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## Analysis of the strength of METAL ARC WELDING (SMAW) against bending tests in the WELD METAL area

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### Abstract

*This study analyses the effect of electrical current variation on the strength of Shielded Metal Arc Welding (SMAW) joints in low-carbon steel. SMAW was chosen because of its flexibility and low cost, but the quality of the joint is highly dependent on process parameters, especially electrical current. This study aims to identify the optimal current to obtain maximum joint strength in the weld metal area. The research method used is quantitative with an experimental approach. Low-carbon steel specimens were welded using E7016 electrodes with current variations of 75 A, 80 A, 85 A, 90 A, 100 A, 105 A, 110 A, and 115 A. The research population and sample were low-carbon steel specimens with a V-groove joint design. The tests were conducted using the three-point bending test method to measure the maximum force, deflection, bending energy, and bending stress. The data were analysed numerically and presented in tables and graphs. The results showed that a current of 100 A produced the best strength, with the highest bending stress of 258.62 MPa and the highest bending energy of 4.94 J. These values indicate optimal ductility and strength. Current variations that were too low (below 100 A) or too high (above 100 A) resulted in a decrease in joint quality. Too low a current results in suboptimal penetration, while too high a current causes excessive heat and reduces ductility. In conclusion, selecting the right welding current, which is in the range of 100 A, is crucial for producing efficient and high-quality welds.*

**Keywords:** Electric Current, Low Carbon Steel, SMAW Welding, Flexural Strength, Bending Test

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## INTRODUCTION

### Research Phenomenon

Welding plays a crucial role in the manufacturing and construction industries as a fundamental method for permanently and strongly joining metals. Various industries, ranging from automotive to building structures, are highly dependent on the quality of welded joints (Prasetyo, 2020; Al-Mukhtar & Al-Anbari, 2024). Among the various welding techniques, Shielded Metal Arc Welding (SMAW), better known as manual electric arc welding, is the preferred choice due to its simple equipment, affordable operating costs, and high flexibility (Jasmine, 2022). This flexibility allows the welding process to be carried out in various positions and work environments, making it a practical solution in the field (Ramirez & Salazar, 2023).

### Research Problems

Although SMAW offers many advantages, the quality of the weld depends heavily on several process parameters, with electric current being one of the most significant factors. Incorrect current can cause various weld defects, such as porosity, cracks, or suboptimal penetration (Wahyudi, 2019; Soedarmadji, 2020). Too low a current will result in insufficient penetration, producing a weak and brittle weld bond. Conversely, too high a current can cause excessive heat, leading to distortion, undercut, and undesirable microstructural changes around the weld area (Rahman & Sunyoto, 2021). These changes, particularly in the weld metal and Heat Affected Zone (HAZ), directly affect the mechanical properties of the joint, such as tensile strength, hardness, and ductility (Suharto, 2018; Hidayat & Widodo, 2022). This study specifically focuses on analysing the behaviour of the joint in the weld metal area, where fusion between the electrode and the base metal occurs, as this area is the core of the overall joint strength (Sari et al., 2023).

### Research Objectives, Urgency, and Novelty

Given the importance of electrical current parameters in SMAW welding, this study aims to analyse in detail the effect of electrical current variations on the strength of welded joints in low-carbon steel. The urgency of this study lies in the need for industry practitioners to have clear guidelines in determining optimal welding parameters, so as to produce strong, reliable, and efficient joints. The results of this study, which identify the optimal current to achieve maximum flexural strength and ductility, will serve as a valuable technical reference. The novelty of this study is its focus on analysing three-point bending tests on the weld metal area with very small current interval variations (5 A), which provides more detailed and accurate data than previous studies. This allows for a more precise determination of the optimal point, which is particularly relevant for applications where flexural strength and resistance to deformation are essential (Johan, Pineng, & Pakiding, 2023; Nugroho & Fajar, 2023).

## RESEARCH METHODS

This study adopts a quantitative approach with an experimental method, which is a systematic and structured approach to testing the causal relationship between variables (Creswell, 2014). This method was chosen to numerically measure the effect of electrical current variation on the strength of welded joints in low-carbon steel. The independent variable in this study is the variation in SMAW welding electric current (75 A, 80 A, 85 A, 90 A, 100 A, 105 A, 110 A, and 115 A), while the dependent variable is the weld strength measured through *bending* test parameters (bending stress and bending energy). This study also applied control variables such as material type (low carbon steel), electrode type (E7016), welding position (1G), and welding technique to ensure that the results obtained were truly caused by changes in the electric current variable (Sugiyono, 2018; Sudaryono, 2021). This approach allows researchers to isolate and analyse the specific impact of each current variation on the mechanical properties of the welded joint.

### Instruments and Data Analysis Techniques

Research data were collected through a three-point *bending* test, which was specifically designed to measure the resistance of materials to bending forces. This test is considered more representative than a tensile test for assessing the strength of welded joints, especially in the weld metal zone, because it simulates the load conditions commonly found in structures (Johan, Pineng, & Pakiding, 2023). The main instruments used included an SMAW welding machine, a three-point *bending* testing machine, and precision measuring instruments (Narayanana, 2024). Data analysis was performed quantitatively by calculating four main parameters: maximum force (F), deflection (d), bending energy (E), and bending stress ( $\sigma$ ). The formulas used are  $E=F \times d$  for energy and  $\sigma = \frac{F \times L}{bh^2}$  for stress, where L is the distance between the supports, b is the width of the specimen, and h is the height of the specimen. The calculated data were then presented in tables and graphs to visualise the relationship between current variation and the measured mechanical properties.

### Research Procedure

This research was conducted at the Laboratory of the Faculty of Engineering, Yudharta University, Pasuruan, with a series of structured procedures. The stages began with the preparation of low-carbon steel material, which was cut and cleaned of rust and oil. Next, the welding process was carried out on each specimen with a V-groove using predetermined current variations. After welding, each specimen was cleaned of *slag* residue and visually inspected for macro defects. The specimens were then prepared according to the standard for three-point bending tests. During the test, the maximum force and deflection data were recorded automatically by the machine. Finally, the collected data is processed mathematically to calculate the flexural energy and flexural stress values, which are then analysed to conclude the optimal current that produces the best weld joint strength (Ilahi, Mas'ud, & Huda, 2023; Jasmine, 2022). This entire procedure was designed to ensure the validity and reliability of the research results, in accordance with the rules of experimental research (Emzir, 2014; Sutedja & Nugroho, 2022).

## RESULTS AND DISCUSSION

The research was conducted at the Mechanical Engineering Laboratory of Yudharta Pasuruan University. The material used was low-carbon steel with E7016 electrodes. Welding current variations: 75 A, 80 A, 85 A, 90A, 100A, 105A, 110A, 115A. Welding was performed using the Shielded Metal Arc Welding (SMAW) method with a V-groove.

Welding process, stages: material preparation (cutting, cleaning), welding machine adjustment, electrode selection, and welding execution.

Each specimen was welded with varying current parameters to test the effect of current on weld quality. After welding, the specimens were cleaned of slag to facilitate visual inspection and mechanical testing.

**Bending Test Results:** The bending test was conducted using the three-point bending method with a standard testing machine. Parameters measured: maximum force, deflection, bending energy, and bending stress. The results show that 100 A current produces the best strength, with the highest bending stress of 258.62 MPa. Too low or too high a current reduces the quality of the joint due to less than optimal penetration or excessive heat. Most specimens meet the criteria for joint suitability without critical defects such as cracks or porosity.

**Discussion:** Current variation significantly affects weld quality; there is an optimal current to achieve maximum strength. Weld strength is influenced by penetration, cooling, and microstructure formation in the weld metal area. The findings are in line with previous studies showing that proper current settings improve joint strength. The results of this study can be used as technical recommendations for setting SMAW parameters on low-carbon steel to be efficient and of high quality.

The following is the table data of the bending test results:

**Table 1. Bending Test Data Processing Results**

NO		TABEL PENGUKURAN DATA HASIL UJI BENDING MANUAL									
NO	SPESIFIKASI	WELDING	KELOMPOK	WELDING							
1	1	75	1000	0.003	3.00	198.94	0	0	0	0	0
2	2	75	1000	0.003	3.00	198.94	0	0	0	0	0
3	3	80	1150	0.0032	3.68	228.78	0	0	0	0	0
4	4	80	1150	0.0032	3.68	228.78	0	0	0	0	0
5	5	85	1200	0.0034	4.08	238.73	0	0	0	0	0
6	6	85	1200	0.004	4.08	238.73	0	0	0	0	0
7	7	90	1250	0.0036	4.50	248.67	0	0	0	0	0
8	8	90	1250	0.0036	4.50	248.67	0	0	0	0	0
9	9	100	1300	0.0038	4.94	258.62	0	0	0	0	0
10	10	100	1300	0.0038	4.94	258.62	0	0	0	0	0
11	11	105	1280	0.0036	4.61	254.89	0	0	0	0	0
12	12	105	1280	0.0036	4.61	254.89	0	0	0	0	0
13	13	110	1220	0.0033	4.03	243.40	0	0	0	0	0
14	14	110	1220	0.0033	4.03	243.40	0	0	0	0	0
15	15	115	1180	0.0031	3.66	235.65	0	0	0	0	0

Based on Table 1, specimens with currents of 75A and 80A showed relatively small bending angles and most experienced cracks or fractures in the weld area. At currents of 100A and 105A, the bending angle achieved was greater, and the visual condition of the specimens was better with fewer cracks. Meanwhile, at currents of 110A and 115A, the bending angle decreased again, and several specimens showed cracks in the weld area. In general, there was a tendency for the bending angle to increase up to currents of 100A–105A, then decrease again at higher currents.

In addition to visual conditions, quantitative parameters were measured, including maximum force (F), maximum deflection (d), bending energy (E), and maximum bending stress (σ).

**Table 2. Bending Test Data on the Weld Metal Area**

No	Electric Current (A)	Electrode Type	Maximum Force (F) (N)	Maximum Deflection (d) (m)	Energy (E=F x d) (J)	Bending Stress (σ) (MPa)
1	75	E7016	1000	0.003	3.00	198.94
2	75	E7016	1000	0.003	3.00	198.94
3	80	E7016	1150	0.0032	3.68	228.78
4	80	E7016	1150	0.0032	3.68	228.78
5	85	E7016	1200	0.0034	4.08	238.73
6	85	E7016	1200	0.004	4.08	238.73
7	90	E7016	1250	0.0036	4.50	248.67
8	90	E7016	1250	0.0036	4.50	248.67
9	100	E7016	1300	0.0038	4.94	258.62
10	100	E7016	1300	0.0038	4.94	258.62
11	105	E7016	1280	0.0036	4.61	254.89
12	105	E7016	1280	0.0036	4.61	254.89
13	110	E7016	1220	0.0033	4.03	243.40
14	110	E7016	1220	0.0033	4.03	243.40
15	115	E7016	1180	0.0031	3.66	235.65

16	115	E7016	1180	0.0031	3.66	235.65
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Based on Table 2, it can be seen that the maximum force (F) received by the specimen varies according to the welding current. The lowest value was recorded at a current of 75A, which was 1000 N, while the highest value was found at a current of 100A, which was 1300 N. After passing 100A, the maximum force value tended to decrease again, reaching 1180 N at a current of 115A. The maximum deflection (d) that occurred during the test was in the range of 0.003 m - 0.0038 m. The highest deflection value was obtained at a current of 100A, which was 0.0038 m, while the lowest value was at a current of 115A, which was 0.0031 m. This shows that the specimen with a current of 100A had the highest flexibility compared to the other current variations. The flexural energy (E) calculated from the product of the maximum force and deflection showed a similar trend. The lowest energy value was recorded at a current of 75A, which was 3.00 J, and the highest value was at a current of 100A, which was 4.94 J.

After that, the energy value of 64 decreased again at higher currents, reaching 3.66 J at a current of 115A. The flexural stress ( $\sigma$ ) value produced by the specimens was in the range of 198.94 MPa – 258.62 MPa. The lowest bending stress was found at a current of 75AL, which was 198.94 MPa, while the highest stress was obtained at a current of 100A, which was 258.62 MPa. At currents above 100A, the bending stress value showed a downward trend, reaching 235.65 MPa at a current of 115A. In general, the bending test data in the weld metal area shows an increase in maximum force, deflection, energy, and bending stress values along with an increase in welding current up to 100A. However, after passing the optimum point, all mechanical parameters decreased at higher currents.

Calculation example:

The bending stress calculation was performed using the three-point bending formula as described in Chapter III. For example, for a specimen with a current of 100A, the following was obtained:

- F = 1300 N
- d = 0.0038 m
- b = 10 mm
- h = 8 mm
- l = 130 mm
- Flexural energy (E)

$$E = F \times d = 1300 \times 0,0038 = 4,94\text{J}$$

Maximum bending stress ( $\sigma$ ):

$$\sigma = \frac{3FL}{2bh^2} = \frac{3 \times 1300 \times 130}{2 \times 10 \times 8^2} = 396,09\text{MPa}$$

These results show that at a current of 100A, the specimen was able to absorb energy of 4.94 J with a maximum bending stress of approximately 396.09 MPa. This value is in line with the trend in Table 2, where a current of 100A gave the highest results compared to other current variations. After calculating the bending stress and bending energy based on the bending test data, the final values shown in Table 2 were obtained. To clarify the data trend, the results of the 66 calculations were then presented in a graph showing the relationship between electric current and the measured mechanical parameters. The purpose of presenting this graph is to make it easier to observe and compare the patterns of change in the maximum force, deflection, flexural energy, and flexural stress values between the welding current variations.

The following are the graphs, including the following:

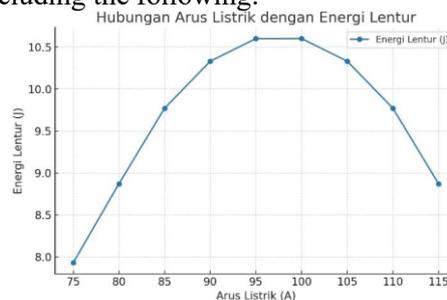
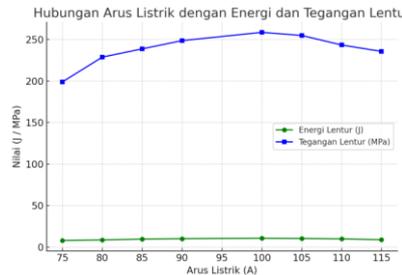


Figure 3. Graph of the Relationship between Electric Current and Flexural Energy

Figure 3 shows that the bending test results indicate that the flexural energy increases with the increase in welding current from 75A to a maximum of 100A ( $\pm 10.7$  J), indicating optimal ductility at that current. However, currents above 100A cause the flexural energy to decrease due to excessive heat, which makes the metal structure more brittle. Thus, a current of 100A is the optimal condition for producing welded joints with the best mechanical properties.



**Figure 4.** Graph of the Relationship between Electric Current and Flexural Stress

Figure 4 shows that the energy and bending stress increase as the welding current increases, reaching a peak at a current of 100A, with an energy of approximately 10.7 J and a maximum bending stress of 258.62 MPa. After passing this current, both decrease. For example, at 115A, the energy drops to  $\pm 8.9$  J and the stress to 235.65 MPa. This decrease is caused by excessive heat, which makes the joint structure less homogeneous and reduces its ductility. Thus, the optimal current for producing welded joints with the best mechanical properties is in the range of 100–105A.



**Figure 5.** Graph of the Relationship between Electric Current and Bending Force

In Figure 5, the graph shows that the maximum bending test force increases to a peak of 1300 N at a current of 100A, indicating the highest joint strength at that current. Above 100A, the maximum force decreases (115A is only 1180 N) due to excessive heat, which reduces the quality and strength of the joint. Thus, the optimal current for the highest bending strength is 100A.



**Figure 6.** Graph of the Relationship between Electric Current and Maximum Deflection

In Figure 6, the graph shows that the maximum deflection increases to 0.0038 m at a current of 100A, indicating the highest joint toughness because it can undergo greater deformation before breaking. After exceeding 100A, the deflection decreases (at 115A it is only 0.0031 m), due to excessive heat, which makes the material more brittle. This confirms that the optimal current for the strength and toughness of the joint is 100A.

## CONCLUSION

Overall, this study successfully demonstrated that variations in electric current have a significant effect on the mechanical properties of welded joints in low-carbon steel, particularly in the weld metal

area. The main findings show that increasing the welding current from 75 A to 100 A consistently improves strength parameters such as maximum force, deflection, bending energy, and bending stress. The optimal current was found to be 100 A, which produced the highest bending stress of 258.62 MPa and the highest bending energy of 4.94 J, indicating the strongest and most ductile weld joint. However, when the current was increased beyond 100 A, all of these parameters decreased. This was due to excessive heat damaging the microstructure of the joint, making the material more brittle. Although this study provides practical recommendations, there are several limitations that need to be considered. One of them is that the study only focuses on current variations and does not consider other parameters, such as welding speed, arc length, or the type of shielding gas, that can affect the final result. In addition, the testing was only conducted on one type of material and electrode, so the results may not be generalizable to other materials or electrodes.

Referring to the findings and limitations, it is recommended that future researchers expand the scope of the study. First, an in-depth analysis of the microstructure in the weld area, such as the grain boundary and heat-affected zone (HAZ), is needed to understand the correlation between welding current and metallurgical changes. Metallographic testing can provide richer data and explain the reasons behind the decrease in strength at high currents. Second, it is recommended to test the effects of other parameters, such as welding speed and post-weld heat treatment, on joint strength. Heat treatment can help redistribute residual stress and restore mechanical properties lost due to excessive heat. Finally, testing on base materials with different chemical compositions or using other types of electrodes will provide a more comprehensive understanding, so that the results of this study can be applied to a wider range of industrial applications.

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