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IMPROVED CORROSION RESISTANCE OF FRICTION STIR ZONE OF RARE EARTH MAGNESIUM ALLOY AE42

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Abstract - Corrosion studies on friction stir welded AE42 magnesium alloy were carried out in 0.1 M ammonium carbonate solution. For better understanding, comparative analysis of corrosion rates was carried out before and after welding. Friction stir weld zone was more corrosion resistant than the parent metal under similar experimental conditions. Grain size was refined at weld zone. Second phase intermetallic particles were refined into tiny pieces of 1-2 micron size and evenly distributed throughout the matrix. Local electrochemical imbalance was eliminated due to the grain refinement and elimination of continuous grain boundary. These phenomena improved the corrosion resistance of weld zone. Scanning electron microscopic images confirmed mild and uniform corrosion of weld zone and rigorous inhomogeneous corrosion of parent metal.

Keywords - *Friction stir welding; weld zone, corrosion, grain refinement; magnesium alloy, polarization.*

I. INTRODUCTION

Magnesium is the lightest commercial metal among all the structural metallic materials. Magnesium alloys have many advantages like high specific strength and stiffness, low elastic modulus, excellent damping capacity, stronger vibration resistance, easy machinability and low dimensional change [1]. Its highest advantage is sought in increasing the fuel efficiency of automobiles and aerospace. Application of magnesium alloys in these industries is increasing continuously because of their ultra lightness and high strength to weight ratio [2]. Aerospace and automobile industries have provided great stimulus to the development of magnesium alloys over the last 40 years [2, 3]. For example, thorium-containing alloys were developed and being used in missiles and spacecraft; AE 42 alloy was developed and used in passenger cars. Die cast magnesium alloy components are used for clutch housings, gear boxes, pedal brackets, instrument panel frames, integral seat frames and wheel hub cover components in passenger cars. One of the largest consumers of AE42 magnesium alloy is Volkswagen where the magnesium alloy components are used in power train [3].

In most of the structural applications, magnesium alloy has to be welded to make complex fabrications. As the weldability of magnesium alloy is poor, solid state welding techniques are found suitable to weld them [4, 5]. Friction Stir Welding (FSW) is one of the most suitable techniques among them. FSW is a process that generates heat through mechanical friction between a moving +rotating tool and work piece to plasticize and fuse/weld two work pieces [5]. A friction stir weld comprises a plasticized zone known as Friction Stir Zone *(FSZ) or weld zone*, thermo mechanically affected zone and Parent Metal (PM). There were many researches in the recent past that explored FSW of various magnesium alloys [4]. But the study was not extended to the corrosion resistance of weld zone of magnesium alloys.

In view of the utility of welded magnesium alloys in automotive and aerospace engineering, studies pertaining to the corrosion resistance of weld zone are of fundamental as well as technological interest. Previous literature on this topic is virtually non-existent. Objective of the present work is studying the corrosion of AE 42 alloy weld zone and the comparison of the same with PM. In the carbonate solution, magnesium hydroxide and magnesium carbonate are formed as corrosion products.

II. EXPERIMENTAL PART

A. Friction stir welding

FSW was performed in vertical type Friction Stir Welding machine. Welding parameters used were: Tool rotational speed of 1000 rpm, welding (traverse) speed of 40 mm per minute. Die cast sheets of AE42 alloy with 3 mm thickness were used for welding trials. Prior to welding, all the samples were thoroughly cleaned by acetone. Photograph of the set up of FSW is shown in Fig 1. After welding, samples were cut into 25mm X 25 mm size with weld zone at the center of sample for corrosion studies and characterization. For comparison of the results with PM, same size samples were cut from the sheets and all the tests were done for both PM and weld zone.

TABLE 1. COMPOSITION OF AE 42 ALLOY BY WEIGHT PERCENTAGE

Elements	Al	Ce	La	Nd	Pr	Th	Mn	Mg

Composition (wt %)	3.9	1.2	0.6	0.4	0.1	0.2	0.3	Rest

Fig. 1 : Experimental set up for FSW Rare Earth Magnesium alloys

B. Corrosion studies

All electrochemical experiments for corrosion studies were conducted with a PGSTAT 302 Autolab system (Ecochemie, Utrecht, The Netherlands). EcoChemie GPES software was used for controlling and data collection. The reference electrode was Ag/AgCl (3M KCl) and the counter electrode was a platinum foil supplied along with the instrument. Electrodes were arranged in a flat cell such that 0.37 cm^2 area of the working electrode (sample) was exposed to the electrolytic medium.

E-log I polarization curves for pure magnesium surface, AE42 magnesium alloy, and weld zone of AE 42 magnesium alloy were carried out and compared. This helps to evaluate the corrosion resistance of weld zone; in other words, corrosion potential of pure magnesium surface and PM serve as reference scales. Also, comparison of corrosion potential of the AE42 alloy with pure magnesium helps in confirming the superiority of the alloys in terms of corrosion resistance.

After the electrochemical experiments, Scanning Electron Microscopic (SEM) analysis of tested portion was done using TESCAN scanning electron microscope. SEM study of weld zone and PM was carried out before and after electrochemical experiments. Standard metallographic technique was used for sample preparation; etching was done with picric acid, ethanol and acidic acid mixture solution for SEM studies before corrosion [6].

III. RESULSTS AND DISCUSIONS

A. Raw material characterization

Chemical composition of AE42 alloy used for the study is shown in Table 1. Chemical analysis was in confirmation with the standard AE42 alloy.

B. Microstructural analysis

Fig. 2 A and B shows the SEM images of AE42 alloy (PM) before and after corrosion respectively. AE 42 alloy has mainly $Al_{11}CE_3$ and Al_2CE intermetallics and small amount of $Mg_{17}Al_{12}$ inter-metallic phase in irregular shapes (white color in Fig. 2A) in α (alpha) magnesium matrix. The darker phase appearing in between the alpha phase and intermetallics is the mixed phase of both α and inter-metallic phases [7, 8]. After corrosion, the surface has corrosion products precipitated in between the grain boundaries that can be seen in Fig. 1B. Here the grain boundaries also show the corrosion in the form of canal that suggest the preferential dissolution of the alloy (at precipitates) followed by the precipitation. Grain boundaries were attacked deep and that leads to accelerated corrosion.

Figure 3 A shows the SEM images (microstructure) of weld zone before corrosion. The image shows finely refined and uniformly distributed second phase inter-metallic particles throughout the matrix. The distinction of α matrix and small precipitates is clear. Continuous network of second phase grain boundary was eliminated. This change was due to welding.

SEM images of weld zone of AE42 alloy after corrosion are shown in Fig. 4. Uniform and comparatively mild corrosion attack is evident from the image. Compare to PM (Fig 2B), the corrosion of weld zone is less. The localized corrosion attack occurred in PM; but it was uniform and mild attack in weld zone.

C. E-log I polarization studies

Figures 5 to 7 show the E-log I polarization curves of pure magnesium surface, AE42 alloy (PM) and weld zone of AE42 alloy respectively in 0.1 M ammonium carbonate solution recorded at the scan rate of 100 mVs^{-1}. After a few scans, the potentio dynamic curve was recorded.

Table 2 shows the corrosion currents and potentials calculated from the polarization curves for AE 42 alloy and weld zone. AE42 alloy contains 4% Al and 2% misch metal. The corrosion morphology of magnesium and its alloys differ and depend on the alloy chemistry and environmental conditions. Pure magnesium is known to undergo transgranular corrosion while the attack on the alloys is more concentrated adjacent to selective phases [6].

The weld zone showed corrosion potential of -1.3189 V; this value suggests the fact that the weld zone has higher corrosion resistivity than PM (-1.3812 V). This result is as per expectation, as weld zone undergoes severe plastic deformation and heat treatment (fast cooling) during the welding process, which changes the microstructure and morphology of secondary phases (elimination of continues network) of the alloy in-situ, thereby tending to be more corrosion resistant. Also the subsequently recorded scans did not differ much from the first one unlike pure magnesium (Fig. 5) which is a measure of stable surface.

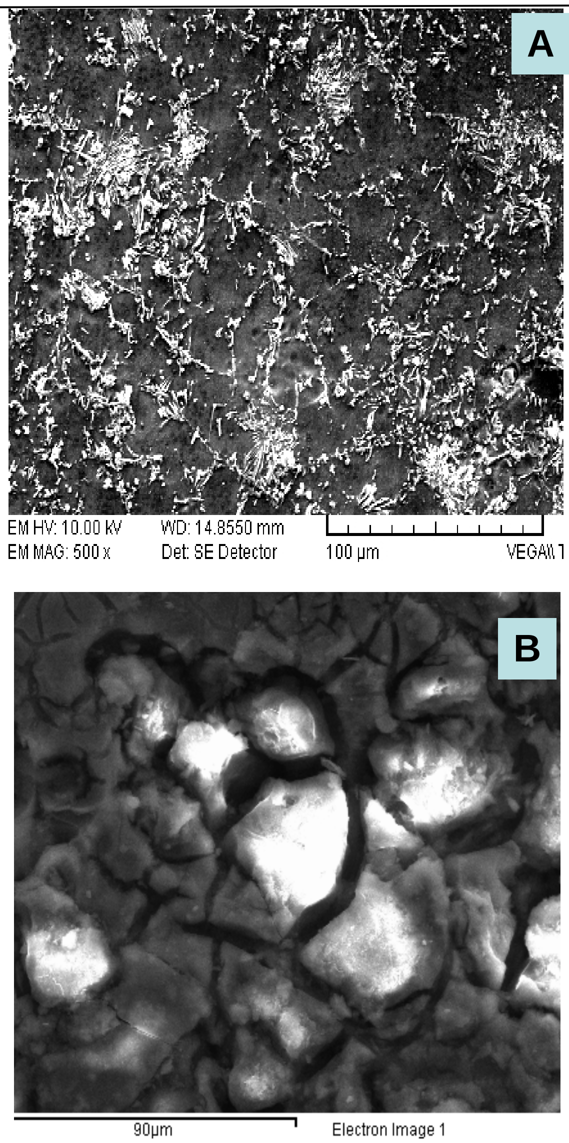

Fig. 2 : SEM images of AE42 magnesium alloy, PM (A) before corrosion (B) after corrosion

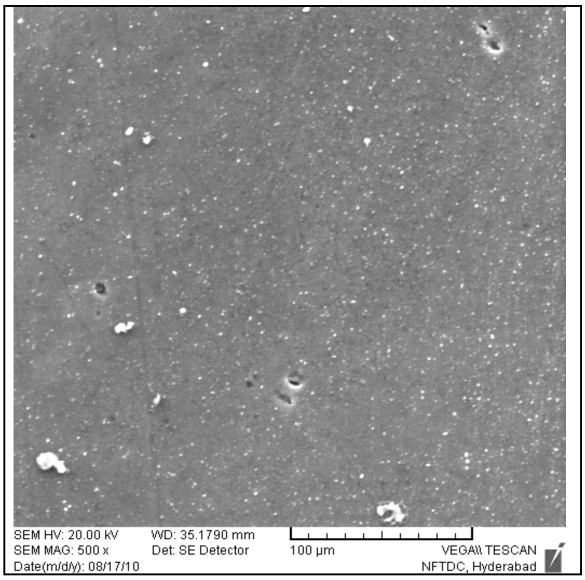

Fig. 3 : SEM image of WELD ZONE of AE42 magnesium alloy before corrosion

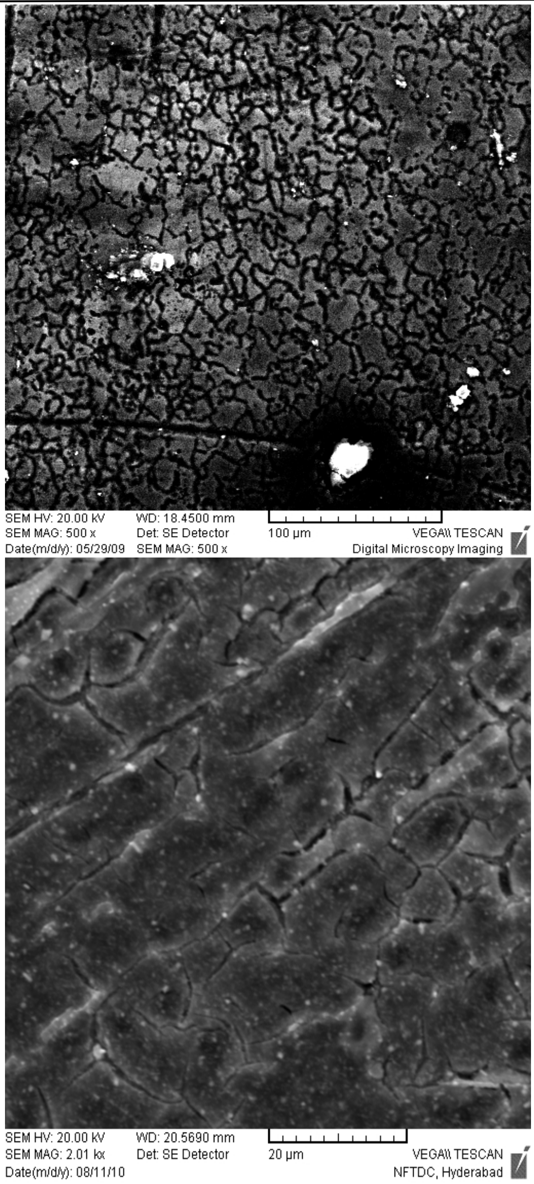

Fig. 4 : SEM image (various magnifications) of WELD ZONE of AE42 magnesium alloy after corrosion

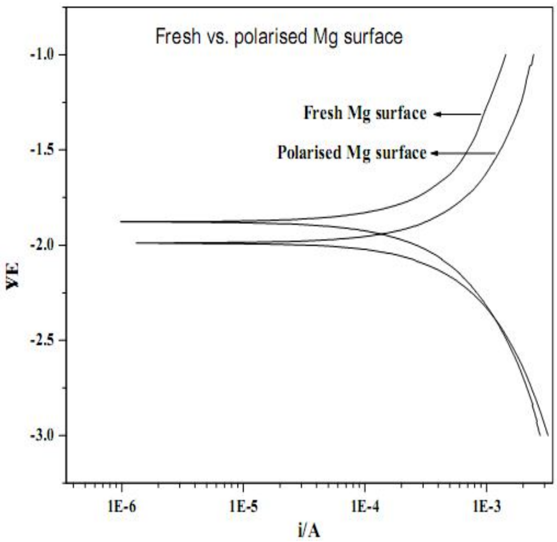

Fig. 5 : E-log I polarization curves for the pure magnesium sample in 0.1 M ammonium carbonate solution

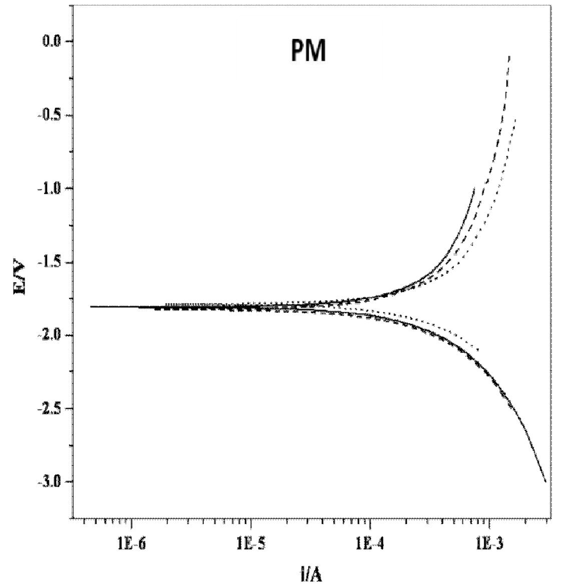

Fig. 6 : E-log I polarization curves for the AE42 alloy sample in 0.1 M ammonium carbonate solution

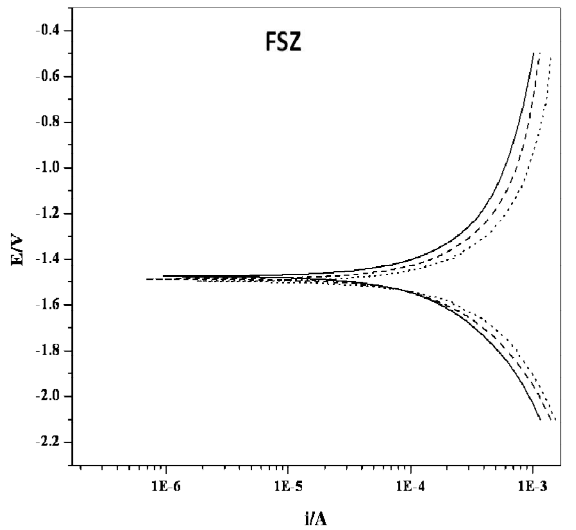

Fig. 7 : E-log I polarization curves for weld zone (FSZ) of AE42 alloy sample in 0.1 M ammonium carbonate solution.

TABLE 2 : PARAMETERS DERIVED FROM THE E-LOG I POLARIZATION CURVES FOR THE ALLOY AND WELD ZONE

Exp.No.	Specimen condition	E_{corr} (V)	I_{corr} (x 10^{-4} A/cm^2)
1	AE42 alloy	-1.378	1.44
2	(parent	-1.384	1.47
3	alloy)	-1.334	1.47
4		-1.412	1.44
5		-1.398	1.48
Average for parent alloy		-1.3812	
1	AE42	-1.329	1.47
2	friction stir	-1.333	1.43
3	zone-WELD	-1.321	1.49
4	ZONE	-1.309	1.51
5		-1.298	1.48
Average for weld zone		-1.318	

IV. CONCLUSIONS

1. Weld zone (FSZ) of AE42magnesium alloy was more resistant to corrosion than the parent metal.
2. Morphology of weld zone showed a noticeable change in grain refinement and corrosion.
3. Due to grain refinement, elimination of continuous network of second phases and electrochemical imbalance, corrosion attack in weld zone was less than parent metal.
4. Parent metal corrosion was not uniform in nature but stir zone was uniform and less.

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