The Influence of Current on Laser Welding on Mechanical Properties and Microstructures of Dissimilar Metal Joints

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ABSTRACT

The joints of dissimilar metals have several problems because they have different mechanical properties and microstructures. This problem can be solved by using laser welding because the resulting energy focus and the hot zone around the welding joint are minimal. The parameters that are important in welding either using welding laser or other welding process is the current. Thus, this study examined the joint of dissimilar metals, i.e., low carbon steel (mild steel A36) and stainless steel (stainless steel 304) using laser welding. The result of the laser welding joint with a variation of current tested its mechanical properties with tensile test and seen its microstructure with photo Scanning Electron Microscopy (SEM). Tensile test results on the current variable 410 - 440 Ampere obtained fracture is on the side of mild steel A36, while at 450 Ampere current obtained a fault on the laser welding joints, where the point of the break is below the point of broken mild steel A36. Based on the tensile test, the suitable current for nonlinear steel joint of A36 mild steel with stainless steel 304 is 410 - 440 Ampere. In the result of the SEM photo, it is seen that on all variables of the current is obtained a photo of the porosity. Based on the microstructure, it is obtained that the results of laser welding are not perfect. This causes easy corrosion and cracks occur so that the laser weld tensile test results are initially good, after some time the results will go down.

KEYWORDS*: Dissimilar Metal, Laser Welding, Current, Tensile Test, Scanning Electron Microscopy (SEM)*

1.0 INTRODUCTION

The development of material technology requires a durable but lightweight material, not easily corroded and can be formed under industry needs (Noh, Zin, Alnasser, Yusoff, & Yusof, 2017). Currently, there are many material joints, especially in dissimilar metallic materials. For example, the use of non-metal joints is in the application of heat exchangers, i.e., there is a metal joint between carbon steel and stainless steel (Corleto & Argade, 2017). The use of non-aliphatic metals is in the automotive and aircraft industries, i.e., the use of non-metal joints between aluminum and steel (Zhao, Ren, Zhao, Pan, & Guo, 2017). The use of a joint of other unlike metals is an aluminum joint with titanium (Tomashchuk, et al., 2017). In the marine industry, the stainless-steel materials from seawater using a dissimilar metal joint between austenite material and duplex (Ramkumar, et al., 2017).

Dissimilar metals have different material properties, including melting point differences, tensile strength differences, differences in corrosion resistance, and so on.

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Uncoated metal joint technology will result in changes in mechanical, chemical, and thermal properties of the material (Martinsen, Hu, & Carlson, 2015). Connecting two different materials poses several problems, that are the metallurgical and thermo-physical problems that can arise from connecting (Oliveira, et al., 2017). To know the mechanical properties of the nonwoven metal joints with the laser weld, a tensile test (Enz, et al., 2017) was used, while the microstructure of the dissimilar metal joint was performed with a scanning electron microscopy (SEM) (Xu & Zhang, 2016).

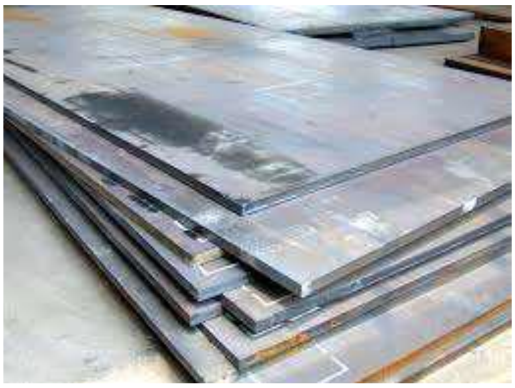
To reduce the change in the properties of dissimilar metal joints, the process of welding uses lasers. The advantages of using laser welding versus arc welding are the minimal heat-exposed zones, rapid cooling and solidification poses, can reach the problem dimensions, the energy that the focus generates and are able to melt two types of material at different points of melting (Meco, Cozzolino, Ganguly, Williams, & McPherson, 2017). In the process of laser welding and other welding processes, weld geometry (penetration depth and weld width) can be controlled with parameters of laser power and travel speed (Ayoola, Suder, & Williams, 2017).

In this research, we will connect dissimilar metals such as low carbon steel (mild steel A36) and stainless steel (stainless steel 304) using laser welding. To know the mechanical properties of different types of laser weld joints is done by tensile test, while to see the microstructure is done with photo Scanning Electron Microscopy (SEM). The laser welding machine used is the HT-WY 180-MK automatic laser welding machine with current variables: 410 A, 420 A, 430 A, 440 A, and 450 A, while the plate thickness is 2 mm.

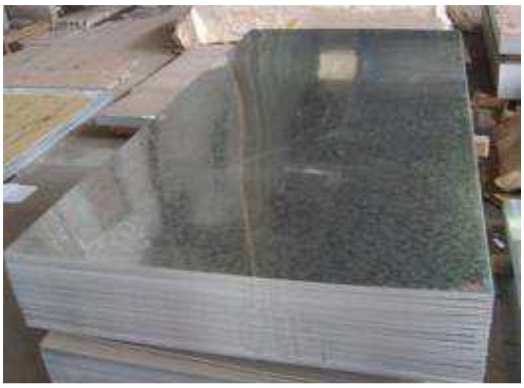
2.0 MATERIALS AND METHODOLOGY

2.1 Materials

The materials used in this study are A36 stainless steel (mild steel) and stainless steel 304. The carbon steel used is A36 carbon steel is often also called black steel carbon. The stainless steel used is austenitic stainless steel, which is Stainless Steel 304. Both materials are a sheet-shaped plate with a thickness of 2 mm. The raw materials can be seen in **Figure 1**.



a. mild steel A36



b. stainless steel 304

Figure 1. Raw Materials

The preparation of raw materials into specimens with dimensions is based on the standard of ASTM E 646 98 or as per standard tensile testing specimen in mm. Details of the workpiece size can be seen in **Figure 2**.

Plate with a thickness of 2 mm is tough to be made by a frais machine. So the process of making specimens uses laser cutting. Neater laser cutting results also result in a high degree of precision. Samples that have been made with laser cutting can be seen in **Figure 3**.

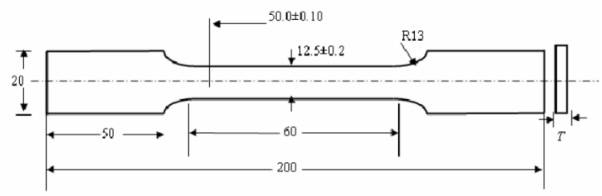


Figure 2. Standard dimension of the tensile testing specimen

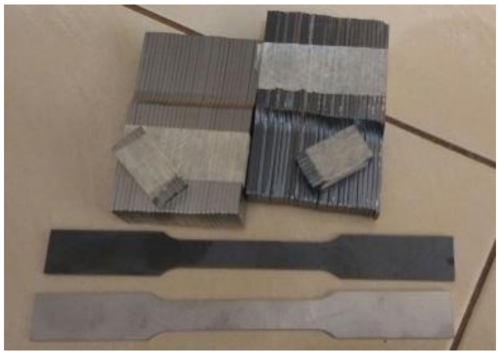


Figure 3. The specimen result from the laser cutting process

After the specimen is ready, then the next stage is the process of grafting two dissimilar materials, that are mild steel A36 with Stainless Steel 304 using laser welding. The laser welding machine used is the HT-WY 180-MK automatic laser welding machine, as shown in **Figure 4**. This laser welding device uses a water cooling medium, so every few times the welding process, the cooling water must be replaced.

Figure 4. Automatic Laser Welding Machine HT-WY 180-MK

During the welding process, the welding material uses is stainless steel. The selection of welding materials based on the metal that has a better tensile strength that is stainless steel (

2.2 Methodology

Briefly, after the implementation of research after the welding process with laser welding, then the next stage is the test tensile strength (tensile test) and seeing the microstructure with Photo Scanning Electron Microscopy (SEM). The results of tensile tests and photos of microstructure were then analyzed and concluded.

The welding process using laser welding is carried out with variations of current, ranging from 410 A, 420 A, 430 A, 440 A, and 450 A. Each variation of current is performed three times. The process of laser welding can be seen in **Figure 5**. As for the welded metals, the result of the joint of dissimilar metal can be seen in **Figure 6**.

Figure 5. Laser welding process using a laser welding machine

Figure 6. The result of the lasers on dissimilar metal joints

The size of the specimen, as shown in **Figure 6**, refers to the standard dimension of ASTM E 646 98 specimens tensile testing, as shown in **Figure 2**. The next step is the test. To know the mechanical properties of dissimilar metal joints to the laser welding machine. It is done by tensile test. Meanwhile, to see the quality of the joint is by looking at the microstructure on the joint of dissimilar metal using SEM photo. In addition to knowing the joint condition, SEM photos can be used to view changes in microstructure and chemical element changes due to heat during the welding process. This test equipment can be seen in **Figure 7**.

a. Tensile test machine   b. SEM photograph equipment

Figure 7. The testing equipment of mechanical and microstructure

3.0 RESULT AND DISCUSSION

3.1 Tensile Test Results and Discussion

Based on the test results through the tensile test, it can be known that the maximum stress (ultimate strength) and the stress when the specimen starts to crack (fracture). The location of ultimate strength and fracture is shown in **Figure 8** (Reviewer C). The maximum stress (σ_{max}) of stainless steel specimens (without joints), low carbon steel (without joints), and the joining of stainless steel and low carbon steel with variations of current can be seen in **Table 1**. As for knowing the result of fracture stress (σ_f), see **Table 2**. The average of Table 1 and Table 2 is showed in **Table 3**.

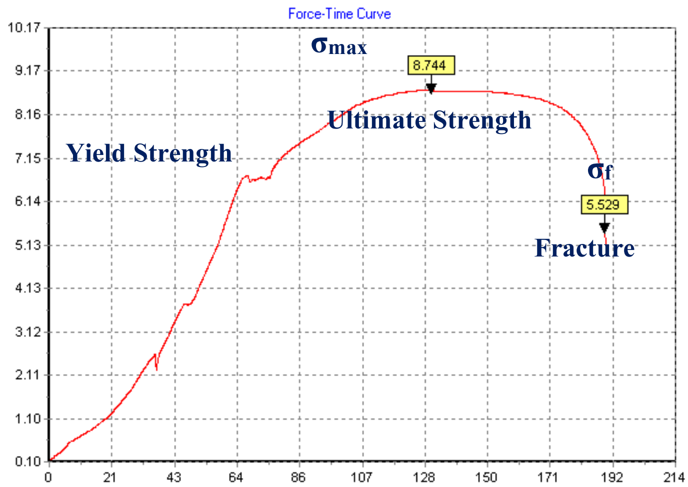


Figure 8. The location of ultimate strength and fracture in the stress-strain diagram

Table 1. The value of maximum stress (σ_{max}) of tensile test results

No	Material	Current (A)	σ_{max} (N/m^2)		
			Test 1	Test 2	Test 3
1	Stainless Steel (SS 304)	450	16,483	-	-
2	Mild Steel (A36)	450	8,568	-	-
3	SS 304 + A36	410	8,744	8,603	8,621
4	SS 304 + A36	420	8,656	8,799	8,850
5	SS 304 + A36	430	8,674	8,621	8,842
6	SS 304 + A36	440	8,780	9,009	8,921
7	SS 304 + A36	450	8,285	8,674	8,250

Table 2. The value of fracture stress (σ_f) of tensile test results

No	Material	Current (A)	σ_f (N/m^2)		
			Test 1	Test 2	Test 3
1	Stainless Steel (SS 304)	450	12,723	-	-
2	Mild Steel (A36)	450	5,178	-	-
3	SS 304 + A36	410	5,529	5,542	5,025
4	SS 304 + A36	420	5,053	5,433	5,335
5	SS 304 + A36	430	5,187	5,184	5,450
6	SS 304 + A36	440	4,982	5,475	5,411
7	SS 304 + A36	450	4,940	5,385	4,954

Table 3. Average of maximum stress (σ_{max}) and fracture stress (σ_f)

No	Material	Current (A)	Average σ_{max} (N/m^2)	Average σ_f (N/m^2)
1	Stainless Steel (SS 304)	450	16,483	12,723
2	Mild Steel (A36)	450	8,568	5,178
3	SS 304 + A36	410	8,656	5,365
4	SS 304 + A36	420	8,768	5,274
5	SS 304 + A36	430	8,712	5,274
6	SS 304 + A36	440	8,903	5,289
7	SS 304 + A36	450	8,403	5,093

Based on Table 3, we can make a graph, as shown in **Figure 9** for the value of maximum stress (σ_{max}) and **Figure 10** for the value of the fracture stress (σ_f).

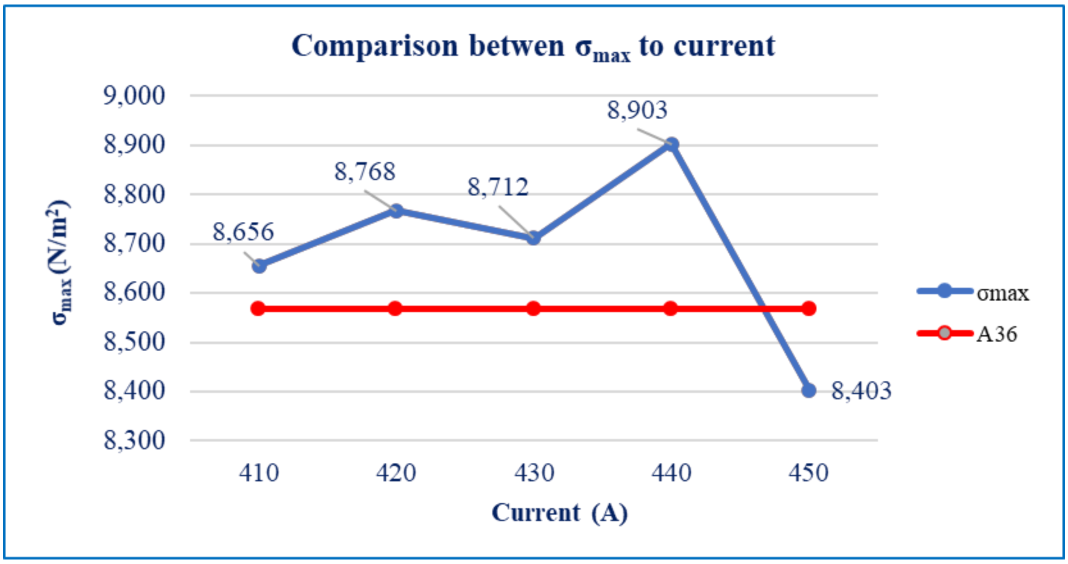


Figure 9. Comparison of maximum stress (σ_{max}) to currents

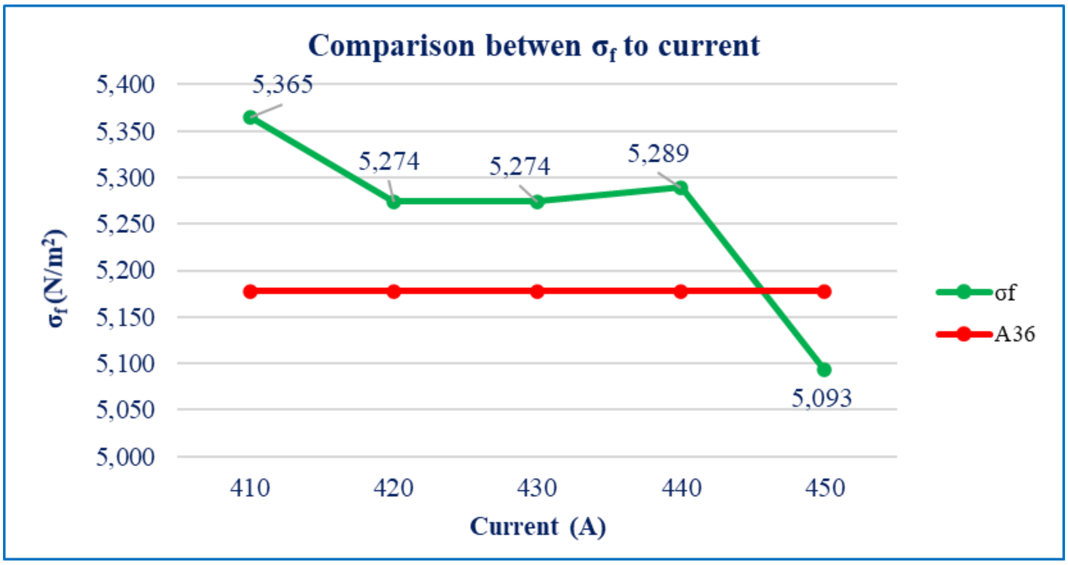


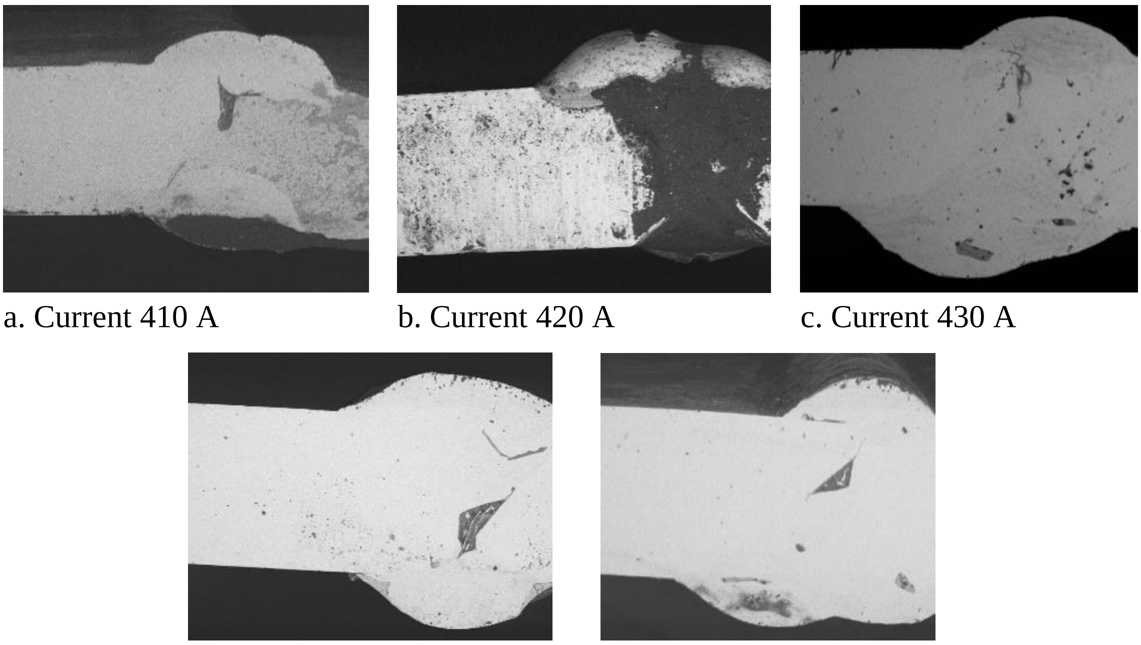
Figure 10. Comparison of fracture stress (σ_f) to current

Based on **Figure 9**, it can be seen that in the current of 410 A up to 440 A, the maximum stress value of the uniform metal joint (blue line) is higher than the maximum stress value on mild steel A36 (red line). While at a current of 450 A, its maximum stress value falls to lower than the maximum stress on mild steel A36. All metal joints are not similar from variations of current; their maximum stress value is far below the maximum stainless steel 304 value. Thus it can be said that the joints between stainless steel and low carbon steel, based on its tensile strength is lower than stainless steel but higher than low carbon steel.

Based on **Figure 10**, the fracture stress values of the current from 410 A up to 440 A are rated above the fracture stress at mild steel A36. While at a current of 450 A, the stress when it breaks below the stress when broken mild steel A36. Thus, based on the discussions of **Figures 9** and **Figure 10**, the recommended current for laser welding machines on unbonded metal joints with a 2 mm thick plate is 410 A up to 440 A.

3.2 The SEM Photo Result and Discussion

These are the results of micro-photo structure using Photo Scanning Electron Microscopy (SEM) with a sample of each variation of current. There are five (5) photos, as shown in **Figure 11**.



a. Current 410 A

b. Current 420 A

c. Current 430 A

d. Current 440 A

e. Current 450 A

Figure 11. Results of SEM photographs of laser welding seen from various variations of current during the welding process

Based on **Figure 11**, it can be seen that all laser welding results of various current variations have porosity. This can be caused by the power of the laser welding machine is less stable, or protective gas is used less than the maximum. The porosity that occurs causes the power to withstand the voltage (tensile test) to drop (drop). Therefore, the result of the tensile test of stainless steel joint with low carbon steel obtained lower voltage very far below the voltage on stainless steel.

4.0 CONCLUSIONS

Laser welding machines require a very large current, but the resulting melting power is minimal. Proven with currents of 410 A up to 450 A is only able to provide penetration (melt) welding and filling added materials for specimens with a thickness of 2 mm. The results of the laser welding tensile test on the joint of different type of material (stainless steel and low carbon steel) resulted that the current of 410 A up to the current of 440 A has the maximum stress and fracture stress above low carbon steel (A36), but still far below stainless steel (SS 304). While the tensile test results on a current of 450 A, the maximum stress and fracture stress is under low carbon steel (A36) and stainless steel (SS 304). Recommended current for different type material joints, i.e., stainless steel (SS 304) with low carbon steel (A36) is 410 A up to 440 A.

5.0 ACKNOWLEDGEMENT

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