Materials and Design 53 (2014) 217–225

Contents lists available at SciVerse ScienceDirect

Materials and Design

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

A novel approach to develop aluminum matrix nano-composite employing friction stir welding technique

Mohsen Bahrami [a,*], Kamran Dehghani [a], Mohammad Kazem Besharati Givi [b]

[a] *Faculty of Mining and Materials Engineering, Amirkabir University of Technology (AUT), Hafez Ave., Tehran, Iran*
[b] *Department of Mechanical Engineering, University of Tehran, Tehran, Iran*

A R T I C L E I N F O

Article history:
Received 22 February 2013
Accepted 2 July 2013
Available online 12 July 2013

Keywords:
Friction stir welding
Aluminum alloy
SiC
Aluminum matrix nano-composite
Mechanical properties

A B S T R A C T

The main object of the present study is to investigate the effect of nano-sized SiC particle on the mechanical properties of the friction stir welding (FSW) joints. Prior to FSW, nano-sized SiC particles were incorporated into the joint line. A combination of three rotational speeds and three traveling speeds were applied. Microstructural evaluation using optical microscopy (OM) and scanning electron microscopy (SEM) revealed a banded structure consisting of particle-rich and particle-free regions in stir zone (SZ). The joints fabricated with rotational speed of 1250 rpm and traveling speeds of 40 and 50 mm/min, exhibited the highest mechanical properties. Owing to the presence of SiC nano-particles, at 1250 rpm and 40 mm/min, ultimate tensile strength (UTS) and percentage of elongation were improved by 31% and 76.1%, respectively. Significant increase in UTS and percentage of elongation were attributed to the pinning effect and increased nucleation sites associated with SiC nano-particles. Moreover, reinforcement particles resulted in breaking of primary grains. On the other hand, at 1250 rpm and 40 mm/min, SiC-included specimen showed superior ductility to SiC-free specimen. The fracture morphologies were in good agreement with corresponding ductility results.

1. Introduction

In fusion welding of aluminum alloys, the defects such as porosity, slag inclusion, and solidification cracks deteriorates the weld quality and joint properties [1]. On the other hand, employing conventional fusion welding techniques to join aluminum matrix composites (AMCs), leads to defective welds. The drawbacks associated with the fusion welding include: (a) gas occlusion, (b) undesired interfacial chemical reactions between the reinforcement and the molten matrix alloys, and (c) segregation of particles during solidification [2,3]. In spite of fusion welding processes, the primary material does not melt and recast during friction stir welding process. In other words, FSW is a solid state method of joining materials [1]. Accordingly, FSW eliminates the above mentioned problems. This process was invented at the welding institute (TWI), UK in 1991 [4]. More recently, various metal matrix composites have successfully been friction stir welded (FSWed), including 7005/Al2O3/10p [2], AZ91/SiC/10p [5], 6061/TiC/3 and 7p [6], 6063/B4C/6 and 10.5p [7].

On the other hand, over the recent years, friction stir processing (FSP) has widely been investigated. FSP, an outgrowth of FSW, has been employed to produce surface composite layers by using macro, micro, and nano-sized reinforcements [8,9]. Several researchers have studied the influence of number of passes on the particles distribution. It was discovered that there is a direct correlation between improved particles distribution and the number of passes [10–13]. Besides, the effect of different ratios of rotational speed to traveling speed on the mechanical properties of the fabricated composites is studied [14–16]. Barmouz et al. [8] fabricated Cu-based SiC reinforced composite and observed that increasing rotational speed or decreasing traveling speed, reduced the grain size in stir zone. They also reported that the grain size of the fabricated composite layers were considerably finer than that of the specimen fabricated without the addition of SiC particles. Dolatkhah et al. [17] found that in FSP of Al5052 with SiC particles, the uniform powder distribution was achieved at 1120 rpm and 80 mm/min. Moreover, the effect of reinforcing particle size as well as the shift of rotational direction between passes on microstructure and mechanical properties have been addressed in literature [17,18].

According to a novel approach proposed by Sun and Fujii [19], micro-scaled SiC particles were introduced into the 2 mm thick copper plates using FSW technique. As a result, a copper matrix composite was successfully made within the stir zone (SZ). This approach, however, has never been attempted for other metals and alloys. Accordingly, with the aim of fabricating AMC, FSW was carried out on 7075 aluminum using nano-sized SiC

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* Corresponding author. Tel.: +98 9337492475; fax: +98 6626917717377.
E-mail address: mohsen.bahrami@aut.ac.ir (M. Bahrami).

0261-3069/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.matdes.2013.07.006

reinforcements. Unique combination of metallurgical and mechanical properties such as strength comparable to steels, noticeable stress corrosion cracking resistance and excellent fatigue resistance were the main driving forces to work on 7075 aluminum alloy as the base material [20,21]. In this study, the effects of SiC nano-particles as well as traveling and rotational speeds on microstructure, hardness, and tensile behavior of the FSWed joints have been investigated.

2. Experimental procedures

In this study, a 6 mm thick 7075-O aluminum plate with the chemical composition shown in Table 1 was used. Table 2 and Fig. 1 show properties and transmission electron micrograph of the as-received SiC nano-particles, respectively. The friction stir welding tool was machined out of H13 hot working steel and heat treated to 58HRC, Fig. 2. The tool had threaded taper pin profile, shoulder diameter of 16 mm and pin height of 5.7 mm.

After cutting the aluminum plate into 100 mm × 60 mm strips, a profile with 0.2 mm width, 5 mm depth and required length was machined on the adjoining side of each strip. The schematic view of the profile is shown in Fig. 3. The profile allowed a groove to be formed when two strips were put together. Using a purpose-built fixture shown in Fig. 4, two strips were fixed. Afterward, the reinforcements were put into the groove and pressed tightly. Next, all combinations of three rotational speeds i.e., 800, 1000, and 1250 rpm and three traveling speeds i.e., 30.5, 40, and 50 mm/min were tested. In each case, a single-pass FSW was performed. The data related to specimens and processing condition are summarized in Table 3. The optimum rotational and traveling speeds were 1250 rpm and 40 mm/min, respectively. In other words, specimen No. 8 exhibited the highest mechanical properties. To understand the effects of SiC nano-particles on the microstructure and mechanical properties of the joints, FSW was carried out under the optimum processing condition but without using SiC nano-particles. While specimens No. 1–3, 4–6, and 7–9 were FSWed sequentially, the specimen No. 10 was FSWed individually.

Table 1
Chemical composition of 7075-O aluminum alloy (in wt.%).

Element	Zn	Mg	Cu	Fe	Mn	Cr	Si	Ti	Al
%	6.3	1.85	1.37	0.3	0.24	0.22	0.43	0.02	Balanced

Table 2
Properties of SiC nano-particle.

Purity	Size range	Bulk density	Free C	Free Si
99 + %	45–65 nm	0.05 g/cm^3	0.76%	0.23%

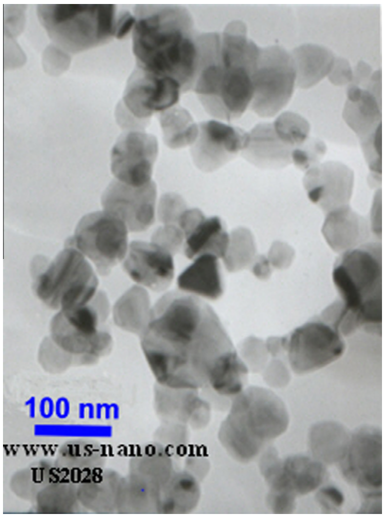

Fig. 1. TEM micrograph of the as-received SiC nano-particles.

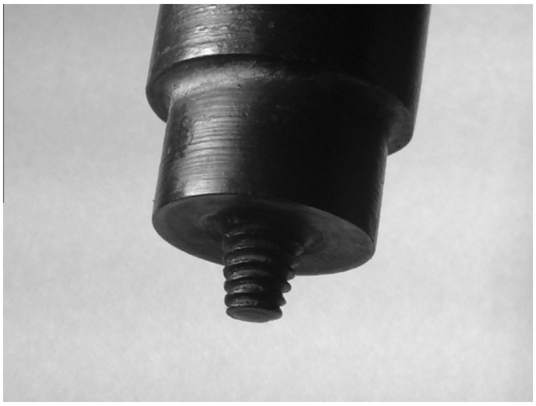

Fig. 2. Friction stir welding tool.

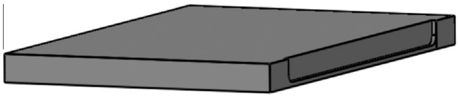

Fig. 3. Schematic view of the profile made adjoining side of a strip.

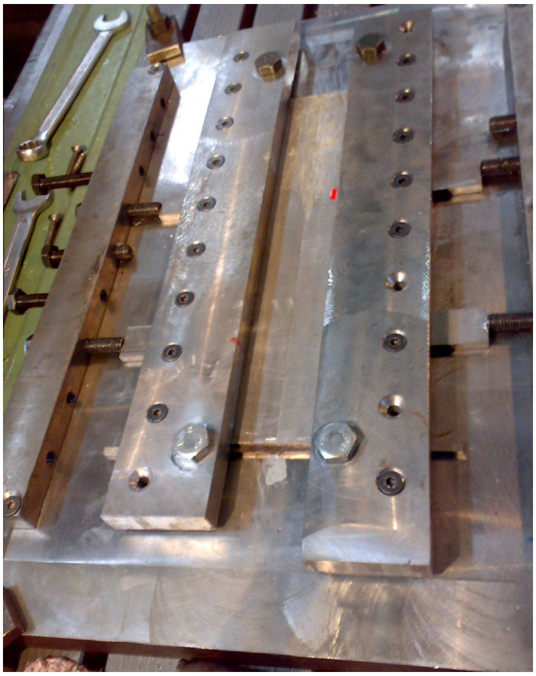

Fig. 4. Friction stir welding fixture.

Prior to the preparation of tensile and metallographic specimens, top surfaces of FSWed joints were machined to remove the marks left by the shoulder. According to ASTM: E8, the sub-sized tensile specimens were electrically discharged machined perpen-