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Fabrication of Al–2 vol% Al_2O_3/SiC hybrid composite via accumulative roll bonding (ARB): An investigation of the microstructure and mechanical properties

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ABSTRACT

An $Al/Al_2O_3/SiC$ hybrid metal matrix composite was fabricated by accumulative roll bonding (ARB). A mixture of Al_2O_3 and SiC (2 vol%) powders was poured between four Al layers during the first two ARB cycles. The process was continued up to eight cycles without adding the powders in subsequent cycles. For comparison, non-reinforced (monolithic) Al was also processed by ARB under the same conditions. At the initial stages, particle free zones as well as particle clusters were observed on the microstructure of the composite. After eight ARB cycles, a composite with a uniform distribution of particles was produced. At this stage, the tensile strength of the hybrid composite and the monolithic Al reaches to about 195 MPa and 150 MPa, respectively, about 5.3 and 4 times larger than that of annealed Al. The hardness of the composite and the monolithic Al was measured as 83 and 58 VHN, respectively. Fracture surface after tensile testing revealed dimples at some regions after eight ARB cycles.

1. Introduction

During the past two decades, researchers have been attracted by metal matrix composites (MMCs) due to their excellent physical and mechanical properties and their application in aerospace and automotive industries [1,2]. Most MMCs are based on aluminum because it is light and inexpensive in comparison with other light metals, such as titanium and magnesium. Conventionally, the manufacturing methods for MMCs can be classified into liquid-state processing, semi-solid state processing and powder metallurgy [1,2]. Some drawbacks of the conventional methods are agglomeration, poor wet ability of the reinforcement, contamination and high manufacturing cost. In recent years, it has been shown that accumulative roll bonding (ARB) is an effective tool for manufacturing MMCs in the form of sheets. ARB is one kind of severe plastic deformation that can produce sheet metals with ultrafine-grained microstructure and superior properties [3]. ARB consists of multiple cycles of stacking, rolling and cutting in which large strains are imposed into the material without any change in the cross section [4].

In general, MMCs can be fabricated by ARB with two different routes. In the first route, the starting material consists of two or more dissimilar metals, named multilayer. During the co-deformation of dissimilar metals, necking occurs due to the differences in flow properties of the constituent phases and further deformation causes the hard phase to rupture. At a relatively large number of ARB cycle, the hard phase is uniformly distributed within the matrix. Al/Mg [5], Al/Ni [6], Al/Cu [7], Cu/Ag [8], Al/Zn [9], Cu/Zn [10] and Cu/Zn/Al [11] are some examples of multilayer systems that have been produced by this method. In the second route, ceramic powders such as B_4C [12,13], Al_2O_3 [14,15], SiC [16,17] and WC [18] are uniformly dispersed between the metal strips where they are stacked over each other. ARB is then carried out to several cycles until a uniform distribution of particles is achieved. It has been shown that, during ARB, a critical reduction/strain is needed to get a uniform distribution of particles within the matrix [19,20].

To date, many particulate MMCs that have been fabricated by ARB contain a single reinforcement while only a slight attempt has been made to fabricate hybrid composites whose microstructure consists of two different types of reinforcements. To the authors' knowledge, the hybrid MMCs that have been fabricated by this method are $Al/Al_2O_3/TiC$ [21], $Al/Al_2O_3/SiC$ [22] and $Al/Al_2O_3/B_4C$ [23–25]. Except for Ref. [23], the production of these hybrid composites consists of a combination of ARB and anodizing process. The procedure is to form a thin layer of Al_2O_3 on the Al strip using anodizing process. Then, the anodized strip is placed between the two surfaces of the Al strips, while the ceramic particle is dispersed between the layers. During ARB, the anodized

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layer is broken and finally a uniform distribution of the reinforcements is achieved within the matrix.

In the present study, Al/Al_2O_3/SiC hybrid composite is fabricated by ARB without using anodizing process as an additional process. The Al_2O_3 and SiC powders are dispersed directly during the first two cycles. The ARB process is carried out up to eight cycles. The microstructure evolution and mechanical properties of the hybrid composite are investigated by using the appropriate characterization methods. The results are compared with annealed Al and with monolithic Al processed by ARB at the same conditions.

2. Materials and methods

Particles of Al_2O_3 and SiC were used as reinforcements. The powders were mixed through a milling process for 5 h under dry conditions. The ball to powder weight ratio was 10 and the diameter of the zirconia balls was 5 mm. Scanning electron microscope (SEM) images of the particles before and after mixing are shown in Fig. 1. The average size of Al_2O_3 and SiC particles was about 1 μm and 5 μm, respectively. As received commercially pure Al (AA1050) in the form of a sheet with the thickness of 0.5 mm was used as the matrix material. The chemical composition of the Al strip is presented in Table 1. The strips were cut into 150 mm × 70 mm and annealed at 400 °C for 2 h.

The annealed Al was considered as the base material at zero ARB cycle. To set the prepared surfaces in contact and closely fixed to each other, four holes were drilled near the edges of the strips. The annealed strips were degreased by acetone and scratch brushed with a circular stainless steel brush having a 0.3 mm wire diameter. To fabricate the Al/Al_2O_3/SiC hybrid composite, ARB process was carried out in two steps (Fig. 2). In the first step, 1 vol% mixture of Al_2O_3 and SiC particles was uniformly distributed between the four layers of Al strips (about 0.33 vol% between each layer). The stacked strips were fastened at both ends by copper wires and rolled through a 50% reduction in thickness at ambient temperature without lubrication. The roll-bonded strip was then cut into two halves. Following the preparation of the surfaces, two strips were stacked and roll-bonded again under the same conditions as the first cycle, while 1 vol%

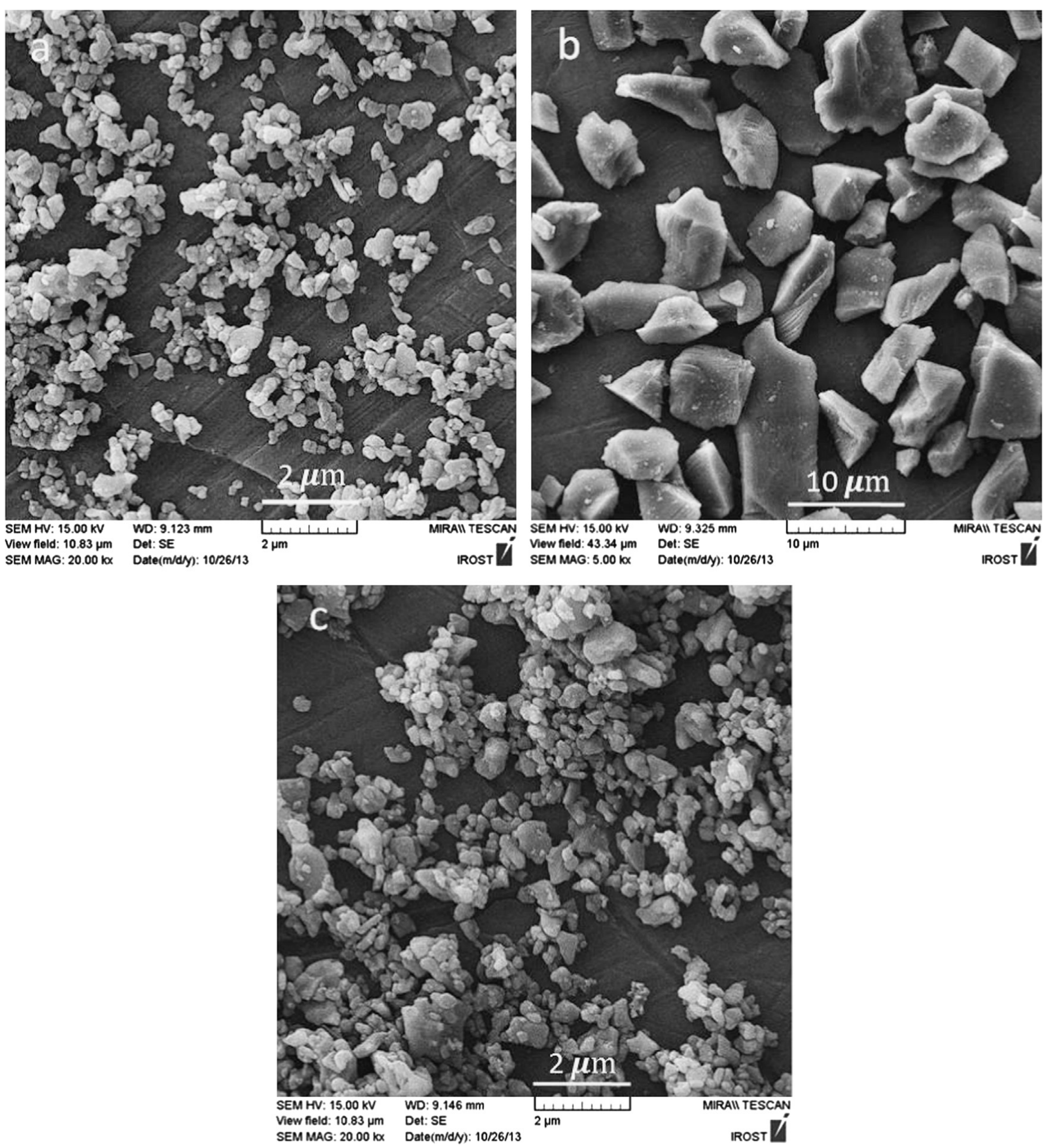

Fig. 1. SEM images of the particles: (a) Al_2O_3, (b) SiC and (c) mixture of Al_2O_3 and SiC.