Available online at www.sciencedirect.com

ScienceDirect

journal homepage: http://www.elsevier.com/locate/acme

Original Research Article

Effect of nano/micro B_4C particles on the mechanical properties of aluminium metal matrix composites fabricated by ultrasonic cavitation-assisted solidification process

R. Harichandran [a,*], *N. Selvakumar* [b,1]

[a] *Department of Mechanical Engineering, National Engineering College, K.R. Nagar, Kovilpatti 628 503, Tamilnadu, India*
[b] *Centre for Nano Science and Technology, Department of Mechanical Engineering, Mepco Schlenk Engineering College, Sivakasi 626 005, Tamilnadu, India*

ARTICLE INFO

Article history:
Received 17 March 2015
Accepted 23 July 2015
Available online 29 August 2015

Keywords:
Al–B_4C (micro and nano) composites
Ultrasonic cavitation
Mechanical and wear properties

ABSTRACT

Lightweight aluminium metal matrix nanocomposites play a major role in automobile, aerospace and other industries. This work aimed to investigate the effect of the addition of micro- and nano-boron carbide particles to aluminium on the mechanical properties of the composites. The micro- and nanocomposites containing different weight % of B_4C particles were fabricated using stir- and ultrasonic cavitation-assisted casting processes. The fabricated micro and nano B_4C particle-reinforced composites were characterized using scanning electron microscopy (SEM) and an X-ray diffractometer. Tensile, hardness, impact and wear tests were carried out in order to evaluate the mechanical properties of the micro- and nanocomposites. The tensile test results showed that the properties of the samples containing up to 6% nano B_4C-reinforced composites were better than the micro B_4C-reinforced composites. The study also indicated that the ductility and impact energy of the nanocomposites were better than the micro B_4C particle-reinforced composites. The wear resistance of the nanocomposite significantly increased when the B_4C content was increased up to 8% of addition, and this increase was more pronounced than that resulting from micro B_4C particle-reinforced composites.

1. Introduction

Aluminium-based metal matrix composites (AMCs) have been widely used in automotive and aircraft applications due to their low density and concurrent high wear resistance, strength, corrosion resistance, stiffness and thermal conductivity [1,2]. AMCs are fabricated by incorporating micro-sized ceramic particles, such as SiC, Al_2O_3 and B_4C, into the aluminium matrix. Boron carbide is a superior ceramic reinforcement material for AMCs than SiC and Al_2O_3 due to its high hardness, low density, high strength, high wear and

* *Corresponding author*. Tel.: +91 9944087728.
E-mail addresses: harichandra@nec.edu.in (R. Harichandran), nselva@mepcoeng.ac.in (N. Selvakumar).
[1] Tel.: +91 4562 235641.
http://dx.doi.org/10.1016/j.acme.2015.07.001

impact resistance, high melting point, low coefficient of thermal expansion and good chemical stability [3].

Shoroworthi et al. [4] investigated the tribological behaviour of Al–B_4C and Al–SiC composites fabricated using the stir-casting method for the same process parameters. They reported that the wear rate and coefficient of friction of Al–B_4C were lower than Al–SiC composites. Recent studies have used micro-sized B_4C particles to improve the mechanical properties of AMCs. However, the poor ductility and reduced fracture toughness have limited the application of micro-sized ceramic particle-reinforced AMCs with higher concentrations of ceramic particle [5–7]. The use of nano-sized B_4C particles to improve the mechanical properties of the AMCs is attractive because this approach could maintain good ductility and improve fracture toughness.

Many techniques are currently available to fabricate the metal matrix nanocomposites (MMNCs), such as mechanical alloying [8,9], high-energy ball milling [10], spray deposition, powder metallurgy, nano-sintering and various casting techniques [11]. The powder metallurgy processing method cannot be used for bulk production of large and complex structural MMNCs components. The fabrication of MMNCs by powder metallurgy route is time-consuming, expensive and energy intensive. The liquid phase processing method can produce AMC parts with a uniform reinforcement distribution and complex shape, and this method offers better matrix-particle bonding and an easier control of the matrix structure. It is economical for bulk production. Uniform distribution and dispersion of nano-sized B_4C particles in molten aluminium is extremely difficult due to their large surface-to-volume ratio and poor wettability using a conventional mechanical stir casting method. The conventional mechanical stir casting method can be used to disperse micro-sized B_4C particles in molten aluminium without agglomeration and clustering. Several researchers have proposed the ultrasonic cavitation technique to distribute and disperse ceramic nano-sized particles in an aluminium melt which enhances their wettability, the degassing of liquid metals and the dispersive effects for homogenizing [12,13]. The liquid phase processing of MMNCs using high-intensity ultrasonic waves could be useful to disperse B_4C nanoparticles in molten aluminium because this process features transient cavitation and acoustic streaming. Acoustic cavitation is the formation and collapse of thousands of micro-bubbles in molten aluminium liquids under cyclic high intensity ultrasonic waves. The collapsing of micro-bubbles in molten aluminium produces transient micro-hot spots that can have pressures of approximately 1000 atm, temperatures above 5000 °C and heating and cooling rates exceeding 10^{10} K/s. Transient cavitation could result in strong impact coupling with the local high temperatures. It is sufficient to break up the clustered nanoparticles, disperse nanoparticles, refine grains, remove gas and homogenize the material.

Recent studies have attempted to fabricate B_4C nanoparticle-reinforced aluminium matrix composites [14,15]. Mohammad Sharifi et al. [14] investigated the mechanical and tribological properties of B_4C nanoparticle-reinforced aluminium metal matrix composites produced by mechanical alloying and hot pressing. They observed the improvement in the compressive strength and wear resistance of the composites by adding nano B_4C ceramic particles as reinforcement in the aluminium matrix. In another study, Akhlaghi and Khakbiz [8] only synthesized and characterized Al–B_4C nanocomposite powders. Alizadeh [10] investigated the effect of boron carbide nanoparticles on the mechanical and tribological behaviour of Al2024 composites fabricated by mechanical milling and hot extrusion. They concluded that increasing B_4C nanoparticles content in aluminium matrix leads to improvement in tensile strength and wear resistance of the composites. Abdollahi et al. [15], in their study on the sliding wear behaviour and mechanical properties of Al2024/B_4C composites, stated that mechanical properties and wear resistance of B_4C nanoparticles reinforced composites was higher than that of the unreinforced matrix alloy.

In the present work, ultrasonic cavitation-based solidification processing was utilized to fabricate B_4C nanoparticle-reinforced aluminium matrix composites by varying the concentration of B_4C. Micro-sized B_4C particle-reinforced AMCs were produced by stir casting. Moreover, the mechanical and wear properties of AMCs reinforced with B_4C nanoparticles and microparticles were compared.

2. Material and methods

Pure aluminium was selected as a primary matrix material because it can be readily casted and has been widely used. B_4C was used as a secondary reinforcement particle to fabricate the samples. The pure aluminium was purchased from M/s. BMC Enterprises, Bangalore, India. The size of the B_4C particles was measured by SEM (SU1510) as 70 μm. B_4C nanoparticles were synthesized by milling the received B_4C powders in a high energy planetary ball mill (Fritsch, Model Pulverisette 6). A vial was charged with the received B_4C powders (made up of WC and 250 ml in volume) with 100 balls (made up of WC and diameter 10 mm). The ball to powder ratio and rotational speed were 32:1 and 300 rpm, respectively. The ball milling operation was performed at room temperature under an argon gas atmosphere for 30 h.

Toluene was used as the milling medium to avoid internal friction between the ball and powders. To avoid overheating of the vial, the ball milling experiments were periodically paused for every half an hour. The B_4C powder samples were examined after 30 h of ball milling for morphological and structural studies. The size of B_4C particles was measured by SEM and Atomic Force Microscopy (AFM). To avoid the agglomeration of particles, a very small quantity of nano-sized B_4C particle was mixed with 50 ml of acetone, and this mixture was placed in the ultrasonic sonicator for 10 min. The mixture was then characterized using SEM and AFM (XE70 park system). The final mean size of the B_4C particles was 80 nm. The synthesized B_4C was characterized using a Philips X-ray diffraction spectrometer (XRD) to verify the purity and crystalline phases of the particles.

3. Experimental setup

The metal matrix composite was prepared with a liquid metallurgical process using ultrasonic cavitation-assisted stir casting. Fig. 1 shows the experimental setup for the ultrasonic