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Effect of SMAW welding current variations on mechanical properties in ASTM A240 grade 304L

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Abstract

Welding current is one of the important parameters in the welding process, because inappropriate currents will result in welding defects in the welded material, resulting in reduced weld joints. This study aims to determine the effect of current variations on SMAW welding joints of ASTM A240 Grade 304L material on mechanical properties. This study uses ASTM A240 Grade 304L material with variations in welding currents of 80 A, 100 A, and 120 A using SMAW welding and using E308-16 electrodes with a diameter of 3.2 mm. Specimens were tested for chemical composition, visual test, penetrant test, and tensile test. Comparative data of tensile test explained that the highest tensile stress from variations in welding currents of 80 A, 100A, and 120 A was 625.27 MPa. Using a welding current of 100 A, the highest yield stress is 337.35 MPa, using a welding current of 100 A, and the highest elongation is 38.34% using a welding current of 100 A. From the data from the tensile test results for ASTM A240 Grade 304L material, the results obtained show that the material data without welding treatment has the lowest tensile strength compared to a group of variations in welding current. And the highest tensile strength value is in the 100 A current variation group.

1. Introduction

Currently, the growth and development of industrial technology are advancing rapidly, one of which is the food and beverage processing machinery industry. The technology used in food and beverage processing machinery cannot be separated from metal joining processes, commonly known as welding. Stainless steel is an alloy steel with excellent corrosion resistance, making it widely used in chemical industries, food and beverage industries, marine-related industries, and other applications requiring high corrosion resistance [1]. ASTM A240 Grade 304L is extensively employed in the manufacture of equipment and components that require good overall performance, particularly corrosion resistance and formability. This material does not corrode under outdoor conditions and remains resistant to oxidation even at temperatures up to 1400°F [2].

One of the important factors to consider in the Shielded Metal Arc Welding (SMAW) process is the welding current or variation in welding current. Proper adjustment of welding current is essential to achieve the desired welding quality. The expected welding results include not only a sound weld bead geometry but also sufficient mechanical strength of the welded joint [2][3].

Previous researchers have conducted several studies on the effect of welding current variation [3]–[6]. For example, Abdul Hamid investigated the effect of SMAW welding current on the mechanical strength of low-carbon steel joints using S355JO material. The Charpy impact test results showed that the highest impact value was obtained at a welding current of 80 A, while the highest hardness value occurred at a welding current of 70 A [7].

Based on these findings, further research using different materials is necessary. Therefore, this study aims to investigate the effect of welding current variation on the mechanical properties of SMAW-welded ASTM A240 Grade 304L joints.

2. Research Methods

The materials used in this study were ASTM A240 Grade 304L plates with dimensions of 250 mm in length, 250 mm in width, and 8 mm in thickness. An E308-16 electrode with a diameter of 3.2 mm was employed as the filler metal. The specifications of the base metal and filler metal (electrode) are presented in Table 1.

Table 1. Base Metal and Filler Metal Specifications

	ASTM A240 Grade 304L	E 308-16
Dimension	250 mm x 250 mm x 8 mm	Ø 3,2 mm x 350 mm
Tensile strength	588,9 N/mm2	600 N/mm^2

Before cutting the ASTM A240 Grade 304L material to the required dimensions, a chemical composition analysis was first conducted to verify that the material complied with the specified grade. Spectrometric testing was performed using an X-MET 8000 analyzer. During the test, the device probe was placed directly on the surface of the material for 10 seconds, after which the elemental composition was analyzed using emitted X-ray radiation. The chemical composition results were displayed directly on the instrument monitor. The spectrometric testing equipment is shown in Fig. 1.

Fig. 1. Chemical composition testing equipment

The material used in this study was ASTM A240 Grade 304L with dimensions of 250 mm × 250 mm × 8 mm as shown Fig. 2.

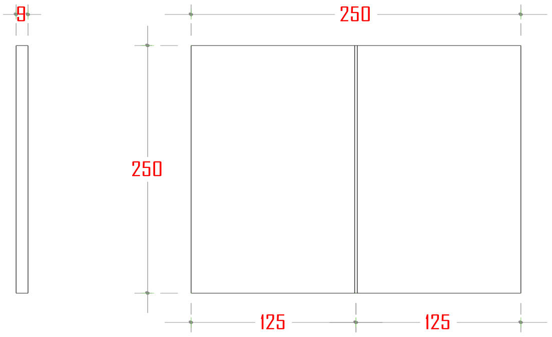

Fig. 2. Material Dimensions

The plates were beveled at an angle of 30°, followed by the preparation of a single V-groove joint with a groove angle of 30° on each side, leaving a 2 mm root face, as reported in previous studies [8] (Fig. 3).

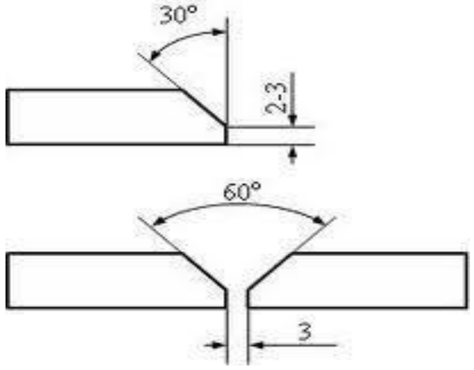

Fig. 3. Groove

Before welding, all required equipment and materials were prepared, and the welding machine was set up in accordance with the established welding procedure. The welding process was then carried out using welding currents of 80 A, 100 A, and 120 A. After completion of welding, the slag formed on the weld surface was carefully removed before conducting non-destructive testing and specimen preparation.

After welding, non-destructive testing was performed beginning with visual inspection using a digital camera. The specimen surfaces were cleaned to remove dirt and residual slag from the welding process, after which images of each welded joint were captured. The welds were then examined to evaluate weld appearance and identify any surface defects. Subsequently, dye penetrant testing was conducted by cleaning the specimen surface with a cleaner, applying red dye penetrant to the welded area, and allowing a dwell time of 10–15 minutes to enable the penetrant to seep into surface discontinuities. Excess penetrant was removed using a clean cloth, followed by the application of a developer and a waiting period of approximately 5 minutes or in accordance with the ASME standard dwell time. The test results were evaluated based on the appearance of red indications on the surface, which signified the presence of welding defects. All test results were documented photographically, and the specimens were finally cleaned using a cleaning solution [9].

Tensile test specimens were prepared in accordance with the ASME QW-462.1 standard after the welding process was completed. The welded plates were machined into tensile specimens following the specified standard and subsequently subjected to tensile testing. For each welding current variation, two tensile specimens were prepared, while one unwelded specimen was used as a reference. Consequently, a total of seven tensile specimens were tested, consisting of six welded specimens from three welding current variations and one unwelded specimen.

3. Results and Discussion.

3.1 Spectrometric Analysis

Spectrometric analysis was conducted on ASTM A240 Grade 304L stainless steel as the test material in this study. The obtained results were compared with the standard chemical composition. The comparison results are presented in Table 2.

Table 2. Chemical composition ASTM A240 Grade 304L

ASTM A240 *GRADE* 304L			
Spectrometer Test (%)		**Standart (%)**	
V	0,18	**C**	0,03 maks
Mn	1,30	**Mn**	2,00 maks
Fe	71,79	**p**	0,045 maks
Co	0,22	**S**	0,030
Cu	0,17	**Si**	0,75 maks
Cr	**18**	**Cr**	**18 – 20**
Ni	**8,06**	**Ni**	**8 – 12**
Mo	0,14	**N**	0,1 maks
		Iron	Balanced

After comparison with the standard chemical composition, the material used in this study was confirmed to comply with the requirements of ASTM A240 Grade 304L stainless steel. Although the spectrometric results did not exactly match the standard values, the nominal chemical composition remained within the acceptable standard range for ASTM A240 Grade 304L.

3.2 Heat Input Data

Based on the obtained data and results, the heat input values during the welding process were calculated and are presented in Table 3 [10].

Table 3. Welding parameter

No	Welding Current	Voltage	Welding Speed	Heat input (J/mm)
1	80 A	27 V	1,04	186.923
2	100 A	27 V	1,27	191.338
3	120 A	27 V	1,4	208.285

The data in Table 3 indicate that the welding current is directly proportional to the heat input value; higher welding currents result in increased heat input. Low heat input leads to insufficient penetration and reinforcement, whereas excessively high heat input can reduce joint strength and promote the formation of welding cracks. An appropriate heat input level significantly influences hardness, tensile strength, and the resulting microstructural characteristics of each specimen.

3.3 Non-Destructive Testing Results

In this study, non-destructive testing consisted of visual inspection and dye penetrant testing.

3.3.1 Visual Inspection

Based on visual observation, several welding defects were identified at the root area of specimens welded using currents of 80 A and 120 A. The observed defect was classified as incomplete penetration. The results of the visual inspection are presented in Fig. 6.

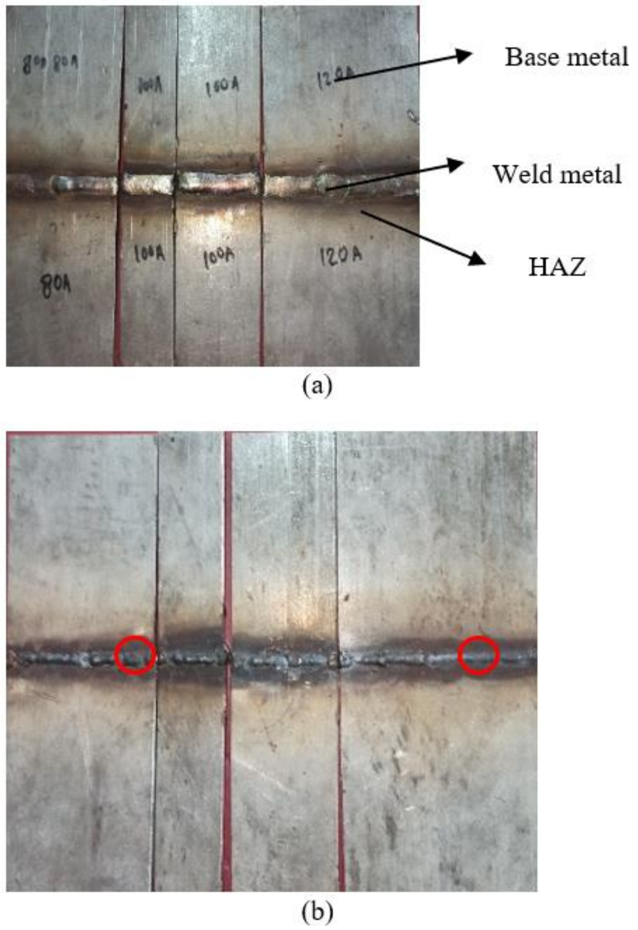

Fig. 5. Visual Test. (a) Caping, (b) Root

3.3.2 Dye Penetrant Test

After visual inspection, dye penetrant testing was conducted to detect surface defects that might not be clearly visible during visual examination. The results of the dye penetrant test are presented in Fig. 6.

Fig. 6. Penetrant Test Results

Penetrant testing revealed porosity in the specimen using a welding current of 120 A. Visual and penetrant testing revealed several welding defects, including incomplete penetration and porosity. Incomplete penetration in this case occurred because the electrode or arc distance was too high during welding at the root pass. The porosity occurred because the arc distance was too high during welding at that point, and hydrogen gas was generated due to the heat.

3.4 Tensile Testing

Tensile testing was conducted to evaluate the mechanical properties of ASTM A240 Grade 304L as the test material in this study. The tensile test results generally include strength parameters, such as ultimate tensile strength and yield strength, as well as toughness or ductility parameters, which are represented by the percentage of elongation and the percentage of reduction in cross-sectional area. The tests were performed using a universal testing machine with a load capacity of 10 tons at room temperature. The test specimens consisted of SMAW-welded ASTM A240 Grade 304L joints using E308-16 electrodes. The tensile test specimens are shown in Fig. 7.

Fig. 7. Tensile Test Specimen

The tensile test data for the raw material and the specimens welded under different welding current variations are presented in Fig. 8.

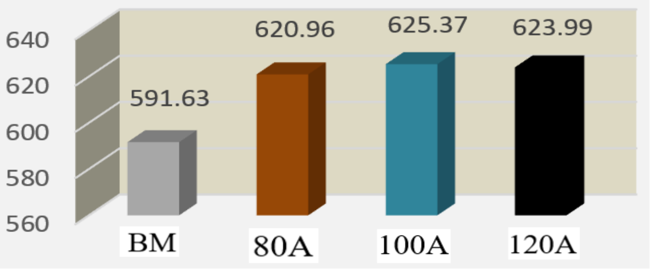

Fig 8. Ultimate tensile strength

The data in Fig. 8 indicate that the ultimate tensile strength of the raw material is 591.63 MPa. The tensile strength of the specimens welded using a current of 80 A reached 620.96 MPa, representing an increase of 29.33 MPa compared to the raw material. For the specimens welded at 100 A, the tensile strength increased to 625.37 MPa, corresponding to an improvement of 33.74 MPa relative to the raw material. Meanwhile, the specimens welded at 120 A exhibited a tensile strength of 623.99 MPa, which is 32.36 MPa higher than that of the raw material. The highest tensile strength obtained in this study was 625.37 MPa, achieved at a welding current of 100 A. Yield strength diagram shown in Fig. 9

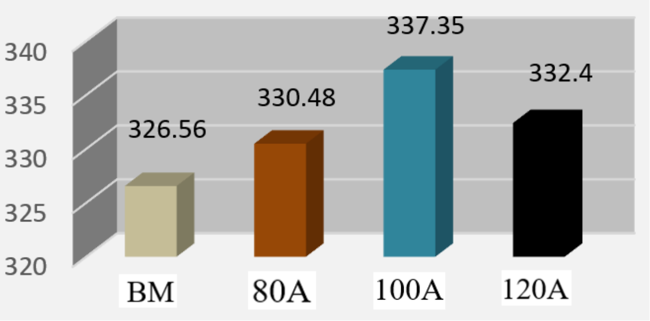

Fig. 9. Yield strength diagram

The data in Fig. 9 show that the yield strength of the raw material is 326.56 MPa. The yield strength of the specimens welded at a current of 80 A increased to 330.48 MPa, representing an improvement of 3.92 MPa compared to the raw material. For the specimens welded at 100 A, the yield strength reached 337.35 MPa, corresponding to an increase of 10.79 MPa relative to the raw material. Meanwhile, the specimens welded at 120 A exhibited a yield strength of 332.44 MPa, which is 5.88 MPa higher than that of the raw material. The highest yield strength obtained in this study was 337.35 MPa, achieved at a welding current of 100 A. Elongation diagram shown in Fig. 10

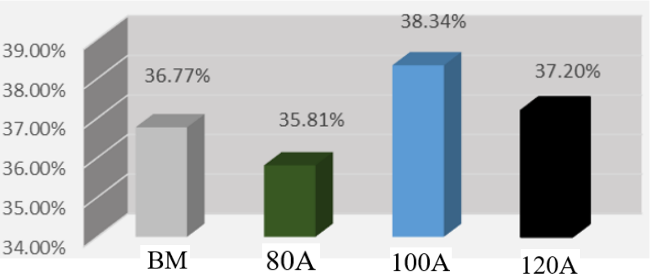

Fig. 10. Elongation diagram

The data in Fig. 10 indicate that the elongation of the raw material is 36.77%. The specimens welded at a current of 80 A exhibited an elongation of 35.81%, representing a decrease of 0.96% compared to the raw material. For the specimens welded at 100 A, the elongation increased to 38.34%, corresponding to an improvement of 1.57% relative to the raw material. Meanwhile, the specimens welded at 120 A showed an elongation of 37.20%, which is 0.43% higher than that of the raw material. The highest elongation value obtained in this study was 38.34%, achieved at a welding current of 100 A.

The comparative tensile test data indicate that among the welding current variations of 80 A, 100 A, and 120 A, the highest ultimate tensile strength was 625.27 MPa, obtained at a welding current of 100 A. Similarly, the highest yield strength of 337.35 MPa and the maximum elongation of 38.34% were also achieved at a welding current of 100 A.

Based on the tensile test results of ASTM A240 Grade 304L stainless steel, the unwelded material exhibited the lowest tensile strength compared to all welded specimens. The highest tensile strength was observed in the specimen welded at a current of 100 A. For the specimens welded at 80 A, the welding current was relatively low, resulting in difficulty in arc initiation and an unstable electric arc. Consequently, the generated heat input was insufficient, leading to low penetration and inadequate weld reinforcement.

At a welding current of 100 A, the heat input was more optimal, producing a more stable and larger arc, faster electrode melting, and improved fusion. As a result, the tensile properties of the welded joint were superior compared to those obtained at 80 A. In contrast, welding at 120 A involved excessive current and heat input, causing overly rapid electrode melting and excessive penetration, which resulted in a wider weld bead and reduced tensile strength, as well as increased brittleness of the welded joint.

Based on these results, it can be concluded that increasing the welding current enhances the tensile strength of SMAW-welded ASTM A240 Grade 304L joints up to an optimal current range of 100 A. However, excessively high welding currents (>100 A) lead to a reduction in tensile strength due to excessive heat input and deterioration of joint properties.

4. Conclusions.

After conducting an experimental and numerical investigation on the effect of welding current variation on the mechanical properties of SMAW joints of ASTM A240 Grade 304L, it can be concluded that the welding current is directly proportional to the heat input; higher welding currents result in increased heat input. Variations in welding current, or heat input, significantly influence the tensile strength of ASTM A240 Grade 304L joints. The optimal heat input parameter in this study was achieved at a welding current of 100 A and a voltage of 27 V, which produced the highest tensile strength of 625.37 MPa. For comparison, the tensile strength of the unwelded material was 591.63 MPa, while tensile strengths of 620.96 MPa, 625.37 MPa, and 623.99 MPa were obtained at welding currents of 80 A, 100 A, and 120 A, respectively. Fracture surfaces from tensile testing of all welded specimens were located in the weld metal region. This behavior is attributed to the slightly higher tensile strength of the E308-16 electrode compared to the base material, where the tensile strength of the base metal was approximately 588.9 MPa, while that of the electrode reached about 600 MPa.

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