JOURNAL OF APPLIED MECHANICAL ENGINEERING INNOVATION

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Analysis of Tensile and Bend Strength with Current and Voltage Variations in GMAW Welded Joints of SS400 Steel for Train Underframes

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ARTICLE INFO

Article history:

Received	17.03.2026
Revised	27.03.2026
Accepted	05.04.2026

Keywords:

GMAW, SS400 steel, welding current, welding voltage

ABSTRACT

This study investigates the effect of welding current and voltage variations on the tensile and bend strength of Gas Metal Arc Welding (GMAW) joints in SS400 steel for train underframe applications. SS400 steel plates with a thickness of 4.5 mm were welded using a single-V groove with a 60° angle. The welding parameters consisted of two current levels, 100 A and 120 A, and three voltage levels, 20 V, 23 V, and 26 V. The research used a quantitative experimental method. The tensile test data were analyzed by calculating the average maximum tensile strength and elongation, while the bend test results were evaluated based on visual defects on the convex surface of the specimens. The results show that the 100 A-23 V parameter produced the highest average maximum tensile strength of approximately 458.3 MPa with an average elongation of 13.9%. However, the bend test results indicated that the safest and most acceptable parameter was 120 A with moderate voltage, particularly 23 V, because the specimens showed no visible defects after testing. Therefore, the 120 A-23 V welding parameter is considered the most optimal combination for balancing tensile strength and bend toughness in GMAW welded joints of SS400 steel for train underframe structures

1 Introduction

The development of science and technology in manufacturing has created new improvements in industrial production, including the railway industry. Welding is one of the most important processes in manufacturing and repair because it directly affects the strength, integrity, and safety of structural products. In railway manufacturing, the quality of welded joints is critical for maintaining structural reliability and reducing the risk of service failure.

Gas Metal Arc Welding (GMAW) is widely used because it provides high productivity and is suitable for joining low-carbon steel structures. In this process, welding current and voltage strongly influence heat input, fusion quality, weld penetration, and the mechanical properties of the joint. Improper parameter selection can lead to inadequate penetration, cracks, or insufficient mechanical performance in structural applications [1], [2].

SS400 steel is a low-carbon steel commonly used in plate and structural components because it has good ductility, weldability, and moderate strength. Low-carbon steel generally contains less than approximately 0.3% carbon and is often used in plates, profiles, screws, bolts, and welded structures [3], [4]. For railway underframes, the weld joint must withstand tensile and bending loads while maintaining structural integrity under service conditions.

The welding problem encountered in underframe production requires parameter optimization to ensure that the joint satisfies the expected mechanical requirements. Tensile and bend testing are important destructive tests for assessing welded-joint strength and defect acceptability [5], while previous GMAW studies on SM490A and SS400 steels have shown that welding-current variation influences tensile performance [6]. Therefore, this study analyzes the effect of welding current variations of 100 A and 120 A combined with voltage variations of 20 V, 23 V, and 26 V on the tensile and bend test results of GMAW welded SS400 steel joints. The objective is to determine the welding parameter combination that provides the most balanced tensile strength and bend-test acceptability for train underframe applications.

2 Method

This research used a quantitative experimental approach to evaluate the tensile and bend strength of GMAW welded joints of SS400 steel. The test specimens were produced from SS400 steel plates with dimensions of 300 mm × 125 mm × 4.5 mm. Six plates were prepared with a single-V groove geometry at an angle of 60°. The welding process was performed in the down-hand position using a butt-joint configuration.

The welding process used GMAW/MIG with current variations of 100 A and 120 A. For each current level, three voltages were applied, namely 20 V, 23 V, and 26 V. The filler wire used was ER70S-6 with a diameter of 1.2 mm. After welding, the welded joints were prepared into tensile and bend test specimens. The tensile test was used to obtain the maximum tensile stress and elongation, while the bend test was used to observe defects on the convex surface of the specimens.

The data analysis was performed using a descriptive quantitative method following the principle that quantitative data can be presented systematically through tables, diagrams, and explanatory descriptions [7]. Tensile strength values were averaged for each parameter combination, and the bend test results were evaluated visually based on the presence or absence of defects such as cracks and lack of penetration. The research workflow is presented in Figure 1.

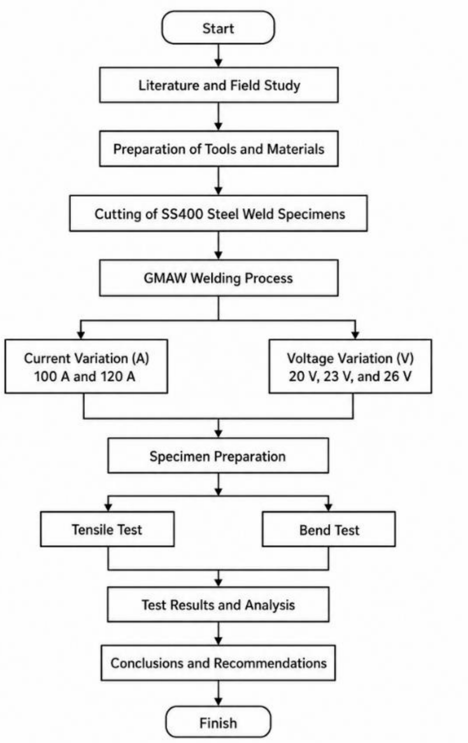

Figure 1. Research flowchart

3 Result and discussion

3.1 Tensile Test Results

The tensile test results indicate that each welding parameter produced different mechanical responses. At 100 A and 20 V, the welded joints showed relatively consistent tensile behavior among the specimens and produced an average maximum tensile stress of 442.1 MPa. This parameter can be considered stable, but it was not the strongest among the tested variations.

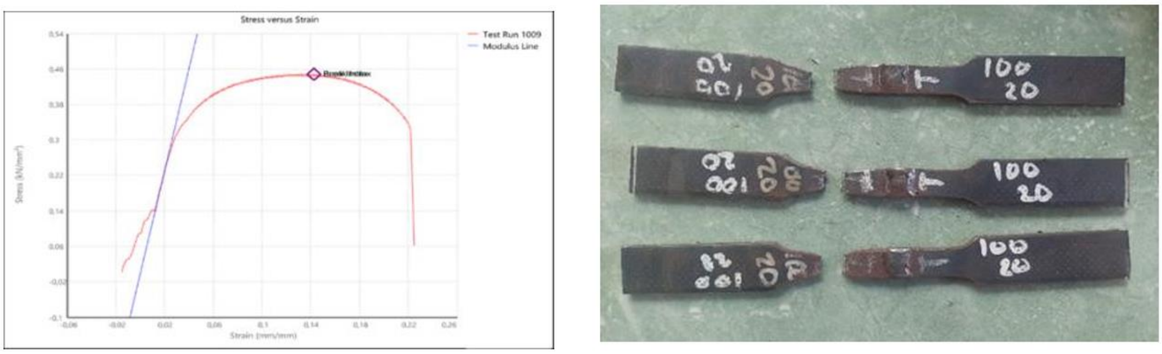

Figure 2. Tensile test graph and specimens at 100 A and 20 V

At 100 A and 23 V, the welded joint produced the highest average maximum tensile stress. The average maximum tensile stress reached 458.3 MPa, with an average elongation of 13.9%. This result indicates that the 100 A-23 V combination provided sufficient heat input for fusion while still maintaining ductility.

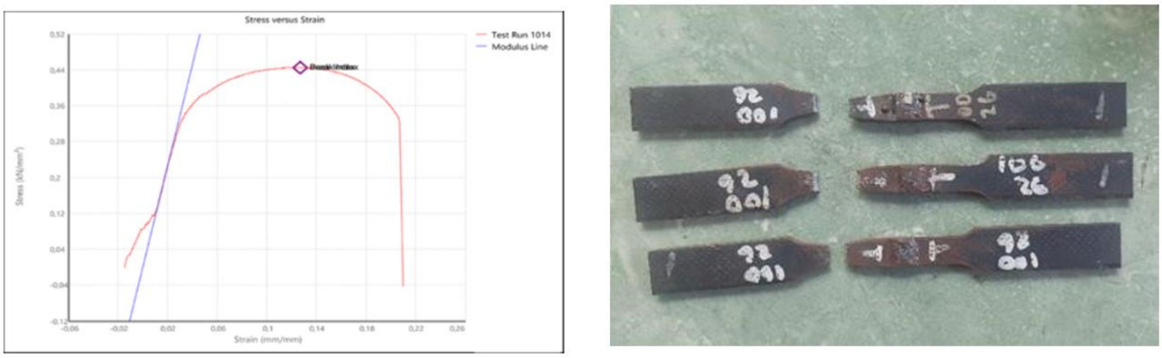

Figure 3. Tensile test graph and specimens at 100 A and 23 V

At 100 A and 26 V, the tensile strength remained competitive, but the average elongation decreased to 12.6%. This condition suggests that increasing voltage beyond the optimum range may reduce ductility even when the tensile strength is still acceptable.

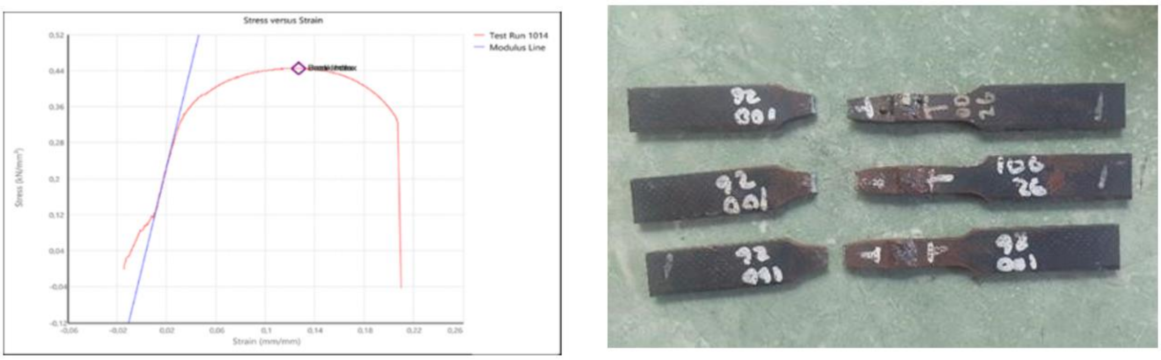

Figure 4. Tensile test graph and specimens at 100 A and 26 V

The 120 A welding current produced relatively balanced tensile results at the three voltage levels. At 120 A and 20 V, the average tensile stress was 443.1 MPa with the highest average elongation of 14.8%. At 120 A and 23 V, the average tensile stress increased to 446.4 MPa with an elongation of 14.4%, indicating a good combination of strength and ductility. At 120 A and 26 V, the average tensile stress was 443.03 MPa with an elongation of 13.5%.

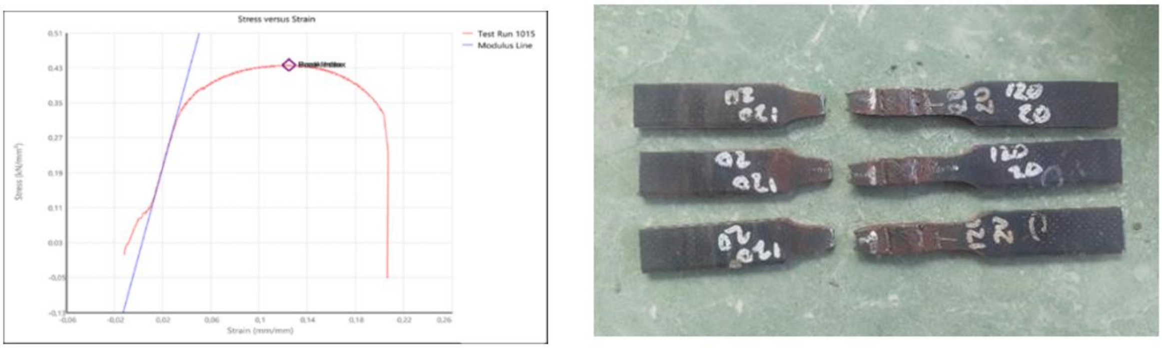

Figure 5. Tensile test graph and specimens at 120 A and 20 V

Figure 6. Tensile test graph and specimens at 120 A and 23 V

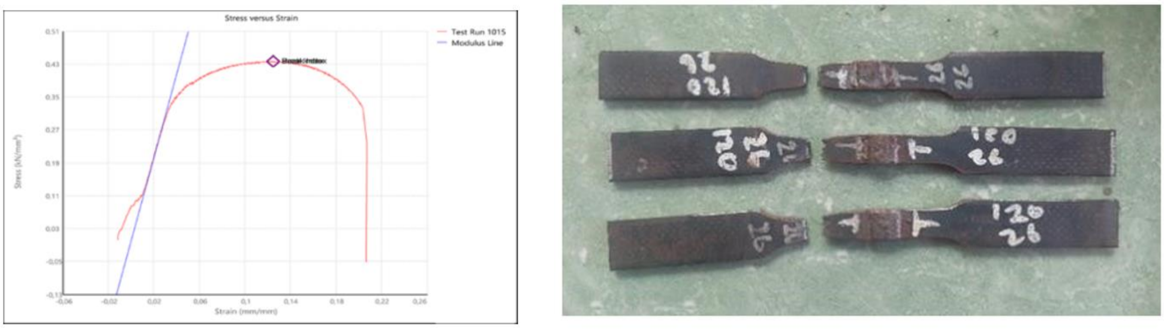

Figure 7. Tensile test graph and specimens at 120 A and 26 V

Table 1. Tensile stress and elongation results

Current (A)	Voltage (V)	Test run	Max tensile stress (MPa)	Average tensile stress (MPa)	Elongation (%)	Average elongation (%)
100	20	1008	432.9	442.1	13.95	13.7
100	20	1009	447.4	442.1	14.26	13.7
100	20	1010	446.0	442.1	12.83	13.7
100	23	1011	466.6	458.3	14.58	13.9
100	23	1012	454.3	458.3	13.03	13.9
100	23	1013	454.1	458.3	14.09	13.9
100	26	1014	445.1	439.9	12.67	12.6
100	26	1015	436.2	439.9	12.46	12.6
100	26	1016	438.3	439.9	12.78	12.6
120	20	1017	437.0	443.1	15.59	14.8

Current (A)	Voltage (V)	Test run	Max tensile stress (MPa)	Average tensile stress (MPa)	Elongation (%)	Average elongation (%)
120	20	1018	440.1	443.1	15.58	14.8
120	20	1019	452.1	443.1	13.13	14.8
120	23	1020	438.1	446.4	15.30	14.4
120	23	1021	455.4	446.4	13.49	14.4
120	23	1022	445.7	446.4	14.38	14.4
120	26	1023	438.9	443.03	14.14	13.5
120	26	1024	447.1	443.03	13.13	13.5
120	26	1025	443.1	443.03	13.11	13.5

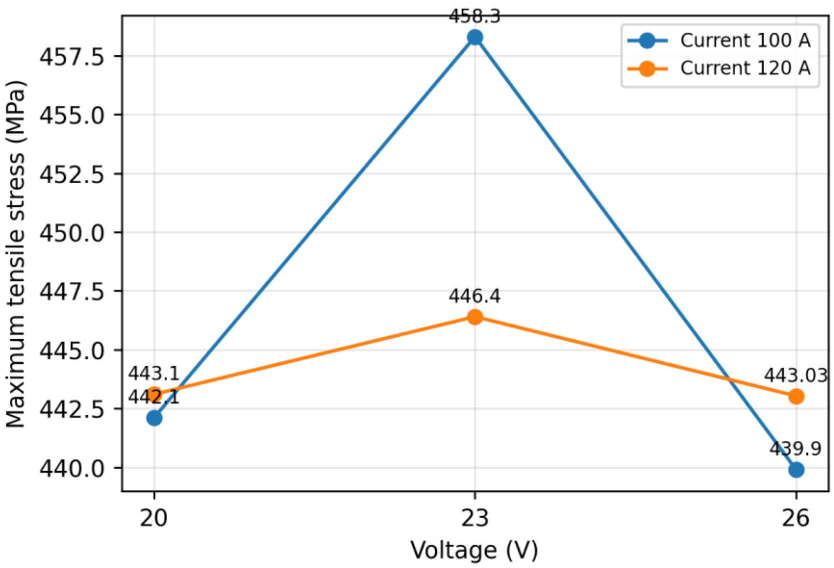

Figure 8. Maximum tensile stress versus voltage at different welding currents

Figure 8 shows that the highest tensile strength was obtained at 100 A and 23 V. However, tensile strength alone is not sufficient to determine the best welding parameter for structural underframe applications because bend-test performance is also essential for evaluating weld soundness.

3.2 Bend Test Results

The bend test was used to evaluate the weld joint surface after deformation. The 100 A-20 V specimens showed no dominant visual defects, although slight incomplete penetration was observed on one specimen. The 100 A-23 V specimens showed improved penetration tendency, but visual defects related to non-uniform groove-wall fusion were still found. At 100 A-26 V, visible defects remained, including an open crack with a length of approximately 5.9 mm.

Figure 9. Bend test specimens at 100 A and 20 V

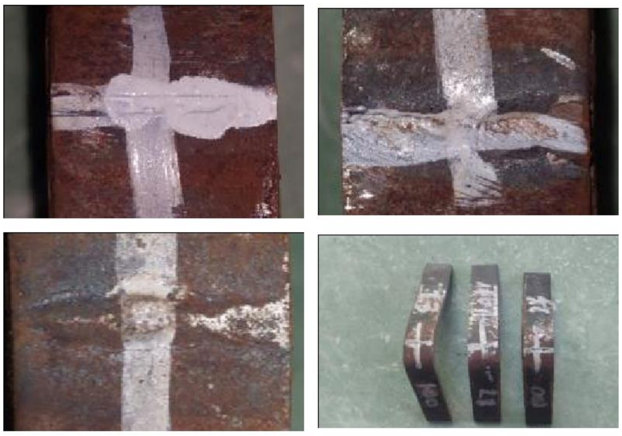

Figure 10. Bend test specimens at 100 A and 23 V

Figure 11. Bend test specimens at 100 A and 26 V

At 120 A and 20 V, the heat input was sufficient to produce more uniform fusion, but a lack of penetration was still observed. At 120 A and 23 V, all three specimens passed the acceptance criteria because no visible defects appeared on the convex surface after testing. At 120 A and 26 V, visible cracks of approximately 3.8 mm and 9.5 mm appeared on one specimen, causing that specimen to fail, while the other two specimens passed.

Figure 12. Bend test specimens at 120 A and 20 V

Figure 13. Bend test specimens at 120 A and 23 V

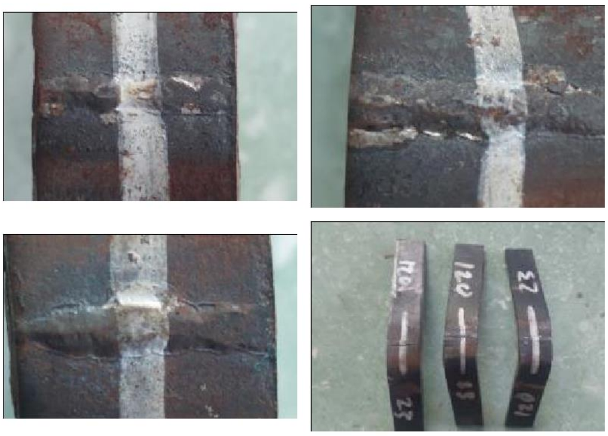

Figure 14. Bend test specimens at 120 A and 26 V

Table 2. Bend test visual evaluation

Current (A)	Voltage (V)	Visual observation	Evaluation
100	20	No dominant defect; slight incomplete penetration was indicated	Conditionally acceptable
100	23	Crack and lack of penetration were observed	Not recommended

Current (A)	Voltage (V)	Visual observation	Evaluation
100	26	Visible crack of approximately 5.9 mm and lack of penetration were observed	Not recommended
120	20	Lack of penetration of approximately 7.3 mm was indicated	Needs improvement
120	23	No visible defect on the convex surface of the specimens	Accepted
120	26	One specimen showed visible cracks of approximately 3.8 mm and 9.5 mm	Partially failed

Based on the combined tensile and bend test results, the 100 A-23 V parameter produced the highest tensile strength, but the 120 A-23 V parameter provided better overall performance because it achieved adequate tensile strength and passed the bend test without visible defects. Therefore, 120 A and 23 V can be regarded as the most suitable parameter for GMAW welded SS400 steel joints in train underframe applications.

4 Conclusion

The tensile test results show that the highest average maximum tensile stress was obtained using 100 A and 23 V, with a value of approximately 458.3 MPa and an average elongation of 13.9%. However, the bend test results show that the safest parameter was obtained at 120 A with moderate voltage, particularly 23 V, because the specimens did not show visible defects on the convex surface after testing. Considering both tensile strength and bend-test acceptance, the 120 A-23 V combination is the most optimal GMAW welding parameter for SS400 steel joints for train underframe applications. Further studies should include Charpy impact testing, microstructural analysis, and a wider current-voltage parameter window. Numerical thermal simulation is also recommended to predict heat distribution and residual stress during welding.

Acknowledgements

The author is grateful to the Department of Mechanical Engineering and Automotive, Universitas Negeri Yogyakarta for all the support extended in conducting research.

Conflicts of Interest

The authors declare no conflict of interest.

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