

Evaluation of Weld Joint Quality in Drill Pipe Based on Heat Input Variation in Bending and Microstructure Test

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Abstract

Drill pipes are critical components in oil, gas, and geothermal drilling operations, serving as conduits for circulating drilling fluids from the surface to the borehole while simultaneously transmitting mechanical loads. Due to severe operating conditions, including high pressure, cyclic loading, and corrosive environments, the integrity of welded joints in drill pipes must be ensured through appropriate welding methods and quality evaluation. This study investigates the effects of heat input variations on the mechanical properties and microstructural characteristics of welded joints in ASTM A106 Grade B steel pipes produced using Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW). Welding was performed using a single V-groove butt joint configuration in the 1G position with a constant welding current of 140 A. SMAW welding employed E7018 electrodes, while GMAW utilized ER70S-6 filler wire with a shielding gas mixture of 70% argon and 30% CO₂. Mechanical performance was evaluated through bending tests, including root and face bends, in accordance with applicable standards. In addition, microstructural analysis of the weld metal and Heat Affected Zone (HAZ) was conducted using optical microscopy after chemical etching to identify phase distribution and grain morphology. The bending test results revealed that SMAW-welded joints exhibited higher ultimate stress (σ_u) values than GMAW-welded joints. The highest σ_u value of 1327.14 MPa was obtained from the SMAW face bend specimen, while the lowest value of 922.10 MPa was recorded for the GMAW root bend specimen. Furthermore, face-bend tests consistently yielded higher σ_u values than root-bend tests for both welding methods, indicating superior mechanical resistance at the weld surface. Microstructural observations showed that SMAW welds exhibited coarser ferrite-pearlite grain structures due to higher heat input and slower cooling rates associated with flux-covered electrodes. In contrast, GMAW welds exhibited finer, more homogeneous microstructures due to lower heat input and faster cooling rates. These differences in microstructure significantly influenced the mechanical behaviour of the welded joints. The findings of this study provide valuable insights into selecting welding methods for ASTM A106 Grade B pipes, particularly in applications that require a balance between mechanical strength and microstructural stability.

Keywords: Drill Pipe, SMAW, GMAW, Microstructure, Bending Test.

1. Introduction

The rapid development of the oil and gas industry is inseparable from technological advancements, particularly in material selection and connection methods. During oil and gas pipeline construction, the selection of materials and welding methods should be based on applicable standards. This is important because pipes operating in high-temperature environments and those subject to high corrosion levels require materials and welding procedures that meet the technical requirements and safety standards established [1][2].

Drilling for oil, gas, and geothermal resources is known for the equipment that supports drilling operations, namely drilling pipes. The drill pipe serves as a place for the extraction of fluids pumped by the sludge from the surface to the hole. Drilling operations are subject to a wide range of loads, including tensile, bending, hydrostatic pressure, and vibration [3]–[6].

Of the various welding methods, Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW) are among the most commonly used techniques because of their ease of application, relatively low cost, and ability to produce joints with good strength [7][8].

ASTM A106 Grade B material is a specification of steel pipes of both types, seamless and welded pipe, designed for applications in piping systems with high strength requirements as well as pressure resistance. This steel is classified as fully killed steel, which undergoes full deoxidation by adding elements such as aluminum (Al) and silicon (Si) in specific amounts. The deoxidation process removes dissolved oxygen from the molten metal to prevent gas bubbles from forming during freezing. After the freezing process in the mold (ingot), one usually sees shrinkage at the top of the metal, which indicates a perfect freezing and compaction process [9][10].



The bending test is a mechanical testing method used to evaluate material quality by visually observing the deformation. In addition, this test aims to measure the ability of materials to withstand loads to the limit of elasticity, especially in weld joints, both in the welded metal areas and in the Heat Affected Zone (HAZ) [11].

The microstructure of the results of Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW) has changed in the welded metal area and the HAZ, because the greater the heat applied to the material, the more perlite grains are spread [12] [13].

This study focused on the effect of heat input on mechanical testing (bending tests) and microstructures of weld joints produced by Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW) processes on ASTM A106 Grade B materials.

2. Methods

The material used in this study is ASTM A106 Grade B steel pipe, schedule 80. The welding process is carried out using two methods, namely Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW), with butt joints in a single V-groove shape and in the 1G (horizontal) welding position. In the GMAW welding process, a mixed shielding gas of 70% argon and 30% CO₂ is used, with the ER70S-6 electrode as the filler. Meanwhile, for SMAW welding, the E7018 electrode is commonly used for welding steel pipe structures. The pipe specimen used has a length of 150 mm and a thickness of 10 mm. Before the welding process, the pipe is cut and formed into a V-shaped groove with a 30° angle and a root face gap of 2 mm [14]. The welding current is set to 140 amperes and adjusted according to the type of welding wire for each method. Meanwhile, the chemical requirements of ASTM A106 Grade B pipe materials are specified in Table 1, while the mechanical properties of the material are given in Table 2.

Table 1. Chemical Requirements Drill Pipe ASTM 106 Grade B [15]

Carbon % max	% Eaten	Phosphorus % max	Sulfur max %	Silikon min %
0.30	0.29-1.06	0.025	0.025	0.10

Table 2. Mechanical Properties of Drill Pipe ASTM A106 Grade B

Tensile Strength (Mpa)	Yield Strength (Mpa)	Elongation (%)	Hardness Vickers (HV)
415	290	24	248

2.1. Bending Test

The bending test is one of the mechanical testing methods used to evaluate the quality of materials, especially weld joints, by visual observation of the deformation. Bend tests are carried out on the weld surface (face) and the weld root of different types of welding. In addition to serving as a visual, non-destructive test, this method can also provide information about the mechanical properties of joints, such as strength, toughness, and ductility, in the weld metal and heat-affected zone (HAZ). The ASTM E190-14 standard specifies the dimensions of the curve test specimen specifically, which are 152 mm in total length, 12.5 mm in width, and 10 mm in thickness.

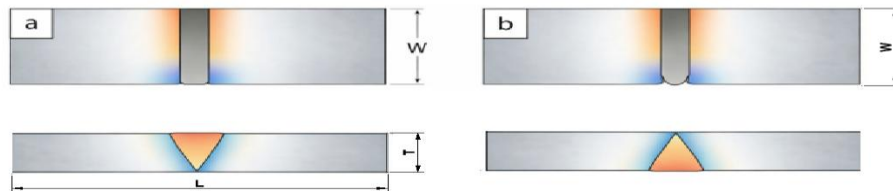


Fig 1. Bending Tets Specimens

2.2. Microstructures Test

Microphoto testing was performed at various magnifications. Still, previously, liquid alcohol and HNO₃ were used to scrape the surface of unshielded metal, creating designs by an acidic solution. The comparison of HNO₃ and alcohol was 5 ml: 95 ml, then the specimen was dipped for ±10 seconds. The metal surface scraping is shown in Figure 2 below.

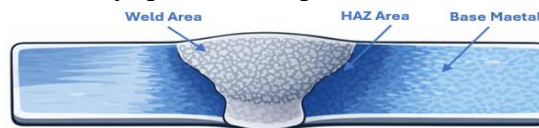


Fig2. Structural Micro Test Specimens

3. Results and Discussion

3.1. Bending Test

In this study, the welding process was carried out using two methods, namely *Shielded Metal Arc Welding* (SMAW) and *Gas Metal Arc Welding* (GMAW), with a welding current of 140 A. The SMAW process uses E7018 electrodes, while the GMAW process uses ER70S-6 filling wire. After welding is complete, mechanical testing is performed using a bending test to evaluate the weld joint's quality. The results of the curve test are presented in Table 2.

Table 2. Bending Test Results

Variations	Specimens	σ_u (MPa)	Remarks
SMAW	1	1225,64	Root Bend
	2	1223,46	
	3	1339,29	
	Average	1262,79	

GMAW	1	1425,88	Face Bend
	2	1228,40	
	Average	1327,14	
	1	941,04	Root Bend
	2	864,29	
	Average	922,1	
1	1085,63	Face Bend	
2	1173,69		
Average	1129,66		

Based on the average results of the bending tests on the Root Bend and Face Bend areas for SMAW and GMAW welding, the test results are shown in Figure 3 below.

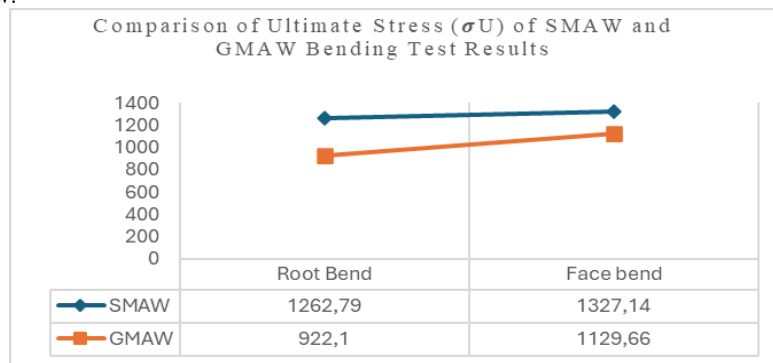


Fig 3. Curve Testing Average Graph

Based on **Figure 3**. The ultimate stress (σ_u) from the curve test results showed a significant difference between weld joints produced by the SMAW and GMAW methods. In the root bend test, the SMAW weld joint had an average σ_u of 1262.79 MPa, while the GMAW weld joint had a lower σ_u of 922.10 MPa. The 340.69 MPa difference indicates that SMAW weld joints exhibit greater flexural resistance at the weld root than GMAW weld joints. In the face-bend test, the average value σ_u for the SMAW weld joint increased to 1327.14 MPa. Meanwhile, the GMAW weld joint reached 1129.66 MPa. Although both methods showed higher σ_u values than in the root bend test, SMAW weld joints still showed higher values, with a difference of 197.48 MPa. An increase in σ_u values in face-bend testing indicates that the weld surface area has better mechanical resistance than the weld root area [16][17].

3.2. Microstructure Test

The microstructure of the specimen was examined using the ZEISS Vert.A1 microscope to observe the microstructure around the weld metal, HAZ, and base metal due to welding. The test specimen was then treated with liquid alcohol and HNO₃ on the surface to be observed.

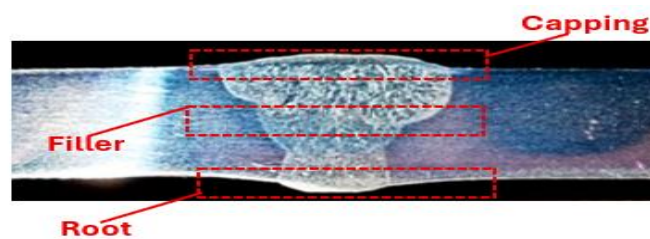


Fig 4. Results of Liquid Smear Alcohol and HNO₃

3.2.1. Microstructure Analysis of Welding Metal Regions in SMAW and GMAW Welding

Microstructures in weld metal are examined to determine the characteristics of structures formed by the welding process using two methods: Shielded Metal Arc Welding (SMAW) and Gas Metal Arc Welding (GMAW). The results of the observations are presented in Figure 5a for the SMAW process and in **Figure 5b**, for the GMAW process.

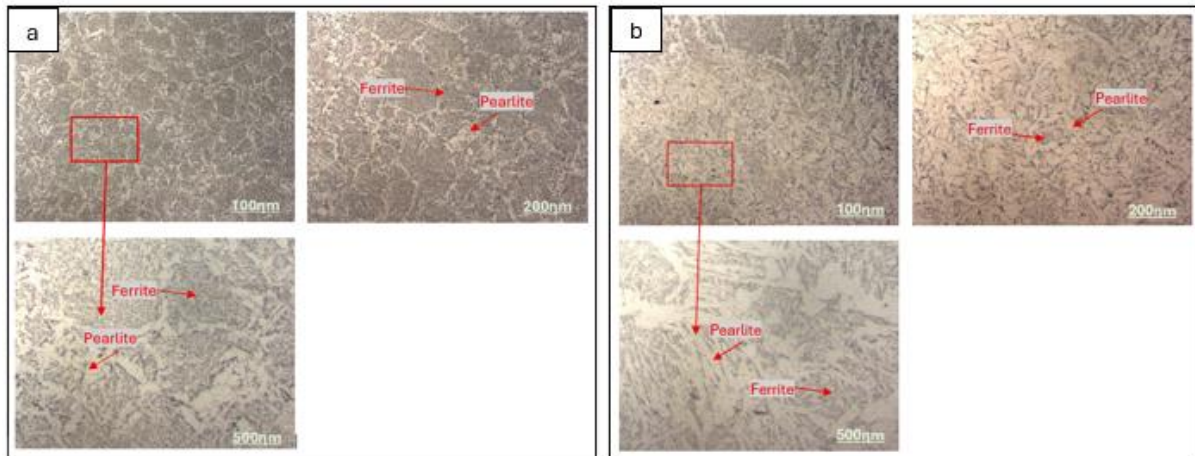


Fig 5. Weld Metal District Microstructure: a) SMAW, b) GMAW

Figure 5a. Showing the microstructure of the welded area using the SMAW method. The microstructures formed are dominated by ferrite and pearlite phases with an even distribution of ferrite among pearlite colonies. At magnifications of 100–500 μm , it can be seen that ferrite is polygonal in shape with a random orientation, while pearlite appears to be spread out to form smooth lamellar layers. The grain size in SMAW-welded metal is comparatively coarser compared to the parent metal and GMAW-welded results. This is due to the higher heat input in the SMAW process and the slower cooling rate due to the flux layer of the E7018 electrode. The flux layer retains heat during solidification, allowing the growth of larger ferrite and pearlite grains. The slow solidification process also leads to the formation of coarse pearlite structures at the ferrite grain boundaries. This condition generally degrades the mechanical properties of the joint, especially tensile strength and toughness, because differences in grain size and structural inhomogeneity can serve as precursors to crack initiation.

The welded metal microstructure of GMAW welding is shown in **Figure 5b**. The observations reveal the presence of finer microstructures with evenly distributed ferrite and pearlite phases. The ferrite grain size in GMAW is smaller than in SMAW, and the pearlite layer shows a closer lamella spacing. This condition is caused by lower input heat and faster cooling in the GMAW process. Using a mixed shielding gas of 70% argon and 30% CO_2 results in a more stable arc and higher heat transfer efficiency, thereby accelerating the solidification rate of molten metals. As a result, the growth of ferrite grains is stunted and results in a smoother, more uniform structure. The fine ferrite grains and the dense distribution of pearlite at GMAW indicate an increase in the mechanical strength of the weld joint, as the small grain size contributes to increased strength through grain boundary strengthening (strengthening the grain limit). Microstructures like these also generally have better resistance to cracking due to cyclic loads (fatigue crack initiation).

Based on the observations, the main difference between SMAW and GMAW welding lies in the grain size and the distribution of the ferrite–pearlite phase. The SMAW process results in structures with larger grains and uneven pearlite distributions, whereas GMAW produces finer ferrite grains and a more uniform pearlite distribution [18][19].

3.2.2. Microstructure Analysis of Welding Metal Regions in SMAW and GMAW Welding

Microstructure observations were carried out in the Heat Affected Zone (HAZ) area as a result of welding using the Gas Metal Arc Welding (GMAW) and Shielded Metal Arc Welding (SMAW) methods. The purpose is to determine the phase changes that occur due to the effect of welding heat on the microstructure of the base material of ASTM A106 Grade B steel pipes.

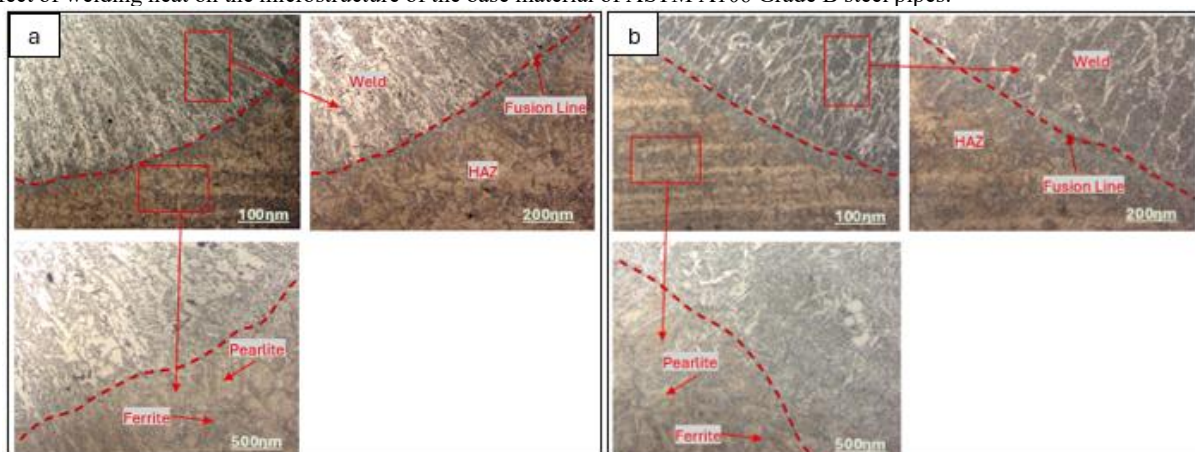


Fig 6. HAZ District Microstructure: a) SMAW, b) GMAW

Figure 6a. Showing the results of microstructure observations in the HAZ area as a result of SMAW welding. Similar to the GMAW process, the HAZ area can be divided into three main zones, namely the welded metals (weld metal), HAZ, and the parent metal. However, the ferrite and pearlite grains in the HAZ from SMAW are coarser than those from GMAW.

The coarseness of these grains indicates that the input heat in the SMAW process is higher and that the cooling rate is slower, thereby providing a longer time for grain growth during cooling. In addition, the use of the E7018 flux-coated electrode produces a slag layer that slows heat dissipation, which impacts the formation of larger grains in the HZ area.

Figure 6b. show the results of microstructure observations of HAZ regions in GMAW welding with several magnification levels. It can be seen that there is a difference in grain morphology between weld areas (weld metal), heat-affected areas (BEAM), and the parent met-

al (base metal). At the boundary of the fusion line, the microstructure shows coarser grains due to the slow cooling process in this area. The dominant phases in the HAZ of GMAW welding are ferrite and pearlite, with a more even distribution of ferrite than in the welded area. The size of the ferrite grains in the HAZ is relatively finer than in this fusion line area, indicating that the GMAW process produces a faster cooling rate. This is due to the use of argon CO₂ shielding gas, which improves arc stability and heat transfer efficiency. Based on observations of both welding methods, it can be concluded that the GMAW weld microstructure has finer grains than the SMAW weld microstructure. The finer grain size in GMAW can improve joint strength and toughness. In contrast, the coarser grain size in SMAW can reduce mechanical properties, particularly tensile strength and resistance to cyclic cracking [20][21].

4. Conclusion

1. The SMAW method produces a higher ultimate tensile strength (σ_u) than GMAW, with a maximum of 1327.14 MPa (SMAW–face bend) and a minimum of 922.10 MPa (GMAW–root bend).
2. Face bend testing yielded a greater σ_u value than root bend in both methods, indicating better mechanical resistance at the weld surface.
3. GMAW results in finer microstructures than SMAW, whereas rougher structures in SMAW correlate with higher bending strength.

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