eliminate the problem HIC [16]. SSC and HIC are still related because in NACEMR0175 [17] both corrosions are closely related because they are both types of material damage caused by interaction with hydrogen and sulfur-containing environments. Therefore, still there is an indication of crack evidence in each specimen from the HIC corrosion test results.

CONCLUSIONS

Based on the welding parameters used as well as analysis and discussion of the results of residual stress and corrosion tests with variations of PWHT1, PWHT2, and PWHT3 in SAW welding of X65 material, it can be concluded that the highest average value of residual stress on PWHT 3 is 20.61% SMYS. The PWHT temperature difference in the pipe does not affect the remaining stress value. The results of corrosion testing on the three test objects showed that the three test objects still had evidence of cracking but following NACE MR0175 they still met the acceptance criteria. So, the best welding parameter is to use the PWHT 3 variation because it has the best crack sensitivity ratio (CSR), which is around 0.0007%.

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DECLARATION OF CONFLICTING INTERESTS

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