Materials Characterization 136 (2018) 144–151

Contents lists available at ScienceDirect

Materials Characterization

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

Novel preparation of Al-5%Cu / BN and Si_3N_4 composites with analyzing microstructure, thermal and mechanical properties

A. Lotfy[a,b,*], A.V. Pozdniakov[a], V.S. Zolotorevskiy[a], M.T. Abou El-khair[b], A. Daoud[b], A.G. Mochugovskiy[a]

[a] NUST "MISiS", 119049 Moscow, Leninskiy ave. 4, Russian Federation
[b] CMRDI, P.O. Box 87, Helwan, Cairo, Egypt

ARTICLE INFO

Keywords:
Metal matrix composites
Squeeze casting
Scanning electron microscopy (SEM)
Ageing
X-ray diffraction
Thermal expansion

ABSTRACT

The purpose of this research is to develop and characterize composites of Al-5%Cu alloy reinforced by silicon and boron nitride (Si_3N_4, BN). The developing of this type of composites gives a new trend of metal matrix composite synthesizing, especially in the case of boron nitride. The stir cast composites showed large areas of porosity and agglomeration. On the other hand, the squeezed cast composites exhibited a fairly uniform particles distribution throughout the matrix alloy. The microstructure and XRD results of the composites confirmed a reaction occurred at the interface between the particles and alloy. AlN and AlB_2 phases were identified in Al5%Cu-Si_3N_4 and Al5%Cu-BN composites respectively. The ageing results showed that the time to reach peak hardness decreased with addition of the particles. Also, the ageing kinetics was significantly accelerated due to the presence of BN particulates. The coefficient of thermal expansion (CTE) results of the matrix alloy and its composites were practically and theoretically determined. Difference between experimental and calculated values of CTE was less than 8%. Increasing the concentration of Si_3N_4 increased YS from 215 MPa in the matrix alloy to 285 MPa in the Al-5%Cu-7%Si_3N_4 composites at a testing temperature of 20 °C.

1. Introduction

Among all types of metal matrix composites (MMCs), considerable attention has been paid to aluminum-based composites for automotive industry due to their excellent properties, such as low density, light weight, low thermal expansion, high wear and corrosion resistance [1–7].

As one of the heat-treatable aluminum alloys and due to the superior properties, including low density, high fracture toughness and fatigue strength Al—Cu alloys has become an attractive light-weight material for inertial instruments and aircrafts [8–12]. However, the alloy has relatively high coefficient of thermal expansion which may lead to dimensional instability when the alloy is in the alternating temperature field or under stress [12]. Reinforcing Al—Cu alloys with ceramic particles would give a good solution for that [6].

In the previous research Pozdniakov et al. [6] developed composites of Al-5%Cu alloy reinforced with B_4C particulates with a low coefficient of thermal expansion using stir and squeeze casting route. While, Mathew et al. [13] prepared Al-4.5% Cu-5% TiB_2 in-situ cast composites by flux assisted synthesis and discussed the effect of semisolid processing on microstructure and mechanical properties of Al-4.5% Cu alloy, also, Lei Wang et al. [14] incorporated 5–9 vol% nano-sized TiCx particles into Al-Cu-Mg matrix by combustion synthesis (CS) and hot pressing process combined with hot extrusion and concluded that the tensile strength, yield strength and fracture strain of the composites were simultaneously improved. Also the same author Lei Wang et al. [15] used semi-solid stir casting and hot extrusion processes to disperse nano-sized SiCp/Al master alloy into the molten Al—Cu alloy and results showed that adding of nano-sized SiCp to the Al—Cu matrix, increased the tensile strength of the described composites. Moreover, Chunhong Li et al. [16] studied the Effect of carbon nanotubes additions and high temperature extrusion on the microstructure evolution of Al—Cu alloy and showed that hardness and density of the composites can be increased via extrusion and CNTs addition. In our research we aim to study the effect of silicon nitride and boron nitride addition on the microstructure, thermal expansion (CTE), compression properties of Al-5%Cu alloy using stir and squeeze casting route.

In the form of fibers, whiskers or particulates in aluminum alloy matrix, different types of ceramics like SiC [17,18], Si_3N_4 [19,20], B_4C [21,22] etc., have been used as reinforcement materials. Silicon nitride used as reinforcement particulate in MMCs owing to their remarkable combinations of mechanical, chemical and thermal properties, such as

* Corresponding author at: NUST "MISiS", 119049 Moscow, Leninskiy ave. 4, Russian Federation.
E-mail addresses: alotfy@misis.ru (A. Lotfy), pozdniakov@misis.ru (A.V. Pozdniakov), zolotor@misis.ru (V.S. Zolotorevskiy).

https://doi.org/10.1016/j.matchar.2017.12.015
Received 26 October 2017; Received in revised form 11 December 2017; Accepted 11 December 2017
Available online 14 December 2017
1044-5803/

high hardness, good wear resistance, oxidation and corrosion resistance and excellent thermal shock resistance [23,24]. However BN has good properties such as high hardness, low density, excellent wear and corrosion resistance [25], but very little interest paid to the use of BN particles as reinforcement in the production of MMCs. This is due to the very poor wettability for BN by most molten metals [26]. MMCs synthesizing by Squeeze casting after main process stir casting improves the wettability between the particulates and the matrix alloy due to the action of pressure and facilitate the incorporation of particulates into the melt [7,27].

In our research we aim to synthesis, characterize and compare between two different nitrides composites Al-5%Cu-Si_3N_4 and novel Al-5%Cu-BN using stir casting and squeeze casting techniques in order to give a suitable replacement for AlSi piston alloys by Al5%Cu alloy. The challenge and novelty in this research is to produce these composites by means of liquid route especially in the case of BN.

2. Materials and Methods

2.1. Composites Synthesys

In present work, vortex method was used for mixing 2, 5, and 7 wt% of silicon nitride and 2, 5 of boron nitride (Si_3N_4, BN) in the Al-5%Cu alloy to produce composites. During this process, the matrix alloy was stirred mechanically, using titanium stirrer with four blades. During stirring, the preheated particles were added manually with a uniform feed inside the vortex that is created by stirrer. After that, the stirring was lifted until the temperature of the melt increased. Just before pouring, the melt was again stirred for 1 min and immediately cast into graphite mold.

The stir cast composites and matrix alloy were subjected to a secondary process, namely squeeze casting. In squeeze casting, the metal was solidified under pressure to reduce the contained porosity due to stirring. The main components used in the pressure unit were a punch and a cylindrical special tool steel die (50 mm inner diameter and 150 mm height). There was a clearance between the punch and the die, about 0.05 to 0.1 mm, to maintain all the pressure inside the die and avoid leakage of the melt during pressing. The produced composites from stir casting were remelted and directly cast into the preheated die mold (250 °C), afterwards the punch was immediately lowered to the surface of the liquid metal. The applied pressure was maintained to a level of 100 MPa within a period of 2 min, and then the solidified casting was ejected, this method was described by authors [5,6,13].

2.2. Density Measurements

Archimedes' principle was used to measure the densities of as cast and squeezed samples for the matrix and its composites. The theoretical densities of the composites as well as the matrix alloy were calculated using the rule of mixture. After calculating theoretical and experimental densities the apparent porosity was calculated [6,21].

2.3. Microstructure Investigations

For microstructural investigations, samples of 20 mm diameter and 15 mm thickness were cut from stir cast and squeezed matrix and composites. The samples were cold mounted, grinded, and mechanically polished according to metallographic aspects. The prepared samples were scanned with a TESCAN VEGA 3LMH scanning electron microscope (SEM) equipped with an energy dispersive X-ray analyzer XMAX-80. X-ray diffraction analysis was performed on Bruker D8 Advance diffractometer using monochromatic radiation $Cu_{K\alpha}$.

The substructure of the foils was investigated using a JEM 2100 transmission electron microscope (TEM) operating at 200 kV. The specimens were prepared using the standard electrolyte A2 on Struers Tenupol-5 equipment.

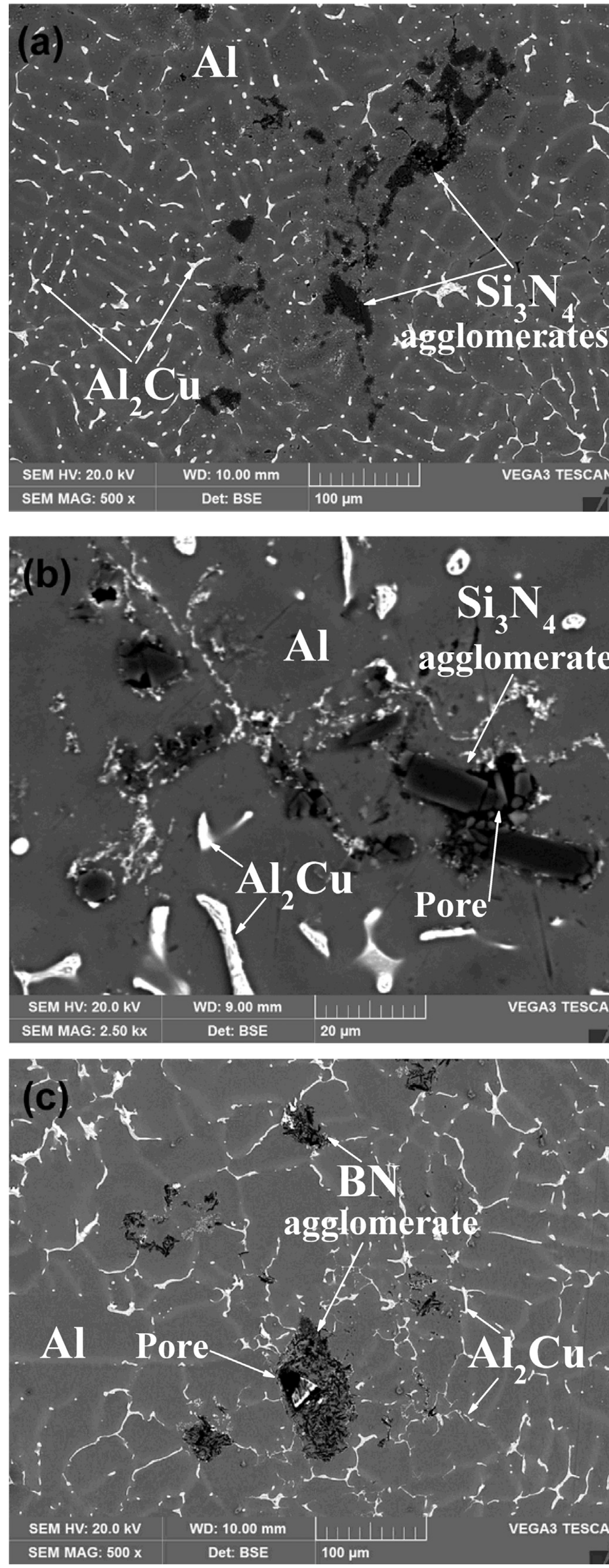

Fig. 1. SEM images of stir cast Al-5%Cu-Si_3N_4 (a, b) and Al-5%Cu- BN (c) composites.