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Microstructure and tensile properties of SiC nanoparticles reinforced magnesium matrix composite prepared by multidirectional forging under decreasing temperature conditions

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ABSTRACT

Multidirectional forging (MDF) under decreasing temperature conditions was adopted to process SiC nanoparticles reinforced magnesium matrix composite. The results showed that grains of the nanocomposite were effectively refined while the amount of precipitated phases was significantly increased after MDF under decreasing temperature conditions. The precipitated phases as well as dispersed SiC nanoparticles could hinder the growth of dynamic recrystallization. The yield strength and ultimate tensile strength of the nanocomposites were increased compared with that of as-cast nanocomposite. This improvement could be attributed to obvious grain refinement as well as Orowan strengthening effect introduced by the dispersed SiC nanoparticles and the precipitated phases. Microcrack could initiate within the SiC nanoparticle dense zones during tensile test at room temperature, resulting in decrease of the elongation.

1. Introduction

Combining metal matrix and reinforcement to form a metal matrix composite has potential to stretch the performance of monolithic materials [1–4]. Magnesium matrix nanocomposite, a combination of magnesium matrix and nano-sized reinforcement, is promising to meet the increasing demand on materials with exceptional performance [5]. It is expected that significant enhancement of properties in magnesium matrix can be obtained by the addition of ceramic nanoparticles. However, obtaining expected property enhancement is hard to achieve, mainly due to the difficulty of distributing and dispersing the nanoparticles uniformly in magnesium matrix [6]. To address this challenge, semisolid stirring assisted ultrasonic vibration was used to disperse nanoparticles in a magnesium matrix [7]. It has found that semisolid stirring can be utilized to incorporate the nanoparticles and disperse the nanoparticles macroscopically while the ultrasonic vibration can break nanoparticle clusters and clean the nanoparticle surface from the view of microcosmic.

In order to extend high performance applications of magnesium matrix nanocomposites such as on the automotive, aerospace and defense industries, various methods have been carried out to further improve their mechanical properties. Several conventional deformation processes, such as extrusion, rolling and forging [8–10], have been successfully used to enhance the strength and ductility of nanoparticles or micron-particles reinforced magnesium matrix composites. In recent years, severe plastic deformation (SPD), which can refine the grain size of metallic materials into submicrocrystalline and nanoscale, has been applied to process magnesium alloys [11–16]. Among SPD techniques, the best known are: accumulative roll-bonding (ARB), high-pressure torsion (HPT), multidirectional forging (MDF) and equal channel angular pressing (ECAP). MDF seems to be especially attractive for its potential for scaling up of relatively large samples that can be suitable for industrial applications [17,18]. So far, most investigations have been conducted to understand the effect of MDF on the microstructure and properties of pure metals or metallic alloys [17–22]. Our previous work has investigated the microstructure and mechanical properties of micron-SiCp/AZ91 magnesium matrix composite as well as nano-SiCp/AZ91 magnesium matrix composite processed by MDF under constant temperature [23–25]. Ultrafine grains with average size of about 20 nm were observed in the nano-SiCp/AZ91 composite after MDF under constant temperature. However, open literature search indicates that little attention was paid to the effect of MDF under decreasing

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temperature conditions on microstructure and mechanical properties of nanoparticles reinforced magnesium matrix composite.

In general, a lower deformation temperature usually generates smaller recrystallized grains. Accordingly in the present study, SiC nanoparticles reinforced magnesium matrix composite is subjected to MDF under decreasing temperature conditions. The improvement in mechanical properties is discussed correlating with microstructure characterization.

2. Materials and methods

Magnesium matrix nanocomposites were fabricated by semisolid stirring assisted ultrasonic vibration. The details of fabrication process were described in Ref. [7]. AZ91 alloy with the nominal composition of Mg–9.07Al–0.68Zn–0.21Mn was used as the matrix alloy. SiC nanoparticles with an average diameter of 60 nm and volume fractions (vol%) of 1% were selected as the reinforcement. To dissolve the $Mg_{17}Al_{12}$ phase, as-cast SiCp/AZ91 nanocomposites were homogenized at 415 °C for 24 h followed by water quench at 25 °C.

Then the as-cast SiCp/AZ91 nanocomposites were machined into samples with dimensions of 30 mm × 30 mm × 60 mm. The MDF was carried out at a pressing speed of 15 mm s^{-1}, using a press with a 2000 kN load limit. A well lubricated sample with graphite-based mixture was heated in an electrical resistance furnace at deformation temperature for 1 h. The MDF die was also heated to the desired temperature. In the present work, MDF procedure was developed with the MDF temperature decreasing from 400 °C to 300 °C by a drop of 50 °C every three successive forging passes. In total, nine processing passes were used. The dimensional ratio of 1 × 1 × 2 of the samples was maintained constant throughout MDF processing while the press direction was turned by 90° from pass to pass [23–25]. The samples were reheated to deformation temperature before subsequent deformation. The imposed strain of each MDF pass was 0.693, which could be calculated by the equation [26]:

$$\xi = \left| \ln\left(\frac{h_0}{h}\right) \right|$$

Microstructure of the MDFed nanocomposites was determined by optical microscopy (OM), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). Samples for microstructure analysis were carried out in the central part of specimens parallel to the last compression axis. A standard metallographic

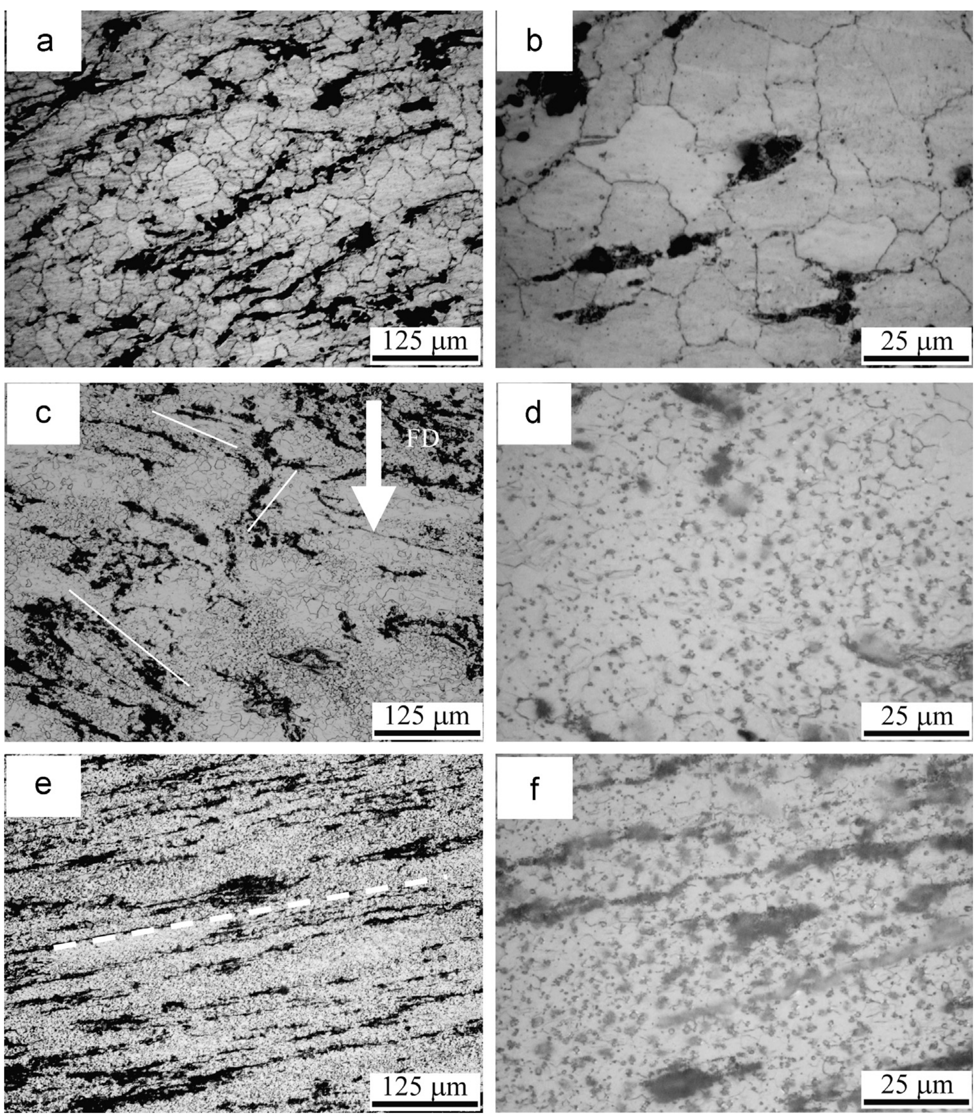

Fig. 1. OM micrographs of SiCp/AZ91 nanocomposites after MDF under decreasing temperature conditions: (a, b) 400 – 3P, (c,d) 400 – 3P + 350 – 3P, (e,f) 400 – 3P + 350–3P + 300 – 3P.