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Analysis of Dye-Penetrant Test, Tensile Test, and Bending Test Results of Shielded Metal Arc Welding (SMAW) on Carbon Steel ASTM A106 Grade B Pipes in 6G Welding Position at PPSDM Migas Cepu

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Abstract

The weld quality its significantly depends on the mechanical characteristics of weld joint, the welding process, parameters weld process and also material selection. Insufficient parameter values and welding method can lead to welding defects and distortion that adversely affect mechanical properties. Consequently, carefully selecting appropriate weld method at an optimal level becomes crucial to mitigate defects, enhance productivity, and achieve desirable mechanical attributes in shielded metal arc welding (SMAW). PPSDM Migas has special facilities for conducting welding workshops or training and for equipment inspection or testing in the metallurgy laboratory. One of the inspected items is the welding used to join pipes. In this study, the inspected pipe is Carbon Steel ASTM A106 Grade B, welded using SMAW in the 6G position from the PPSDM Migas Cepu Refinery Unit area. The inspection methods used in this study are the Dye-Penetrant Test, Tensile Test, and Bending Test to identify welding defects and material strength. The tests conducted refer to ASME Section IX. Based on the Dye-Penetrant Test results on the Carbon Steel ASTM A106 pipe joint, five rounded defects were found on the weld surface, still within the acceptance criteria of ASME Section IX, thus the pipe is declared accepted. According to the Tensile Test results, spesimens 1 and 2 broke in the weld area but met the ASME Section IX criteria with tensile strengths of 464.098 MPa and 713.597 MPa, respectively, both exceeding 415 MPa, which is the tensile strength of ASTM A106 carbon steel. However, the Bending Test results showed open defects up to 3 mm, causing the pipe joint to be declared declined.

Keywords: Carbon Steel Pipe; Dye-Penetrant Test; Tensile Test; Bending Test; ASME Section IX

Introduction

Pusat Pengembangan Sumber Daya Manusia Minyak dan Gas Bumi (PPSDM Migas) is an institution operating under the Ministry of Energy and Mineral Resources of the Republic of Indonesia. This institution focuses on developing the competencies of the workforce in the oil and gas sector through various training programs, certifications, and professional development. PPSDM Migas aims to enhance the skills and knowledge of

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workers in the oil and gas industry so they can meet the required national and international qualification standards.

PPSDM Migas is equipped with various facilities to support training and competency development activities (Dirjen Migas, 2010). These facilities include office areas, technical laboratories, boiler and refinery unit areas, workshops for various types of training, and more. One of its technical laboratories is the metallurgy laboratory, used for material inspection and testing, including pipe welding tests. This laboratory conducts various testing methods such as Dye Penetrant Test, a type of Non-Destructive Test, and Tensile Test and Bending Test, which is destructive tests. These tests ensure the quality and strength of materials according to ASME Section IX standards (ASME, 2019).

The ASTM A106 Carbon Steel Pipe is a commonly used pipe in the oil and gas industry, particularly for transporting fluids under high pressure and temperature. This pipe is known for its strength and resistance to pressure, as well as its ability to withstand high temperatures, making it suitable for various industrial applications, including oil refineries. ASTM A106 Grade B is one of the most frequently used grades, offering a good balance between strength and flexibility (ASTM, 2021).

The number of methods were employed to bond metallic elements, and welding is highly efficient and expeditious. Shielded metal arc welding (SMAW), alternatively named stick welding, is widely used in several components in biomedical industries, such as research and testing equipment (Sasikumar, et. al., 2022).

In the SMAW, the electrical energy converted into heat energy (Atkins, et al., 2002). Welding of ASTM A106 Carbon Steel Pipes at the PPSDM Migas refinery uses the SMAW (Shielded Metal Arc Welding) method in the 6G position, which is a fairly complex welding position. The 6G position means the pipe is set at a 45° angle and cannot be rotated during the welding process. This welding is crucial to ensuring strong and safe pipe joints capable of withstanding operational pressures in the refinery. Welding process required considerable energy to melt the parent metal and fill metal (Francis, et al., 2009).

Heat energy influenced by three main parameters in the welding which is current, voltage and speed of welding. The speed of welding also affects the heat energy because during the welding process the resulting heat energy does not stay in place but experienced a process of moving at a certain speed (Shivakumara, et al., 2013).

Shield Metal Arc Welding process, known as the SMAW process (Manual Metal Arc Welding), the parent metal is subjected to melting due heating of the arc arising between the tip of the electrode and the workpiece surface (Gowthaman, et al., 2017). Welding Process has significant impact on the mechanical properties of materials and their performance. Residual stresses caused by welding process, especially due heating process can decrease the strength of a material (Benyounis, et al., 2005). Improvement in the fusion zone mechanical characteristics impacted by thermal stresses through butt joint welding (Daniyan et al., 2019).

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Welding inspections are conducted using methods such as Dye Penetrant Test, Tensile Test, and Bending Test to ensure the quality and integrity of the joints according to ASME Section IX standards. This ensures that pipes used at the PPSDM Migas refinery, particularly those involving ASTM A106 Grade B Carbon Steel Pipes, can operate efficiently and safely.

Research Methods

This study aims to understand the inspection process using Non-Destructive Tests like the Dye Penetrant Test and Destructive Tests like the Bending Test and Tensile Test; and to evaluate the results of the SMAW welding inspection on ASTM A106 Grade B Carbon Steel Pipes in the 6G welding position using these methods to determine usability based on ASME Section IX. The research methodology is outlined in a diagram shown in Figure 1.

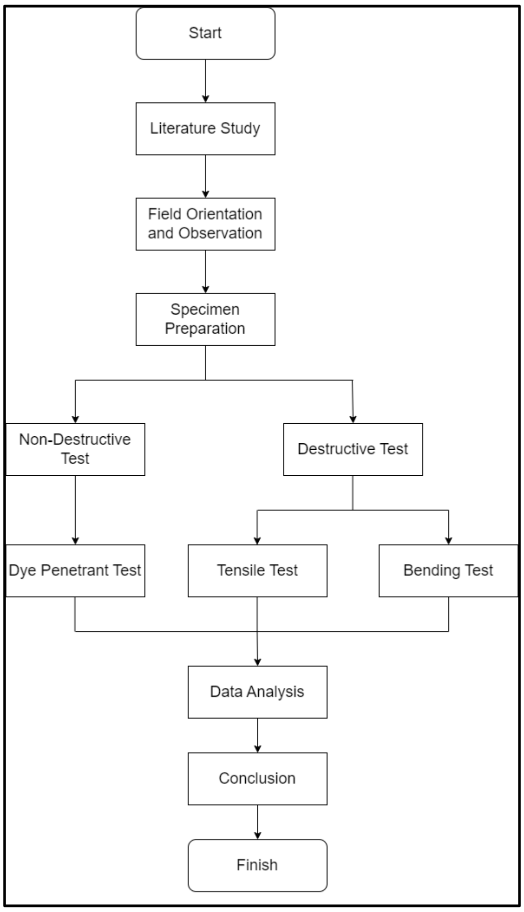

Figure 1 Research Flow Diagram
Source: obtained from primary data, (2023)

The literature study method in this research involves gathering references from various sources such as books, journals, previous research reports, and other relevant

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written and photographic materials. Information is obtained from companies to support and strengthen the necessary analysis. The researcher also uses data processing methods from testing results via Microsoft Excel to determine the strength values of the pipe material and macroscopic observation methods, relating them to theories from the literature to identify welding defects in the pipes. The research objects or specimens observed and tested in this study can be seen in Figure 2.

Figure *2* ASTM A106 Grade B Carbon Steel Pipe in 6G *W*elding *P*osition
Source: obtained from primary data, (2023)

Research and Discussion

Dye Penetrant Test / Non-Destructive Test

The testing begins by cleaning the pipe with a cleaner. Then, a penetrant liquid is sprayed on the welded area for 10 minutes. The penetrant liquid is then cleaned off, followed by spraying a developer liquid. Red spots indicating defects in the pipe will be observed within 30 minutes. For easier observation, the pipe is divided into four cross-sectional areas, labeled A-B, B-C, C-D, and D-A. Table 1 shows the results of the Dye Penetrant Test.

Table 1 Dye Penetrant Test Results

Section A-B			
			
No	Type of Defect	Length (mm)	Description
1	Rounded Indication	1,89	Accepted
Section B-C			

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<table>
<tr><td colspan="4"></td></tr>
<tr><td>No</td><td>Type of Defect</td><td>Length (mm)</td><td>Description</td></tr>
<tr><td>2</td><td>Rounded Indication</td><td>1,03</td><td>Accepted</td></tr>
<tr><td colspan="4">Section C-D</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>No</td><td>Type of Defect</td><td>Length (mm)</td><td>Description</td></tr>
<tr><td>3</td><td>Rounded Indication</td><td>1,1</td><td>Accepted</td></tr>
<tr><td colspan="4">Section D-A</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>No</td><td>Type of Defect</td><td>Length (mm)</td><td>Description</td></tr>
<tr><td>4</td><td>Rounded Indication</td><td>0,34</td><td>Accepted</td></tr>
<tr><td>5</td><td>Rounded Indication</td><td>1,11</td><td>Accepted</td></tr>
</table>

Source: obtained from primary data (2023)

Based on ASME Section IX, the results of the Dye Penetrant Test determine acceptability by considering the dimensions and types of indications. There are two main types of indications: Linear Indication and Rounded Indication. Rounded defects with dimensions less than 5 mm are acceptable, while linear defects less than 2 mm are not acceptable. In this study, five rounded defects were found, as shown in Table 1. Rounded defects can be caused by gas trapped in the molten welding material during welding, excessive distance between the welding arc and material, low current, fast wire movement, and wet or dirty welding wires. Since all rounded defects are less than 5 mm, they are considered acceptable. Cracked or porosity defects can reduce the strength of the specimen and will be easily broken when subjected to tensile test or other material tests (Kumar, et al., 2015). Dissimilar joints and its quality are assessed for different welding technique by analysing

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lack of fusion and other weld defects and the net heat input (Saha, et. al., 2022; Sumit, et. al., 2019; Kumar, et. al., 2023; Qazi, et. el., 2020).

Therefore, specimens with ASTM A106 Grade B Carbon Steel Pipes welded in the 6G position that pass the Dye Penetrant Test inspection according to ASME Section IX standards can be used.

Tensile Test / Destructive Test

The Tensile Test begins by preparing the specimen by vertically cutting the pipe and leveling the welded area. Then, the dimensions are measured and marked for specimen 1 and specimen 2 to facilitate observation. Next, the specimens are placed and positioned on the tensile test machine. During the tensile test, fractures that occur are observed and recorded.

Table 2 Tensile Test Results

No	Width (mm)	Thickness (mm)	Area (mm^2)	Maximum Load (kN)	Ultimate Tensile Strength (MPa)
1	16.00	7.00	112.00	51,979	464,098
2	11.00	7.00	77.00	54,950	713,636

Source: obtained from primary data (2023)

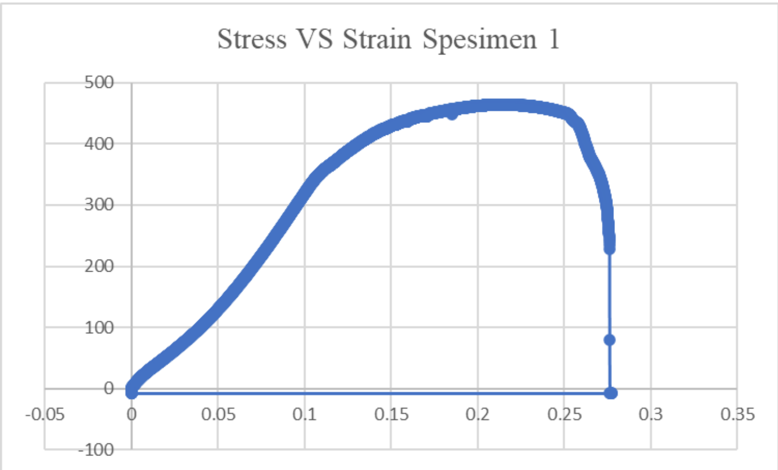

Figure 3 Stress-Strain Graph for Specimen 1
Source: obtained from primary data (2023)

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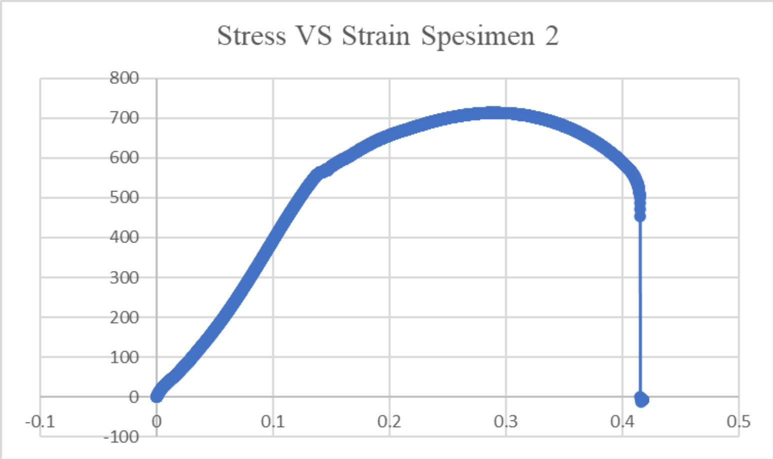

Figure 4 Stress-Strain Graph for Specimen 2
Source: obtained from primary data (2023)

Based on the data recorded and processed from the tensile test machine, data from both specimens are shown in Table 2, along with the Stress-Strain Graph from the tensile and strain data received, as shown in Figures 3 and 4. The tensile test results indicate that the maximum load for specimen 1 is 51,979 kN and for specimen 2 is 54,950 kN. Therefore, with the maximum load that can be accepted against the initial cross-sectional area of specimens T1 and T2, the Ultimate Tensile Strength is 464.098 MPa and 713.636 MPa. The relationship between welding parameters and tensile strength. as welding current increases, the tensile strength decreases gradually. This occurs because higher welding current results in elevated heat input, yielding a larger fusion zone and HAZ, a slower cooling rate, a coarser microstructure, and greater residual stress—all of which collectively diminish the strength and ductility of the weld metal and HAZ (Kose, et. al., 2022).

According to ASME Section IX standards, the minimum tensile strength for ASTM A106 carbon steel is 415 MPa. Ogbunnaoffor et al. (2016) analyzed the tensile strength of a AISI mild steel plate using SMAW. They found the highest tensile strength (421.70 MPa) and yield strength (358.50 MPa) with 75 A welding current and E6011 electrode, showing satisfactory penetration. Moreover, welded joints had higher elongation (14.28%) than the base metal. Therefore, based on the acceptance criteria of the tensile test, specimens 1 and 2 meet the criteria, with tensile strengths greater than the base metal tensile strength, with average maximum tensile strengths of 464.098 MPa and 713.597 MPa. The groove angle has affect to tensile strength, an increase in the groove angle reduces the tensile strength. This effect can be explained by changes in stress distribution within the joint. A larger groove angle can create higher stress concentrations at the edges of the weld, potentially acting as starting points for cracks. This weakening of the joint's integrity reduces tensile strength (Gyasi, et. al., 2017).

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Thus, despite fractures occurring in the weld area during testing, both specimens are still categorized as acceptable. Test results are shown in Figures 5 and 6.

Figure 5 Tensile Test Result for Specimen 2
Source: obtained from primary data (2023)

Figure 6 Tensile Test Result for Specimen 2
Source: obtained from primary data (2023)

Bending Test / Destructive Test

The Bending Test begins by preparing the specimen by cutting the pipe and leveling the welding area until it is flush with the material thickness. Then, dimensions are measured and marked for face bend and root bend specimens. Next, the specimens are placed and positioned on the bending test machine. During operation, defects that occur are observed and recorded.

The Bending Test includes face bend and root bend tests to identify defects in the weld base or Heat Affected Zone (HAZ). As a result, a stress concentration zone is created that potentially serves as a crack initiation point, thus weakening impact strength. A lower groove angle reduces the gap between the plates, resulting in reduced heat input, a smaller fusion zone and HAZ, a faster cooling rate, a finer microstructure, and lower residual stress (Naing, et. al., 2023). These factors improve hardness and impact strength in the weld metal and HAZ. The smaller diameter electrodes lead to a higher count of welding passes and increased heat input. As a result, this leads to the coarsening of grains and reduces the impact strength (Sumardiyanto, et. al., 2023; Talabi, et. al., 2014).

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Based on the bending test results for face bend specimens, there are open defects and cracks in the weld base, with two cracks and two open defects each 1 mm in length. These open defects have diameters of 4 mm and 5 mm that shown in Figure 5.

Figure 7 Face Bend Test Result
Source: obtained from primary data (2023)

The Face Bend test results indicate that the base weld area does not meet the WPS standards due to weld defects at the metal joint. Additionally, the bending test specimens do not meet the acceptance criteria according to ASME Section IX standards, which state that the test pass limit should not exceed 3 mm.

Then, based on the bending test results for root bend specimens, one open defect with a diameter of 6 mm was found, as shown in Figure 8.

Figure 8 Root Bend Test Result
Source: obtained from primary data (2023)

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The Root Bend test results indicate that the base weld area does not meet the WPS standards due to weld defects at the metal joint. The bending test specimens also do not meet the acceptance criteria according to ASME Section IX standards, where the acceptance limit for bending tests is no more than 3 mm for open weld or HAZ defects after bending.

Conclusion

Through data analysis and results obtained from a series of research that has been carried out, there are several conclusions that can be drawn as follows:

1. Based on carbon activity data, it is shown that the acid wash process does not have a significant effect on carbon reactivation.
2. Based on the results of the Dye Penetrant Test on ASTM A106 Grade B Carbon Steel Pipes in SMAW welding in the 6G position, several weld defects were found on the surface. The pipe specimens had only five rounded defects but were still within the acceptance criteria of ASME Section IX, so they were considered accepted. In other words, the defects are tolerable, and the pipe can still be used.
3. Based on the results of the Tensile Test on ASTM A106 Grade B Carbon Steel Pipes in SMAW welding in the 6G position, fractures were found in the weld area for specimens 1 and 2. However, the ASTM A106 Carbon Steel Pipe joints were declared to meet the acceptance criteria of ASME Section IX because the maximum tensile strength of specimens 1 and 2 exceeded 415 MPa, which is the tensile strength of ASTM A106 carbon steel, at 464.098 MPa and 713.597 MPa, respectively.
4. Based on the Bending Test results on ASTM A106 Grade B Carbon Steel Pipes in SMAW welding in the 6G position, face bend and root bend specimens showed defects, and the specimens were declared to have failed the bending test criteria. This occurred because the face bend specimen had open defects with diameters of 4 mm and 5 mm, and the root bend specimen had an open defect with a diameter of 6 mm, exceeding the maximum allowable open defect size of 3 mm.

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