

Research Article

The Effect of Welding Parameter on the Tensile and Impact Properties of Weldments

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Abstract

The mechanical performance of welded joints is significantly influenced by welding parameters, particularly welding current, which governs heat input, fusion quality, and metallurgical transformations. This study examines the effect of welding current on the tensile and impact properties of shielded metal arc welded (SMAW) mild steel joints. Standardized mild steel specimens were prepared and welded using E6016 electrodes at varying current levels (50A, 75A, 100A, 125A, 150A, 175A, and 200A) while maintaining a constant voltage of 220V. Mechanical tests, including tensile strength, impact resistance, and hardness evaluations, were conducted to assess the relationship between welding current and joint properties. The results reveal that moderate welding currents (125A–150A) produce weldments with superior mechanical properties, characterized by high ultimate tensile strength (UTS), favorable ductility, and balanced hardness. Lower currents (<75A) resulted in inadequate fusion, leading to weak joints with reduced strength and toughness. Conversely, excessively high currents (>175A) led to increased brittleness and reduced tensile strength due to grain coarsening and excessive heat input. The hardness test results further confirm that moderate current levels enhance both strength and wear resistance without compromising ductility. These findings emphasize the need for precise control of welding parameters to optimize joint integrity and mechanical performance. The study provides practical guidelines for selecting welding currents in industrial applications, ensuring enhanced weld quality and durability.

Keywords

Shielded Metal Arc Welding (SMAW), Welding Parameters, Tensile Properties, Impact Toughness, Mild Steel Weldments

1. Introduction

Shielded Metal Arc Welding (SMAW) remains one of the most prevalent joining processes in manufacturing and construction industries, particularly valued for its versatility, cost-effectiveness, and adaptability to various operating conditions [1, 2]. The process, which establishes an electric arc between a coated metal electrode and the workpiece, generates sufficient thermal energy to create fusion between the base materials. While SMAW's fundamental principles are well-established, the optimization of process parameters con-

tinues to challenge practitioners and researchers alike [3]. The quality and reliability of welded joints predominantly depend on the careful control of key welding parameters, particularly welding current, voltage, and electrode characteristics. These parameters significantly influence the joint's mechanical properties, including tensile strength, hardness, and impact toughness, through their effects on heat input and solidification behavior [2, 4]. Recent studies have demonstrated that even minor variations in these parameters can lead to sub-

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Received: 23 January 2025; **Accepted:** 8 February 2025; **Published:** 6 March 2025



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stantial changes in weld quality and mechanical performance [5, 6].

Welding current, specifically, plays a pivotal role in determining the heat input and, consequently, the metallurgical transformations within the weld zone and heat-affected zone (HAZ). Higher current levels increase penetration and fusion rates but may lead to detrimental microstructural changes, including excessive grain growth in the HAZ, potentially compromising the joint's mechanical integrity [7]. Conversely, insufficient current can result in lack of fusion defects and reduced joint strength [8]. The arc voltage, while generally more stable in SMAW compared to other processes, significantly influences arc stability and electrode melting characteristics, ultimately affecting weld bead geometry and joint properties [2].

The present study investigates the relationship between welding current and mechanical properties in SMAW-welded mild steel joints. Using standardized mild steel specimens prepared according to ASTM specifications, the research employs an E6016 electrode across a systematically varied current range (50-200 A) while maintaining a constant voltage of 220 V. Seven distinct samples (designated X1 through X7) were produced using single-U butt joint configurations, followed by controlled air cooling. Comprehensive mechanical testing, including tensile strength and hardness evaluations, was conducted to assess the impact of current variation on joint properties.

This investigation aims to: (1) establish quantitative relationships between welding current and key mechanical properties, (2) identify optimal current ranges for achieving superior joint performance, and (3) develop practical guidelines for parameter selection in industrial applications. The findings contribute to the growing body of knowledge in welding parameter optimization [9, 10] and provide valuable insights for practitioners seeking to enhance weld quality in structural and fabrication applications. Additionally, this research addresses the industrial need for more precise parameter control strategies in SMAW processes, particularly in applications where joint reliability is critical.

2. Materials and Methods

Commercial-grade mild steel rods were selected for their availability and widespread use in structural applications, as noted by similar studies that have used mild steel to explore weld property relationships under varying conditions [9, 11]. Each rod was machined according to ASTM E8 standards to obtain standardized circular tensile test specimens as shown in Figures 1 and 2, to ensure precision in geometry and consistency across all specimens.

After preparation, the rods were cut and welded at the mid-point using a butt weld configuration (single-U joint) with an E6016 electrode, a choice that balances weld strength

with ease of use and is commonly applied in manual arc welding on mild steel [12]. A constant voltage of 220 V was maintained during welding, while the welding current was varied across seven levels: 50 A, 75 A, 100 A, 125 A, 150 A, 175 A, and 200 A as shown in Table 1.

Table 1. Welding condition.

Specimen Label	Welding Current (A)	Voltage (V)	Cooling Condition
X1	50	220	Air cooling
X2	75	220	Air cooling
X3	100	220	Air cooling
X4	125	220	Air cooling
X5	150	220	Air cooling
X6	175	220	Air cooling
X7	200	220	Air cooling

The specimens, labelled X1 through X7 according to current settings, were subjected to air cooling post-welding to avoid rapid cooling effects, which has been reported in the literature to cause brittleness and residual stress in welded joints [13, 14].



Figure 1. Tensile test specimens.

The welded specimens were tested at room temperature using a computerized Instron Testing Machine (Model 3369). Each specimen was secured in the testing machine's grips, and a uniaxial tensile load was applied until fracture. Load displacement plots were obtained on an X – Y recorder and ultimate tensile strength, yield strength, and percentage elongation values were calculated from the load-displacement diagrams. The testing, as effected on the welded joints of each sample, shows results that give information on the loads at break, extension at break, tension strain at break, tension stress at break, and energy at break.

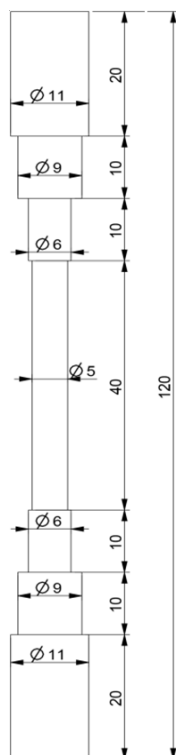


Figure 2. Specimen dimensions.

Hardness testing was performed using a Vickers hardness tester, following ASTM E92 standards to ensure accurate and reliable measurements [15]. A load of 1 kg and a dwell time of 10 seconds were applied to generate an indentation, and the dimensions of the indentation were then measured to calculate the Vickers hardness number (HV). The hardness values were averaged from two separate tests for each specimen to improve the accuracy of the readings.

3. Results and Discussion

The tensile testing results of the shielded metal arc welding (SMAW) mild steel samples is tabulated in Table 2. The tensile stress and strain at break are shown in Figure 3. The load at break and UTS values indicate the maximum strength each sample can sustain before failure. Samples welded with lower currents, such as X1 (50A), displayed a lower UTS (234.4 MPa) and a comparatively low load at break (4601.6 N), suggesting that insufficient current reduces the fusion strength and bonding quality of the weld.

Table 2. Tensile Test Result.

Sample	Load at break (standard) (N)	Extension at break (standard) (mm)	Tensile Strain at break (Standard) (mm/mm)	Tensile Stress at break (Standard) (Mpa)	Ultimate Tensile strength (N/mm ²)
X1	4601.605	5.16687	0.12917	234.3578	
X2	10708.15	12.25015	0.30625		383.8054
X3	5728.936	22.83375	0.57084	291.7723	463.9599
X4	6399.757	25.00015	0.625	325.937	377.8392
X6	6375.089	22.16687	0.55417	324.6806	535.0404
X5	10353.95	10.91703	0.27293	527.3223	498.3881
X7	5913.839	5.08422	0.12711	301.1894	

In contrast, samples welded at higher currents, such as X5 (150A) and X6 (175A), reached higher UTS values of 527.3 MPa and 535.0 MPa, respectively. This increase in UTS with higher currents aligns with existing literature that associates moderate-to-high heat inputs with better fusion and penetration, resulting in stronger, more resilient welds [2, 16, 17]. However, the UTS for sample X7 (200A) dropped to 301.2 MPa, reflecting potential issues with excessive heat that can lead to grain growth and embrittlement, which weaken the weld integrity [18, 19].

Tensile strain and extension at break provide insights into the ductility and deformation characteristics of the samples.

For instance, sample X4 (125A) exhibited the highest tensile strain (0.625 mm/mm) and extension at break (25 mm), indicating an optimal current level that achieved a good balance between ductility and strength. Samples welded at higher currents, such as X5 (150A) and X6 (175A), showed a reduction in tensile strain (0.2729 and 0.5542 mm/mm, respectively) despite higher UTS values, indicating a trade-off where increased strength was achieved at the expense of ductility. This pattern supports the theory that higher currents can lead to harder, more brittle structures with decreased capacity for plastic deformation (Lancaster, 1999).

The tensile stress at break further highlights how welding current affects material resilience. Samples with moderate welding currents, such as X4 (125A), demonstrated a high tensile stress of 325.9 MPa, indicating optimal resistance to stress without premature failure. However, as seen with X7 (200A), excessively high currents reduced tensile stress to 301.2 MPa, suggesting that increased residual stresses and material hardening at high currents compromise the overall mechanical integrity [20, 21]. It can be deduced that moderate currents (125A-150A) yielded the best combination of high UTS, ductility, and tensile stress resistance, providing a well-rounded mechanical profile with both strength and flexibility. Conversely, both lower and higher extremes in welding current compromised either strength or ductility, highlighting the delicate balance required in welding processes.

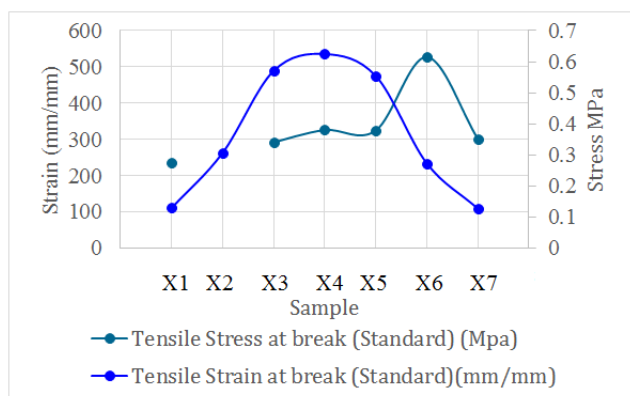


Figure 3. Tensile stress and strain at break.

The hardness test results presented in Table 3 provide significant insights into the influence of welding parameters, particularly welding current, on the hardness characteristics of the mild steel samples. Hardness, as measured by the Vickers Hardness test (HV 1Kg). The hardness values for the seven samples (X1 to X7) vary substantially, indicating that the welding current significantly influences hardness. Sample X4, welded at 125A, exhibits the highest hardness average (537.6 HV), followed by X5 (150A) with an average hardness of 404.3 HV. Samples X1 and X2, which were welded at lower currents of 50A and 75A, show comparatively lower hardness values, with averages of 204.3 HV and 207.5 HV, respectively. This trend suggests that an increase in welding current enhances the hardness of the weld joint up to a certain point, beyond which additional increases in current begin to have a diminishing or even adverse effect on hardness, as seen in samples welded at 175A (X6) and 200A (X7) with hardness values of 319.1 HV and 287.5 HV, respectively.

The observed trend aligns with findings in welding metal-urgy, where moderate heat input from controlled current levels is known to contribute to grain refinement and phase

transformations within the heat-affected zone (HAZ), which can increase hardness [16, 19]. However, excessive current can lead to overheating, causing grain coarsening and reduced hardness, as evidenced by the lower values in samples X6 and X7 [22].

Table 3. Hardness Test.

SAMPLE	Test 1(HV 1Kg)	Test 2(HV 1Kg)	Average (HV 1Kg)
X1	202.4	206.2	204.3
X2	214.5	200.5	207.5
X3	255.8	256.1	255.9
X4	576.8	497.6	537.6
X5	404.5	404.1	404.3
X6	315.3	323	319.1
X7	285.3	289.7	287.5

The relationship between the obtained results hardness and tensile strength in welded joints show direct correlation influenced by the microstructural characteristics and phase composition of the material [2]. The tensile test results showed that samples with moderate welding currents, such as X4 and X5, achieved high ultimate tensile strength (UTS), consistent with their higher hardness values. This suggests that optimal welding parameters result in welds with both high strength and hardness, which is essential for applications requiring strong and durable joints.

However, there is an observed trade-off between hardness and ductility. Samples with very high hardness, like X4, may exhibit brittleness, which could lead to fracture under stress, especially in dynamic or impact-loading applications [18, 19]. The sample with the highest hardness (X4 at 125A) exhibited relatively high tensile strength but may be more susceptible to brittle failure due to its high hardness. In contrast, samples with moderate hardness values, such as X3 (255.9 HV) and X5 (404.3 HV), offer a more balanced combination of strength and ductility, which could improve their performance under variable loading conditions. The hardness test results underscore the importance of controlling welding parameters to achieve desired mechanical properties in welded joints. An optimal hardness level, as seen in samples X3, X4, and X5, indicates a strong resistance to surface wear while maintaining adequate tensile strength and ductility. This balance is critical for applications where welded joints are subjected to complex loading conditions that demand both resilience and toughness. Excessively high hardness can result in brittleness, which reduces the ability of the weld to withstand impact and fatigue stresses [18].

4. Conclusion

This study assessed the effects of varying welding currents on the mechanical properties of shielded metal arc welded (SMAW) mild steel joints, focusing on tensile strength and hardness. Results indicate that moderate welding currents (125A–150A) yield the best mechanical properties, achieving high ultimate tensile strength (UTS), favourable tensile strain, and optimal hardness. Excessive currents (175A and above), however, led to decreased tensile strength and hardness, likely due to grain coarsening from excessive heat. A balance between hardness and tensile properties is essential; high hardness with UTS can increase brittleness, while moderate currents optimize strength and durability. Thus, controlling welding current enhances joint quality and performance. These findings inform welding parameter selection in industrial applications, with future research recommended to explore additional parameters like electrode type and cooling rate.

Abbreviations

ASTM	American Society for Testing and Materials
HAZ	Heat-Affected Zone
HV	Hardness Value
SMAW	Shielded Metal Arc Welding
UTS	Ultimate Tensile Strength

Authors Contributions

Ojo Ayotunde Adigun: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing

Adebayo Adeyinka: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Supervision

Olanipekun Kolade Abiola: Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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