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Research Paper

INVESTIGATIONS ON THE WEAR BEHAVIOUR OF FRICTION STIR PROCESSED MAGNESIUM BASED AZ91 ALLOY

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In this study, a Magnesium based alloy namely AZ91 based hybrid nanocomposite was fabricated using TiC by Friction Stir Processing (FSP). FSP of AZ91 was conducted with particle addition under ambient cooling conditions. Distribution of nano TiC particles in the Mg matrix was studied using Optical Microscope. Grain size analysis of the as-cast and FSP AZ91/(TiC) composite were done using optical microscopy. The performance of the fabricated nanocomposite was investigated using pin on disc wear test on Universal Tribometer using different loads.

Keywords: Magnesium alloys, Friction stir processing, Wear

INTRODUCTION

Mg alloys are gaining importance as a structural material for applications in which weight reduction is crucial, due to their low density and high stiffness to-weight ratio. Still, Mg alloys have not been conventionally used for high performance applications due to their low mechanical properties at room and elevated temperatures (Lee *et al.*, 2006). AZ91, a magnesium based alloy is commonly used to produce cast components due to its superb castability and reasonable mechanical properties (Ni *et al.*, 2009). Magnesium alloys offer lightweight alternatives to conventional metallic alloys, and as a result are finding structural applications in the automotive and light truck industry. Weakness of the alloys due to salt corrosion and to creep at elevated temperatures has limited their applications, but there are still many parts in cars and trucks where the significant weight savings from magnesium alloys can be used to advantage (Ruden and Albright, 1994; and Cole, 1997).

Friction Stir Processing (FSP) based on principle of Friction Stir Welding (FSW) is a relatively novel multifunctional metal working method (Ma *et al.*, 2006; and Sharma and Mishra, 2008). During FSP, partial melting of

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the material takes place due to frictional heating between the work piece and the FSP tool shoulder. Solidification of the partially melted material results in the characteristic nugget zone of the friction stir processed region. This method has been successfully used to modify the microstructures of as-cast Al alloys (Ma *et al.*, 2006; and Sharma and Mishra, 2008), and Mg alloys (Chang *et al.*, 2004; and Zhang *et al.*, 2007). FSP of a magnesium alloy AE42 conducted under different FSP and cooling conditions with rapid external cooling has resulted in enhancement of the microhardness value nearly by 60%. Thus, FSP can be considered as a significant technique for material strengthening through microstructural refinement (Arora *et al.*, 2011).

One of the recent applications of FSP is fabrication of hybrid composites. Hybrid composites are engineering materials reinforced by a combination of two or more different type and/or form of substances in order to achieve the combined advantages of both of them. This gives a rather high degree of freedom in material design (Zhang *et al.*, 2006).

It is observed that the wear rate of Friction Stir Processed (FSPed) AE42 alloy had been reduced under all the conditions for the range of normal loads and velocities. Micro structural refinement of FSPed AE42 alloy results in higher hardness, greater work hardening capability and improved ductility thus resulting in the reduced wear rates (Arora *et al.*, 2013).

The aim of the current investigation is to fabricate AZ91 based hybrid composite using FSP with TiC as reinforcement, as an attempt to enhance its work hardening capability and mechanical properties. FSP of AZ91 alloy was also performed without any particle addition.

MATERIALS AND METHODS

The material used in the current investigation is Mg alloy AZ91 and commercially available TiC powder. The average particle size of the available TiC powder was about 40 μm. FSP was carried out on a Computer Numerical Control (CNC) vertical milling machine (5 H.P) with the help of FSP tool and fixture. Rectangular specimens having dimensions 5 mm × 5 mm and 10mm in length were prepared from the AZ91 ingot. FSP was performed at ambient cooling condition.

For the addition of fine reinforcement powder to the AZ91 alloy, one row of uniformly spaced small holes of 2 mm diameter and 0.5 mm depth were drilled along the longitudinal direction of the AZ91 specimen. TiC powder was added into the drilled holes of the AZ91 specimen. FSP was then carried out using FSP tool. The FSP tool is a commonly used cylindrical element without threads with 15 mm shoulder diameter, 4 mm pin diameter and 0.5 mm pin length. The material used for FSP tool was mild steel. The parameters used for FSP consists of tool rotational speed of 900 rpm, linear speed of 40 mm/min and plunge depth of 0.3 mm which were kept constant in this investigation. For the microstructural characterization, specimens were sectioned, mounted and polished using standard metallurgical procedures. The distribution of TiC powder in the AZ91 matrix was studied using Optical microscope (Make: Leica; Model: DFC295).

The tribological properties of the as-cast as well as FSPed AZ91 alloy, processed at the optimized FSP parameters, were evaluated using pin-on-disc wear testing. Rectangular pin specimens with cross-section dimensions of 5 mm x 5 mm and 10 mm in length were machined from the as-cast as well as FSPed AZ91 alloy for the wear tests. Dry sliding wear tests were carried out on a universal tribometer (CETR UMT3) using a pin-on-disc test configuration. The counter face material used was a stainless steel disc with hardness value of nearly 220 Hv. Before the wear tests, the cross-section of all the specimens were ground using different grades of emery papers down to 1000 grit. All the wear tests were conducted at sliding speeds of 1m/s under normal loads of 5 and 10 N for a total sliding distance of 2000 m. The test was conducted for 11 cycles. Sliding distance for first 5 cycles was taken as 100m each and 250m for 6 cycles. Weight loss after each test cycle was measured to a precision of 0.01 mg and wear rate was determined as a function of sliding distance. Before and after each test, both the disc and specimens were cleaned with acetone and were dried in the air in order to avoid contamination.

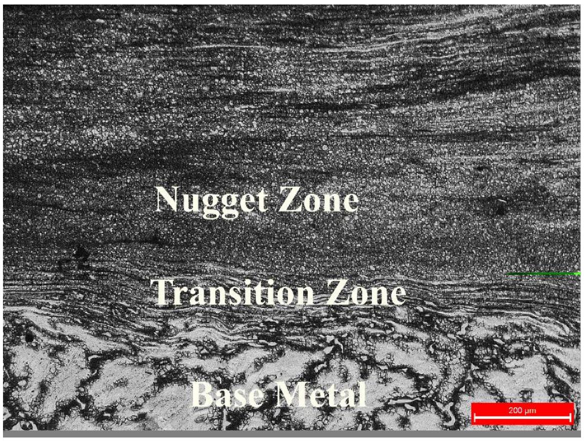
RESULTS AND DISCUSSION

Microstructure

Microstructure of base metal and FSPed metal is shown in Figure 1 as unprocessed zone, transition zone and nugget zone in the micro graph taken by using Optical microscope (Make: Leica, Model: DFC295).

It is evident from the figure that unprocessed zone contains coarse grain structure which turns fine as we move to processed zone, i.e., nugget zone.

Figure 1: Micrograph of Mg-Based AZ91 Alloy Subjected to Friction Stir Processing Showing Base Metal, Transition Zone and the Nugget Zone



Wear Behaviour

The line chart showing the weight loss per unit cross sectional area for the as cast AZ91 alloy and FSPed AZ91 with TiC powder during the pin on disc test on universal tribometer for variable loads is shown in Figures 2a and 2b. The weight loss per unit cross section area was more in case of as cast material compared to FSPed metal. It is evident from the chart that the wear of FSPed material is gradual as compared to as cast material when

Figure 2a: Curve Representing the Wear Rate at V = 1 m/s and L = 5 N

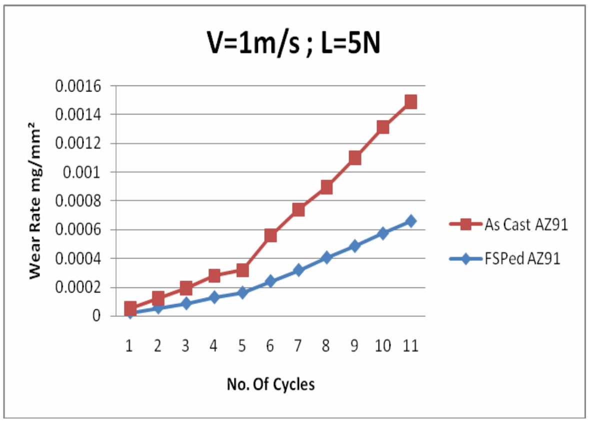
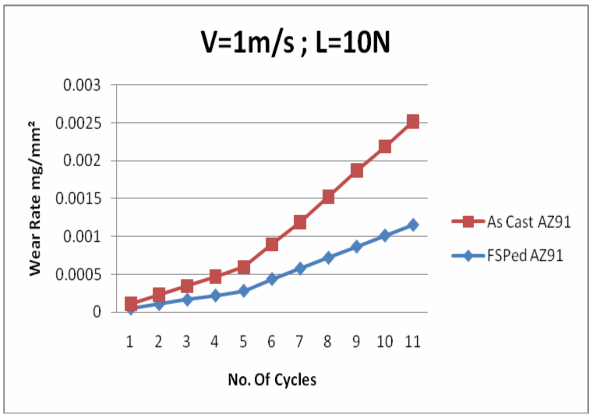


Figure 2b: Curve Representing the Wear Rate at V = 1 m/s and L = 10 N



tested for different loads at constant velocity of disc.

CONCLUSION

AZ91 based surface nanocomposite was fabricated with TiC reinforcement using FSP successfully. The fabricated nanocomposite exhibited improved wear resistance which may be attributed to the evolution of finer grain structure and presence of fine reinforcement particles. Under the action of intense shearing and high axial pressure during FSP, TiC particles were able to disperse beyond the nugget zone. The similarity between semi-solid processing and the current technique is limited to formation of fine grain size and better dispersion of reinforcement. Since there is no pool of liquid melt all through, the grains do not show the characteristic sphericity. Further studies focused on evolution of structure in the nugget zone may throw more light on the manner in which the structure evolves.

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