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Influence of Alloying Element in Filler Metal on Mechanical Properties of A6061 Al Alloy Welded Joints

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Abstract: The current work is intended to study the influence of using ER4043 and ER5356 filler metals on mechanical properties of A6061 Al alloy welded joint made by gas metal arc welding process (GMAW). For this study, 12mm plates of these materials were joint using a type single V groove butt joints with four layers and five passes configurationof welded joints. The soundness of the quality of the weld joint was investigated by X-ray Ct-Scan technique. The joint made with the ER4043 presented an enhancement of mechanical properties. In comparisonwith the joint made with ER5356, Al A6061 with ER4043 welded joint shows to have an advantage due to the formation of very fine grain and have uniformly distributed porosity in the weld region area.

Index Terms: A6061 Al alloy, welded joint, filler metal, mechanical properties, porosity.

I. INTRODUCTION

In steel structure manufacturing and oil and gas industries, welding and joining application is extensively applied especially in fabrication process. It involves the heating work to the metals until its melting point using an electric arc. The common welding process in fusion welding such as GMAWspecifically applied an electric arc in the joining process [11]. The process is shielded by shielding gas from contaminants and dirt that exposeddirectly to the atmosphere. The GMAW process favored good advantages when compared to other welding technique because of its benefits which has higher rate of metal deposition. This permitsa thickmetal to be joined at higher welding speeds. Furthermore, a good and skilled manpower factor possess by the good authorized welder is definitely a crucial aspect in producing asoundness welded joint structure.

Principally, prior to the suitable choice of filler metal, another factor that need full attention which includes the weld strength, good ductilitywith permitted brittleness, operating temperature parameters, and industrial demand on heat treatment like PWHT become specifically important quality in welding [5]. Moreover, failure that usually occurred on welded joint such as hot cracking and weld decay [7] which typically due to the metallurgical and chemical weaknesses during solidification process take place. The metallurgical instability may result from wrong selection of filler metal due to the mismatch in alloying composition [2,3]. Therefore, in order to minimize the problem, suitable filler metals selection need to be utilized. In addition to that, the welding technique applied when welding different types of materials and fillers need to give full attention and more important is how to increase the strength of welded material increases. Torch angle, feed roll tension, burn back, arc and puddle position, vertical down welds, gaps, crater fillings and arc starting are several factors that influenced the welded joint quality [13]. Gaps can cause lots of problems and also related with depth penetration. As gaps appear, the heat input must be reduced, or as a consequence burn through will occur. Moreover, due to shrinkage in the weldment, the susceptibility for crack to be appears very high [15]. Thus, this paper deals with the effects and influence of using different types of filler metal to determine the strength of the weld.

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II. MATERIALS AND METHODS

A. Material Preparation

A6061 Al Alloy plates with thickness of 12 mm, were selected and prepared into required size of 300 x 200 mm by machining process. The V-groove butt joint type with designed configuration as shown in Fig. 1,was welded by using GMAW process. The welding machine with model number, NT-350D, using welding parameters of 22-25V and 185-200A were applied to join the A6061 Al alloy using two types of filler metals which are ER 4043 and ER 5356. Fig. 1 shows the weld configuration and weld bead sequence of the samples. The elemental compositions of weld and base metal are given in Table 1. After completion the welding process, a non-destructive testing was carried out using the X-ray Imaging System. The machine model is HMX 160Xi as shown in Fig. 2 were used to determine the quality of the welded joints. The task was carried out at The National University of Malaysia (UKM). In this work, appropriate voltage for X-ray penetration was 110 kV and using 160 µmA currents. The weld joints were sliced using cutting machines to the required dimensions for preparing tensile test specimens. Uniaxial tensile tests were performed using a Hydraulic Universal Testing Machine at room temperature (25ºC) on both types of welded joint with stress rate of 1 kgf/mm2/sec and strain rate of 40% per minute, respectively. The test was conducted using a cross head speed of 30 mm/min and force increase rate of 10kgf/min until fracture. The micro hardness test was performed for both welded joints using Vickers micro hardness machine with diamondhead indenter.

The measurement was carried out on the base metal and heat-affected zone (HAZ) regions with a load of 200 gf and a distance of 5 mm from the surface of the weld.

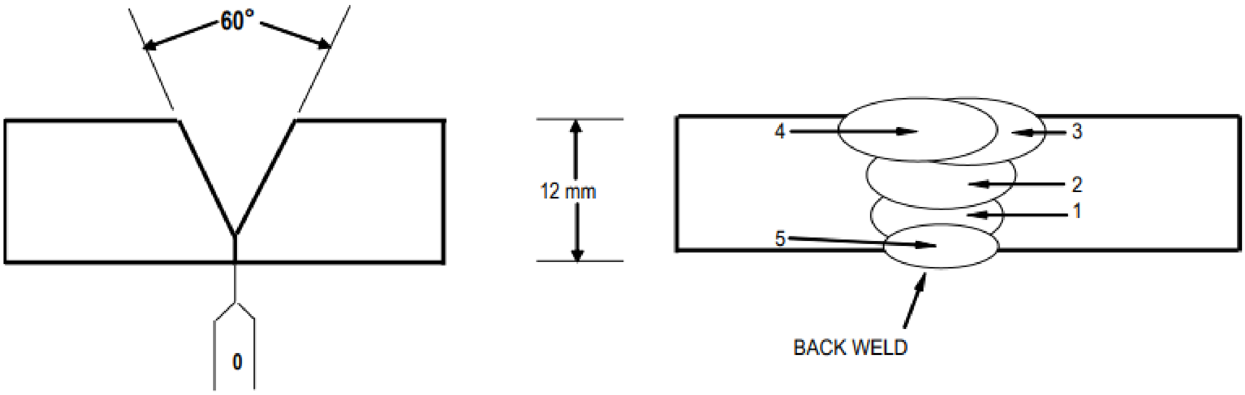

Fig. 1 Weld joint design and weld bead sequence

Table 1.Elemental composition of A6061 Al alloy and the selected filler metals used.

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Sn	Al
AA6061	0.8	0.7	0.4	0.15	1.2	0.35	0.25	0.15	-	Balance
ER 5356	0.27	0.40	0.10	0.10	5.00	-	-		-	94.13
ER 4043	5.20	0.80	0.25	0.05	0.05	-	-		-	93.65

B. Non-destructive and Mechanical Testing

After completion the welding, non-destructive testing were carried out using the X-ray Ct-Scan, model number HMX 160Xi as depicted in Fig. 2. In this work, appropriate voltage for X-ray penetration was 110 kV and using 160 µmA currents. The weld joints were sliced using cutting machines to the required dimensions for preparing tensile test specimens. Uniaxial tensile tests were performed using a Hydraulic Universal Testing Machine at room temperature (25ºC) on both types of welded joint with stress rate of 1 kgf/mm^2/sec and strain rate of 40% per minute, respectively.

Fig. 2 Non-destructive technique using X-ray imaging system model HMX 160Xi

The test was conducted using a cross head speed of 30 mm/min and force increase rate of 10kgf/min until fracture. The micro hardness test was performed for both welded joints using Vickers micro hardness machine with diamond headindenter. The measurement was carried out on the base metal and heat-affected zone (HAZ) regions with a load of 200 gf and a distance of 5 mm from the surface of the weld.

III. RESULTS AND DISCUSSION

A. X-ray Ct-Scan Images

According to the results, the image of porosity in A6061 welded joints appeared as dark circle spots and has uneven shape and was found in a row. This dark spots known as porosity was produced due to entrapment of gas in the weld during welding. In other words, it also the results of gas attempting to escape and this suggested to happen while the metal is still in a liquid state [9]. In addition to that, it is evident from the previous research that hydrogen is suggested to be highly soluble in molten Al, thus the potential for porosity to accumulate in the weld metal is greatlyincrease [3]. It is believed that moisture is one of the main sources of hydrogen to exist and it is suggested to be one of the main causes of porosity in Al weld during welding process takes place. It also comes from the oxide and foreign material on the filler wire; therefore it is easy to expose hydrogen through any types of contaminants and dirtin the environment.

Figs. 3 and 4 showed that the distribution of pores were uneven for both type of Al welded joints and A6061 welded joint with ER4043 shows less internal discontinuity which is porosity than A6061 welded joint using ER5356 filler metal. As depicted in the figures, it shows that Al welded joint with both filler metals clearly presented large pores with ppproximatediameter in a range of 0.2 to 1.5 mm.

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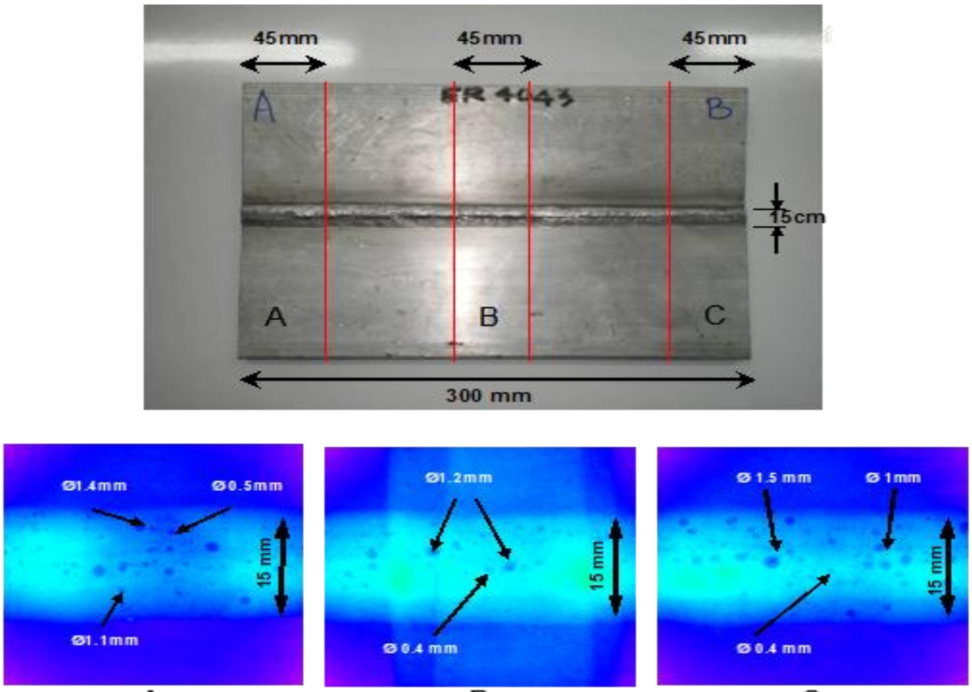
According to the pattern, a clustered porosity with linked pores. It was clearly found basically at the weld edgeof the ER5356 welded joint. It is suggested that from moisture turns into a gas when heated and becomes trapped in the welded joint regions [3]. In addition to that, the clustered pore could even appearlike a regular pore. The difference is thatthe pores were found in a group which is close to each other as indicated in Fig. 4.



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.Fig. 3 Micrograph shows porosity distribution on for A6061 Al welded joint using filler metal ER4043.

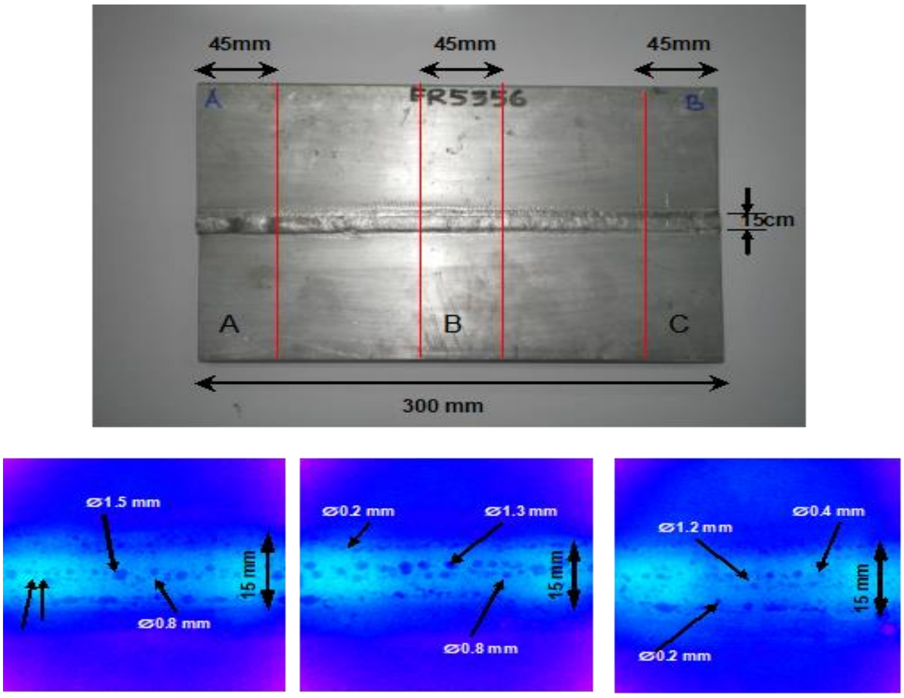

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Fig. 4 Micrograph shows porosity distribution on for A6061 Al welded joint using filler metal ER 5356

Moreover, it is recorded in the previous research that a pore is not a too critical as compared to other internal discontinuity like void resulted from lack of fusion during welding process. It will become dangerous if it exceeds the limit of shape and sizes values and amounts. Apart of that, the influence of this weakness like porositytowards weld performance mostly depends on several factors which includes the quantity, size, shape, alignment and orientation of the pore itself [14].

Besides contamination, moisture is a major concern when dealing with porosity in Al weld since hydrogen was soluble in molten Al. During weld solidification, when the Al solidifies at rapid cooling rate, this leads the metal to retain much less hydrogen. This phenomenon will definitelycause an internal discontinuity mainly porosity. In addition to that, although porosity is not vital factor in metal discontinuity, but it will critically decrease the mechanical strength depending on the amount and if it reached certain limits [10]. Thus, the pores which developed inside the weld metal region need to give full attention because this discontinuity will act as high stress concentration area. This area will then become a location where subsequent failure will dominated.

Table 2. Ultimate tensile strength and % elongation of Al welded using 4043 filler metal

Sample	Ultimate Tensile Strength (MPa)	0.2% Yield Strength	% of Elongation	Fracture Stress in MPa	Length before deformation (mm)	Length after deformation (mm)
Al A6061 ER 4043	114	72	40.4	94	200	208
Al A6061 ER 5356	72	18	27	53	200	205

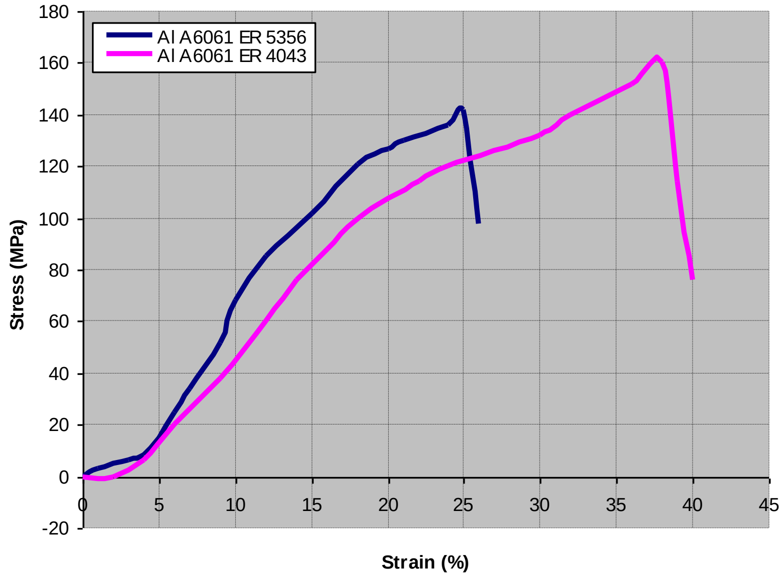

Fig. 5 Tensile strength of Alweld using ER4043 and ER5356 filler metals.

B. Tensile Properties

The ultimate tensile strength (UTS) and percentage elongation of each welded joints were presented in Table 2. Table 2 and Fig. 5 indicated that the UTS and % elongation of Al A6061 weld joint with ER4043 shows higher value compared to A6061 ER 5356 welded joint. In this case, it is well known that the purpose of using ER4043 (Al-Si filler) allows highly crack sensitive alloys to be joined, and whereas using ER5356 (Al-Mg filler) offered corrosion resistance especially when it is exposed to environment that contain salt water. Furthermore, the data indicates that the higher values of UTS and % of elongation of Al A6061 ER4043 were due to change in microstructure and contained less internal discontinuity which shows that the weld performed higher strength and ductility value [10].

In each condition, it shows that the yield and tensile strength of A6061 ER4043 are 90MPa and 160MPa, respectively. Meanwhile, the yield and tensile strength of A6061 ER5356 are 80MPa and 142MPa, respectively. It shows that there is a value of 11% reduction in strength values due to ER5356 application in GMAW process. Moreover, elongation of the A6061 ER4043 shows an increment compared to A6061 ER5356. From the result, it can be said that there is a value of 33% reduction in ductility due to ER5356 application as a filler metal in A6061 welded joint. From the two types of welded joints selection, the joint fabricated using ER4043 filler metal exhibited higher ductility value.

C. Micro hardness Test

For comparison, Fig. 6 shows the significant hardness value varying in weld regions for both Al alloy welded joints with different filler metals.

The graphs of hardness value of the weld zones revealed the heterogeneous structure of the Al. Moreover, the peaks of hardness were located in the weld metal (WM) zone related to the existence of addition of elements from filler metal.It shows that the addition of alloying elements in filler metal increases its performance such as hardenability and causes an evolution in terms of microstructure distribution. Definitely, in terms of mechanical properties, a higher quantity of alloying elements causes, will lead to an increase in mechanical properties which includes the rupture strength, yield strength and metal hardness. This factor will also greatly influenced impact strength values [12].

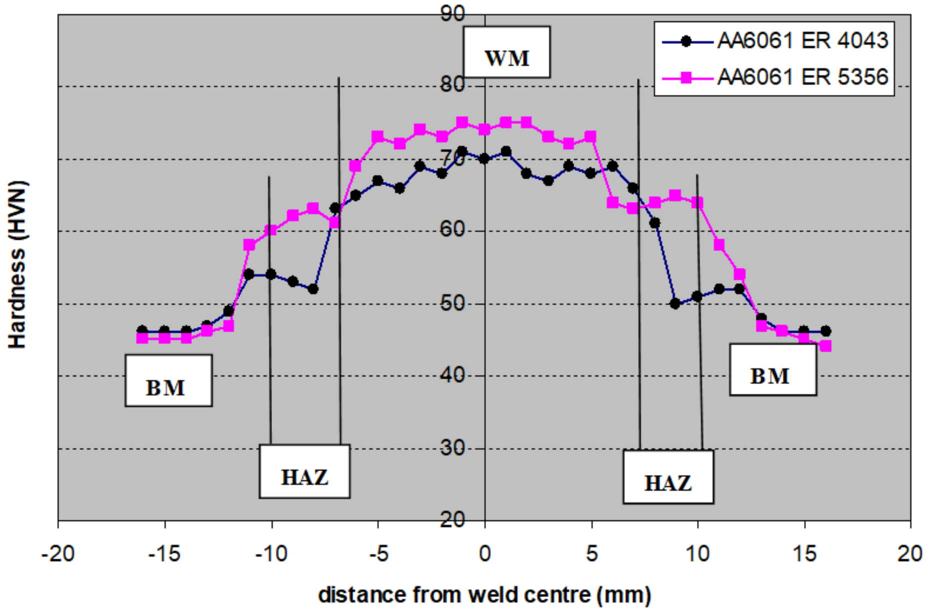

Fig. 6 Micro hardness profile of Al alloy A6061 with ER4043 and ER5356 filler metals.

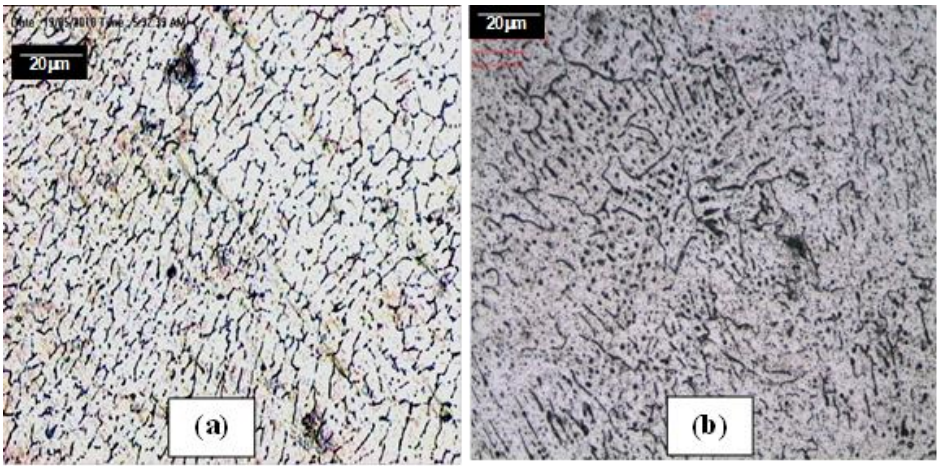

Fig. 7 Optical microstuctures of aluminum welded joint using (a) ER4043, and (b) ER5356 filler metals.

The behavior described by the hardness profiles revealed that Al weld using ER5356 indicated higher value compared to Al weld using ER4043. From previous study, it is well defined that the thermal heat input experienced during welding process and with weld sequence of four layers becomes the main factors [12]. The extensive strength in A6061 weld using ER4043 compared to ER5356 can be attributed with the finer grain size and an even distribution of crystal structures in the weld regions [8] as shown in Fig. 7. It is proposed that the high ductility of A6061 weld using ER4043 shows finer distribution of crystal grain structure and the proportion of an even grain size compared to narrow and non equiaxed grain particles in A6061 weld using ER5356. It is believed that this could happen when it is directly related with thesolidification rate and leads to a significant increase in crystalline growth [1]. Considering the high hardness value of A6061 welds using ER5356, it is an indication that the joint performed low ductility value as being performed in previous tensile test. Therefore, it is possible to conclude that the effect of the cooling speed and chemical composition through filler metal addition affecting the strength characteristic of the welded joint.

According to the internal porosity result using X-ray imaging, as shown in Figures 3 and 4, the displayed radiographs and invariably consists of course and medium pores, which are an indication that both of the tensile specimens failed in a ductile manner, definitely under the action of tensile loading.

Additionally, the difference exists in the size of pores with respect to the types of filler wire used. Since coarse porosity with larger diameter are seen in A6061 with ER5356 welded joint compared to A6061 with ER4043, it shows that AA 6061 ER4043 has shown higher ductility in both test. In this case, pore size and high hardness exhibits a directly indication relationship with strength and ductility of the welded joint. It is an indication that if the pore size is finer, then the strength and ductility of the respective structure is higher [6].

IV. CONCLUSION

In this work, the tensile properties of AA6061 ER4043 and AA6061 ER5356 were evaluated. As a result, the following important conclusions have been derived:

(a) Of the two welded joints, the joints fabricated using ER4043 shows higher strength and improvement in strength value approximately 12% compared to A6061 ER5356.

(b) Grain of the weld metal of A 6061 weld using ER4043 shows finer grain distribution as evidenced by the enlargement and an even distribution grain particles that promote high ductility properties with low hardness value compared to A 6061 weld using ER5356.

(c) The formations of porosity which consist of coarse and medium pores in the weld region are the reasons for a reduction in tensile properties of A6061 ER 5356 welded joint compared to A6061 ER 4043.

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