Aspects of Friction stir weldments of rare earth AE42 Magnesium Alloy

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Abstract

The aim of the present work was to develop a similar friction stir joint conducted on rare earth containing magnesium alloy AE42, by joining two plates aligned perpendicular to the welding directions we are investigating the microstructural and mechanical properties. The influence of the tool movement on weld properties during welding, light optical microscopy was used to observe and study the weld zone characteristics. There was a clear decrease in the precipitate size from the base material through the TMAZ and in to the weld zone. SEM with EDX analysis performed on the weld region showed the presence of intermetallic phases. The precipitates observed were Al_2RE, $Al_{11}RE_3$ etc. The welds were free of porosities, Vickers micro hardness testing was done along the thickness (Transverse direction) of the plate in the weld region to study and understand the variations of hardness with thickness. A good correlation between the grain size and micro hardness was observed.

Keywords: Friction Stir welding, AE42 alloy, rare earth magnesium, Weld properties.

INTRODUCTION

Magnesium alloys are among the lightest commercial structural alloys and hence are considerable interest to automobile and aerospace industries. Most of the magnesium alloy components are produced by die casting [1]. However magnesium alloys have several limitations. Due to HCP (Hexagonal Closely Packed) crystal structure and coarse microstructure in the as-cast condition, magnesium alloys have low formability and low toughness. The service temperature of magnesium alloys is also low as they have poor high temperature mechanical properties. Friction stir welding (FSW), a novel solid joining technology is a potential candidate since it has many advantages compared with the traditional fusion welding. As a solid state joining process, FSW can produce pore-free joints, since pores caused by metal solidification are eliminated. In this process, a rotating tool consisting of a shoulder and a probe is plunged into the joint and traversed along the joint line to form a weld [2]. A friction stir weldment consists of a Thermo-Mechanically – Affected Zone(TMAZ), dynamically re-crystallized zone (known as Friction Stir Zone-FSZ or Weld Nugget-WN), extensively deformed but not re-crystallized surrounding region, heat affected zone and unaffected Base Material (BM) [3].

Friction Welding and FSW are two important solid state welding techniques which can readily be performed on magnesium alloys and there are many studies in recent past about these welding [4]. AE42 is magnesium aluminium rare earth alloy which was developed for high temperature applications due to superior creep resistance over commercial magnesium alloys.

In this paper, the focus is on the mechanical properties and microstructural characteristics of friction stir weld of AE42 Mg alloy. AE42 is a newly developed die-casted Mg alloy, characterized by elongated grains, the grains being oriented in the casting direction.

MATERIALS AND METHODS

FSW experiments were conducted on AE42 alloy (Rare earth containing Magnesium) sample plate with dimensions (140X70X3mm³). The composition of the alloy used was Al 4%, RE 2% RE contains (1.2 % Cerium, 0.6% Lanthanum, 0.4% Neodymium, 0.1% Praseodymium) Mn 0.3% and rest is Mg.The Mechanical properties of AE42 alloy is tabulated in table 1. These plates were produced by pressure die casting.

The tool used for FSW experiments was H13 steel. The tool was designed with a shoulder diameter 12mm and total length of 75mm and tapering pin had 2.5mm diameter with thread of 1mm pitch and pin length 2.9mm. A schematic of the FSW process is shown in fig.1
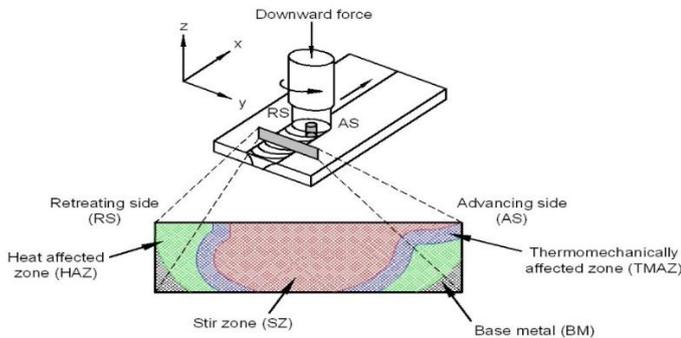
Figure 1: Schematic of the FSW showing the process and different zones in the weld region

Initially tests were carried out to find optimum processing conditions: tool speed, load and traverse speed. The process parameters were optimized as shown in the table 2. After conducting experiments, the results were analysed and the optimum FSW parameters were chosen. The optimum processing parameters were selected by conducting tensile testing was carried out using Intron 5500R Universal Test Machine (UTM) on specimens as per ASTM E8 were made out perpendicular to the FSW direction such that the gauge length contains all three regions, namely Base metal (BM), Thermo-mechanically affected zone (TMAZ), and friction stir zone (FSZ). If the tensile specimens failed at FSZ, TMAZ or at the TMAZ, BM interface they were considered inferior as the strengths were lower than that in the BM. If the failure occurred at BM, it was considered superior because the FSZ and TMAZ had higher strength. Superior FSZ in terms of mechanical properties was taken as optimum. In addition to the tensile tests, visual examination for surface imperfections (surface cracks, projections, voids, and surface finish) was also carried out. Hardness in both (BM) and in the vicinity of the (FSZ) for the various processing conditions was tested using Fuel instruments and Engineering Pvt Ltd, Model IT 30 ASTM machine across the weld direction. Microstructural analysis by SEM with EDAX analysis of the BM, TMAZ and FSZ of the AE42 alloy was carried out after standard metallographic preparation of samples. Etching was done with Picral solution (50ml ethanol, 10ml H20, 5ml acetic acid, 2.5ml picric acid) [5].

Table 1: Mechanical Properties of AE42 Mg alloy

Alloy	Yield Strength (Mpa)	UTS (Mpa)	Elongation (%)	Hardness (VHN)
AE42	130	225	6	75

Figure 2: Tensile Samples of AE42 alloy
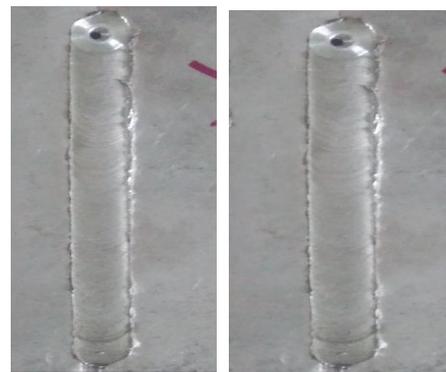
Figure 3: FSW on plates of AE42 alloy

Table 2: Welding Parameters

S. No.	SP	T	TDF	TD	IHT	TS	WL
1	600	3	30	2.9	2	40	110
2	700	3	35	2.9	2	50	110
3	800	3	30	2.9	2	60	100
4	900	3	35	2.9	2	70	100
5	1000	3	30	2.9	2	80	100
6	1200	3	35	2.9	2	100	110
7	1400	3	30	2.9	2	120	110

SP: Spindle speed (rpm),T: Thickness (mm), TDF: Tool down Force (N/mm), IHT: Initial Heating Time (sec), TS: Travel Speed (mm/min), WL: Welding Length (mm)

DISCUSSION

Mechanical Properties

At room temperature hardness and tensile tests measurements

Hardness: Hardness measured with 5kg load and diamond indentation time of 10sec. The relatively higher tensile strength, percentage elongation and hardness of FSZ region

compared to the PM can be attributed to the following reasons:

1. Ultra-fine precipitates which are fragmented by FSW and distributed homogenously in the matrix.

2. Elimination of continuous and large network of second phases at the grain boundaries.

3. Elimination of any micro-porosity and surface imperfections in the as cast-PM which can lead to poor mechanical properties.

4. Overall grain refinement as a result of FSW.

5. Due to fragmentation, increase in number of AlRE precipitates during FSW hence, increased pinning effect.

However, the hardness of FSW magnesium AE42 alloy does not increase beyond certain range due to softening effect in the alloys depending on the processing parameter [6, 7]. Hardness results are tabulated in table 3 with the corresponding graphs plotted in fig 3.

Results showed clear indication of an increase in hardness in the processing zone to the plastic deformation action of the tool shoulder on the alloy and the grain refinement and a gradual decrease in hardness in thermos mechanically affected zone leading to the base metal hardness.

Table 3: Variation of Vickers hardness number across the weld joint

S. No	SP	TS	BM	TMAZ	FSZ
1	600	40	71.0	70.0	68.9
2	700	50	70.8	69.8	68.2
3	800	60	69.8	69.9	67.0
4	900	70	67.3	70.0	66.8
5	1000	80	62.9	68.9	66.0
6	1200	100	61.4	68.5	65.7
7	1400	120	60.8	68.0	64.0
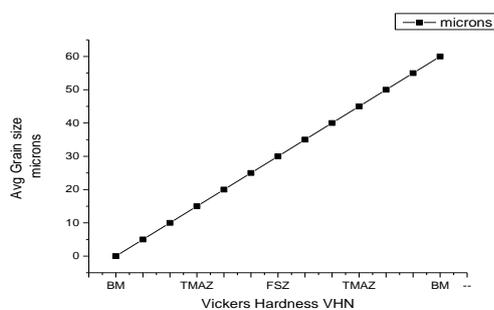
**Figure 4:** Variation of Average Grain size with VHN in the longitudinal direction
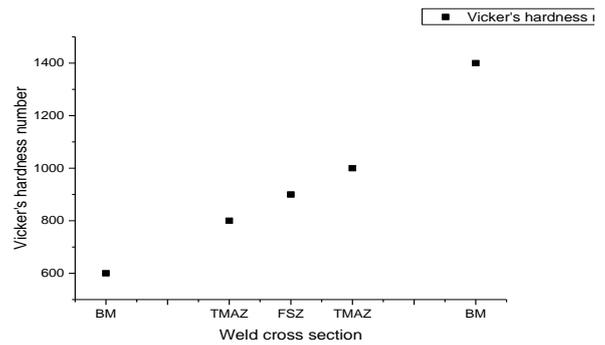
Figure 5: Vickers Hardness Distribution

Tensile strength: Tensile test results are tabulated in table 4 and the corresponding graphs are plotted in the fig. In conventional FSW, welding is performed along the weld line and loading takes place perpendicular to the weld line.

Table 4 Variation of Tensile Strength

FL	SP	TS	W	T	SP.GL	0.2%Y.L	0.2%Y.S	ML	SM	EL
Fsz	600	40	5	3	25	2.55	100	2	130	5
Bm	700	50	5	3	25	2.55	100	2	140	6
Tmaz	800	60	5	3	25	3.00	110	2	150	6
Tmaz	900	70	5	3	25	3.00	120	2	155	6
Fsz	1000	80	5	3	25	3.20	125	2	160	5
in.tm	1200	100	5	3	25	350	130	2	180	6
Fsz	1400	120	5	3	25	350	130	2	190	5

FL: Failure Location, Fsz: Friction stir zone, bm: Base metal, tmaz: Thermo-mechanically heat affected zone, In.tm: Interface Thermo-mechanically affected zone, W: width, Sp.GL: Special Gauge length, Y.L: Yield Load, Y.S: Yield Stress, ML: Max Load, SM: Stress at Max Load, EL: Elongation.
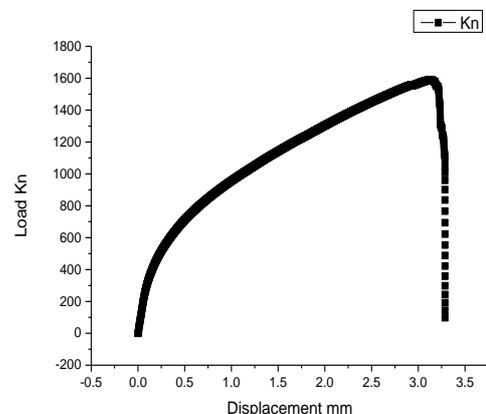

**Figure 6:** Graph of Load verses displacement
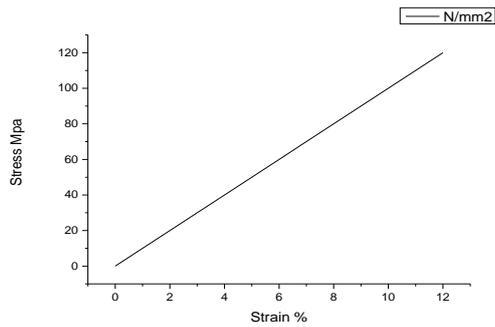
Figure 7: Graph of Stress verses Strain

Light Optical Metallography

Magnesium samples were prepared for Optical Metallography taking precautions required to minimize contamination. The etchant solution used for Mg samples [5]. The etched samples were analysed using a Leica made Light Optical Microscope with image analyser attachment. The overall weld cross-section was analysed at low magnifications (12.5X) to view the entire span of the weld zone, showing the base material, the transition zones and the FSZ. The weld zone was further analysed at higher magnifications (200X) to view the intercalated FSW microstructures.
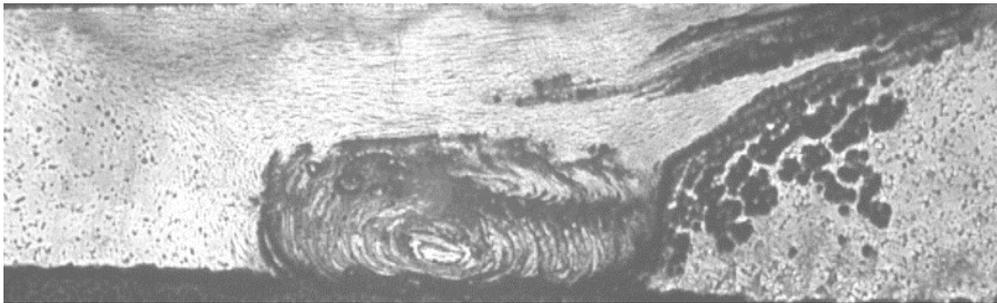

Figure 8: Macrostructure of Magnesium AE42 alloy with 12.5X magnification
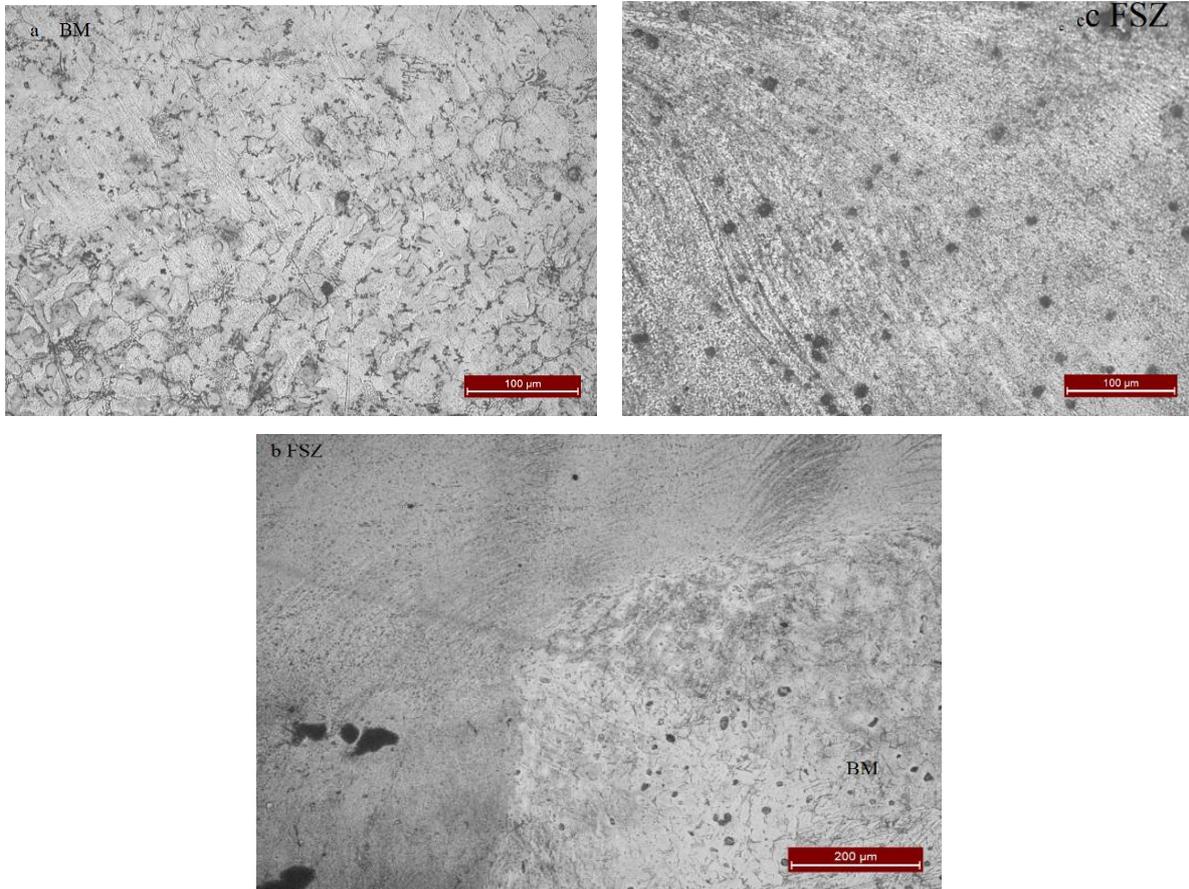
Figure 9: Microstructures of Magnesium samples a) Base metal b) Base metal + FSZ c) FSZ

SEM ANALYSIS

The obtained microstructures are shown in the fig6. Analysis of the micrographs indicate the presence of fine grains oriented along the loading direction substantiating the results obtained in form tensile strength. It indicates the smooth flow of the extruded material into the other side of the welded joint and good metallurgical bond with superior mechanical properties. BM microstructure showed coarse grains with a continuous network of precipitates along the grainboundaries. Grain boundary Al_2RE precipitates are shown in fig 6. From FSZ microstructures it is observed that the coarse elongated precipitates of Al_2RE and $Al_{11}RE$ in the BM were fragmented mechanically into very fine sized precipitates in the FSZ region.
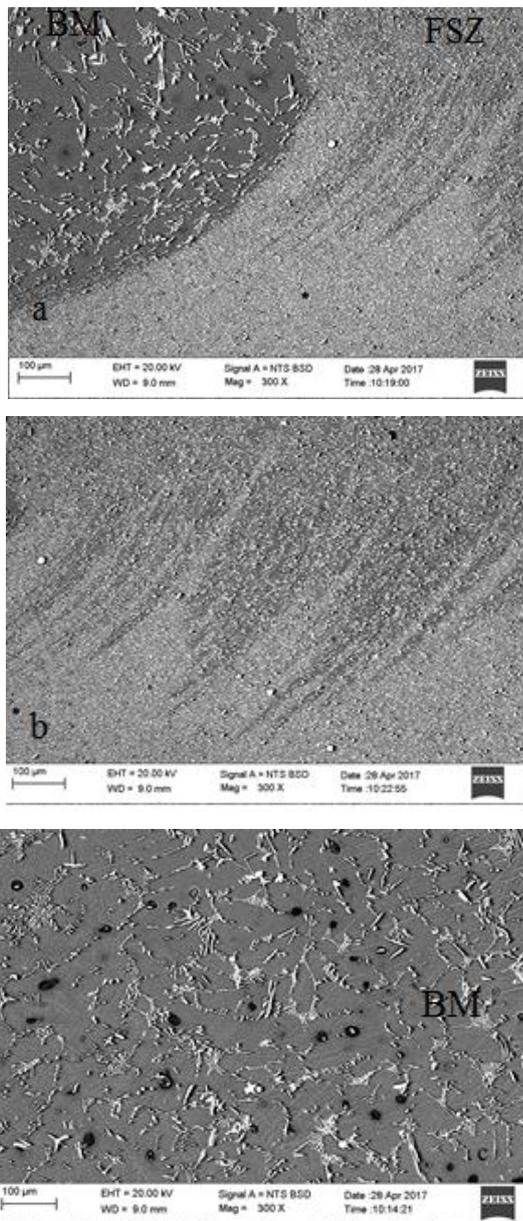
Figure 10: SEM microstructures a) Base metal + friction stir zone b) friction stir zone c) Base Metal

Figure 11: SEMEDX spectrum of Mg alloy AE42 base metal.

CONCLUSIONS

1. AE42 die-cast magnesium alloys were successfully friction stir welded. The weld zones were apparently defect free.

2. Optimum FSW parameters were identified as 10KN vertical load, 1200 rpm tool speed and 100 mm/min traverse speed.

3. Although the overall average hardness values in the FSW joint is lower than the base metal local variation in hardness in the weld region seems to have some correlations with the grain size.

4. Direction of welding in this method is normal to the conventional FSW.

5. The tool movement direction, the orientation of the tool shoulder and texture it creates influences the mechanical properties.

6. Compared with the base material, magnesium precipitates in friction stirred zone (FSZ) were greatly refined due to dynamic recrystallization.

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