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Effect of Welding Current on Mechanical Properties and Microstructure of Aluminium AA1135 Alloys by Gas Tungsten Arc Welding (GTAW)

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ABSTRACT

Aluminium alloys have a wide range of applications in the defence and aerospace industry, including for the manufacture of fuel tanks. The welding Current and type of filler metal significantly affect the microstructure formed and the mechanical strength of metal joints. This study aimed to determine the effect of the kind of filler metal (ER5356 filler metal) and welding current (140 amperes, 160 amperes, and 180 amperes) on the mechanical properties and microstructural of aluminium alloys AA1135 by the GTAW welding process. The results showed that the dendrite size increased with increasing welding current. Furthermore, the micro-hardness of the weld metal shows a decreasing trend with increasing welding current. The maximum tensile strength was obtained at a current power of 160 amperes, and all specimens failed at HAZ. The fracture surface of tensile test observations using SEM showed brittle fracture for Er5356 filler metal specimens, while on the fracture surface of the base metal tensile test specimens, it was observed to show ductile fracture. Welding with a current strength of 180 amperes has met the standard acceptance criteria because no cracks were found on the face bend or the root bend specimen

Keyword: Aluminium AA1153, Er5356, GTAW, welding current.

ABSTRAK

Paduan aluminium memiliki beragam aplikasi dalam industri pertahanan dan dirgantara, termasuk untuk pembuatan tangki bahan bakar. Arus pengelasan dan jenis logam pengisi berpengaruh nyata terhadap struktur mikro yang terbentuk dan kekuatan mekanik sambungan logam. Penelitian ini bertujuan untuk mengetahui pengaruh jenis logam pengisi (logam pengisi ER5356) dan arus pengelasan (140 ampere, 160 ampere, dan 180 ampere) terhadap sifat mekanik dan mikrostruktur paduan aluminium AA1135 pada proses pengelasan GTAW. Hasil penelitian menunjukkan bahwa ukuran dendrit bertambah seiring bertambahnya arus pengelasan. Selanjutnya kekerasan mikro logam las menunjukkan tren menurun seiring dengan meningkatnya arus pengelasan. Kuat tarik maksimum diperoleh pada daya arus 160 ampere, dan seluruh benda uji mengalami kegagalan pada HAZ. Pada permukaan patahan hasil pengamatan uji tarik menggunakan SEM menunjukkan adanya patah getas pada benda uji logam pengisi Er5356, sedangkan pada permukaan patah pada benda uji tarik logam dasar terlihat patah ulet. Pengelasan dengan kuat arus 180 ampere telah memenuhi kriteria penerimaan standar karena tidak ditemukan retakan pada benda uji tekuk muka maupun benda uji tekukan akar.

Kata Kunci: Aluminium AA1153, Er5356, GTAW, kuat arus

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1. Introduction

Aluminium alloy has good ductility, corrosion resistance, and a high strength-to-weight ratio [1]. Aluminium alloys are widely used in rocket tanks and aircraft shells [2], manufacturing high-speed trains [3], and petrochemical and naval structures [4]. However, with its high thermal conductivity, aluminium has poor weldability [5]. The GTAW method is the most commonly used welding method for aluminium welding, which has the advantages of good stability, high quality, and little spatter [6]. Several parameters, such as polarity, welding speed, type of filler metal, and welding current, greatly influence the mechanical properties and microstructure of aluminium alloy welded joints using Gas Tungsten Arc Welding (GTAW).

Liang et al. [6] stated that an increase in welding current increases the heat input of the welding process so that it gives a coarse microstructure of the joint, the HAZ of joints enlarged, and the width of the partial melting zone (PMZ) so that it has the impact of reducing the mechanical properties of the joint. The welding process causes non-uniform in the mechanical properties and microstructure of the joints [7]. Furthermore, Kumar et al. [8] mention that welding current affects the fusion zone, penetration depth and weld geometry. Increasing the welding current (110 to 150 A) increases the tensile strength of Al1050 aluminium welded joints.

The use of filler metal dramatically influences joint aluminum alloys' mechanical properties, microstructure and porosity formation. Many researchers have compared the use of filler metals in welding aluminium alloys. Jayashree et al. [9] carried out welding of Al6061 using filler metal ER5356. Yelamaseti et al. [10] compared mechanical properties by using two types of filler metal (ER4043 and ER5356) in welding dissimilar Al5052 and Al7075. The results show that connections using filler metal ER4043 produce higher tensile strength and toughness than ER5356. Different results were obtained by Yan et al. [11]. They mentioned that the tensile strength of aluminium alloys Al6082 and Al5083 with filler metal ER5356 was higher than that with filler metal ER4043. However, the joint hardness value using ER5356 is lower than that of ER4043. Furthermore, Takhti et al. [12] compared four filler metal types (ER, ER4043, ER4047 and ER5356) in welding cast aluminium A356. The research results show that toughness is obtained at the connection using ER4047, while the highest hardness value is obtained using filler metal ER5356. Next, Deng et al. [13] found that increasing the Mg content in filler metal increased the porosity and depth of penetration in Al6082 aluminum welded joints.

This study used the GTAW welding process to join aluminium AA-1135 using filler metal ER5356 by varying the welding current. The effect of filler metal and welding current on mechanical and microstructural properties has been investigated.

2. Method

In this study, aluminium alloy AA1135 was used with the composition presented in Table 1, and the process parameters during welding are presented in Table 2. Aluminium plates with 150 x 300 mm x 2 mm dimensions were made with V grooves, as shown in Figure 1.

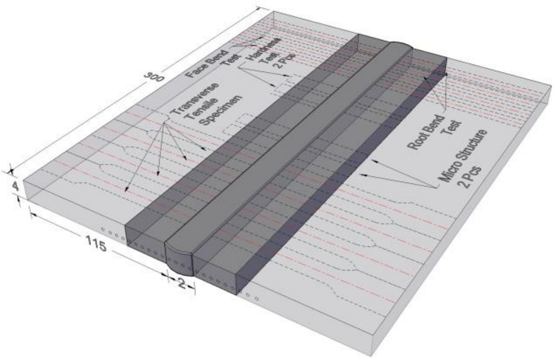

Figure 1. Test Coupon of AA1135 Alloy

Before welding, the aluminium plate is polished with sandpaper to remove the oxide layer. The coupons were then welded using the GTAW with polarity (DCEN) (ESAB Buddy TIG 160).

Table 1. Composition of AA1135 and filler metal Er5356

Materials	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA1135	0.116	0.558	0.002	0.004	0.008	0.002	0.003	0.025	Bal
ER5356	0.12	0.287	0.03	0.05	4.83	0.07	0.008	0.08	Bal

Welded and non-welded plates are cut to produce tensile test, hardness, and bend test specimens (Figure 2). The micro-hardness test was carried out on a cross-section of polished weld metal along the weld line from the centre of the weld metal to the base metal by relating a load of 100 grf using (Future Tech-FM 800 series) according to ASTM E92 standard (figure 3). The effect of welding current on the microstructure was evaluated with the coupon cut 100 mm long to observe the various weld zones according to the E3-01 standard. Samples were polished and etched with (2.5 ml HNO_3, 1 ml HF, 1.5 mL HCL, and 95 mLequivalent). Microstructure of base metal, Heat affected zone (Haz), and weld metal (WM) observations were observed using the Olympus BX51RF.

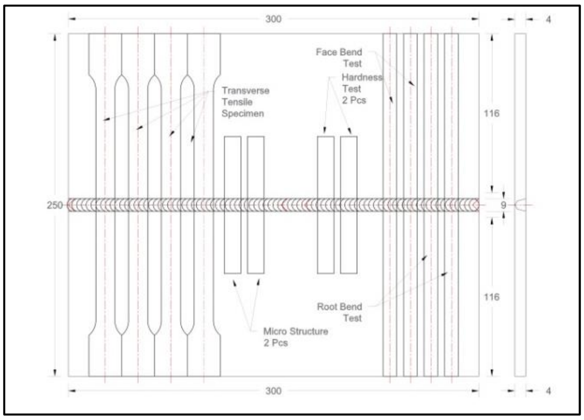

Figure 2. Schematic Of The Tensile Test, Bend Test, Hardness, And Microstructure

The tensile test specimens comply with AWS AWS D1.2/D1.2M:2008 standards, An American National Standard. The tensile test specimens were tested using a universal testing machine, Universal Testing Machine MC Model WEW 300D, with a loading of 0.02 mm/s.

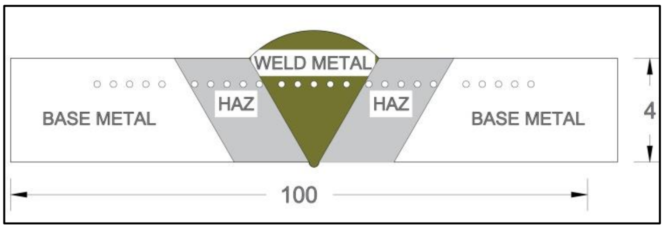

Figure 3. Micro-Hardness Test Coupon of AA1135

The fracture surface of the tensile test specimen was observed using scanning electron microscopy (Zeiss Germany EVO MA 10 operated at 20 kV) equipped with energy dispersive X-ray spectroscopy EDX.

Table 2. Welding Parameters Used In This Study

Welding process	Current, A	Welding speed, mm-s^{1}	Gas flow rate, L min^{-1}	Filler metals	Diameter filler metals (mm)
GTAW 1	140	5.17	12	ER 5356	2.6
GTAW 2	160	5.26	12	ER 5356	2.6
GTAW 3	180	5.08	12	ER 5356	2.6

3. Result and Discussion

Microstructure analysis

The microstructure of the base metal, partial melting zone (PMZ), Heat affected zone (HAZ), and welding metal (WM) of AA1135 alloy is shown in Figure 4. The base metal distributes Si particles irregularly (Figure 4-a). The grain in the Haz of the joint obtained coarse compared to the weld metals and the base metal, with a size of 50-60 µm, which is a globular shape (Figure 4-b). The dendrite formed in the weld metal roughness compared to the base metal with an irregular freezing direction (Figure 4 –c)

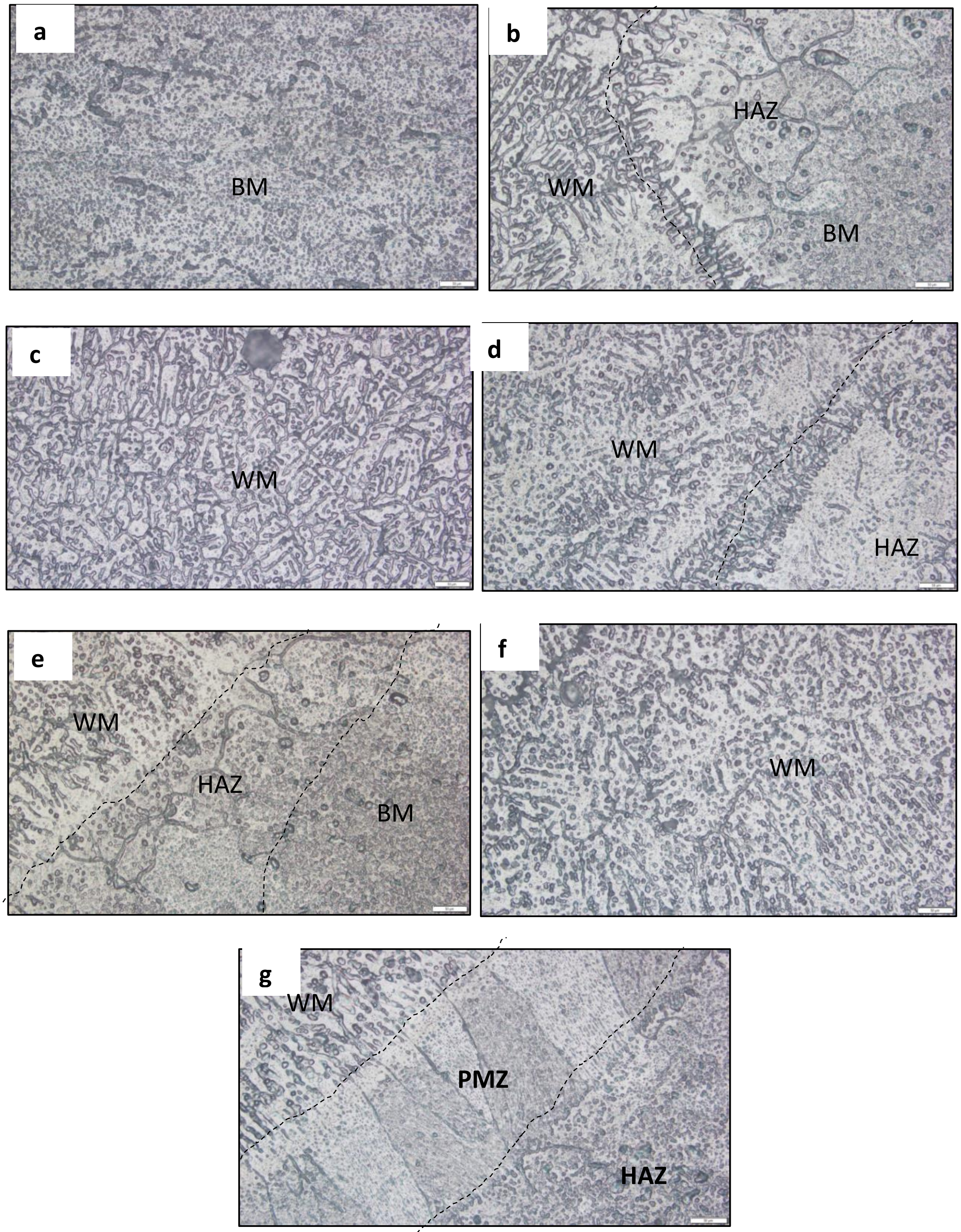

Figure 4. Microstructures A) Raw Materials, B) HAZ 140 A, C) WM 140 A, D) WM 160 A, E) HAZ 160 A, F) WM 180 A, G) HAZ 180 A

As shown in Figure 4, with increasing GTAW current, the grain size of WM increases. Because increasing GTAW current increases heat input and the cooling rate slowly, causing an increase in grain size [14]. The length of the dendrite on the weld metal with a current strength of 160 amperes is slightly rougher than the specimen with a welding current of 140 amperes (Figure 4 d). Furthermore, the current magnitude causes the Haz's coarse grain size. Figure 4-g shows coarse columnar grains along the heat dissipation direction close to the welding zone at a welding current of 180 amperes.

Micro-hardness

Figure 5 shows the profile micro-hardness of WM, HAZ, and base metal. The results show a different hardness. The base metal microhardness is lower than the weld metal. The microhardness of the weld metal increases significantly. Increasing the welding current generated decreases the micro-hardness of the welded joint for all weld joints. This is because the heat input also increases, causing the grains in the weld metal to be coarser. The highest hardness was found in weld metal at a current strength of 160 amperes (74 VHN), followed by a current of 140 amperes (57 VHN) and the lowest at a welding current of 180 amperes (44 VHN). This correlates with the tensile test results (Table 3), which show that the maximum tensile strength is found in specimens with a welding current of 160 A. Furthermore, low hardness is found at HAZ for all coupons, confirming that a soft zone is formed at HAZ, which causes failure of the tensile test specimen [15]. Microhardness was observed at HAZ 30 VHN, and the lowest was 25 VHN, where this hardness value was 17 % lower than that of the base metal.

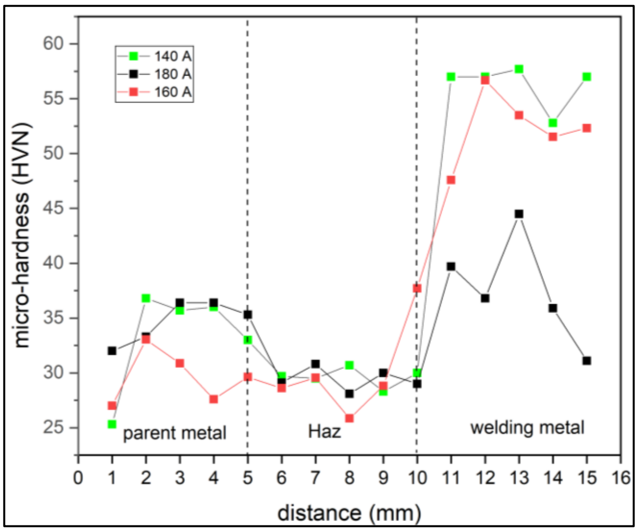

Figure 5. Micro-Hardness Distribution GTAW of AA135

Ultimate Tensile Strength Test

Table 3 shows the tensile test results of the base metal and coupon after welding with variations in welding current. The base metal's ultimate tensile strength (UTS) and elongation are 93 MPa and 3.6%, respectively. The maximum tensile strength decreases with increasing welding current (140 amperes, 160 amperes, and 180 amperes) at 9.41%, 3.34% and 10.71%, respectively. The highest tensile strength was obtained at a welding current of 160 A (90 MPa) and the lowest at 180 A (85 MPa), as shown in Table 4. The non-uniform heating and cooling temperatures in the welding process caused the mechanical properties of the welded joint to be much lower than the base material [16]. All coupons failed 12 mm from the center weld metal near the heat-affected area (HAZ). Wan et al. [17] mentioned that welding aluminum with TIG welding results in a tensile fracture that starts from the melting zone partly due to stress concentration at the end of the weld. This is related to the micro-hardness value profile, showing that all samples in HAZ have a lower hardness value (Figure 5).

Table 3. Failure Area Of Tensile Test

Materials	YS (MPa)	UTS (MPa)	Elongation (%)	Failure
BM	85	93	3.6	-
GTAW 140 A	77	85	1.67	HAZ
GTAW 160 A	79	90	3.33	HAZ
GTAW 180 A	75	84	2.6	HAZ

SEM Analysis Of Fracture Surface

SEM is used to analyze the fracture behavior of tensile test specimens. Figure 6 shows the fracture surface morphology observed by SEM after the tensile test. The tensile test sample of base metal shows a ductile fracture surface with fine and deep dimples with an average of 10 µm, as illustrated in Figure 6-a. Furthermore, the fracture surface of the joint with the Er5356 weld metal shows brittle fracture, where the fracture cuts grain caused by the presence of cavities in the weld metal, which act as crack initiation (Figure 6-b).

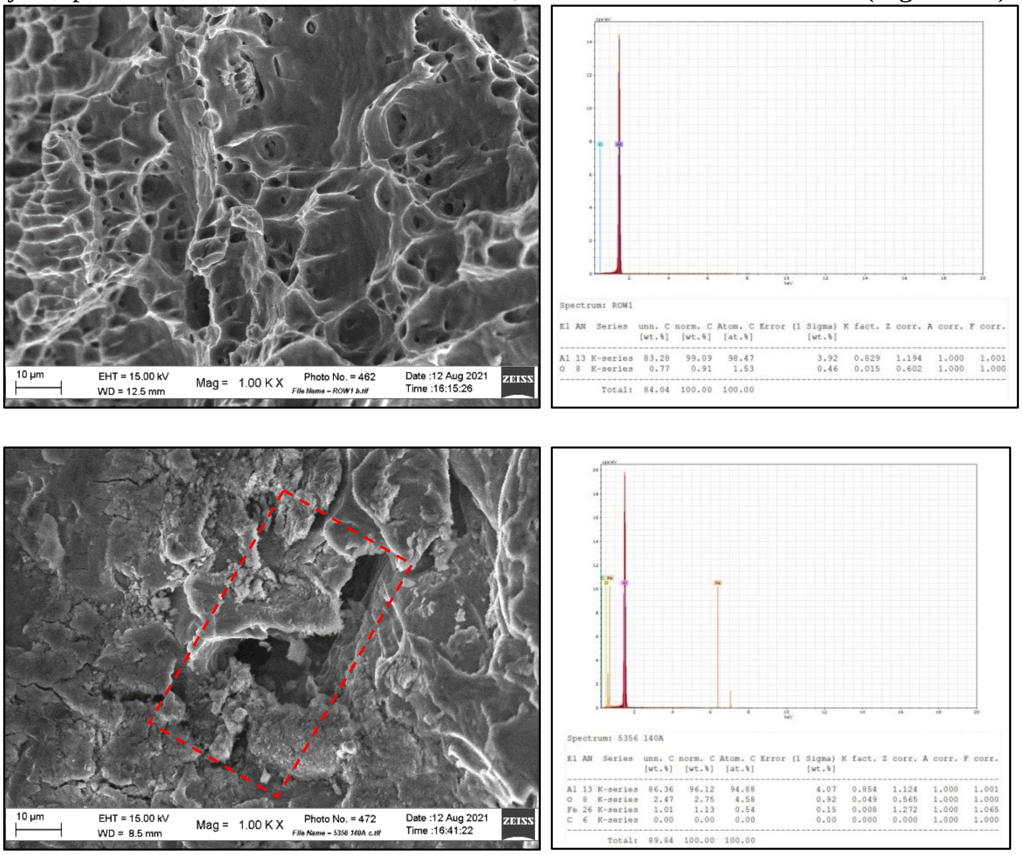

Figure 6. SEM of a) Base Metal AA1135 b) Filler Metals ER5356

Bend Test

The bend test was carried out to determine the bending strength at the surface and root of the weld. The difference between the strength of the welding current and the bending strength is presented in Table 4. The Welding current of 180A fulfills the acceptance criteria ASME IX where cracks on the face or the root of weld metals. The bend test of a sample with welding currents of 140 amperes and 160 amperes found damage on the face and root bend test sample of the weld joint.

Table 4. Bend Test Of Coupon With Different Welding Current

Specimen	Crack (mm)	
	Face	Root
(140) 1	oke	2.47
(140) 2	oke	-
(160) 1	oke	1.8
(160) 2	oke	2.21
(180) 1	oke	-
5356 (180) 2	oke	-

4. Conclusion

From the research results, it can be concluded that:

The size of the dendrite in weld metals is affected by the welding current during the welding process. An increase in the welding current in GTAW welding increases the length of the dendrite. The maximum tensile strength was obtained by welding using a welding current of 160 A, while the results of the bending test with a welding current of 180 amperes fulfilled the acceptance criteria without cracks on the face and root. The micro-hardness distribution shows an increase in micro-hardness in the weld metal with increasing welding current, whereas, in HAZ, the hardness value decreases for all specimens. SEM observations on the fracture surface of the tensile test specimen showed ductile fracture for the base metal AA1135 alloy, while GTAW welding using filler metal Er5356 showed brittle fracture.

5. Acknowledgement

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