FRICTION STIR WELDING OF AZ31B MAGNESIUM ALLOY WITH ER4043 ALUMINIUM ALLOY FILLER

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Abstract - Magnesium Alloys (Mg) are well-known for the lightweight structural behaviour that makes them an excellent choice in applications requiring higher fuel efficiency such as in the automotive and aircraft industries. Their usage is limited in such structural applications owing to their poor weld ability. Formation of defects such as porosities, loss of alloying elements and distortion are common when conventional fusion welding techniques are employed. However, friction stir welding a solid-state joining can be used to join two materials without any risk of melting. This research is focused on friction stir butt-joining of 2mm thick AZ31B Mg alloy with the aid of aluminium (Al) alloy filler (ER4043). A tapered cylindrical shaped tool that was made from H13 tool steel was used with a tool tilt angle of 1˚. By applying a rotational tool speed (RS) of 1200 rpm and welding travel speed (WS) of 90 mm/min an ultimate tensile strength of 188.8 MPa was obtained contributing to a joint efficiency of 72.6 %. The maximum hardness in the stirred zone (SZ) was found to be 70 H_v, while in the thermo-mechanically mixed zone (TMAZ) was 66 H_v followed by a significant reduction in the heat-affected zone (HAZ) to a minimum of 57 H_v. The failure occurred between SZ and HAZ retreating side owing to weaker and complex intercalated microstructures comprising of swirls and vortexes that were indicative of a flow pattern of dissimilar metals.

Keywords - AZ31B Mg Alloy, Friction Stir Welding, Aluminium Filler, Mechanical Properties

I. INTRODUCTION

In vehicle design and development, more than half of the weight of the car is composed of metals for the chassis, doors, rims, engine block, engine head, intake manifold and many etc [1]. These metallic alloys such as that of boron steel, duplex steel etc. are required to be joined to produce functional structural components such as B pillar, transfer case, or roof joints etc. However, the usage of heavy steel components makes a significant impact on fuel consumption. For instance, a research has proven that weight reduction of 100 kilograms represents a fuel saving of about 0.5 litres per 100 kilometres for a vehicle [2].

Magnesium (Mg) and its alloys are now finding great applications in light-weight structural applications because of the strength to weight ratio that contributes to greater fuel economy and environmental conservation [3]. By having a density of 1.74 g/cm^3, Magnesium is 1.6 and 4.5 times less dense than aluminium and steel respectively. Other researchers have claimed that Mg is 35% lighter than aluminium (2.7 g/cm3) and over four times lighter than steel (7.86 g/cm^3). Magnesium Alloy can be produced by casting and its product normally used in the automotive industries especially for the die-cast vehicle components due to their better mass-equivalent properties. It would be interesting to see the response of Magnesium joined welding technique that could potentially lead to their usage in automotive applications. Joining magnesium-based alloys is a challenge because Mg is very reactive and conventional fusion-based joining process that imparts significant heat input to the work piece causes porosities hot crack, loss of alloying and above all structural distortions [4]. To overcome the disadvantages of such processes, a solid-state Friction Stir Welding (FSW) technique can be employed which joins two metals by heat generation through friction between the rotating tool and the work piece. FSW process is said to be energy efficiency, environmentally friendly [5].

Although Mg alloys have been successfully friction stir welded, there are some challenges such as low consistency and symmetry in the microstructure, larger shoulder affected zone [6]. To overcome such irregularities, it is therefore proposed that a suitable filler is employed that could enhance the mixing and weld quality. Aluminium based filler is designed for welding heat-treatable based metals. Henceforth, the current study aims to investigate the effect of aluminium based ER4043 filler on the mechanical properties of the joint.

II. EXPERIMENTAL PROCEDURE

A. Material Preparation

Plates of AZ31B Mg alloy with 2mm thickness was cut in dimensions of 120mm x 60mm x 2mm. Aluminium alloy filler ER4043 having a thickness of 1.2 mm was firmly flanked by butt joint of Mg Alloy. Table I presents the chemical composition of these materials. The tool was made of H13 tool steel having a tapered cylindrical tool pin profile. The length of the tool pin was 1.8mm while the shoulder diameter was 10mm and the pin base diameter was 3mm.

Elements	Al	Zn	Mn	Si	Ce	Pb	Ca	Cu	Ni
AZ31	2.96	1.18	0.421	0.0356	0.033	0.013	0.003	0.002	0.002
	Mg	Al	Zn	Si	Fe	Cu	Mn	Ti	Other
ER4043	≤ 0.05	Bal	≤ 0.1	4.5~6.0	≤ 0.8	≤ 0.3	≤ 0.05	≤ 0.2	≤ 0.05

Table I: Materials composition for magnesium alloy AZ31B and aluminium alloy filler ER4043

B. Friction Stir Welding

FSW process was conducted by using CNC controlled Friction Stir Welding machine. The welding process can be referred diagrammatically as showed in Fig. 1. The welding tool tilt angle was fixed at 1˚. Firstly, the Welding Tool was inserted into the spindle chuck and it then was tightened up by using Collet Chuck Spanner and Adjustable Spanner. Then, the prepared specimens were put on the backing plate. Flattered Aluminum Alloy was flanked between the two specimens and they were clamped by the clamping jig (Fig. 1(c)). All the screws of the clamping jig were tightened up to hold the specimen firmly during the welding process. Next, the pin of the welding tool was aligned at the center of the butt joint. Thereafter, the welding tool was started to rotate at rotational tool speed (RS) of 1200 rpm while being was plunged into the specimen slowly. This process is called tool indention and it was continued until the shoulder of the welding tool touches on the metal. The tool will soften the metal, then it can be travelled at a welding travel speed (WS) of 90 mm/min speed along with the butt joint. The two metals will be mixed up and solidified immediately without any subsequent melting.

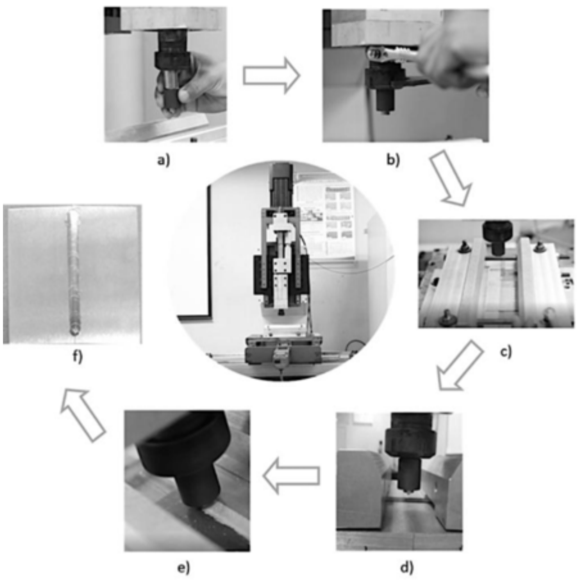

Figure.1. Step flow of welding process; a) tool insertion b) tool tightening c) specimen placement d) tool alignment e) welding process f) finished welded specimen

C. Materials and Mechanical Characterization

After the FSW process, the welded materials were cut dimensions of the dog-bone tensile specimen according to ASTM E8/M8. Thereafter, INSTRON Universal Testing machine was used at a speed of 1mm/min with an applied load of 48kN. For metallography, the samples were sectioned, mounted using epoxy resin. This was followed by grinding with SiC emery paper and subsequent polishing by diamond suspension liquid. The microstructure was observed by an optical microscope (Prog Res C3). Vickers hardness machine (MMT-X7) was used to evaluate the micro hardness at a load of 500g (HV0.5) for a dwell time of 10 seconds.

III. RESULTS AND DISCUSSION

A. Microstructure and Weld Surface Morphology

Fig. 2(a) shows the surface morphology for the joining of Magnesium Alloy with ER4043 filler. The specimen showed minor flash ribbon at the retreating side. The macrostructures can be divided into distinct zones which are stir zone (SZ), thermo mechanical affected zone (TMAZ), heat affected zone (HAZ) and base metal (BM).

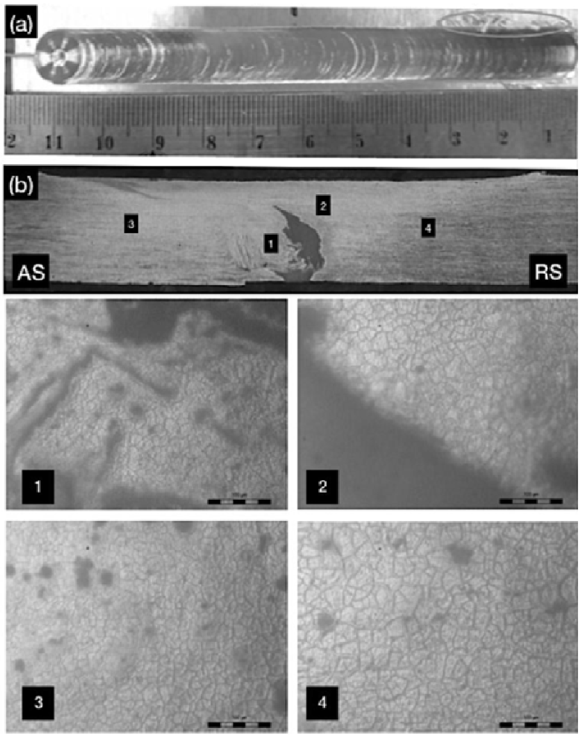

Figure.2. a) the weld appearance, b) the macro structural overview of the welded zone with inset 1) SZ, 2) TMAZ, 3) HAZ-AS and 4) HAZ-RS

that is 2.786μm when compared with base metal grain size. This recrystallization was enabled by frictional heat from the tool shoulder and tool probe, the heat generated by the mechanical stirring of the materials by the probe and mostly adiabatic heat contributing to dynamic recrystallization through the deformation. Friction stir welding has a lower input compared with fusion welding because Mg and filler metal diffused in the stir zone in the form of solid atoms.

a) Tensile Strength				
Base Metal	Tensile Strength (MPa)	Weld Tensile Strength (MPa)	Weld Efficiency	Extension (mm)
AZ31	260	188.8	72.62%	1.91
b) Hardness (H_v)			Base Metal 60 H_v	
Advancing Side			Retreating Side	
HAZ	TMAZ	SZ	TMAZ	HAZ
57	66	70.4	67	58
c) Grain Size (um)			Base Metal 10.31 um	
HAZ	TMAZ	SZ	TMAZ	HAZ
8.56	6.59	2.78	6.58	10.12

Table II: Tensile Strength, hardness and grain size of the friction stir welded sample

Thus, it was found that the presence of eutectic structure, and evidence of “constitutional liquation” lead to the formation of inter metallic compounds (IMC) between Mg and filler that is observed at TMAZ [6]. Insufficient plasticizing due to low rotational speed resulted in poor intermixing between Mg and Al can lead to the formation of the IMC layer. This can be observed in the TMAZ zone as showed in Fig. 2(b) inset 3. The HAZ-AS has 8,56 µm grain size that is smaller than HAZ-RS which is 10.23µm, that was almost similar to BM.

B. Mechanical properties

Table II shows the mechanical properties of the welded joint. The welded samples registered a joint efficiency of 72% at a tensile strength of 188.8MPa. Base metal elongated 13.95mm that was greatly reduced to about 1.91 µm. The Vickers hardness showed an uneven distribution across the cross-section. The micro hardness is significantly related to the microstructure changes. SZ exhibits highest Vickers hardness compare to other zones due to its finer grain size. The dynamic recrystallization takes place that leads to a fine grain at the center of the weld region. The hardness distribution drops when indention goes to TMAZ area since the grain size gets coarser [7]. The lowest Vickers hardness clearly can be seen at HAZ area for both retreating and advancing side. This is because both HAZ side had a larger grain size compared to other regions. Fig. 3 shows the fractured sample at TMAZ location. This is due to almost 80% of the equiaxed filler metal was located at the end of SZ-RS. Therefore, the bonding between Magnesium and filler metal was quite weak and brittle. A possible reason could be the formation of IMCs in the joints between the filler metal and BM. The poor intermixing caused by the insufficient deformation of Mg and more liquation cracks and IMCs caused by the high heat input both contributed to the poor weld appearance and the low tensile strength [8].

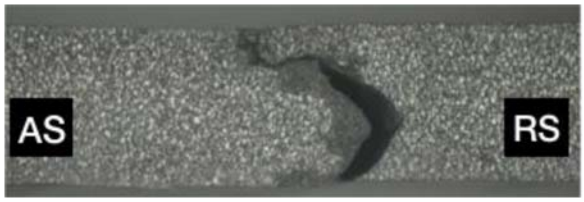

Figure.3. Cross-sectional view of fractured samples

IV. CONCLUSION

Complex intercalated microstructures were observed in the stir zone of joining with filler, with swirls and vortexes indicative of the flow pattern of the dissimilar metals leading to a reduced tensile strength of about 188.8 MPa. The joining of AZ31B with A-based filler has a weak micro structural bonding that fractured at TMAZ.

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