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The Effect of Welding Current on the Mechanical Properties of AISI 1040 Steel and AISI 1020 Steel in Bimetal Welding Using the Shielded Metal Arc Welding Method with AWS E 7016 Electrodes

Aditya Angga Wijaya[1], Tarkono[1], Irza Sukmana [1], Rizal Nazarrudin[1,*]

[1] Department of Mechanical Engineering, Faculty of Engineering, University of Lampung, Jl. Prof. Dr. Soemnantri Brodjonegoro No. 1, Gedong Meneng, Bandar Lampung, 35145, Indonesia

*Corresponding Author: rizalnazar@eng.unila.ac.id

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Abstract
This article discusses bimetal welding between AISI 1040 steel and AISI 1020 steel using the Shielded Metal Arc Welding (SMAW) method with AWS E 7016 electrodes. The purpose of the study was to evaluate the quality of the welded joint, including the mechanical properties and microstructure of the bimetal welding results. The use of high-strength AISI 1040 steel and AISI 1020 steel with malleable properties aims to produce a joint that optimizes the characteristics of each material. The welding process was carried out with varying current parameters to determine its effect on the welding results. Testing included tensile testing, hardness testing, impact testing, and microstructure analysis. The results showed that variations in welding parameters affected the mechanical properties of the joint and the distribution of microstructures in the weld zone, heat-affected zone (HAZ), and base metal. The optimal welded joint was obtained by setting certain current parameters that produced maximum tensile strength and even hardness distribution. This study contributes to the development of bimetal welding technology, especially for applications that require a combination of mechanical properties of two types of steel.

Keywords: Bimetal Welding; AISI 1040 Steel; AISI 1020 Steel; SMAW; AWS E 7016 Electrode.

1. Introduction

Welding is a joining technique that involves melting a base metal and a filler metal, with or without pressure, and with or without additional metal, to produce a continuous joint. [1]. Bimetallic welding is the process of joining two different types of metal. Welding dissimilar materials has distinct characteristics, requiring several welding techniques. Examples include selecting the right electrode, adjusting the appropriate electrical current, and selecting the materials to be joined. [2]. Bimetallic welding is more complex than welding similar materials. Therefore, bimetallic welding is rarely used in the industrial world.

Bimetallic welding is often used in the shipping industry. In the shipping industry, bimetallic welding is used to join materials to be placed on ship hulls. [3]. The disadvantage of bimetallic welding is the large voltage spikes caused by changes in the microstructure in the weld area, which can reduce the material's strength and lead to residual stresses that can lead to defects and cracks during the welding process.

[4] The research that will be conducted is the process of joining two different or dissimilar materials using the SMAW or Shielded Metal Arc Welding method and LB52U electrodes and using varying currents on the welding machine. The currents that will be used in this study use 2 currents, namely 60 amperes and 80 amperes with an electrode thickness of 26 mm. It is hoped that the results of this study can help increase understanding of the strength produced by welding, one of which is influenced by the welding current. Therefore, the results of this study can determine the appropriate welding current to obtain maximum results in welding bimetals.

2. Literature Review

2.1 Welding

Welding involves joining two or more metal materials using heat energy [5]. Therefore, welding is a vital method in the manufacturing and construction industries, as it allows for high-strength joining of materials. This process can be performed using various techniques and using various heat energy sources, such as electric arcs, gas, or lasers, depending on the specific needs of the application. Therefore, a thorough understanding of the welding process and the materials used is crucial to achieving high-quality and safe welding results [6].

The welding process has advantages and disadvantages. The advantages of this welding process include affordable costs, faster processing, the possibility of varying shapes, permanent joints, and greater strength of the weld. However, the disadvantage of welding is that the joints are permanent, meaning the welded steel cannot be separated. Therefore, this welding method is less suitable for dismantled products [7].

In bimetal welding, the electrode selection, current usage, and connection type must be precise, as they determine the quality of the welding process itself. To select the right electrode for bimetal welding, first consider the material type and then determine the type of electrode to be used, as this depends on the material thickness [8].

Bimetal welding is a process of joining two metals with different properties. A common problem in bimetal welding is the weld area, which is susceptible to failure. Common failures in the weld area include welding defects in the form of cracks [9].

SMAW, or Shielded Metal Arc Welding, is one of the most commonly used welding methods. This process involves forming an electric arc between a shielded electrode and the base metal to be joined as shown in Figure 1. During the welding process, the electric arc generates heat high enough to melt the base metal and the electrode tip simultaneously. At the same time, the flux coating the electrode melts and forms a protective layer around the weld point. The flux on the electrode serves several important functions in the SMAW welding process. One of these is protecting the weld point from atmospheric contamination such as oxygen and nitrogen, which can cause defects in the weld. The flux also helps regulate the flow of molten metal and form slag, thereby helping to improve weld quality. The use of flux on the electrode also allows welding to be performed in a variety of conditions, including outdoors or exposed to wind. Furthermore, the flux also helps provide additional strength to the weld joint. Therefore, SMAW welding is a powerful and versatile technique for joining metals, with the flux protecting and helping to produce strong, high-quality welds [5].

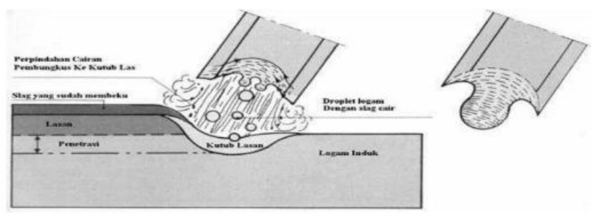

Figure 1. SMAW Welding

2.2 AISI 1040 Carbon Steel

AISI 1040 carbon steel is a medium-carbon steel with a carbon content of less than 0.40%. In its applications, AISI 1040 carbon steel is typically used in gears, bearings, and shafts. Based on its application, this steel must have wear resistance, often defined as resistance to dimensional erosion of the material due to friction [10]. Table 1 below is a table of the elements of AISI 1040 carbon steel.

Table 1. Elements of AISI 1040 Carbon Steel

Elemental	Composition (%)
Carbon	0.42 – 0.5%
Iron	98.51 – 98.98%
Manganese	0.6 – 0.9%
Phosphorus	0.04%
Sulfur	0.05%

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2.3 AISI 1020 Carbon Steel

AISI 1020 steel is classified as a low-carbon steel with a carbon content of 0.20%. AISI 1020 steel is characterized by low hardness, easy forming, and high ductility. Due to its easy forming properties and high ductility, AISI 1020 steel is widely used in various applications. Some common applications include the manufacture of gears, shafts, steel plates, and components in power plants such as superheated steam pipes and boiler systems at certain temperatures. The ductility and formability characteristics of AISI 1020 steel make it a popular choice in the manufacturing industry, especially where high strength is not a top priority and the forming process is an important factor in the design and production of these components [11]. Table 2 below is the chemical composition of AISI 1020 steel.

Table 2. Elements of AISI 1020 Carbon Steel

Elemental	Composition (%)
Carbon	0.20 – 0.30%
Silicon	0.15 – 0.35%
Manganese	0.50 – 0.70%
Molybdenum	0.20 – 0.30%
Phosphorus	0.035%

3. Material and Methods

The materials used in this research were bimetallic welding of AISI 1040 and AISI 1020 steel, with varying currents of 60A and 80A.
The equipment used in this research includes:
1. Sample preparation equipment
2. Welding equipment
3. Tensile testing machine
4. Impact testing machine

3.1 Research Procedure

1. Sample Preparation

Results of bimetallic welding of AISI 1020 and AISI 1040 steel with varying welding currents.

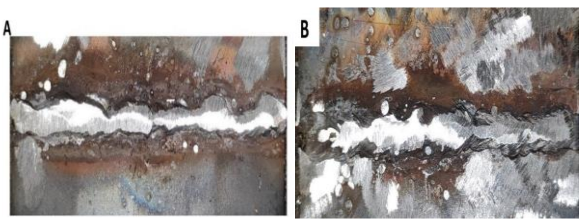

Figure 2. Welding Results (a) 60A, (b) 80A

2. Tensile test specimens

Figure 3. Tensile test specimens

3. Impact test specimens

Figure 4. Impact test specimens

4. Static tensile testing

Figure 5. Tensile testing

5. Impact testing equipment

Figure 6. Impact testing machine

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4. Results and Discussions

4.1 Penetrant Testing

Based on the penetrant test, weld defects in AISI 1020 and AISI 1040 steel were identified. In the tensile test specimen, weld defects were found in the 80-ampere weld. These defects included undercut defects, which were of high intensity. Figure 7 shows the results of the penetrant test on the tensile test specimen.

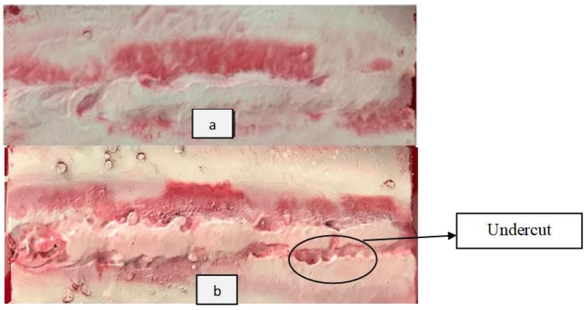

Figure 7. Penetrant Test Results for Tensile Test Specimens (a) 60A, (b) 80A

Next are the penetrant test results for the impact test specimens, which had more weld defects than the tensile test specimens. The defects found in these specimens were: At a welding current of 60 amps, underfill and undercut defects were present, both of which were of high intensity, as seen in the numerous images. Furthermore, at a welding current of 80 amps, underfill defects were present, which were also of high intensity. Figure 8 shows the results test of the impact test specimens.

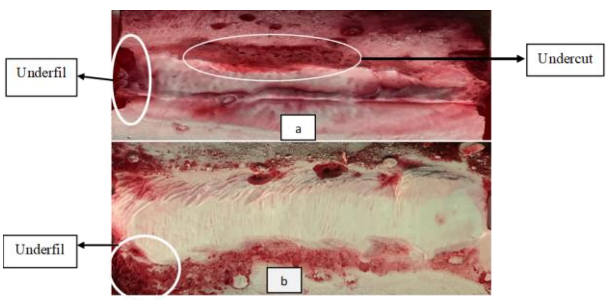

Figure 8. Penetrant Test Results for Impact Test Specimens (a) 60A, (b) 80A

4.2 Tensile Testing

Table 3. Tensile Testing Data

Specimen	Ultimate Tensile Strength(σu), Mpa	Yield Strength (σy), MPa	Young Modulus (E), GPa	Elongation (%)
L60A 1	380,15	284,04	60,51	19,12
L60A 2	394,78	263,11	63,18	10,92
L60A 3	328,72	276,93	67,50	3,66
Rata-rata	367,88	274,70	63,73	11,23
L80A 1	482,14	349,15	77,97	19,36
L80A 2	357,07	252,90	73,39	6,73
L80A 3	414,04	303,19	63,49	22,66
Rata-rata	417,75	301,75	71,62	16,24

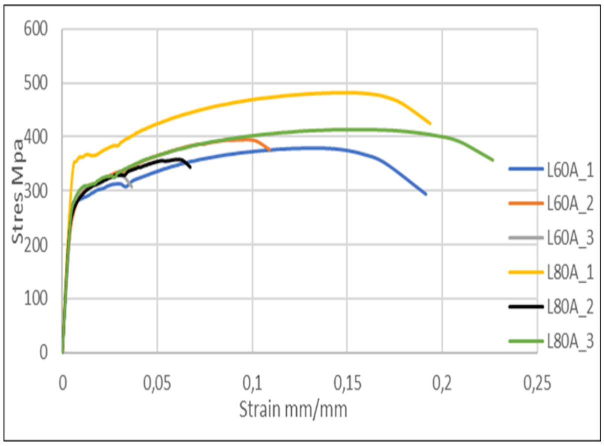

Figure 9. Tensile Testing Results Graph

As seen in the correlation between the results of table 3 and figure 9, the highest tensile strength was obtained with a welding current variation of 80 amperes on specimen L80A 1. The average ultimate tensile strength was 417.747 MPa, which is higher than the tensile strength obtained with a current variation of 60 amperes, which was only 367.881 MPa. In the tensile test with a current variation of 60 amperes (L60A), the tensile strength value was lower than that of the 80 amperes. This indicates the influence of current strength on the welding of AISI 1020 and AISI 1040 steel for tensile testing. This test is consistent with the results of (Yusuf & Mahadi, 2020), which stated that the higher the welding current used, the greater the average stress. The following are fracture images for 60 and 80 amperes of current.

Figure 10. Tensile test fracture results

Figure 10 shown the fracture results of tensile test specimens subjected to 60 and 80 amperes of current. Based on the fracture images above, in the 60-ampere current variation, specimen L60A 1 experienced ductile fracture, characterized by plastic deformation and surface necking at the tip. The fracture in specimen L60A 1 occurred in the base material area of the 1020 material, due to 1020 steel having a lower carbon content than 1040 steel. Furthermore, specimen L60A 2 fractured in the HAZ, and L60A 3 fractured in the weld joint area due to a welding defect. For the 80-ampere current variation, ductile fracture occurred for specimens L80A 1 and L80A 3, while for specimen L80A 2, the fracture occurred in the weld area due to weld defects. The tensile strength value for specimen L80A 2 is lower than that of specimens L80A 1 and L80A 3.

4.2 Impact Testing

Impact tests conducted on AISI 1020 and AISI 1040 steel yielded the values shown in Table 4.

Table 4. Impact Test Results

Current Variation	Specimen	Impact Energy (Joule)	Average (Joule)	Impact Value (J/mm^2)	Average (J/mm^2)
	1	164		1.31	
60A	2	165	145.33	1.34	1.13
	3	107		0.85	
	1	89		0.63	
80A	2	91	93	0.72	0.71
	3	99		0.81	

The data in Table 4 shows that a current of 60 amperes has a higher value than a current of 80 amperes. At 60-ampere current, the value for specimen 1 was 164 joules, for specimen 2 it was 165 joules, and for specimen 3 it was 107 joules. The average impact energy for these three specimens was 145.33 joules. The following is a fracture result from an impact test using a current of 60A.

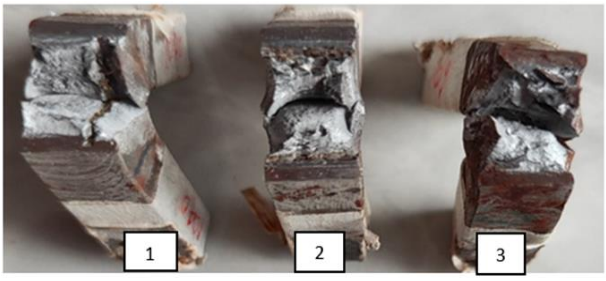

Figure 11. Fracture results from a 60A impact test

Figure 11 shown the results of the impact test where specimen 1, subjected to shock loading, exhibited ductility, and fracture occurred in the notch area, without breaking. Specimen 2 exhibited similar properties to specimen 1, exhibiting ductility under shock loading and fracture only in the notch area. Specimen 3, similar to specimens 1 and 2, exhibited ductility and fracture only in the notch area. All three specimens experienced significant plastic deformation, as evidenced by their tapered fractures. Using a current of 80 amperes, the data above yielded a value of 89 joules for specimen 1.91 joules for specimen 2, and 99 joules for specimen 3. The average impact energy for these three specimens was 93 joules.

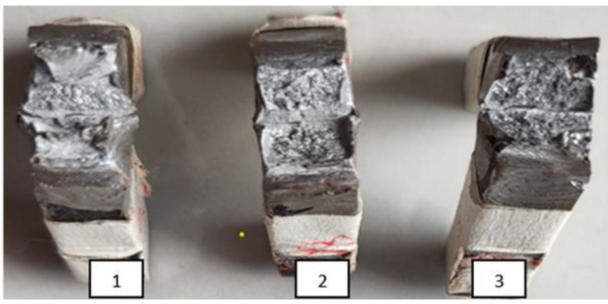

Figure 12. Fracture results from the 80A impact test

In the Figure 12, ductile fracture occurs for specimen 1, where the material undergoes plastic deformation, resulting in a fibrous or rough fracture surface. Then for specimen 2, a brittle fracture occurred where the fracture results had differences on the surface, for specimen 2, this looked flatter for the fracture results, but still occurred in the notch area. Meanwhile, for specimen 3, the same as specimen 2, the fracture that occurred was brittle and occurred in the area. From the data above, it can be concluded that the use of different welding currents can affect the results of the impact test value.

The higher the welding current, the lower the resulting value, while the lower the welding current, the resulting value will be higher [16], [17]. This is proven at a current of 60 amperes, the value obtained tends to be greater than the value at a current of 80 amperes, this is because the current of 60 amperes is the right point to use for the AWS A5 1. E 7016 type electrode with an electrode diameter of 2.6 mm, while for the current of 80 amperes, the value is smaller because at this current of 80 amperes is the maximum current point of the type of electrode used in this study.

5. Conclusion

The defects found in bimetallic welding using AISI 1020 and AISI 1040 steel include splatter, underfill, and undercut defects. Each test specimen exhibited these three types of defects, and almost all of the amperage variations used were present. Furthermore, to determine the joint strength of the bimetallic weld, tensile and impact testing were performed. In the tensile test with a current variation of 60 amperes, the average ultimate strength value obtained was 367,881 MPa, while for the 80 amperes current variation, the average ultimate strength value was 417,447 MPa. This value proves that the use of 80 amperes has a higher strength compared to the use of 60 amperes. Then for the impact test itself in welding with a current variation of 60 amperes, the average impact energy absorbed was 145.33 joules and the average impact price was 1.13 J/mm^2. Furthermore, in the 80 amperes current variation, the average impact energy absorbed was 93 joules and the average impact price was 0.71 J/mm^2. In the case of impact testing, large values occurred in the 60 amperes current variation, the cause of this was the influence of defects in the welding which allowed the test material to experience a decrease in strength during testing.

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