



Analysis of Factors Influencing Tensile Strength in Shielded Metal Arc Welding (SMAW)

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Abstract. Tensile strength in Shielded Metal Arc Welding (SMAW) is a critical parameter that significantly impacts the material's performance in mechanical structures. This welding method is widely used in various industrial applications, especially for carbon steel materials, due to its practicality and relatively low operational costs. This study aims to analyze the factors affecting tensile strength in SMAW welding, including welding current, electrode type and size, welding position, cooling medium, and welder skill. The analysis results show that increasing welding current can improve penetration and tensile strength, although it carries the risk of defects such as porosity and reduced weld quality. Selecting the right electrode, such as E7016, provides better tensile strength results compared to E7018, which excels in crack resistance. The horizontal welding position produces more consistent weld quality, while overhead position increases the risk of defects. Additionally, the cooling medium plays a significant role, with slow cooling using air or sand leading to a microstructure that supports better tensile strength compared to rapid cooling with water. Welder skill is also an important factor in controlling welding parameters to achieve optimal and strong welding results.

Keywords: SMAW welding; tensile strength; carbon steel; electrode; welding current

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1. Introduction

Shielded Metal Arc Welding (SMAW) is one of the most commonly used welding methods in the industry due to its practicality and relatively low operational costs. In the SMAW process, welding parameters play a crucial role in determining the quality of the joint, particularly in terms of tensile strength. Tensile strength is a key mechanical parameter that reflects the material's ability to withstand loads until it reaches its breaking point.

The use of carbon steel such as ASTM A36 shows better tensile and yield strength compared to JIS G3101 carbon steel (1). ASTM A36 has been widely used in various engineering applications, including vehicle construction (2). Revealed that the maximum tensile strength of this material ranges from 400 to 550 MPa, obtained through finite element simulations to analyze critical stress and deformation in vehicle chassis frames (3). Choosing the right material, such as ASTM A36, allows for the optimization of tensile strength when designing strong and safe structures.

In addition to material selection, welding current is a significant factor that influences penetration and the metallurgical quality of the joint. Research has shown that variations in welding current result in significant differences in tensile strength. Low currents tend to produce shallow penetration, while high currents can lead to defects such as porosity and undercut. With the correct current, the joint can achieve maximum tensile strength while minimizing welding defects (4,5).

The type and size of the electrode are also important parameters. Electrodes such as E7018 are known for their good arc stability and sufficient penetration to produce a homogeneous microstructure. Variations in electrode diameter affect heat distribution and fusion zone formation, ultimately influencing the tensile strength of the joint (5).

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Welding position also contributes to the final result. For example, the vertical position requires more precise parameter control to achieve a higher tensile strength joint compared to other positions such as horizontal or flat (6).

The cooling medium after welding affects the material's microstructure. Rapid cooling using water can result in a hard but brittle martensitic structure, while slow cooling with air or oil tends to produce a more ductile structure with better tensile strength (7,8).

The final factor is the welder's skill. The technical ability and experience of the welder play a role in determining the quality of the weld. Specialized training, such as the Conversation Analysis and Variation Theory Approach (CAVTA), has been shown to improve welder skills, resulting in joints with optimal quality (9).

2. Methodology

This research uses a literature review approach to analyze the effect of Shielded Metal Arc Welding (SMAW) parameters on the tensile strength of carbon steel joints. Data was collected from various sources such as scientific journals, technical books, and conference proceedings published in the last 10 years. The selection criteria for literature included relevance to SMAW welding, tensile strength, and quantitative test results related to welding current, electrode type, welding position, cooling medium, and welder skill on the mechanical properties of the joint.

After data collection, the selected literature was analyzed to identify trends and key findings related to the effect of SMAW welding parameters on tensile strength. This analysis covers the impact of variations in welding current, electrode type and size, welding position, and cooling medium on microstructure and joint strength. The results of this analysis are used to understand the relationship between welding parameters and tensile strength of carbon steel joints, providing recommendations for further research in SMAW welding.

3. Factors Influencing the Tensile Strength of SMAW

3.1 Effect of welding current on tensile strength

The effect of welding current on tensile strength can be observed through variations in the current used during the welding process. At lower welding currents, such as 90 A, the tensile strength tends to be lower due to insufficient weld penetration, resulting in weaker joints (3,5). Conversely, at higher currents, such as 140 A, the tensile strength increases, but there is a risk of increased porosity and distortion in the weld. The maximum tensile strength is recorded at a current of approximately 120 A, where sufficient penetration is achieved without causing significant defects in the weld (4,7). Therefore, selecting the optimal welding current is crucial to achieving maximum tensile strength without introducing defects into the welded joints (10,11).

Table 1. The effect of welding current variations on the tensile strength of SMAW welds

No.	Current (A)	Tensile strength	Reason/effect	Ref.
1	90	Low	Insufficient weld penetration, resulting in weaker joints.	(3,5)
2	120	Medium	Sufficient weld penetration is achieved without causing significant defects in the weld.	(4,7)
3	140	Maximum	Higher tensile strength, but there is an increased risk of porosity and distortion in the weld.	(4,7)

Table 2. Effect of electrode type on tensile strength in SMAW welds

No.	Electrode Type	Main Characteristics	Description	Ref.
1	E7016	High stability, suitable for low-carbon steel	Stable characteristics support welds with better tensile strength	(6)
2	E7018	Better crack resistance	Lower performance in tensile strength when used under the same welding current and position	(5)

3.2 Effect of electrode type on tensile strength

The E7016 electrode has been proven to produce higher tensile strength compared to the E7018 electrode. This advantage is attributed to the more stable characteristics of the E7016 electrode, making it highly suitable for welding low-carbon steel, as explained in the study (6). On the other hand, although the E7018 electrode offers superior crack resistance, its performance in terms of tensile strength is slightly lower than that of the E7016, particularly when used under similar welding current conditions and positions, as revealed in the research (5).

3.3 Effect of welding position on tensile strength

The welding position has a significant impact on the tensile strength of the weld. Welding in the horizontal position generally produces better tensile strength compared to vertical or overhead positions. This is due to the ability of horizontal welding to maintain a more stable flow of molten metal, which in turn reduces the likelihood of defects such as poor weld quality or insufficient penetration. Horizontal welding allows for more controlled heating and cooling, resulting in optimal tensile strength in low-carbon steel, as demonstrated in tests on TRS 400 steel using E7016 and E7018 electrodes (6).

Moreover, variations in welding positions can affect the welding outcomes, with vertical welding often leading to porosity formation and other defects that reduce tensile strength in medium-carbon steel. This supports the argument that horizontal welding offers advantages in terms of molten metal flow stability and overall weld joint quality (12). Therefore, selecting the appropriate welding position is a critical factor in enhancing the quality and tensile strength of the weld, as evidenced by various studies investigating the effect of position on the mechanical properties of welds (13).

Table 3. The effect of welding position on tensile strength in SMAW welding

No.	Welding Position	Impact on Tensile Strength	Description	Ref.
1	Horizontal	Better tensile strength	Horizontal position ensures more stable molten metal flow, reducing the risk of defects	(6)
2	Vertical	Generally lower tensile strength	Vertical position often leads to porosity formation and other defects	(12)
3	Overhead	Lower tensile strength	Difficult to control molten metal flow, increasing the likelihood of defects	(12,13)

3.4 Effect of cooling on tensile strength in SMAW welds

In SMAW welding, the cooling medium plays a crucial role in determining the quality of the weld joint, particularly in terms of tensile strength. The choice of an appropriate cooling medium can significantly influence the mechanical properties of the weld. For S45C carbon steel, the type of cooling medium used has a direct impact on the tensile strength of the weld. Faster cooling media, such as water, accelerate the solidification of the weld metal, resulting in a harder microstructure but with a potential risk of cracking due to high residual stress. This indicates that while water provides rapid and hard results, caution is needed to avoid damage (7).

For ST52 carbon steel, the importance of selecting the right cooling medium to achieve optimal tensile strength is emphasized. Experiments have shown that slower cooling media, such as air, produce a more stable microstructure and improve the tensile strength of the weld. Although air cooling may be slower, it results in a more durable and stronger weld joint, making it an ideal choice for applications requiring high tensile load resistance (8).

Table 4. The effect of cooling media on tensile strength in SMAW welding

No.	Cooling Medium	Effect on Tensile Strength	Ref.
1	Water	Accelerates cooling, resulting in a harder microstructure but with a high risk of cracking due to residual stress.	(7,13)
2	Air	Slower cooling produces a more stable microstructure, enhancing tensile strength in carbon steel.	(7,8,13)
3	Quenching Media	Creates a finer microstructure, increasing hardness and tensile strength but can cause brittleness in the weld.	(13)

Furthermore, studies have found that using quenching media on S45C carbon steel results in a finer microstructure and increases weld hardness, which positively affects tensile strength. However, it is important to note that excessively rapid cooling, such as with extreme quenching media, can lead to embrittlement or reduced material toughness, posing a risk of weld joint failure under heavy loads (14).

3.5 Factors influencing welder's effect on tensile strength

The skills of a welder play a crucial role in determining the quality of welding results, particularly on carbon steel materials. Research indicates that a welder's expertise not only affects welding techniques but also their ability to optimally manipulate various welding parameters. In welding S45C steel, trained welders are capable of producing stronger weld joints with higher tensile strength. Skilled welders excel in controlling weld penetration depth and welding speed, which significantly influence the quality of the weld joint (7).

Mastery of proper welding techniques by welders can result in a more homogeneous microstructure, contributing to the improved tensile strength of the weld joint. The appropriate expertise of a welder is essential in achieving weld quality that is not only strong but also exhibits optimal mechanical properties, as evidenced by enhanced tensile strength across various materials (8).

Table 5. Factors influencing the welder's effect on tensile strength

No.	Factor	Impact on Tensile Strength	Ref.
1	Welder's Skill	Skilled welders can produce stronger weld joints with higher tensile strength, particularly on carbon steel, such as S45C steel.	(7)
2	Mastery of Proper Welding Techniques	Mastery of proper welding techniques by welders results in a more homogeneous microstructure, improving the tensile strength of the weld joint.	(8)
3	Control of Welding Parameters	Skilled welders can optimally control weld penetration depth and welding speed, which significantly affect the quality and tensile strength of welds.	(7,8)

4. Conclusion

The tensile strength in the SMAW welding process is influenced by several key factors, including welding current, electrode type, welding position, cooling medium, and welder skills. Research shows that the optimal tensile strength is achieved at a welding current in the middle of the standard welding current range. At this current, sufficient penetration is achieved without causing significant defects in the weld joint.

The electrode type also affects tensile strength, with the E7016 electrode providing better results than the E7018 due to its higher stability, although the E7018 excels in crack resistance. Welding in the horizontal position offers better results compared to vertical or overhead positions due to more stable molten metal flow and more controlled cooling, leading to optimal tensile strength.

The cooling medium plays a significant role in the microstructure and tensile strength. Faster cooling media, such as water, increase hardness but may cause cracking, while slower cooling media, such as air, result in more stable and durable weld joints. Additionally, the welder's expertise is crucial in controlling welding parameters, leading to a more homogeneous microstructure and optimal tensile strength.

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