Journal of Alloys and Compounds 743 (2018) 87–98

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

Abnormal deformation behavior and particle distribution during hot compression of fine-grained 14 vol% SiCp/2014Al composite

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ARTICLE INFO

Article history:
Received 9 November 2017
Received in revised form
26 January 2018
Accepted 30 January 2018
Available online 1 February 2018

Keywords:
Metal matrix composites
Plastic deformation
High-temperature properties
Particle distribution
Electron backscatter diffraction (EBSD)

ABSTRACT

The compressive deformation behavior of an extruded 14 vol% SiCp/2014Al composite fabricated by stir casting was investigated at temperatures of 355–495 °C and strain rates of 0.001–1 s^{-1}. An abnormal variation of flow stress with temperature was observed at low strain rates. This anomalous behavior was attributed to abnormal grain growth in the matrix alloy above a critical temperature, resulting in higher deformation resistance of the composite at elevated temperatures. Furthermore, the effect of the compression parameters on the particle distribution was investigated by the marked trace lines. It was indicated that after hot deformation, the particle free bands (PFBs) were commonly observed in the hard-to-deform region and shear deformation region. Increasing temperature and strain rate hardly improved particle distribution uniformity, while large compressive strain could eliminate the PFBs.

1. Introduction

In the past half century, the processing, mechanical properties and microstructures of silicon-carbide (SiC) particulate reinforced Al matrix composites (PRAMCs) have been extensively studied [1–6]. Although the PRAMCs generally exhibit low ductility, it is possible for the PRAMCs to undergo secondary processing if the reinforcement volume fraction is less than 40% [7]. The presence of SiC particles makes the composite be more prone to internal damage (such as debonding, cracking or particle fracture) than unreinforced metals, thus the secondary processing is generally conducted at elevated temperatures where the matrix alloy does not exhibit work-hardening behavior.

During the hot deformation of the PRAMCs the distribution of reinforcing particles varies with the plastic flow of matrix alloy. At the same time, the reinforcing particles also significantly affect the microstructural evolution of matrix alloy. An accurate understanding of deformation behavior is helpful to select appropriate processing parameters for fabricating the composite components with particular microstructures, thereby enhancing service performances (e.g., superior creep resistance and high-temperature strength).

Hot deformation is a dynamic process, and generally the stress-strain curves can be regarded as a manifestation of the deformation mechanisms of the PRAMCs. So far, the corresponding relationship between the shape of flow stress curves and the microstructural evolution for the PRAMCs has been rarely investigated in detail.

Generally, the strength of metallic materials decreases with increasing temperature. However, there exists exception in a few of alloys. For instance, in some Al-Li alloys [8,9] and their single crystalline alloys [10], at temperatures from −200 to 150 °C dislocations move in pairs cutting the δ'-Ll_2 precipitates, and the resistance to the motion of the super-dislocations by the δ'-particles enhances with increasing temperature, which leads to a positive temperature dependence of yield stress. In some nickel-based alloys [11,12], Kear-Wilsdorf locks, formed during screw dislocation cross-slip from {111} plane to {010} plane, multiply with increasing temperature. As a consequence, the yield strength increases with temperature.

The anomalous stress-temperature relationships have also been found in the PRAMCs [13], but the relevant mechanisms have not been explained concurrently. Compared to unreinforced aluminum alloys, the particles have significant effect on the microstructures of the matrix during hot working, thereby resulting in more complicated microstructural evolution. Therefore, the effect of microstructural evolution on the deformation behavior of the PRAMCs

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https://doi.org/10.1016/j.jallcom.2018.01.397
0925-8388/

should be carefully investigated.

Compared with the unreinforced alloys, an important microstructural evolution of the PRAMCs is the re-distribution of particles during hot deformation, which has a strong effect on the mechanical properties of the composite. The cluster or inhomogeneous distribution of reinforcing particles can promote the nucleation and propagation of cracks [14–16]. In contrast, the uniform distribution of particles can enhance ultimate tensile strength and elongation [3,17], and improves fatigue performance [18,19]. However, during hot working (e.g., forging or rolling) the effect of processing parameters on the uniformity of particle distribution has received few attentions.

In the present work, extrusion bars of stir cast 14 vol% SiCp/2014Al composite was subjected to hot compression tests. The reversed relationship between flow stress and temperature was observed and explained on the basis of microstructure evolution. Zener equation was taken into account to evaluate the stability of grain size during hot deformation. Furthermore, the effect of processing parameters and local stress and strain states on the distribution of particles was investigated in detail.

2. Experimental

The composite used in this study was 14 vol% SiC particle reinforced 2014Al (SiCp/2014Al) composite with a nominal particle size of 20 μm. The nominal chemical composition of 2014Al is Al-4.8Cu-0.6Mg-0.7Mn-0.7Fe-0.9Si [20]. The composite was fabricated by stir cast technique and subsequent extrusion which were described in references [21]. Details of the processing technique are considered to be proprietary by the manufacturer. The extruded bars were machined into cylindrical specimens 8 mm in diameter and 12 mm in height with the axis parallel to the extrusion direction.

The isothermal compression tests were conducted in temperature range from 355 °C to 495 °C with a temperature interval of 35 °C and at strain rates of 0.001, 0.01, 0.1 and 1.0 s^{-1} using the Gleeble-3800. Tantalum sheets 100 μm thickness were used to prevent adhesion between the end surfaces of cylindrical specimens and the anvils. The specimens were compressed to an ultimate true strain of 0.9. After hot compression, the specimens were water quenched immediately to retain the deformed microstructure. The specimens were cut through the centerline along the compression direction for microstructure examinations.

The samples for optical microscope (OM) were mechanically polished and etched using Keller's reagent, then observed by stereo microscopy (SM; Zeiss Stemi 2000-C), optical microscopy (OM; Zeiss Axiovert200 MAT). Electron back-scattered diffraction analysis was used to characterize grain boundaries orientation and confirm the OM examination. The specimens for electron backscatter diffraction (EBSD) were firstly mechanically polished, and were ion milled using a beam milling system (IBMS; Lecia EM RES101). The EBSD analysis was conducted using a field emission scanning electron microscopy (FESEM; Zeiss Supra 55).

3. Results and discussion

3.1. Initial microstructure

Fig. 1 shows the microstructure of the as-received composite. The distribution of SiC particles was characterized by string-like arrays with the orientation of most aligned SiC particles parallel to the extrusion direction (Fig. 1a) and the substantial recrystallized microstructure was observed in the matrix with most of the

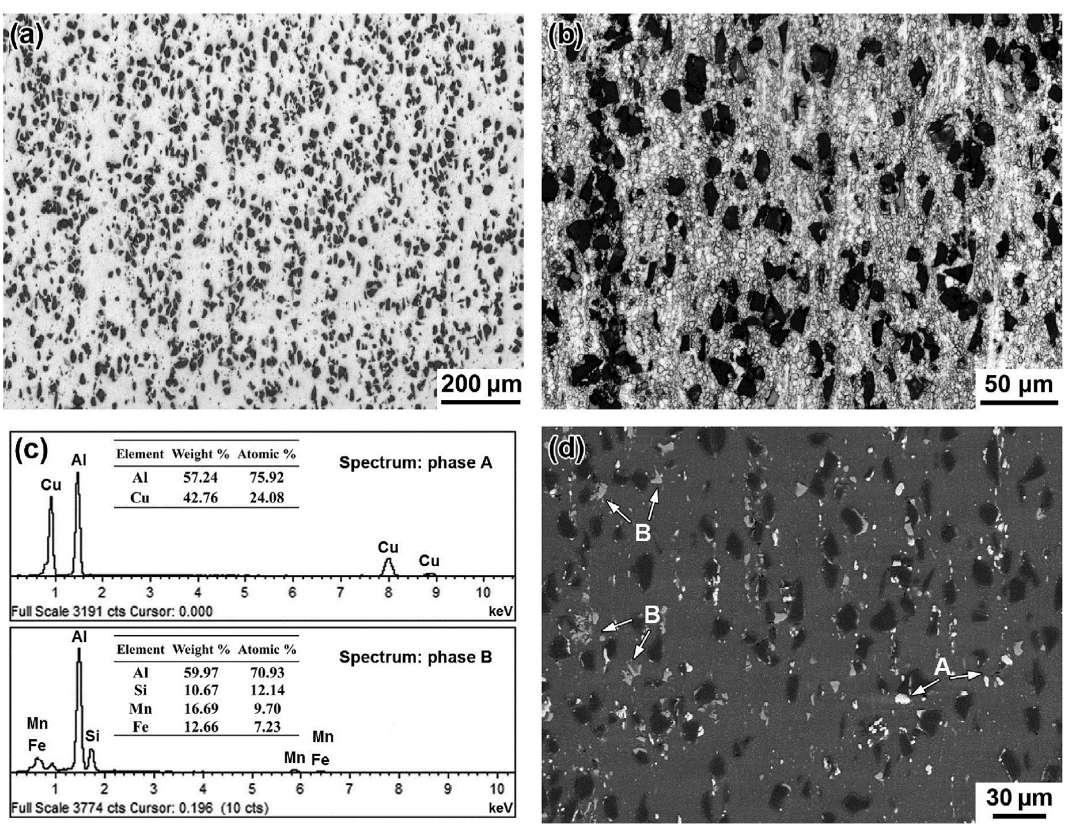

Fig. 1. Initial microstructure of the as-received 14 vol% SiCp/2014Al extrusion bars: (a) distribution state of SiC particles, (b) fine-grained configuration of matrix alloy, (c) SEM/EDS of precipitated phases, (d) SEM backs-scattered electron image (Extruded direction is perpendicular to the horizontal.).