Materials and Design 43 (2013) 367–372

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

Evaluation of mechanical properties of 1060-Al reinforced with WC particles via warm accumulative roll bonding process

C.Y. Liu, Q. Wang, Y.Z. Jia, B. Zhang, R. Jing, M.Z. Ma, Q. Jing, R.P. Liu *

State Key Laboratory of Metastable Materials Science and Technology, Yanshan University, Qinhuangdao 066004, Hebei Province, China

ARTICLE INFO

Article history:
Received 23 May 2012
Accepted 10 July 2012
Available online 17 July 2012

Keywords:
A. Metal–matrix composite
B. Microstructure
B. Mechanical properties
E. Accumulative roll bonding

ABSTRACT

In the present study, aluminum metal matrix composites (AMMCs) reinforced with tungsten carbide (WC) particles are manufactured through warm accumulative roll bonding (ARB). The composite microstructure shows excellent WC particle distribution in the Al matrices, and no reaction between Al and WC is observed. Compared with the ARBed 1060-Al, the Al/WC composites show a higher number of dislocations, as suggested by the introduction of WC particles. The tensile, hardness, and wear properties of the Al/WC composites are determined. The introduction of 3 vol% WC particles to the Al matrix via the warm ARB process leads to significantly enhanced mechanical properties.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Aluminum-based metal matrix composites (AMMCs) have attracted considerable attention because of their light weight, high strength, high stiffness, and wear resistance [1–3]. In recent years, the high hardness of tungsten carbides (WCs) led to their emergence as a new reinforcement particle in AMMCs [4–9]. WC–AMMCs are manufactured through several methods such as high-energy milling [4], sputtering [5], plasma and high-velocity oxygen fuel sprays [6], and laser alloying techniques [7–9]. In these methods, the WC layers adhere to the Al matrices, and the hard coatings improve the wear properties of AMMCs.

To date, there has been a lack of studies on the WC–AMMCs with a uniform WC particle distribution. However, squeeze casting and powder metallurgy methods are hardly used because of the significantly higher density and melting point of WCs compared to Al. Accumulative roll bonding (ARB) [10] is a new method that can overcome the above problems. Lu et al. [11] and Alizadeh and Paydar [12] used this method to produce particle-reinforced AMMCs in 2009. Subsequently, several AMMCs have been fabricated by ARB. Rezayat et al. [3] and Jammaati et al. [13,14] have succeeded to produce Al_2O_3–AMMCs with the volume fraction of Al_2O_3 from 3% to 15%. Yazdani and Salahinejad [15] and Alizadeh et al. [16,17] evaluated the microstructures and mechanical properties of the B_4C–AMMCs which fabricated by ARB method. The SiC–AMMCs were researched by Alizadeh et al. [2,18]. Not only ceramic particles but also carbon fibers [19], metallic Cu particle [20], and W particle [21] have been employed as reinforced phase in AMMCs fabricated by ARB method process. Furthermore, ARB is well known as one of the severe plastic deformation (SPD) techniques used to fabricate ultrafine-grained (UFG) materials with grain sizes below 1 μm [1,22,23]. With the properties of high corrosion resistance, melting point, degree of hardness, and wear resistance, WC particle have good application potential as reinforced particle in the AMMCs. However, as of this writing, no detailed study has been conducted on the fabrication of WC–AMMC by the ARB process.

Thus, the present study aims to fabricate WC–AMMCs with high uniformity, consisting of UFG structures, and good mechanical properties via ARB. The ARB process at 250 °C is selected for this research. Microstructures and mechanical properties of AMMC fabricated by warm ARB are compared with those of AMMCs fabricated by cold (at room temperature) ARB [2,3,13,14,16–18].

2. Experimental procedures

As-annealed 1060-Al sheets cut parallel to the sheet-rolling direction into 150 mm × 100 mm × 1 mm pieces, as well as WC particles less than 800 nm, were used as raw materials. Table 1 presents the chemical composition of the 1060-Al and Fig. 1 shows the SEM image of the WC particles used in the current study.

Eight pieces of the original 1060-Al sheets were degreased using acetone and then wire-brushed. A total of 0, 1.72, 3.19, and 4.83 g WC particles were uniformly distributed between the two pieces of 1060-Al sheets using a scraper knife. Every two pieces of 1060-Al were stacked together. The four samples containing different amounts of WC particles were then heated in a furnace at 250 °C

---

* Corresponding author. Tel.: +86 335 8074723; fax: +86 335 8074545.
E-mail address: riping@ysu.edu.cn (R.P. Liu).

0261-3069/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2012.07.019

Table 1
Chemical composition of the Al sheets used.

Element	Fe	Mg	Si	Zn	Ti	Cu	Al
wt.%	0.03	0.03	0.25	0.05	0.03	0.05	99.56

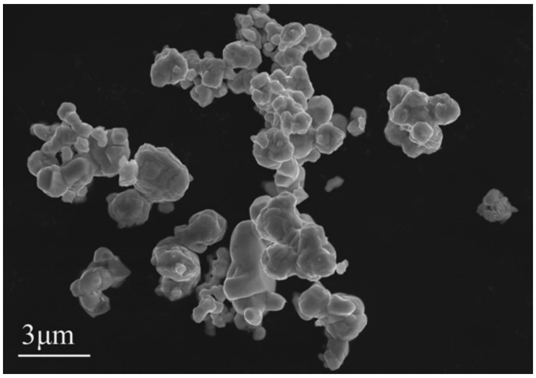

Fig. 1. SEM image of the WC particles used.

for 5 min. Roll-bonding was performed without lubrication, and a laboratory rolling mill with a 300 mm diameter and 220 mm barrel length was used. The rolling speed and rolling reduction were 0.6 m/s and 50%, respectively. The rolled samples were cut into two halves, and the processes were repeated up to three cycles. Thus, Al/1 vol%WC, Al/2 vol%WC, Al/3 vol%WC, and monolithic Al were manufactured. The above procedure was repeated up to 10 cycles without the addition of WC particles to achieve a uniform distribution of reinforcement particles in the matrices.

The microstructures of the samples in the rolling direction–transverse direction (RD–TD) plane were observed via scanning electron microscopy (SEM) and transmission electron microscopy (TEM). X-ray diffraction (XRD) analyses were performed to determine the phases that constitute the Al/3 vol%WC composites. The tensile samples were machined with the tensile axis parallel to the rolling direction. Tensile tests were performed at the strain rate of $4 \times 10^{-4}\,s^{-1}$ using the Instron-5982 type test machine. Hardness measurements were conducted using a Vickers microhardness tester (using 50 N loads for 20 s). Wear tests were conducted using a "pin on disc" wear testing machine, with the 60 mm × 30 mm × 1 mm samples used to fit into the fixture. A stainless steel pin 8 mm in diameter and 30 mm long was used. The wear parameters were 1 m/s sliding velocity, 20 N load, and 500 s test time. The surfaces after the tensile and wear tests were observed via SEM.

3. Results and discussion

The SEM micrograph and XRD pattern of the Al/3 vol%WC composite after warm ARB process are shown in Fig. 2. Fig. 2a shows that the unification of the reinforcement is high. Almost no particle clusters and particle-free zones are found in the sample. Fig. 2b reveals that the Al/3 vol%WC composite consists of only Al and WC and has no W_2C, Al_4C_3, and Al–W intermetallics. The XRD pattern shows that heating at 250 °C for 5 min is not conducive to reactions between Al and WC in the ARB process.

Fig. 3 shows the TEM micrographs of the annealed 1060-Al, ARBed 1060-Al and Al/3 vol%WC composite. Fig. 3a shows that the grain size in annealed 1060-Al is significantly large that a whole grain could not be observed in the field of vision. Fig. 3b shows that the grain size of the 1060-Al became finer and reached to 0.7 μm after 13 cycles of warm ARB. Compared with the TEM micrographs of Al undergone by cold ARB process [1,2,18–20], the Al grains in the present study is larger and equiaxed. The obtained structure is a strong indication of the occurrence of dynamic re-crystallization during the warm roll-bonding process. Adding 3 vol% WC particles to Al matrices, geometry necessary dislocations (GND) [2] are introduced by the WC particles. More dislocations are generated at the WC–Al interface [Fig. 3c].

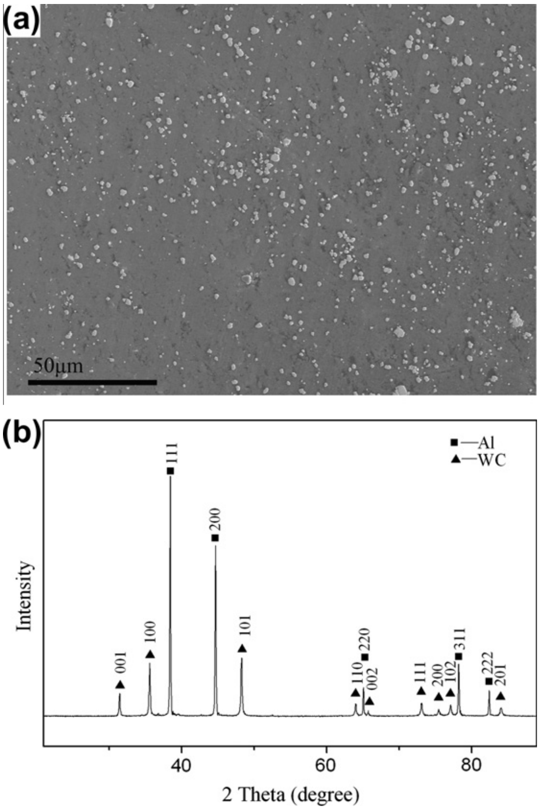

Fig. 2. (a) Scanning electron microscopy (SEM) images and (b) X-ray diffraction (XRD) patterns of the Al/3 vol%WC composite.

The tensile properties of annealed, ARBed 1060-Al, and Al/WC composites are shown in Fig. 4. As shown by the curves of ARBed 1060-Al and Al/WC composites, flow stress rapidly reaches its maximum value with increasing strain, and tensile fracture exhibits low elongation. Compared with the tensile properties of the annealed 1060-Al, ARBed samples are clearly stronger. The smaller the grain sizes, the more grain boundaries are observed in the material. Grain boundaries act as obstacles during the plastic deformation process [24,25]. The grains are refined when annealed Al sheets undergo several cycles of roll bonding (Fig. 3), thus increasing the strength levels of ARBed 1060-Al accordingly. Moreover, the deformed structure consists of a considerable amount of dislocations that also increase the strength level of ARBed 1060-Al [26]. Thus, grain refinement and strain hardening by dislocations are the two key strengthening mechanisms of the Al sheets after 13 cycles.

The strength and the elastic modulus increases with increasing WC particle amount. The Al/3 vol%WC strength reached as high as 175 MPa, and the uniform elongation decreased to as low as 2.1%. The Al/WC composites are not only strengthened by grain refinement and strain hardening through the dislocations that formed during the SPD process, but also through the reinforcement of the WC particles in the AMMCs. Two key effects of the WC particles on the Al matrix were observed: (1) The harder WC particles impede the motion of the softer Al grains during ARB, resulting in increased dislocation density in the matrix near the matrix-reinforcement interfaces, as shown in Fig. 3c. (2) During the plastic

Download English Version:

https://daneshyari.com/en/article/830421

Download Persian Version:

https://daneshyari.com/article/830421

Daneshyari.com