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Full Length Article

Development and characterization studies on magnesium alloy (RZ 5) surface metal matrix composites through friction stir processing

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Abstract

Surface metal matrix composite is produced on the as cast Magnesium Rare Earth alloy – RZ 5 by single pass friction stir processing using various micro/nano sized reinforcement particles namely Boron Carbide (B_4C), Multi Walled Carbon Nano Tubes (MWCNTs), and a mixture of $ZrO_2+Al_2O_3$ particles. Fine grained metal matrix composites having the grain size ranging 0.8 µm to 1.87 µm are achieved. Grain boundary pinning by the reinforcement particles has resulted in the transformation of coarse grained (~81 µm) base material into fine grained (<1 µm) metal matrix composite. Finer grain structure and the presence of reinforcements at the stir zone have resulted in increased and improved mechanical properties of the developed composites. Microhardness ranging between 125 HV and 403 HV is achieved. Uni-axial Tensile Testing of the developed composites exhibited improvement in tensile strength. Metal matrix composites developed using various reinforcements exhibited an increase in strength ranges between 250 MPa and 320 MPa.
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Keywords: Friction stir processing; Magnesium Rare Earth alloy – RZ 5; B4C; MWCNT; ZrO2+Al2O3; Microhardness; Grain boundary pinning.

1. Introduction

Magnesium alloys owing to their light weight are finding high technology applications in automotive and aerospace industries. Various types of magnesium alloys were subjected to friction stir processing for the generation of surface composites [1,2]. Friction stir processing (FSP) [3] is employed for the purpose of development of surface composites using various reinforcement particles [4–9]. Being a solid state processing technique, simplicity and versatile in its methodology, FSP has gained a lot of momentum and it has induced intense research, and experimentation studies on a wide range of materials. FSP variants, namely, single/multiple passes, and multiple pass with overlapping have resulted in enhancement of mechanical properties of various materials. The surrounding conditions with which the FSP is performed such as ambient atmosphere and in submerged conditions using various fluids such as water, dry ice, and cryogenic fluid have proved to play a major role/factor during dynamic recrystallization of the plasticized material generated during FSP at the stir zone [10,11].

Selection of tool parameters in FSP namely the tool rotation speed (ω) and the traverse speed of the tool (v) in conjunction with the pin diameter and shoulder diameter ensures requisite amount of heat generation on the work piece during the FSP [6,12]. Tool dwelling for a short duration at the stir zone is necessary and subsequent traverse motion of the tool along the entire length of the work piece result in the generation of defect free, fine grained metal matrix composite.

Nano Al_2O_3 particles were dispersed in AZ 91 alloy by FSP using a tool pin profile of square cross section. It is reported that at 40 mm/min traverse speed of the tool, better particle distribution is observed at the stir zone of the alloy [5]. Multi pass FSP is carried out on AZ 91 alloy for the introduction of nano SiO_2 particles and concluded that selection of process parameters are vital in the distribution of the reinforcements within the matrix. Increasing the number of

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FSP passes resulted in the improved and uniform distribution of SiO_2 particles at the stir zone. Moreover, the microhardness of the developed composites showed increase in the hardness with the increase in the number of FSP passes. The grain size at the sir zone decreased with the increase in the traverse speed of the tool. Refinement of grains is attributed to the fact of presence of nano SiO_2 particles along the boundaries of the grain and thereby restrictions are provided during grain growth. [6].

Nano SiO^2 is introduced in the matrix of AZ 61 alloy to develop metal matrix composites by performing 4 pass FSP. Grain refinement is achieved and the hardness is increased twice as that of the parent material [7]. MWCNTs were dispersed in AZ 31 alloy by FSP. It has been understood that the dispersion of the MWCNTs in the metal matrix is governed by the FSP tool traverse speed and its rotational speed. A higher tool speed of 1500 rpm with a tool traverse speed of 25 mm/min resulted in excellent dispersion of MWCNT reinforcements in the metal matrix of AZ 31 alloy with no particle aggregation. The amount of heat generated due to friction is dependent on the tool traverse speed of the tool. Additionally, these multi walled CNTs promoted grain refining of the alloy and grains of 500 nm size have been achieved [9]. Use of Al_2O_3 and CNT particles in various mixing proportion were used in the development of composites on AZ 31 magnesium alloy by FSP methodology. It has been reported that a particular mixing proportion of Al_2O_3 and CNT particles enhanced the wear characteristics of the developed composites and were free of any defects with uniform distribution of these reinforcements were reported [13].

The influence of providing heat sink during FSP and hence its role on the formation of microstructure and grain size of AZ 91 magnesium alloy has been studied and was found that controlling the heat sink temperature plays a vital role in improving the refinement of the grains [14]. FSP on AZ 61 alloy in combination with a heat sink has resulted in the formation of ultra fine grains of 300 nm and the average microhardness of the processed alloy is increased twice that of the base material. The heat sink is made of Copper with provisions for the flow of liquid nitrogen during FSP. The recrystallized grains present at the bottom most stir zone of the AZ 61 alloy were ultra fine and nano sized [15]. Similarly methanol at −20 °C is used as a cooling medium and flown underneath AE 42 alloy during single and double pass FSP thereby fine grains are achieved [2]. FSP on cold rolled AZ 31 alloy specimens exhibited tensile characteristics that are governed by the grain size and are influenced by the basal slip and twinning action. The tensile characteristics varied with the orientation of tensile specimen prepared from the processed zone [16]. Two pass FSP on die cast AZ 91 alloy demonstrated an extraordinary high strain rate super plastic behavior at 330 °C due to the formation of ultra fine grains 0.5 µm. Higher Aluminum in AZ 91 forms β-$Mg_{17}Al_{12}$ intermetallics which plays a vital role in the thermal stability of the alloy [17].

However, work on surface metal matrix composite on magnesium alloy (RZ 5) containing rare earth elements is scarce. Surface metal matrix composites were developed on RZ 5 magnesium alloy through FSP using micro/nano sized particle reinforcements namely B_4C, MWCNT, and a mixture of $ZrO_2 + Al_2O_3$ particles. The developed composites are subjected to metallurgical examinations to understand the nature of grain structure evolved.

Table 1
Composition of various elements of RZ 5 magnesium alloy.

Elements	Wt%
Zinc	4.05
Zirconium	0.57
Total rare earth elements (Neodymium, Cerium and Lanthanum)	1.54
Mg	Balance

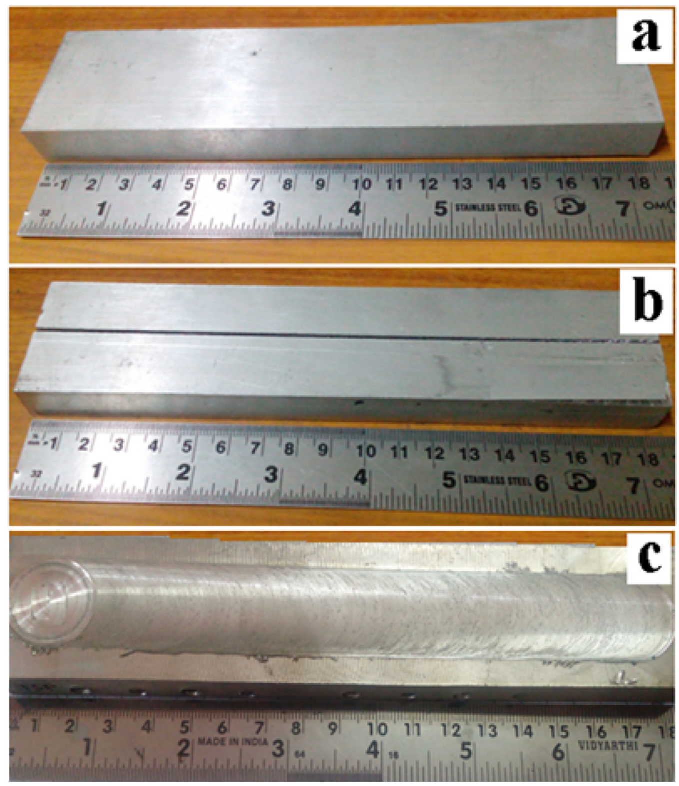

Fig. 1. (a) Work specimen cut from the bulk as cast Mg RZ 5 alloy as per dimension. (b) Groove is made on the top surface of the work specimen by milling operation. (c) Work specimen after groove closure operation.

2. Experimental method and materials

Friction stir processing was performed on as cast RZ 5 magnesium alloy. The main constituents of RZ 5 magnesium alloy are Zinc (Zn), Zirconium (Zr), and rare earth elements (REE) namely Neodymium (Nd), Lanthanum (La) and Cerium (Ce) and the rest being magnesium (Mg). The percentage weight compositions of these individual elements are tabulated in Table 1. To perform FSP experimentation, work specimen of size 180 mm (length), 40 mm (width), and 10 mm in thickness was cut from the as cast RZ 5 magnesium alloy block. On the flat surface of this cut work specimen, a groove of size 1.5 mm (width) and 3 mm in depth was made by milling operation. This groove was cleaned

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