Journal of Alloys and Compounds 509 (2011) 8664–8669

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: www.elsevier.com/locate/jallcom

Processing, microstructure and mechanical properties of magnesium matrix nanocomposites fabricated by semisolid stirring assisted ultrasonic vibration

K.B. Nie, X.J. Wang*, K. Wu, L. Xu, M.Y. Zheng, X.S. Hu

School of Materials Science and Engineering, Harbin Institute of Technology, No. 92, West Da-Zhi Street, Harbin 150001, PR China

ARTICLE INFO

Article history:
Received 12 May 2011
Received in revised form 21 June 2011
Accepted 21 June 2011
Available online 28 June 2011

Keywords:
Magnesium matrix nanocomposite
Semisolid stirring
Ultrasonic vibration
Nanoparticle distribution
Grain refinement

ABSTRACT

Particulate reinforced magnesium matrix nanocomposites were fabricated by semisolid stirring assisted ultrasonic vibration. Compared with the as-cast AZ91 alloy, the grain size of matrix alloy in the SiCp/AZ91 nanocomposite stirring for 5 min was significantly decreased due to the addition of SiC nanoparticles. SiC nanoparticles within the grains exhibited homogeneous distribution although some SiC clusters still existed along the grain boundaries in the SiCp/AZ91 nanocomposite stirring for 5 min. With increasing the stirring time, agglomerates of SiC nanoparticles located along the grain boundaries increased. The ultimate tensile strength, yield strength and elongation to fracture of the SiCp/AZ91 nanocomposite stirring for 5 min were simultaneously improved compared with the as-cast AZ91 alloy. However, the ultimate tensile strength and elongation to fracture of the SiCp/AZ91 nanocomposite decreased with increasing the stirring time.

1. Introduction

Many efforts are under way to develop magnesium-based materials that have great potential as structural materials for the aerospace and automobile industries and offer significant weight savings targeted primarily for their further development [1,2]. However, the relatively low strength, poor room temperature ductility and toughness limit the range of magnesium applications [3]. As a result, magnesium matrix nanocomposites due to their low density and superior mechanical properties have fueled significantly research activities [4,5].

Processing technique is the key to fabrication of magnesium matrix nanocomposites with optimized properties. Stir casting that utilizes mechanical stirring is a widely used technique of producing magnesium matrix composites reinforced with micro ceramic particles. A combination of good distribution and dispersion of micro particles can be achieved by stir casting. However, it is extremely challenging for the conventional stir casting to distribute and disperse nanoparticles uniformly in magnesium melts because of their large surface-to-volume ratio and their low wettability in metal melts. In general, magnesium matrix nanocomposites are mostly made with expensive powder metallurgy, disintegrated melt deposition, friction stir processing, mechanical milling and ultrasonic vibration [6–17]. Another study on the synthesis and characterization of the $Mg_{65}Y_{10}Cu_{20}Ag_5$-based amorphous composite reinforced by ZrO_2 nanoparticles has shown improvements in hardness and distribution of nanoparticles in the matrix [18]. Among these processing techniques, ultrasonic vibration is efficient in dispersing nanoparticles in metal melts (including magnesium alloy) [15–17]. It was reported [19] that ultrasonic cavitation could produce transient (in the order of nanoseconds) micro "hot spots" that could have temperatures of about 5000 °C, pressures above 1000 atm, and heating and cooling rates above 10^{10} K/s. But it was a time-consuming process to introduce the nanoparticles into the magnesium melt through ultrasonic vibration as reported by Li et al. Thus, it is considered that the stir casting could be combined with ultrasonic vibration to produce magnesium matrix nanocomposite. Semisolid stirring can be utilized to incorporate the nanoparticles and disperse the nanoparticles macroscopically. And the strong impact coupled with local high temperatures introduced by ultrasonic vibration can break nanoparticle clusters and clean the nanoparticle surface from the view of microcosmic.

To the best of our knowledge, open literature reports so far suggested that no systematic attempt is made to fabricate the magnesium matrix nanocomposite by semisolid stirring assisted ultrasonic vibration. Accordingly, the experiments described in the present work were designed to examine the microstructure and mechanical properties of particulate reinforced magnesium matrix

* Corresponding author. Tel.: +86 45186402291; fax: +86 45186413922.
E-mail addresses: kaibo.nie@gmail.com (K.B. Nie), xjwang@hit.edu.cn (X.J. Wang).

0925-8388/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jallcom.2011.06.091

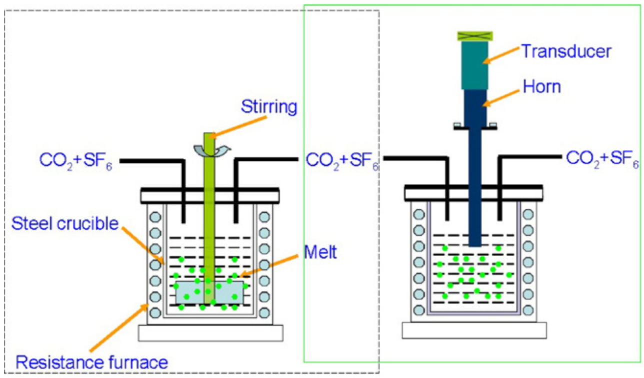

Fig. 1. Schematic of experimental setup for semisolid stirring assisted ultrasonic vibration of magnesium melt.

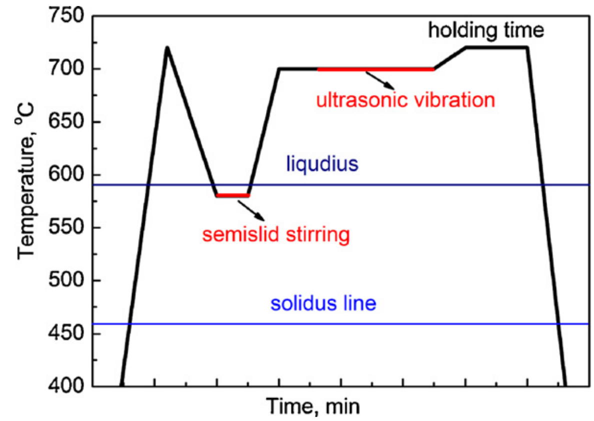

Fig. 2. Schematic illustration of the temperature–time sequences for semisolid stirring assisted ultrasonic vibration.

nanocomposites fabricated by semisolid stirring assisted ultrasonic vibration.

2. Experimental conditions

2.1. Materials

A commercial AZ91 alloy ingot (supplied by Northeast Light Alloy Company Limited, China) with a nominal composition of Mg–9.07Al–0.68Zn–0.21Mn was selected as the matrix alloy of the SiCp/AZ91 nanocomposite. SiC nanoparticles (supplied by Hefei Kaier Nanometer Energy & Technology Company Limited, China) with an average diameter of 60 nm were used as the reinforcement.

2.2. Preparation of materials

The experimental setup for semisolid stirring assisted ultrasonic vibration is given in Fig. 1. Fig. 2 gives a flow to show the whole fabrication process against temperature. First, about 1 kg of AZ91 alloy was melted at 720 °C under an atmosphere containing a gas mixture of CO_2/SF_6 and then cooled to 590 °C at which the matrix alloy was in semi-solid condition; SiC nanoparticles which were preheated to 550 °C were quickly added into the semi-solid alloy. The volume content of SiC nanoparticles in the SiCp/AZ91 nanocomposites was 1% while the stirring time for the SiCp/AZ91 nanocomposites was 5 min, 10 min and 25 min (ST5, ST10 and ST25), respectively.

After adequately stirring the melt, the melt was rapidly reheated to 700 °C and held at this temperature for 5 min. Then the ultrasonic probe was dipped into the melt for about 20 mm after the stirrer was removed from the melt. The ultrasonic vibration device consists of a transducer with a maximum power of 2 kW and frequency of about 20 kHz. The melt was ultrasonically processed for 20 min before the ultrasonic probe was removed. Then the melt was elevated to a pouring temperature of 720 °C and cast into a preheated steel mould (450 °C) and allowed to solidify under a 100 MPa pressure. It should be noted ultrasonic vibration was not used during the solidification process but in molten nanocomposite. For comparison, an AZ91 alloy ingot without semisolid stirring assisted ultrasonic vibration was also cast under the same conditions. Two ingots were cast for each condition.

2.3. Microstructural characterization

Optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM) were used to study the microstructure modification of the matrix and reinforcement distribution in the SiCp/AZ91 nanocomposites intro-

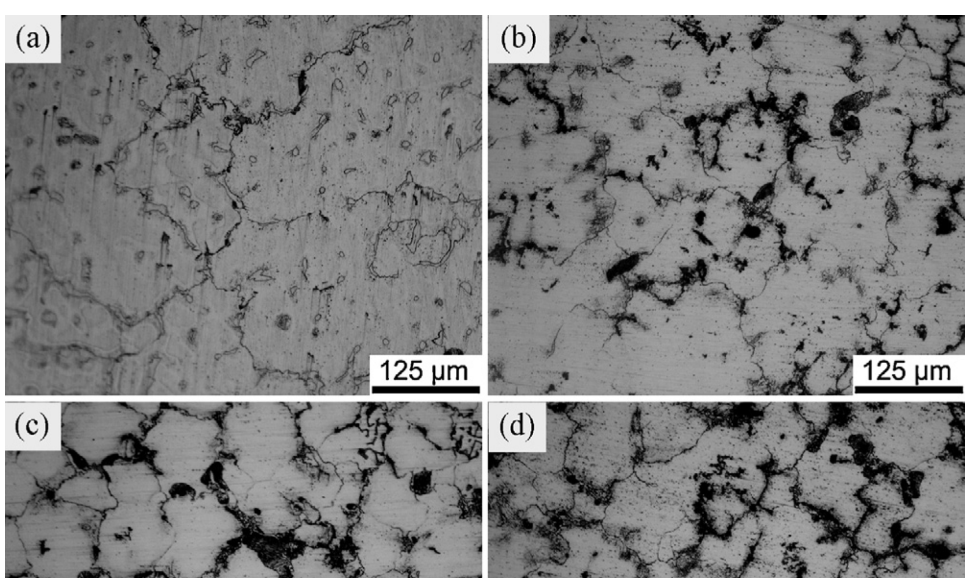

Fig. 3. OM micrographs of (a) AZ91 alloy; SiCp/AZ91 nanocomposites (b) stirring for 5 min; (c) stirring for 10 min; and (d) stirring for 25 min.