Composites Communications 3 (2017) 42–46

Contents lists available at ScienceDirect

Composites Communications

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

Influence of rice husk ash particles on microstructure and tensile behavior of AA6061 aluminum matrix composites produced using friction stir processing

Isaac Dinaharan[a], Kumaravel Kalaiselvan[b,*], Nadarajan Murugan[c]

[a] Department of Mechanical Engineering Science, University of Johannesburg, Auckland Park Kingsway Campus, Johannesburg 2006, South Africa
[b] Department of Mechanical Engineering, Dr. N.G.P. Institute of Technology, Coimbatore 641048, Tamil Nadu, India
[c] Department of Mechanical Engineering, Coimbatore Institute of Technology, Coimbatore 641014, Tamil Nadu, India

ARTICLE INFO

Keywords:
Aluminum matrix composites
Rice husk ash
Microstructure
Tensile strength

ABSTRACT

Rice husk ash (RHA) is an economical and potential reinforcement for producing aluminum matrix composites (AMCs). The present work reports the production and characterization of AA6061/18 vol% RHA AMC using the novel method friction stir processing (FSP). The microstructure was studied using optical microscopy (OM), scanning electron microscopy (SEM) and electron back scattered diagram (EBSD). A homogenous dispersion of RHA particles was obtained in the composite. No agglomeration or segregation was observed. The produced composite exhibited a fine and equiaxed grain structure. RHA particles fragmented during FSP. An improvement in the tensile strength was observed subsequent to reinforcement of RHA particles. The fracture surface was dispersed with fractured RHA particles confirming excellent interfacial bonding with the aluminum matrix.

1. Introduction

Aluminum matrix composites (AMCs) are one of the important classes of advanced engineering materials in the present era. AMCs possess unique combination of properties which are sought after in several industries and replace conventional aluminum alloys in numerous applications [1,2]. The cost of producing AMCs is high which may limit the wider usage. One method to minimize the cost of production is to utilize industrial waste and natural minerals as reinforcement particles [3]. Rice husk ash (RHA) is an economical reinforcement in comparison to conventionally applied ceramic particles. RHA is an agricultural waste which is available in surplus quantities across the globe. The constituents of a typical milled paddy are rice, bran and husk. Rice mills make use of this husk as fuel to produce steam for the parboiling process. The volatile matter in the husk evaporates during the process of burning and the residual husk is transformed to ash which is named as RHA [4–6].

AMCs reinforced with RHA particles were successfully produced by few researchers using various methods such as stir casting and compo casting [7–12]. Nevertheless, liquid metallurgy processing was associated with inhomogeneous distribution [8,9], agglomerations [7], porosity [8–10], poor bonding [10] and interfacial reactions [7]. Further, the wettability of RHA with molten aluminum is poor which necessitated additional treatment. Hence, the mechanical and tribological properties were lower compared to AMCs reinforced with conventional ceramic particles [12]. Therefore, an improved production method is required to overcome those drawbacks and enhance the performance of AMCs reinforced with RHA particles.

Friction stir processing (FSP) is the latest addition to the spectrum of production methods for AMCs [13]. FSP evolved from the principles of friction stir welding (FSW) which was invented at the welding institute (TWI) in 1991. The reinforcements are mixed with the matrix material in solid state. Reinforcement particles are initially compacted in a groove of required dimensions along the FSP direction. The rubbing action of the tool plasticizes the matrix and the particles are embedded into it due to the rigorous rotating action of the tool. The plasticized composite material is subsequently forged at the back of the tool by the application of an axial force. FSP is capable of producing sound AMCs without porosity, segregation, agglomeration and interfacial reaction [14,15].

Few works were reported on the production of AMCs reinforced with industrial waste particles such as fly ash (FA) and RHA using FSP. Dinaharan et al. [16] produced AA6061/FA AMCs and showed a uniform distribution of FA particles which improved the wear resistance of the composites. Zuhailawati et al. [17] prepared AA1100/RHA AMCs and studied the microstructure under different processing

* Corresponding author.
E-mail addresses: dinaweld2009@gmail.com (I. Dinaharan), kalaiselvanmohit@gmail.com (K. Kalaiselvan), drnmurugan@gmail.com (N. Murugan).

http://dx.doi.org/10.1016/j.coco.2017.02.001
Received 8 December 2016; Received in revised form 26 January 2017; Accepted 7 February 2017
Available online 16 February 2017
2452-2139/

Table 1
Chemical composition of AA6061 aluminum alloy.

Element	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ni	Ti	Aluminum
wt%	0.95	0.54	0.22	0.13	0.17	0.09	0.08	0.02	0.01	Balance

conditions. Since literatures on this field are scantly, the present work is aimed at producing AA6061/RHA AMCs using FSP and study the microstructural evolution and tensile behavior.

2. Experimental procedure

Rolled aluminum alloy AA6061 plates having 10 mm thickness were employed for this work. The breadth and length of the plates were respectively 50 mm and 100 mm. The composition of the aluminum alloy plate was tested using optical emission spectrometry and is furnished in Table 1. The plates were machined at the middle along the length direction using wire EDM to create a groove for packing the RHA particles. The length, width and depth of the grooves were respectively 100 mm, 1.2 mm and 5.5 mm. The groove dimensions correspond to 18 vol% of reinforcement particles. The volume fraction was estimated based on mathematical expressions reported elsewhere [18].The groove was carefully packed with RHA particles (~8 µm) to the brim. Fig. 1 and Table 2 represent the SEM micrograph of the RHA particles and its composition. The RHA particles were collected from a rice mill located in south India. RHA particles exhibit irregular polygonal morphology. FSP was accomplished using an indigenously built FSW machine (M/s RV Machine Tools, Coimbatore, INDIA). The process parameters used were tool rotational speed of 1600 rpm, traverse speed of 60 mm, axial force of 10 kN and one pass. The process parameters were chosen based on literatures and author's past experience to yield a uniform distribution of reinforcement particles across the stir zone. The tool was made from high carbon high chromium (HCHCr) steel with shoulder diameter of 18 mm, pin diameter of 6 mm, pin length of 5.8 mm. A straight cylindrical threaded profile was adopted for tool pin. A tool without pin was processed in the traverse direction to cover the opening of the groove with little plastic deformation of the surface aluminum layer to arrest the expulsion of packed particles. A detailed FSP procedure is available in literatures [14,15].

Specimens for microstructural characterization were machined from the friction stir processed plates. They were mounted, polished and etched with Keller's reagent. The etched specimens were observed using an optical microscope (OLYMPUS BX51M), field emission scanning electron microscope (CARL ZEISS-SIGMAHV) and electron backscatter diffraction (EBSD). EBSD was carried out in a FEI Quanta FEG SEM equipped with TSL-OIM software. The mean grain size was measured according to ASTM E1382-97. Mini tensile specimens of

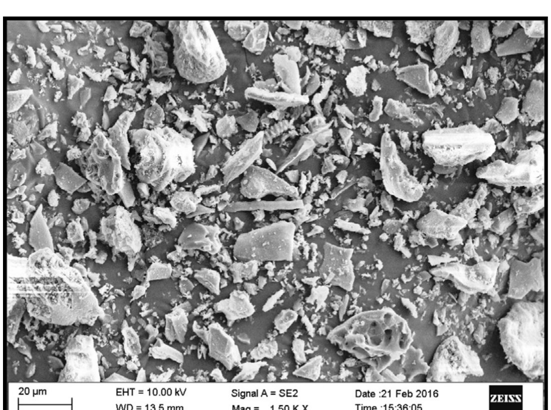

Fig. 1. FESEM micrograph of RHA particles.

Table 2
Chemical composition of rice husk ash.

Element	SiO_2	Al_2O_3	C	CaO	MgO	K_2O	Fe_2O_3	LOI*
wt%	90.23	3.54	1.23	1.58	0.53	0.39	0.21	2.29

LOI – Loss on Ignition.

gauge length 30 mm, width 4 mm and thickness 4 mm were prepared from the FSP zone using wire EDM. The ultimate tensile strength (UTS) was estimated using a computerized tensile tester with a cross head speed of 0.5 mm/min. The fracture surfaces were studied using SEM.

3. Results and discussion

3.1. Microstructure of AA6061/RHA AMCs

The representative optical and SEM micrographs of the prepared AA6061/RHA AMC are shown in Fig. 2a–d. The micrographs were recorded at different spots randomly chosen within the stir zone. It is evident from the micrographs that the dispersion of the RHA particles covers the whole micrographs. There are no regions within the micrograph which are left with any particles. This observation suggests that the AA6061/RHA AMC was successfully produced using FSP method. RHA particles were effectively reinforced into the aluminum matrix across the stir zone. The dispersion of the RHA particles is nearly homogenous. There is reasonable and uniform spacing between the particles. There are no agglomerations i.e. group of particles located closely or touching each other. Homogeneous dispersion is a prerequisite to obtain isotropic properties from the composite. The frictional heat produced by the rubbing tool shoulder and shearing action of the pin surface causes the aluminum matrix to plasticize. The transverse motion results in the transportation of plasticized aluminum from advancing side to retreating side. During such material flow, the groove is sheared off. The rotating action of the tool causes the compacted particles to mix with the plasticized aluminum to produce the composite. The process parameters, especially the stirring action of tool greatly influence the final dispersion in the composite [15]. The homogenous dispersion can be attributed to optimum stirring conditions prevailing under the set of experimental conditions in this work. Secondly, the aluminum matrix does not melt during the process since FSP is a solid state method. The peak temperature may be close to 0.7–0.8T_m of matrix material [13]. Once the composite is formed in the solid state, the free movement of reinforcement particle due to density gradient with the aluminum matrix is restricted. On the contrary, the reinforcement particle will tend to float up or sink down due to density gradient in molten aluminum. This has been the major setback of stir casting which is overcome by FSP. It is also interesting to observe in the micrographs that the dispersion of particle is almost intragranular. Although grain boundaries are not clearly visible in the optical micrographs (Fig. 2a and b), there is no distinct pattern of continuous arrangement of particles i.e. segregation. Nevertheless, some particles may be sitting on the grain boundaries.

The aluminum matrix and the reinforcement particles are subjected to the severe plastic strain induced by the FSP process. The strain developed during FSP is much higher compared to conventional severe plastic deformation processes. Reinforcement particles commonly breakdown and undergo a change in shape and size [19]. This can be observed by comparing the initial morphology (Fig. 1) of RHA particles and in the produced composite (Fig. 2c and d). The comparison reveals that the RHA particles underwent significant alteration in change and shape subsequent to FSP. Most of the RHA particles lost their initial morphology. The average size of RHA particle was reduced to ~2 µm. RHA particles do not deform plastically unlike the aluminum matrix. Being brittle in nature, RHA particles could not absorb the severe