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The Effect of Submerged Arc Welding Parameters on the Mechanical Properties of Special Steel (A516-60 Steel)

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ABSTRACT :
The demand for clean energy has led to an exponential rise in oil and gas consumption, requiring advanced pipeline technologies for safe and efficient transportation. This study investigates the effect of submerged arc welding (SAW) parameters on the microstructure and mechanical properties of API 5L X70M PSL 2 steel, widely used in pipelines. Chemical composition, tensile strength, and hardness tests were performed to evaluate the mechanical behavior of welded joints. Results demonstrate that SAW significantly impacts the heat-affected zone (HAZ) and weld metal (WM), altering microstructures and mechanical properties. The findings provide critical insights for optimizing welding processes to ensure reliability and safety in pipeline systems.

KEYWORDS: *Submerged Arc Welding, Welding Parameters, A516-60 Steel, Hardness, and Tensile.*

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I. INTRODUCTION

Clean energy demand has caused a 435% increase in world gas consumption since 1965. According to the Energy Information Administration, part of the US Department of Energy the expectations by 2030, the world energy demand will increase by 55%, 2.4% gas consumption per year, Oil consumption by 1.4% annually, while gas will generate 26% of global energy use. The presence of massive shale gas reserves in the world, profoundly changing the energy equation and modern equipment is existing and ready to use. Transmission pipelines are the primary supply of gas and oil industry, when start work full time to provide the energy that we need. Most countries consider this industry very important especially for its economies. Pipelines have been in work for decades, for example the bamboo pipe used by Chinese, since 400 BC to carry the gas and lighting the cities [1-3]. Without the pipelines, we cannot afford the world's demands of oil and gas. Furthermore, the pipelines are safely energy transmission, which are safer than railways 40 times and safer than road tanks 100 times. According to the US Petroleum Pipeline Association, oil pipeline waste 1 gallon per million barrel-mile. A barrel overflowing a mile equivalent one and only barrel, and in the barrel, there are 42 gallons. In terms of household, it is a smaller amount than a teaspoon of oil dropped per thousand miles. For thousands of years the pipeline provides drinking water for the world, also used for irrigation and agriculture. These clay and hollow bamboo pipes used to convey water by old Chinese. Indeed, about 100 years ago, wood (hollow logs) was used for the transport of brine in developed countries. The global energy demand is projected to increase by 55% by 2030, with gas consumption rising by 2.4% annually. Pipelines are essential for transporting oil and gas, offering a safer and more economical alternative to railways and road tanks. However, the reliability of pipelines depends on the mechanical properties of the materials and weld joints used in their construction [1-11]. Submerged arc welding (SAW) finds a wide application in industries for fabrication as it is more reliable, provides deep penetration in work, and produces smooth finish on the objects and results in high productivity. Submerged arc welding (SAW) is a welding method where similarly to other arc welding processes, the base metals are joined by forming an electric arc between the workpiece and an electrode. SAW process's defining element is how it protects the weld metal from atmospheric contamination. Submerged arc welding uses a powdered flux layer, generating shielding and slag while creating a smooth and clean weld. Other methods use shielding gas (MIG/TIG welding), flux-cored wire (FCAW), flux-coated electrode (SMAW), or controlled environment (plasma welding) for protecting the weld [11-13].

This study focuses on API 5L X70M PSL 2 steel, a high-strength steel commonly used in pipelines, to evaluate the impact of submerged arc welding (SAW) on its mechanical properties. The research aims to address challenges such as high pressures and the need for durable weld seams.

II. LITERATURE REVIEW

- **Submerged Arc Welding (SAW)**

SAW is a high-efficiency welding process that uses granular flux to shield the weld pool, preventing atmospheric contamination. The process parameters, such as heat input and cooling rate, significantly influence the microstructure and mechanical properties of the welded joint. The HAZ and WM are particularly affected, requiring careful control to maintain structural integrity [14-16].

- **Role of Alloying Elements**

High-strength low-alloy (HSLA) steels, such as API 5L X70, have excellent strength, toughness, and weldability. These properties are achieved through thermo-mechanical processes, precipitation hardening, and alloying with elements like Nb, Ti, and V. Modern pipeline steels are designed to handle pressures up to 15 MPa, withstanding extreme environmental conditions.

The chemical composition of X70M PSL 2 steel is shown in Table 1. Alloying elements such as Mn, Ni, and Ti play a crucial role in enhancing strength, toughness, and weldability. For instance, Mn refines grains and promotes acicular ferrite formation, while Ni improves low-temperature toughness.

Table 1: Chemical Composition of X70M PSL 2 Steel (API 5L).

Element	%	Element	%
C	0.059	**Mo**	0.144
Si	0.218	**Cu**	0.004
Mn	1.488	**Al**	0.003
P	0.007	**Ti**	0.0095
S	<0.001	**V**	0.0027
Cr	0.230	**Nb**	0.055
Ni	<0.001	**N**	<0.0010

III. RESEARCH METHODOLOGY

- **Welding Sample Preparation**

The welding samples were prepared according to API 5L X70M PSL 2 specifications:

- Material grade: X70M PSL 2
- Thickness: 19.45 mm
- Outside diameter: 1422.2 mm

- **Test Samples**

1. Tensile Samples

Tensile test samples were prepared according to ASTM A370 standards [17], all samples were API5L X70. Samples have been prepared as shown in Figure 1. Three samples from base metal and other three samples included welding zone. Six samples were tested:

- Three from the base metal
- Three from the weld zone

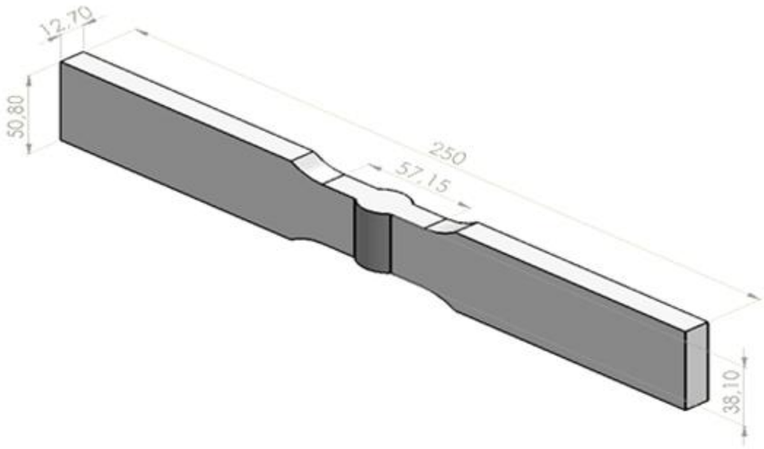

Figure 1: The tensile test sample dimension.

2. Hardness Samples

Hardness samples were prepared according to ASTM E384 standards. The samples included the base metal, HAZ, and weld zone. Testing was conducted using the Vickers hardness test.

IV. RESULTS AND DISCUSSION

1. Tensile Test Results

- Base Metal

The tensile test results for the base metal samples are summarized in Table 2. The base metal exhibited higher tensile strength and elongation compared to the weld zone, as expected. The stress-strain curves for each sample are shown in Figure 2.

Table 2: Tensile Test Results for Base Metal

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)
BM1	586.86	669.06	38.03
BM2	545.45	639.16	38.82
BM3	542.01	636.77	40.45

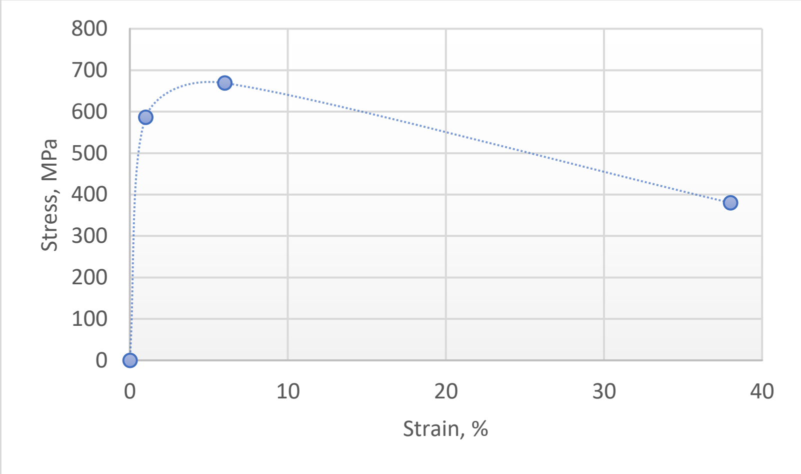

Figure 2: The stress-strain curve of base metal 1.

- **Weld Zone**

The weld zone samples exhibited lower tensile strength and ductility, as shown in Table 3. Heat input and microstructural changes in the HAZ contributed to this reduction. Stress-strain curves for the weld zone samples are presented in Figure 3.

Table 3: Tensile Test Results for Weld Zone

Sample	Yield Strength (MPa)	Tensile Strength (MPa)	Fracture Location
WZ1	641.99	694.02	Base Metal
WZ2	618.96	695.89	Base Metal
WZ3	622.56	695.21	Base Metal

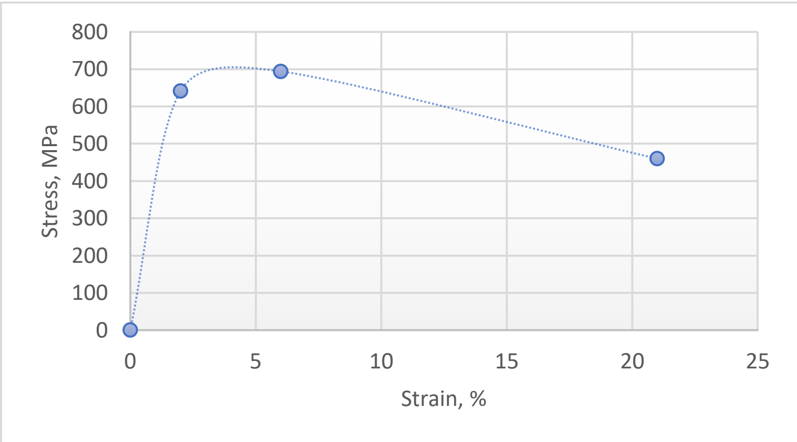

Figure 3: The stress-strain curve of weld area 1.

- **Observations and Discussions**

A reduction in ductility in the weld zone was observed, a common outcome in welded structures. The welds maintained tensile properties above the minimum requirements specified in API 5L for X70M PSL 2, indicating good weld quality. Fracture surfaces were examined to ensure the failure occurred in the gauge length, not in the grip or weld defects. This analysis confirms the mechanical integrity of the welded joint while highlighting the inherent variation in properties between the base metal and the weld zone. Further metallographic analysis could complement these findings by correlating them with microstructural features.

2. Hardness Test Results

The hardness test was conducted in accordance with the ASTM E384 standard [18], which specifies the microhardness testing method using the Vickers hardness test. The prepared samples were taken from welded API 5L X70 PSL2 pipe sections. Figure 4 illustrates the Vickers hardness test setup and the test point locations on the welded sample. These positions are defined as follows:

- Positions 1 & 2: Along the width of the specimen
- Positions 3 & 4: Depth of indentation (penetration)
- Positions 5 & 6: Weld bead height
- Positions 7 & 8: Wall thickness
- Position 9: Misalignment across the weld

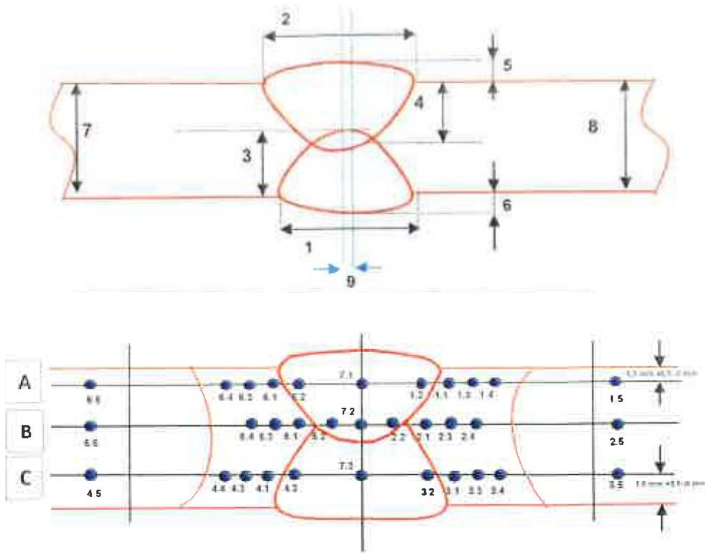

Figure 4: The hardiness test location.

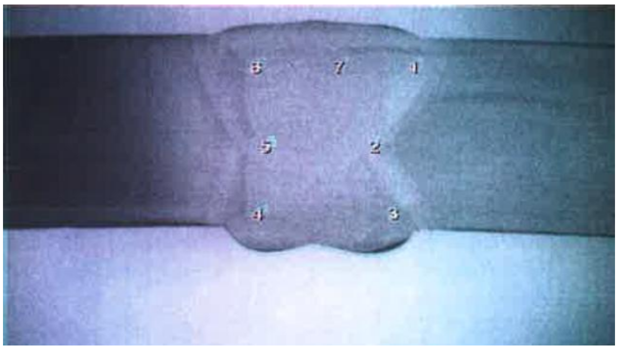

Figure 5: Vickers test according to ASTM E 384.

Figure 5 shows the testing process according to ASTM E384 Figure 5 shows the testing process according to ASTM E384 [18], and Table 4 summarizes the results for three samples labeled A, B, and C, covering the base metal (BM), heat-affected zone (HAZ), and weld zone (WZ). With summarizes the results for three samples labeled A, B, and C, covering the heat-affected zone (HAZ), and summarizes the results for three samples labeled A, B, and C, covering the weld zone (WZ). Figure 4: Vickers hardness testing procedure following ASTM E384 [18]

Table 4: Hardness Test Results (Vickers Hardness Number - HV)

Sample	Region	Positions	Hardness (HV)
A	Base Metal (BM)	1.5, 6.5, 1.1, 1.3, 1.4	212, 224, 226, 204, 213
	HAZ	6.1, 6.3, 6.4, 7.1	223, 216, 221, 224
	Weld Area (WZ)	1.2, 6.2	231, 225
B	Base Metal (BM)	2.5, 5.5, 2.1, 2.3, 2.4	211, 216, 222, 213, 230
	HAZ	5.1, 5.3, 5.4, 7.2	227, 222, 222, 228
	Weld Area (WZ)	2.2, 5.2	227, 229
C	Base Metal (BM)	3.5, 4.5, 3.1, 3.3, 3.4	218, 227, 239, 212, 220
	HAZ	4.1, 4.3, 4.4, 7.3	227, 222, 222, 234
	Weld Area (WZ)	3.2, 4.2	234, 226

Base Metal Hardness: The base metal hardness ranged between 204 HV and 239 HV, indicating uniformity in the material. **HAZ Hardness:** The HAZ recorded hardness values between 216 HV and 234 HV. Slight increases were observed due to localized microstructural changes. **Weld Zone Hardness:** The weld zone hardness ranged from 225 HV to 234 HV, reflecting good fusion quality and acceptable toughness.

- **Observations and Discussions**

No abnormal peaks or dips in hardness were observed, suggesting that the welding procedure was well-controlled and did not cause excessive hardening or degradation. The uniform hardness profile from base metal through the weld supports the structural integrity and reliability of the welded joints. The hardness values observed are within the recommended thresholds for API 5L X70 steel, confirming compliance with ASTM E384 [18], and weld quality standards for pipeline applications. This figure shows the average Vickers hardness values (HV10) for three samples (A, B, and C) of welded API 5L X70 pipeline steel. The hardness is evaluated across three distinct regions in each sample. This figure confirms a consistent pattern across all samples:

- Hardness increases from base metal, HAZ, to weld zone.
- The welding process did not result in excessively high hardness (above ~250 HV), ensuring good ductility and reduced risk of brittleness.
- The results align with the ASTM E384 standard and confirm that the welding process was effective and properly controlled

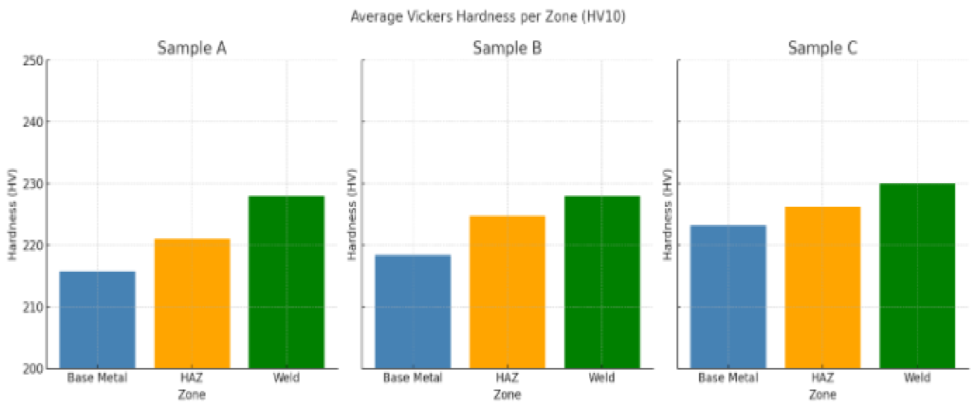

Figure 6: Vickers hardness values (HV10) for three samples (A, B, and C).

V. CONCLUSION

This study successfully investigated and evaluated the influence of Submerged Arc Welding (SAW) parameters on the mechanical properties and zone morphology of API 5L X70M PSL 2 steel, a critical material in high-pressure oil and gas pipelines. The research demonstrated that the SAW process introduces distinct microstructural and mechanical changes across the welded joint, specifically in the Weld Metal (WM) and the Heat-Affected Zone (HAZ). The key findings:

Tensile Strength and Ductility: The welded joints exhibited a reduction in ductility compared to the Base Metal (BM), which is a common characteristic of welded high-strength steels. However, all weld zone samples maintained tensile properties exceeding the minimum requirements stipulated in the API 5L standard for X70M PSL 2 steel, confirming the mechanical integrity of the weld. The fracture locations for the weld zone samples consistently occurred in the Base Metal, indicating the weld metal itself was not the weakest link in tension.

Hardness Profile: Vickers hardness testing revealed a uniform hardness profile across the BM, HAZ, and WZ regions, with values falling within the recommended acceptable thresholds for API 5L X70 steel. The Weld Zone (225 HV to 234 HV) and HAZ (216 HV to 234 HV) showed slight but controlled increases in hardness compared to the Base Metal (204 HV to 239 HV). The absence of abnormal hardness peaks or dips suggests the welding procedure was well-controlled, preventing excessive hardening or degradation that could compromise structural reliability, particularly concerning issues like Hydrogen-Induced Cracking (HIC).

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