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FEASIBILITY STUDY ON JOINING DISSIMILAR ALUMINUM ALLOYS AA6061 AND AA7075 BY TUNGSTEN INERT GAS (TIG)

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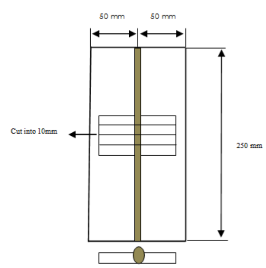
Graphical abstract



Abstract

The aim of this paper is to study the feasibility of welding dissimilar aluminum alloys AA6061 and AA7075 using different types of filler metals which are ER4043 and ER5356. The tungsten inert gas (TIG) welding method was used to butt joint these alloys. The effect of ER4043 (Si-rich) and ER5356 (Mg-rich) on weldability of the joint were studied through visual appearance, microstructures and hardness. It was found that, welding using filler ER5356 produced deeper penetration compared to filler ER4043. The depth of penetration obtained using filler ER5356 was 1.74 mm, while only 0.9 mm of penetration was obtained using ER4043. Microstructures at different zones of dissimilar TIG joints such as the fusion zone (FZ), the partially melted zone (PMZ) and the heat affected zone (HAZ) were identified. The grain size at FZ from filler ER5356 samples was finer compared to filler ER4043 which was 11.4 µm and 19.5 µm, respectively. The average hardness welding value of filler ER5356 samples was higher compared to filler ER4043 samples, which were 100HV and 86HV, respectively at HAZ of AA 6061, 110HV and 88HV, respectively at FZ, while 113HV and 85HV, respectively at HAZ of AA 7075. It can be concluded that TIG welding using the ER5356 filler yields better joint compared to ER4043.

Keywords: Dissimilar welding, AA6061, AA7075, TIG welding

Abstrak

Tujuan kertas ini adalah untuk mengkaji kebolehlaksanaan kimpalan aluminium aloi yang berbeza AA6061 dan AA7075 menggunakan logam pengisi jenis yang berlainan iaitu ER4043 dan ER5356. Kaedah kimpalan Tungsten inert gas (TIG) dengan sambungan kaedah temu telah digunakan untuk menyambung aloi ini. Kesan ER4043 (kaya-Si) dan ER5356 (kaya-Mg) pada kebolehkimpalan sendi telah dikaji dengan penampilan visual, mikrostruktur dan kekerasan. Ia telah didapati bahawa, kimpalan dengan menggunakan pengisi ER5356 menghasilkan penembusan yang lebih mendalam berbanding daripada menggunakan pengisi ER4043. Kedalaman penembusan diperolehi dengan menggunakan pengisi ER5356 adalah 1.74 mm, manakala hanya 0.9 mm penembusan telah diperolehi dengan menggunakan ER4043. Mikrostruktur di zon yang berbeza daripada TIG sendi berbeza seperti zon pelakuran (FZ), zon separa cair (PMZ) dan zon terkesan haba (HAZ) telah dikenal pasti. Saiz bijian pada FZ dengan menggunakan pengisi ER5356 adalah lebih halus berbanding dengan kimpalan menggunakan pengisi ER4043 iaitu masing-masing dengan11.43µm dan 19.51µm. Purata kimpalan nilai kekerasan dengan menggunakan pengisi ER5356 berbanding dengan menggunakan pengisi ER4043 iaitu pada kawasan HAZ 6061 masing-masing adalah 100HV dan 86HV, manakala kawasan FZ masing-masing ada1ah dengan 10HV dan 88HV dan pada kawasan HAZ 7075 masing-masing adalah 113HV dan 85HV. Secara kesimpulannya, hasil menggunakan kimpalan TIG menggunakan pengisi ER5356 adalah lebih baik berbanding ER4043.

Kata kunci: Kimpalan berbeza, AA6061, AA7075, Kimpalan TIG

1.0 INTRODUCTION

Recent trends in the automotive manufacturing worlds have been transitioning from conventional materials to light metal such as aluminum alloy. Aluminum alloys is largely used in various parts of the industry due to their essentially high strength to weight ratio, high thermal conductivity, low density and high corrosion resistance [1-4].

Among these alloys the 6xxx aluminum alloy types are heat treatable, and have reasonably high strength as well as excellent in corrosion resistance. An exclusive element is their extrudability, make them the primary preference for architectural and structural members where extraordinary or mainly strength or stiffness is significant. Higher corrosion resistance in AA6061 alloy finds wide usage in weld structural members such as truck and marine frames, pipelines and railroad cars [5]. On the other hand, the 7xxx aluminum alloy types are also heat treatable which provides the highest strength of all aluminum alloys. Alloy AA7075 is also widely used in aircraft as well as in automotive industries [6]. The joining of dissimilar metal becomes an enormous demand in the industry in order to create a product that can improve the quality in terms of strength and ductility but light in weight. This also include vehicles manufacturing, where there are numerous parts that employ the combination of different metal to reduce fuel expenditure and manage the pollution by using material that have light weight and good corrosion resistance such aluminum alloys [7].

The preferred welding process of thin aluminum alloys is tungsten inert gas (TIG) welding because of its comparatively easier applicability and superior economy [8]. This type of welding process is also suitable to weld thin metals, resulting in high quality and defect free welded joints [9-10]. TIG, also known as Gas Tungsten Arc Welding (GTAW), is widely used for metal joining. Its arc is established between the tip of a non-consumable tungsten electrode and the work piece with a shielding gas applied to protect the arc and the weld pool area [11].

In the fusion welding, some problem may occur during the welds process where the welds may fail in the soft and over aged heat affected zone [12]. The difficulties to join dissimilar aluminum alloys are mainly related to the presence of a tenacious oxide layer. The occurrence of this film weakens grain boundary cohesion and consequently the weld becomes susceptible to inter-granular cracking as a result of shrinkage stresses experienced during weld-pool solidification [13]. Besides that, different thermal conductivity and different composition in alloying elements are one of the major reasons these materials are difficult to join [14-15].

Therefore, the selection of filler metal is one of the most important aspects that need to be considered in TIG welding. In this study, the weldability of dissimilar aluminum alloys 6061 and 7075 were studied using different filler metal which is ER4043 and ER5356. Visual inspections, microstructure and hardness test are conducted to investigate the effect of the welding process.

2.0 EXPERIMENTAL

2.1 Materials

In this investigation, the materials used were Al-Zn-Mg and Al-Si-Mg aluminum alloys, namely AA6061 and AA7075, respectively. The parent metal and filler compositions are given in Table 1.

Table 1 Chemical compositions of parent metal and filler wires (mass %)

	Al	Si	Fe	Cu	Mn	Mg	Zn
AA6061	97.3	97.3	0.790	0.427	0.293	0.0254	0.856
AA7075	89.8	89.8	0.0713	0.274	1.60	0.0185	2.28
ER 4043	Bal	4.5	0.890	---	---	0.856	0.10
ER 5356	Bal	0.25	0.0713	---	---	2.28	0.10

2.2 Experimental setting

Butt joint type welding was carried out by using the manual TIG welding equipment; a tungsten electrode of 3.2 mm in diameter and pure argon as a shielding gas. The current used was 50 A and the voltage used was 22 V for all welding processes.

The aluminum alloys of AA6061 and AA7075 were cut into rectangular shapes with the dimensions of 250 mm × 50 mm × 2 mm. The surface of the material was cleaned using a wire brush to eliminate any oxide layer or stain which can affect welding quality. The quality of the manual TIG welds were evaluated by visual inspection and its microstructure was observed using a metallurgical microscope. The specimens were cut into 10 mm in width as shown in Figure 1. The specimens were then hot mounted, grinded and polished. The specimens were etched by Keller

Reagent for microstructural observation. The hardness of the weld was measured by employing the Matsuzawa MMT-X7 Vickers hardness test.

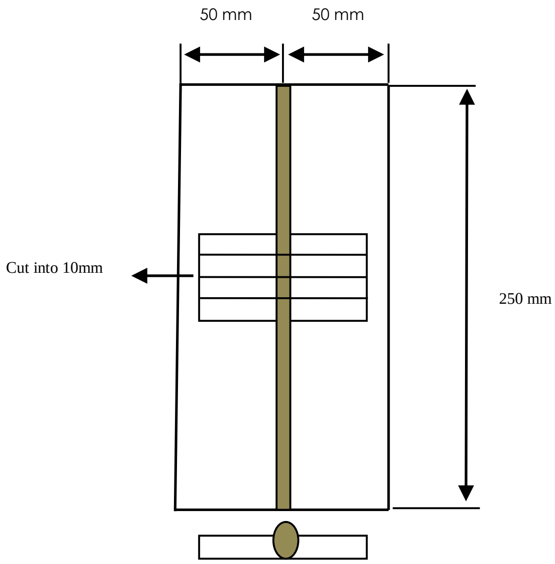


Figure 1 Schematic illustration butt joint welding setup and design for hardness test

3.0 RESULTS AND DISCUSSION

3.1 Weld Appearances

The weld appearance for welding parts of AA6061 and AA7075 using fillers ER4043 and ER5356 are shown in Figure 2 and Figure 3, respectively. It was found that good weld penetration could be achieved using ER5356, with a higher depth of penetration compared to ER4043. Both specimens did not obtain full penetration due to the lack of parameter optimizations on current, voltage and welding speed, which are the main variables in TIG welding. Besides that, welding skills may also contribute to this matter since it was operated manually. The welding work was carried out by the same operator for both specimens. Even so, ER5356 had a higher penetration depth compared to ER4043 which was 1.74 mm and 0.9 mm, respectively. The result of penetration depth, bead height and bead width of both groups are shown in Table 2.

Other than lack of penetration, defect such as distortion can also be seen in the specimen welded using filler ER4043 as shown in Figure 2 (A). Non-uniform of expansion and contraction of weld metal and adjacent base metal during heating and cooling cycle of the welding process can contribute to distortion to occur. This defect resulted from heat of the arc welding process [10]. In addition, uneven weld bead occurred at the end of the welding process for both specimens due to the lack of filler filling as shown in Figure 2 (B) and Figure 3 (B). This is because the material had received excess heat from the welding process while the feed rate of filler metal was slow. From the overall observation of weld appearance, the welded ER5356 specimens were better than its counterpart; ER4043.

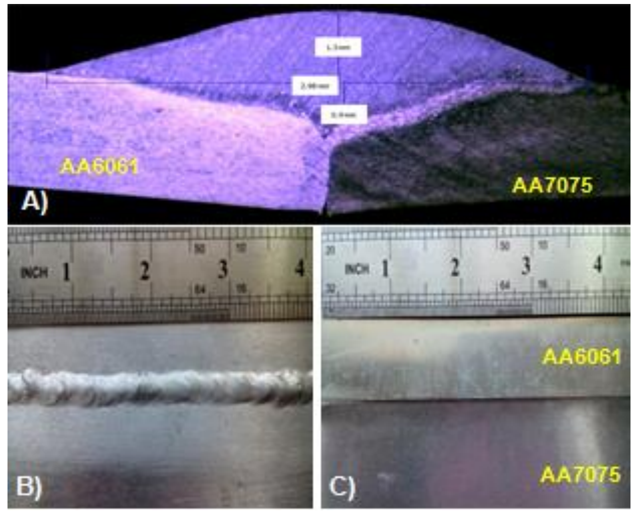


Figure 2 Weld appearance for joining AA6061 and AA7075 by using filler ER4043 where A) Cross section of welded parts B) Top view C) Bottom view

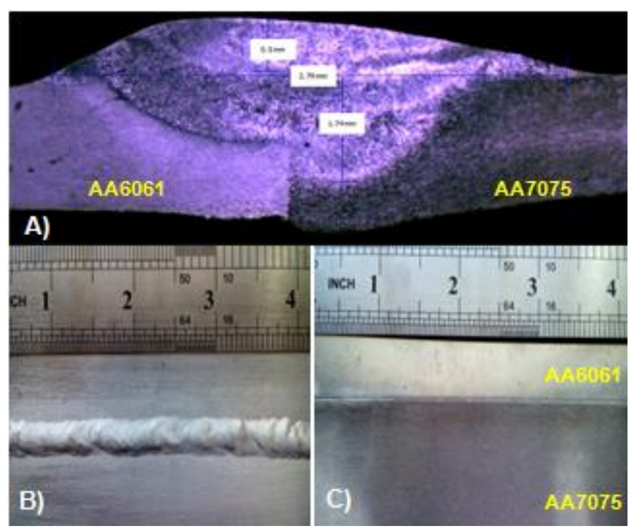


Figure 3 Weld appearance for joining AA6061and AA7075 using filler ER5356 where A) Cross section of welded parts B) Top view C) Bottom view

Table 2 Weld appearance of dissimilar joint with the use of different fillers

Weld appearance (mm)	ER4043	ER5356
Penetration depth	0.9	1.74
Weld bead width	2.98	2.79
Weld bead height	1.3	0.5

3.2 Microstructures

The microstructures of the specimens were observed at different locations using various magnifications. Figure 4 shows the different zones of the dissimilar TIG joints using filler ER4043 such as the fusion zone (FZ), the partially melted zone (PMZ), the heat affected zone (HAZ) and the base metal (BM) zone. The FZ presents an equiaxed dendritic structure as shown in Figure 4 (2). FZ was formed due to melting and resolidification during the welding process [4]. At AA6061's and AA7075's sides, fusion boundary had different grain sizes as shown in Figure 4 (1) and Figure 4 (4), respectively. The grain sizes at HAZ of AA6061, FZ and HAZ of AA7075 for both specimens were measured by taking the average values as shown in Table 3. From the measurements, it was found that the grain size of HAZ at AA6061's and AA7075's sides for both fillers differed slightly. However, at FZ, the ER5356's grain size was finer compared to ER4043 which was 11.43 µm and 19.51 µm, respectively. It is commonly known that a finer grain size constitutes a better joint. This is because finer grain size regions exhibit higher hardness value.

Figure 5 also shows the different zones of dissimilar TIG using filler ER5356. It also has the same boundary as when using filler ER4043. The FZ, PMZ and HAZ on the AA6061's side can be seen in Figure 5 (1). The grain size in FZ shows a mix of shapes as shown in Figure 5 (2). The differences at root position between ER4043 and ER5356 can be seen in Figure 4 (3) and Figure 5 (3) where there was a large lack of fusion area for ER4043 and lesser lack of fusion area for ER5356.

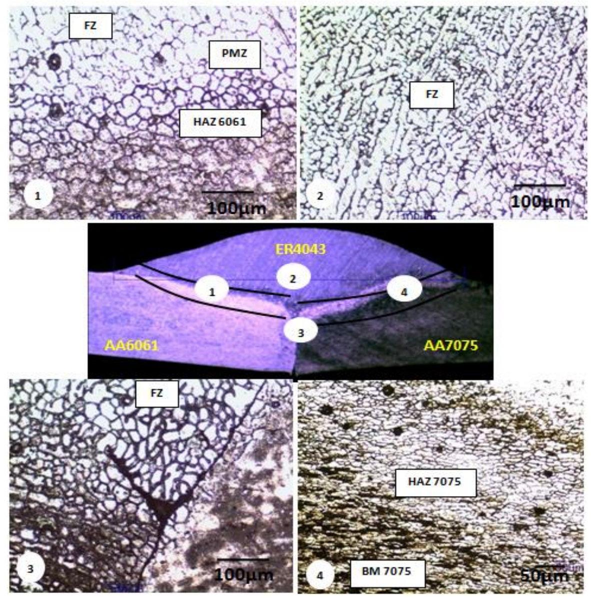


Figure 4 Weld cross section optical microstructure at different points (1) Boundary at 6061 side (2) Fusion zone filler metal ER4043 (3) Lack of fusion (4) Boundary at AA7075 side

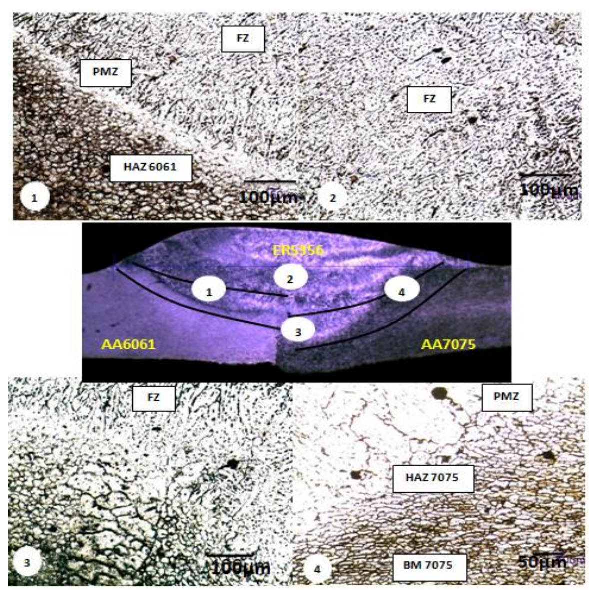


Figure 5 Weld cross section optical microstructure at different point (1) Boundary at AA6061 side (2) Fusion zone filler metal ER5356 (3) Lack of fusion (4) Boundary at AA7075 side

Table 3 The grain size for both specimens

Grain size (µm)	HAZ 6061	FZ	HAZ 7075
ER4043	22.57	19.51	29.29
ER5356	22.86	11.43	30.05

3.3 Hardness Test

The hardness value across the weld cross section was measured using a Vickers Hardness testing machine and the results are shown in Figure 6 and Figure 7. The higher strength of the base metal (BM) is mainly related to the existence of alloying elements such as silicon and magnesium and these two elements consolidates and go through precipitation reaction and form a strengthening precipitate of Mg^2Si [4]. Figure 6 and Figure 7 show the graph of hardness profile at different sections which are BM and HAZ of AA6061, and FZ, HAZ and BM of 7075. Both specimens yielded slightly different average hardness values at BM of AA6061 and BM of AA7075. However, hardness values at HAZ of AA6061, FZ and HAZ of AA7075 showed significant differences, where welding using filler ER5356 showed a higher average hardness value compared to filler ER4043 which were 100HV and 86HV, respectively at HAZ of AA6061, 110HV and 88HV, respectively at FZ and 113HV and 85HV, respectively at HAZ of AA7075. Welding using filler ER5353 yielded a harder value at HAZ of AA6061, FZ and HAZ of AA7075 due to the addition of Mg elements which provided better high strength properties to the joint compared to Si elements [7].

Hardness at boundary for both side and at fusion zone is higher by using filler ER5356 as compared to the joint by using filler ER4043, and this could be due to the refined microstructure and low segregation of strengthening phases. Joint by ER5356 filler metal shows fine equiaxed grains, while columnar grains are found in joints made by ER4043 filler metal. Fine equiaxed grains are more ductile than columnar grains, so it improves mechanical properties in terms of hardness

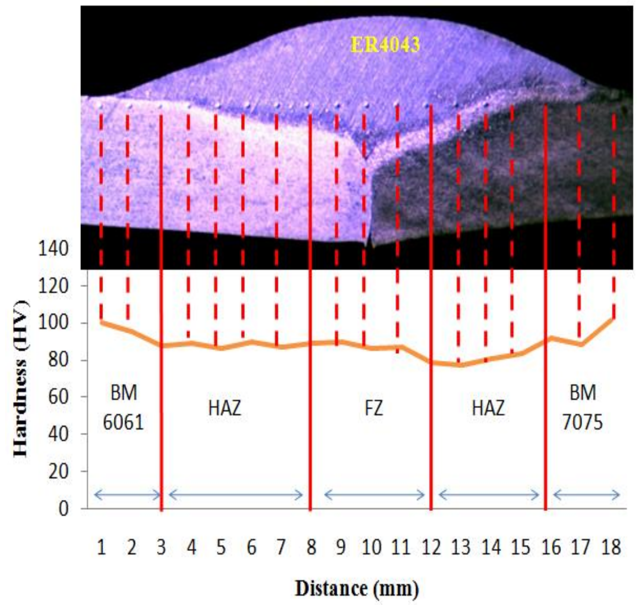


Figure 6 Hardness value test of weld joint AA6061-AA7075 using filler ER4043

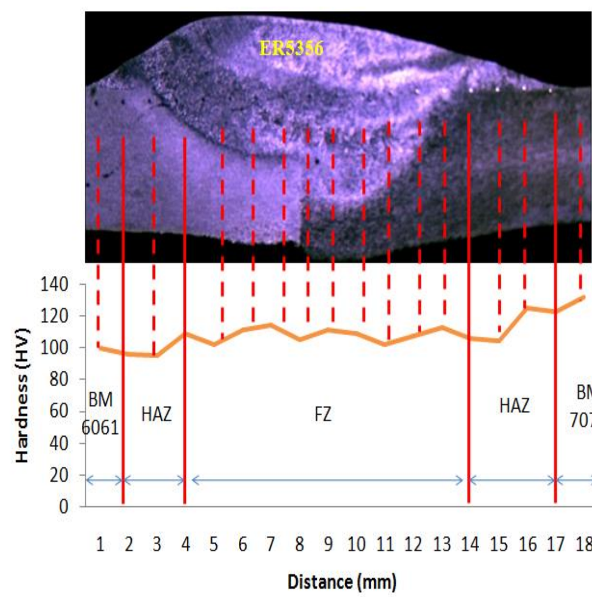


Figure 7 Hardness value of weld joint AA6061-AA7075 using filler ER5356

4.0 CONCLUSION

In this study, the effect of different fillers used on TIG process was investigated. Based on the present investigation, the following conclusion can be drawn:

(1) The aluminum alloys AA6061 and AA7075 were welded successfully using a TIG method with fillers ER4043 and ER5356.

(2) The weld joint fabricated using ER5356 filler exhibited a better weld appearance compared to the weld joint using ER4043. Welding using ER5356 filler had deeper penetration compared to using filler ER4043 which were 1.74 mm and 0.9 mm, respectively.

(3) Welding with ER4043 produced defects such as distortion and cracks. However, fewer defects occurred to weld using filler ER5356.

(4) The grain size at FZ using filler ER5356 was finer compared to welding using filler ER4043 which were 11.43μm and 19.51μm, respectively.

(5) Welding using filler ER5356 showed a higher average hardness value compared to filler ER4043; 100HV and 86HV, respectively at HAZ of AA6061, 110HV and 88HV, respectively at the FZ and 113HV and 85HV, respectively at HAZ of AA7075.

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