Materials Science and Engineering A 528 (2011) 1326–1333

Contents lists available at ScienceDirect

Materials Science and Engineering A

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

Processing, microstructure and mechanical properties of nickel particles embedded aluminium matrix composite

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ARTICLE INFO

Article history:
Received 26 July 2010
Received in revised form 7 October 2010
Accepted 13 October 2010

Key words:
Thermomechanical processing
EBSD
Composites
Grain refinement
Electron microscopy
Mechanical characterization

ABSTRACT

Nickel particles were embedded into an Al matrix by friction stir processing (FSP) to produce metal particle reinforced composite. FSP resulted in uniform dispersion of nickel particles with excellent interfacial bonding with the Al matrix and also lead to significant grain refinement of the matrix. The novelty of the process is that the composite was processed in one step without any pretreatment being given to the constituents and no harmful intermetallic formed. The novel feature of the composite is that it shows a three fold increase in the yield strength while appreciable amount of ductility is retained. The hardness also improved significantly. The fracture surface showed a ductile failure mode and also revealed the superior bonding between the particles and the matrix. Electron backscattered diffraction (EBSD) and transmission electron microscopy analysis revealed a dynamically recrystallized equiaxed microstructure. A gradual increase in misorientation from sub-grain to high-angle boundaries is observed from EBSD analysis pointing towards a continuous type dynamic recrystallization mechanism.

1. Introduction

Al alloys are finding increasing importance in transportation, aerospace, naval and structural application. A major requirement of such applications is high strength along with low density. Strength of Al alloys can be increased by various methods like alloying additions, heat treatment, thermo-mechanical processing and severe plastic deformation (SPD). However, these methods have their own disadvantages which are difficult to overcome. For example, many of the SPD processing techniques produce relatively small quantities of material and hence are very difficult to scale up to produce large amounts of materials at low cost. Furthermore, high-strength metals and alloys are difficult to process by SPD methods. Metal matrix composite technology is a well accepted method to improve strength of variety of metals and alloys. Particulate-reinforced MMCs are of particular interest because of their ease of fabrication, low cost and isotropic properties. The metal matrix is reinforced with ceramic reinforcements like SiC, Al_2O_3, AlN, B_4C, TiC to have beneficial effect of higher strength. However, these MMCs suffer from the disadvantage of low ductility which arises due to different reasons like brittle interfacial reaction products, poor wettability, particle–matrix debonding or presence of porosity or particle clusters. An alternative approach is to design composites having hard metallic phases as the reinforcement [1,2]. Nickel is a good choice as reinforcement because of its high strength (tensile strength of 400 MPa [3] as compared to 80 MPa of Al), high stiffness and good high temperature properties such as creep and oxidation resistance. However, processing of metallic particle reinforced MMCs can pose serious challenges. Liquid metallurgy route is one of the simplest and cost effective methods for processing metal matrix composites. However, because of low solubility of Ni in Al [4], addition of Ni to Al melt will produce Al–Ni intermetallics which are brittle in nature. Reinforcing Al with Ti particles by disintegrated metal deposition (DMD) technique is reported [1]. However, this technique involves several steps like pre-heat treatment of Ti powder, melting the Al–Ti mixture, stirring the melt, disintegrating the melt and then finally casting it. Although a heat treatment is given to Ti powder to prevent reaction between Al and Ti, possibility of formation of brittle intermetallics can never be excluded. Wong et al. [5] reported processing Ni particle reinforced Al composite by the same method of disintegrated metal deposition (DMD). However, in their study also formation of Al–Ni intermetallics and consequent reduction in ductility could not be avoided. Powder metallurgy, which is another common method for producing Al MMCs, also leads to formation of Al–Ni intermetallics from Al and Ni powders [6,7].

Friction stir processing, which originated from friction stir welding (FSW), is a fairly simple and economical process [8]. A cylindrical rotating tool with pin and shoulder is pressed in the material to be processed, and traversed along a particular direction. The side in which the tangential velocity of the tool surface is parallel to the traverse direction is defined as advancing side and the anti-parallel

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0921-5093/$ – see front matter
doi:10.1016/j.msea.2010.10.035

one is defined as the retreating side. Localized heating is produced due to friction and rotating action of the pin generates high strains. Therefore, FSP is essentially a solid state thermo-mechanical process, during which the materials temperature is taken to a range (typically greater than 0.5 T_m) where it can be plastically deformed. The technique can be used for a variety of processing purposes like grain refinement, microstructure homogenization and modification of cast microstructure [9–12]. There are few reports on processing of intermetallic reinforced composites and surface composites by FSP [13–15]. However, as far as the authors' knowledge are concerned there is no report on processing metal particle reinforced composites by FSP. Recently the authors have shown the feasibility of processing metal particle reinforced metal matrix composite by FSP [16].

In the present investigation, Ni particle reinforced Al matrix composite without harmful intermetallics has been processed by FSP and a detailed microstructural and mechanical characterization has been carried out. The novel feature of the processed composite is that it retains most of the ductility while the strength is improved significantly. The microstructure evolution has been studied by electron backscattered diffraction (EBSD) and transmission electron microscopy (TEM) analysis.

2. Materials and methods

Commercially pure (98.2%) 1050 aluminium which had iron, silicon, manganese and copper as major impurities was chosen as matrix material in the form of a plate of 12 mm thickness. A groove of 1 mm in width, 2 mm in depth and 50 mm in length was made on the plate and filled with nickel powder (200 mesh) of 99.8% purity. A tool made of M2 tool steel having shoulder diameter of 12 mm, pin diameter of 4 mm and pin length of 3.5 mm was used to carry out FSP at a rotation speed of 1000 rpm and traverse speed of 60 mm/min. A downward force of 5 kN was applied to the tool. FSP was also carried out on pure Al without Ni for comparison. However, the processing parameters (640 rpm and 150 mm/min) were different as the same set of parameters was not found to be optimum for Ni particle incorporation.

The microstructure was evaluated by scanning electron microscopy (SEM), electron backscattered diffraction (EBSD) and transmission electron microscopy (TEM). X-ray diffraction (XRD) was performed for phase analysis. For SEM study, samples were metallographically polished followed by diamond polishing. For TEM studies, samples were cut at the mid-plane of the stir zone at a depth of 0.3 mm from surface. These samples were carefully polished to a thickness of 90 μm and subjected to twin-jet polishing using a mixture of 20% perchloric acid and methanol at −20 °C. Observations were made in a Philips CM-20 TEM operating at 200 kV. For EBSD studies, samples were metallographically polished and subsequently electropolished using a mixture of perchloric acid and methanol at −12 °C. Polished samples were observed in a FEI Quanta FEG 3D SEM equipped with TSL-OIM software operating at 30 kV. A step size of 250 nm was used. A misorientation angle range of 5–60° was used to calculate the grain size from the EBSD data. XRD was carried out in a Brukers D8 diffractometer using Cu Kα radiation.

Tensile specimens of 1 mm thickness and 10 mm gauge length were sliced from the stir zone parallel to the tool traverse direction by electrical discharge machining (EDM). Tests were carried out as per ASTM standard on an Instron (Model 3367) machine at a strain rate of 10^{-3} s^{-1}. The fracture surface was analyzed under SEM. Vickers microhardness was measured across the stir zone

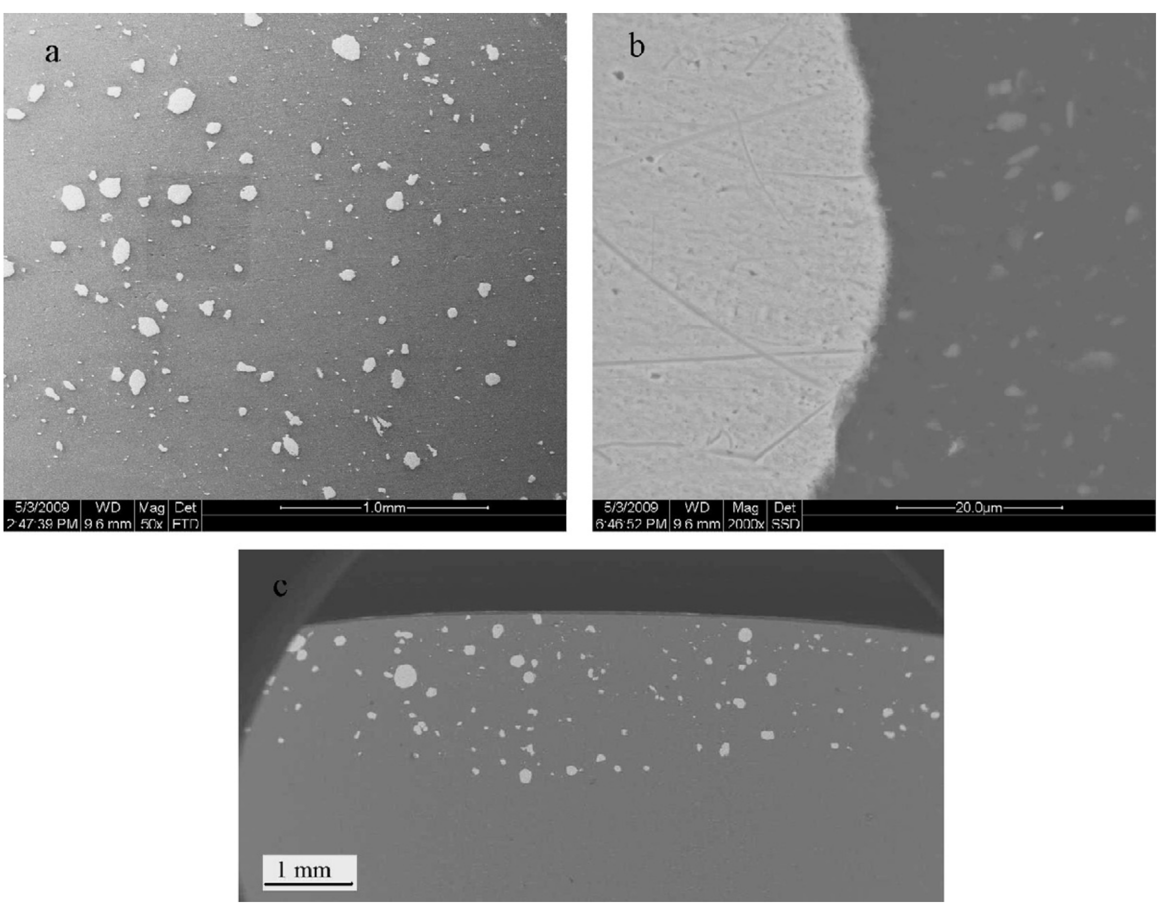

Fig. 1. SEM micrographs showing (a) distribution of Ni particles in the stir zone, (b) particle–matrix interface and (c) cross section of stir zone.