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Analysis of tensile strength and microstructure on GTAW- 6061 Aluminium welding results

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ABSTRACT

GTAW is considered the most suitable method for joining aluminium metal. This research aimed to analyse the tensile strength and microstructure of the GTAW 6061 aluminium welding with various currents. The study employed an experimental research design with a current of 100 A, 115 A, and 130 A. Those were tested using a destructive and tensile test. This study used descriptive analysis in which the data obtained were categorised to be described and concluded. The findings show that GTAW welding stimulated changes in the microstructure among the HAZ and the weld metal. The bigger the heat input, the more spread the Mg_2Si grains will be. Moreover, good structural dispersion only occurred at 130 A current. It is different from the base metal, which did not experience any change in the material structure. While on the tensile test showed that the stress value was 80.9 MPa for 100 A current, 84.9 MPa for 115 A current, and the highest tensile strength of 86.7 MPa at 130 A current, respectively. It can be concluded that the higher the current, the better the microstructure and tensile strength.

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1. Introduction

Today, aluminium is massively used in several industrial sectors in Indonesia, like construction and transportation. President Director of PT Indonesia Asahan Aluminium (Inalum) mentions that Indonesia's aluminium requirements reach 1 million tons, but domestic production is only 250.000 tons in 2022 [1]. Based on several reports, the industrial sectors utilise aluminium as a production material. One industry that needs a high volume of aluminium is the Indonesian Railways Industry (INKA). The need for aluminium in this company keeps increasing, especially for train carriages, since it supports modern designs and lightweight concepts [2], [3]. The assembly of aluminium is done through various methods, one of which is the welding method which requires special methods due to its specific characteristics. It has a layer of aluminium oxide on its surface, so it must be destroyed before welding. Aluminium has good weldability and cutting capabilities [4], [5], and Gas Tungsten Arc Welding (GTAW) has become a standard method for this material [6]. GTAW is usually used on light metals such as magnesium, aluminium, and stainless steel [7], [8]. This welding process is carried out using a power source converted into heat energy through a welding machine which is used as a melting medium from the filler or electrode. The heat generated from the welding process is not only used as a melting medium from the filler or electrode, but the heat from the welding process also affects the microstructure and mechanical properties of the metal. Changes in the microstructure occur due to thermal cycling at each point of the welding area which experiences different heating levels. The microstructure in each area has different characteristics depending on the rate of cooling process [9].

The previous studies reveal the effect of welding and electric current variations on tensile strength and microstructure of TIG welded joints on 6061 aluminium. It reports that the joints of TIG welding with various currents and seams result in different tensile strengths. The average maximum tensile strength is 156.55 MPa with a strain of 24.29% on the X seam and a current of 160 A. It has a full average tensile strength of 144.00 MPa, a strain of 28.58% on the V seam, and a current of 160 A [10]. Another finding claims the hardness of aluminium 6061 from TIG welding with current variations of 100 A, 110 A, and 115 A, respectively, obtained different hardness values. The specimens with 110 A gained a higher hardness level of 65.4 VHN than those with 100 A and 115 A that gained 55.7 VHN and 55.9 VHN, respectively [11].

Similarly, the investigation related to GTAW aluminium welding with current variations of 100 A, 160 A, and 180 A also proves different tensile strength values. The optimum tensile strength value was obtained at a current of 140 A [12]. Based on the explanation above, this study aims to know the variations effect of the current on the tensile strength and microstructure of aluminium 6061 with GTAW welding.

2. Method

This research was conducted using an experimental method. The data retrieval is carried out through the welding process followed by the tensile test specimens and microstructures. The welding process used a 6061 aluminium plate, where the chemical composition of aluminium can be seen in Table 1. The added material used during the welding process used ER4043 filler with 90% argon gas. The aluminium plate for welding had a thickness of 10 mm with a V 70 seam, and the connection's shape is shown in Fig. 1.

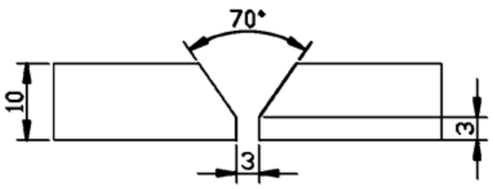

Fig. 1. Welding Specimen

Table 1. Aluminium 6061 Chemical Composition

Materials	Al	Si	Fe	Cu	Mn	Mg
Al 6061	95.08	0.867	0.371	0.161	0.02	1.15

The tensile test revealed the effect of current variations in GTAW welding. It was divided into three categories of current variation, and five tensile test data were taken to validate the results of each current variation in the GTAW welding. The specimen used for tensile test data was ASTM E8m subsize. The shape and size of the tensile test specimen in detail are shown in Fig. 2.

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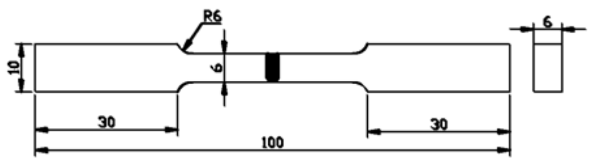

Fig.2. Tensile Test Specimen ASTM E8m

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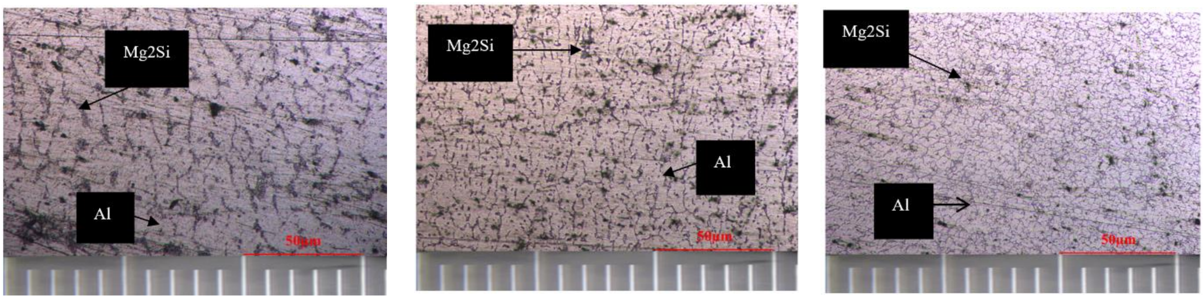
3. Results and Discussion

GTAW welding on aluminium with various currents of 100 A, 115 A, and 130 A was followed by microstructure testing. The results of micro-photo images can be seen in Fig. 3.



(a) (b) (c)

Fig. 3. The microstructure of the weld area with the welding current of (a) 100 A, (b) 115 A, (c)130 A

The microstructure of the weld metal with a current of 100 A shows large equiaxed grains with a few visible columnar grains. As seen in the HAZ, the precipitation of alloy grains disappears in the weld metal because the heat input in the welding makes the precipitate grains change the metal structure. Metal welding with a current of 115 A contains irregularly small equiaxed grains and tends to be rough. The alloy grains in the metal welding are slightly visible, which is different from the structure in a current of 100 A. The structure of the metal welding with a current of 130 A shows the large equiaxed grains that are quite smooth. In contrast to the current 115 A, the weld metal structure at 130 A is rough with tight line spacing. Based on the tensile test, data on the raw material and metal after welding can be generated.

Al 6061 microstructure weld metal tends to form dendrites and wide-spaces eutectic lines. The alloy grains appear to be smaller than the base metal, and the grain size changes in the heat-affected zone (HAZ). The grains of the alloy precipitates are enlarged by forming equiaxed lumps than the base metal. The HAZ at a current of 100 A is larger than the other two current variations. In GTAW welding with a current of 115 A on the base metal, an irregular dendritic structure is formed and tends to be rough. The eutectic line in the weld metal looks more diffuse and has more density. In the HAZ, a silicon eutectic structure line appears that extends across each specimen. The equiaxed structure in the HAZ is not visible in a current of 115 A. The HAZ at 115 A current is narrow compared to that of 100 A current.

In GTAW welding with a current of 130 A, the microstructure of the base metal does not change like the previous variations in current and raw material. Exposure to heat in the welding process does not affect the base metal area. The HAZ of welding with 130 A shows a microstructure with the silicon eutectic line structure. It is elongated but has slack, and grain agglomerations (equiaxed) are visible in the HAZ. The amount of precipitation decreases compared to the previous, current variation. The HAZ at 130 A tends to be narrower than those of 100 A and 115 A currents. The structure of the welded metal with a current of 130 A shows a random dendritic structure and the presence of silicon eutectic grains. In contrast to the current 115 A, the weld metal structure at 130 A is smoother with loose line spacing.

GTAW welding on aluminium with current variations of 100 A, 115 A, and 115 A, respectively, obtain tensile strength test results in Table 3. As a comparison of tensile strength between raw material and welded material, Table 2 shows the tensile strength of each raw material and the average tensile strength.

Table 2. Tensile Test Results of Raw Material Al 6061

Test Material	Tensile Strength (MPa)
Raw Material	297.7
	295.3
	325.7
Average Tensile Strength	306.33

The results of the tensile test in Table 3 show that there are differences in the tensile strength of several specimens regarding the different current treatments, of which the variations in the current strength are 100 A, 115 A and 130 A, respectively. The average value of the highest tensile strength can be found in the welding current of 130A with a tensile strength of 86.7 MPa. The tensile strength decreases in proportion to the current used. The comparison results at lower current variations reveal that the average tensile strength for welding current of 115 A and 100 A is 84.9 MPa and 80.9 MPa, respectively.

Table 3. Calculation results of stress and strain after the welding process

Current (A)	Specimen	$\sigma_{u\ (MPa)}$	ε	$\sigma_{y\ (MPa)}$	Average of $\sigma_{u\ (MPa)}$	Average of ε	Average of $\sigma_{y\ (MPa)}$
100	1	78.9	2.33	76.4	80.9	4.58	58.1
	2	107.2	5.33	53			
	3	73.5	5.00	71.2			
	4	64.0	5.67	31.8			
115	1	83.3	5.00	87.8	84.9	4.75	56.8
	2	86.7	5.00	8			
	3	66.7	3.33	46.1			
	4	102.9	5.67	85.3			
130	1	125.9	8.00	111.8	86.7	5.08	81.3
	2	94.4	4.33	90.8			
	3	126.4	4.67	9			
	4	102.8	3.33	100.7			

Meanwhile, the calculation results of tensile stress indicate that the use of current variations in the GTAW welding process affects the tensile stress of the specimen. Table 2 and Table 3 prove that the tensile stress due to the influence of GTAW welding at currents of 100 A, 115 A, and 130 A, is lower than that of the raw material. It shows the welding results in a thermal cycle in the metal welding and HAZ. The changes in grain size and structure result in different stress values.

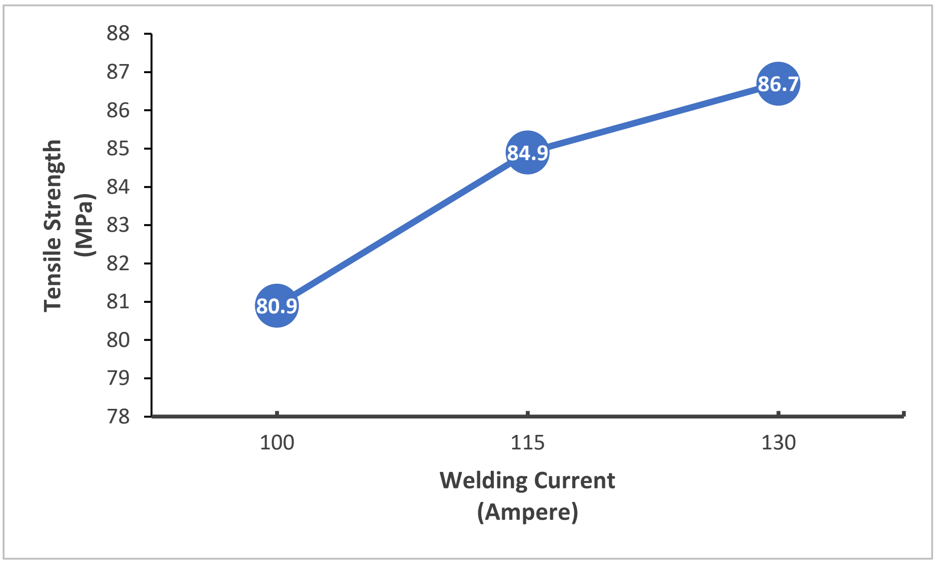


Fig.3. Average tensile strength of GTAW welding results with variations in current

The average tensile strength on raw material is 306.33 MPa, and the average value of tensile strength at 100 A is 80.9 MPa. The average tensile strength value at the current variation of 115 A is 84.9 MPa, an increase of 4.0 MPa from the tensile strength at 100 A. Tensile strength at 130 A current gains an average value of 86.7 MPa, 1.8 MPa higher compared to that of 115 A current and an increase of 5.8 MPa than that of 100 A welding current. It can be seen in Fig. 3 that the greater the current in the welding, the higher the tensile strength due to the different heat inputs for each current variation. It is consistent with previous research [13], which states that the heat input is directly proportional to the current and voltage used and inversely to the travel speed used. And also, the heat input will affect the material properties. Welding with the 100 A current provides a small heat input since inappropriate currents create a wide HAZ. It results in a lower tensile strength. The 115 A current increases the heat input more than the 100 A. It improves the penetration, and the tensile strength is higher than that of 100 A current. The highest tensile strength occurs at the current of 130 A due to the presence of a suitable current and penetration, increasing the object's tensile strength.

The increasing tensile strength which is proportional to the current is in line with previous studies [14], [15]. The results highlight that increasing the current will increase the maximum stress and strain at which the maximum stress is reached. The opposite is in the value of the modulus of elasticity. The current increase will decrease the modulus of elasticity. It is related to the penetration of pure argon as the protective gas where its properties for non-ferrous welding will be good at a certain thickness. The nature of argon causes less welding heat penetration, so repeated welding is required in small currents. It results in a broader HAZ that decreases the tensile strength. The previous research [16] found that the welding process will reduce yield strength and ultimate tensile strength, and also reduces elongation.

4. Conclusion

The result of this study shows that GTAW welding with current variations affects the microstructure of Al 6061 welding. The microstructure changes are so visible in the HAZ and the weld metal that the greater the heat input, the more dispersed the Mg_2Si grains will be. In contrast to the base metal, there is no change in structure, and it even looks the same as the raw material. The changes in the microstructure affect the tensile strength of the metal Al 6061. The tensile strength of each specimen is different based on the current variation. The tensile strength of Al 6061 welding with a current of 100 A, 115 A, and 130 A is 80.9 MPa, 84.9 MPa and 86.7 MPa, respectively.

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