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Influence of ceramic particulate type on microstructure and tensile strength of aluminum matrix composites produced using friction stir processing

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ABSTRACT

Friction stir processing (FSP) was applied to produce aluminum matrix composites (AMCs). Aluminum alloy AA6082 was used as the matrix material. Various ceramic particles, such as SiC, Al_2O_3, TiC, B_4C and WC, were used as reinforcement particle. AA6082 AMCs were produced using a set of optimized process parameters. The microstructure was studied using optical microscopy, filed emission scanning electron microscopy and electron back scattered diagram. The results indicated that the type of ceramic particle did not considerably vary the microstructure and ultimate tensile strength (UTS). Each type of ceramic particle provided a homogeneous dispersion in the stir zone irrespective of the location and good interfacial bonding. Nevertheless, AA6082/TiC AMC exhibited superior hardness and wear resistance compared to other AMCs produced in this work under the same set of experimental conditions. The strengthening mechanisms and the variation in the properties are correlated to the observed microstructure. The details of fracture mode are further presented.

1. Introduction

Reinforcing aluminum alloys with ceramic particles creates high elastic modulus, stiffness and wear resistance. The resultant material is universally called as aluminum matrix composites (AMCs). The research on AMCs is intensified due to the great interest of the automobile, aerospace and defense industries to replace conventional aluminum alloys in several applications [1–3]. The performance and properties of the AMCs depend on several aspects, which are not limited to uniform distribution of reinforcing particles, interfacial bonding between the aluminum matrix and the reinforcing particles and integrity of the reinforcing particle during the production process [4]. Therefore, it is an uphill task to produce sound AMCs showcasing uniform distribution and good interfacial bonding without decomposing of reinforcing particles. Hitherto, powder metallurgy and stir casting were predominantly used to produce AMCs. But, the common defects, such as porosity, clustering and segregation of particles and interfacial reactions, are always encountered [5–9].

Friction stir processing (FSP) has emerged as a potential solid-state technique to produce sound AMCs. It is facile and economic to prepare AMCs using FSP. The ceramic particles are compacted initially along the FSP direction using grooves of various shapes. A square groove is preferred to compact particles. The open end of the groove is closed by traversing a pinless tool prior to FSP to avoid the loss of ceramic particles during processing. The frictional heat generated by the rotating shoulder and the pin helps to plasticize the aluminum alloy. The transverse movement of the tool results in the transportation of plasticized material from the advancing side to the retreading side. Subsequently, the groove portion collapses and the stirring action of the tool disperses the packed ceramic particles into the plasticized aluminum alloy. The AMCs are thus formed and forged at the back of the tool due to the applied axial force. FSP is a low energy consumption process. The entire process is accomplished in solid state without melting of aluminum. Hence, the chances of interfacial reaction and decomposition are remote. Neither the density gradient between the ceramic particle and the aluminum alloy nor the particle size influences the ultimate distribution of particles [10–13].

AMCs reinforced with varieties of ceramic particles produced using FSP were reported in literatures [14–22]. Shahraki et al.

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Table 1
Chemical composition of AA6082 aluminum alloy.

Element	Mg	Si	Fe	Mn	Cu	Cr	Zn	Ti	Aluminum
wt.%	0.78	1.06	0.21	0.55	0.09	0.03	0.06	0.01	Balance

[14] developed AA5083/ZrO_2 AMCs and evaluated the microstructure and tensile behavior. Moghaddas and Bozorg [15] produced AA5754/Si_3N_4 AMCs and correlated the thermal profiles with the evolution of microstructure. You et al. [16] prepared Al/SiO_2 AMCs and analysed the in situ formation of Al_2O_3 particles. Bahrami et al. [17] fabricated AA7075/SiC AMCs and analyzed the role of tool pin geometry on microstructure and mechanical properties. Mazaheri et al. [18] synthesized A356/Al_2O_3 AMCs and investigated the microstructure and tribological behavior. Khodabakhshi et al. [19] created AA5052/TiO_2 AMCs and studied the effect of annealing on the soild-state chemical reactions. Thangarasu et al. [20] produced AA6082/TiC AMCs and examined the effect of TiC content on microstructure and tensile strength. Zhao et al. [21] prepared AA6061/B_4C AMCs and studied the effect of number of passes on the distribution of B_4C particles. Hashemi and Hussain [22] formed AA7075/TiN AMCs and estimated the influence of tool design on dry sliding wear behavior.

It is inferred from the short literature survey that FSP has been successfully applied to produce AMCs reinforced with various ceramic particulates, including SiC, Al_2O_3, B_4C, TiC, ZrO_2, Si_3N_4, SiO_2, TiO_2 and TiN. However, various ceramic particles were not compared in any single research work, which would assist to assess the performance of several potential reinforcements under a set of identical experimental conditions. Therefore, the objective of this research work is to produce AMCs reinforced with SiC, Al_2O_3, TiC, B_4C and WC and evaluate the effect of various reinforcements on the microstructure and tensile behavior.

2. Experimental procedure

Aluminum alloy AA6082 plates of size 100 mm × 50 mm × 10 mm were used for this research work. The chemical composition of AA6082 aluminum alloy is furnished in Table 1. A groove of 5 mm deep and 1.2 width was machined along the center line of the plates

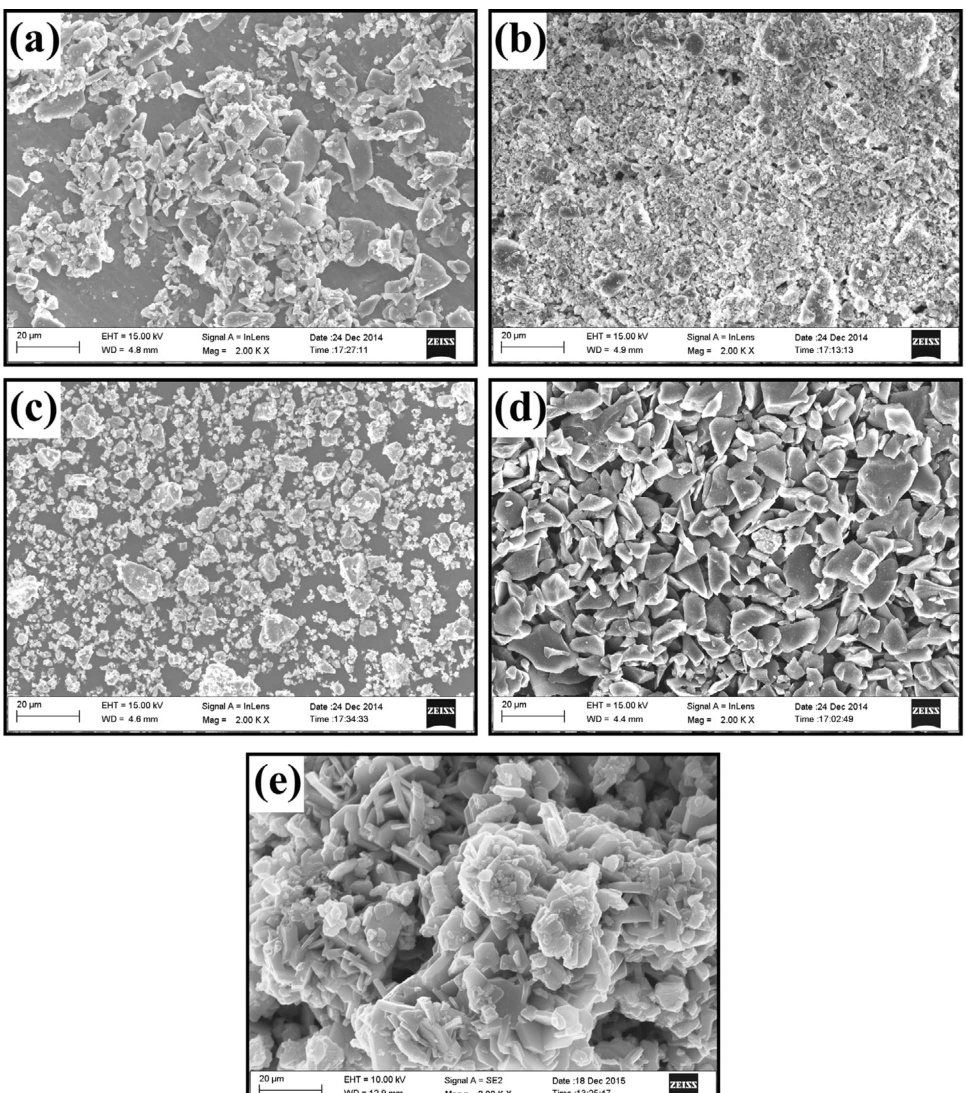

Fig. 1. FESEM micrograph of ceramic particles; (a) SiC, (b) Al_2O_3, (c) TiC, (d) B_4C and (e) WC.