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Synthesis and characterization of sintered hybrid aluminium matrix composites reinforced with nanocopper oxide particles and microsilicon carbide particles

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ABSTRACT

The application of nano-sized particles is increasing because it strengthens the Metal Matrix composites (MMCs) and maintains the ductility of the matrix alloy. The present investigation deals with the synthesis and characterization of hybrid aluminium matrix reinforced with micro SiC particles, and nanocopper oxide (CuO) particles prepared by sintering process. First the powder mixtures containing fixed weight (wt)% of SiC and different wt% of nanocopper oxide as reinforcement constituents that are uniaxially cold pressed. Afterwards the green compacts are sintered in an electric muffle furnace. Microstructure and mechanical properties such as tensile strength, microhardness and density of the composites are examined. Microstructure of the samples has been investigated by using scanning electron microscope (SEM), X-ray diffraction (XRD) and Atomic Force Microscope (AFM). The results indicated that the increase in weight% of nano Cuo particles improves the mechanical properties.

1. Introduction

Metal Matrix composites (MMCs) reinforced with ceramic nanoparticles (less than 100 mm), which has been termed as Metal Matrix Nano Composites (MMNCs), have overcomes the disadvantages associated with the conventional MMCs [1]. When compared with the corresponding MMCs, the properties of MMNCs have enhanced considerably even with lower volume fraction of nanoparticles [2]. The nanosized fillers have been introduced into a metallic matrix because it has the potential to improve the mechanical properties, electrical properties and also to reduce the coefficient of thermal expansion and the coefficient of friction. The dispersion strengthening effect of carbon nanotube (CNT) material has a positive impact on the mechanical properties [3]. Hybrid composites possess better properties when compared with single reinforced composites as they combine the advantages of their constituent reinforcements [4]. Chandrakanth et al. [5] have developed a hybrid composite of copper metal matrix which has been reinforced with TiC and graphite particles through microwave processing. Different weight fraction nanoalumina particles have been injected with argon gas into the semi-solid state of A356 aluminium alloy and it has been stirred by a mechanical stirrer with different speeds [6]. A compocasting method has been employed to incorporate SiC nano-particles into the aluminium alloy and also fabricate the metal matrix nanocomposites with uniform reinforcement distribution [7]. The nano-sized ceramic particle content helps to strengthen the composites, while the ductility is retained [8]. The high yield strength and ultimate tensile strength are obtained with the addition of 3.5% SiC nano-particles [9]. To model and optimize the properties of nano SiC reinforced composites, a finite element method (FEM) with an artificial neural network based genetic algorithm (ANN-GA) model has been developed by Shabani [10,11].

Ma et al. [12] have used X-ray diffraction, metallography, tensile, dynamic compression and high-temperature creep tests to characterize the microstructure and mechanical properties of aluminium-matrix composites reinforced with nanomatric Si–N–C particles. Powder metallurgy (PM) techniques are the most preferred route for many researchers [13,14]. Nanocomposite samples prepared by plasma activated sintering composites show the structural soundness without the formation of observable defects or secondary phase clusters [15]. Wong and Gupta [16] have synthesized Magnesium composites, which containing different amounts of nano-sized Cu particulates by using microwave assisted two-directional sintering. They have also found that the mechanical properties such as hardness, elastic modulus, yield strength, and ultimate tensile strength are improved with the addition of nano-size Cu particulates. Raj et al. [17] have investigated the

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effect of sintering temperature and the time intervals on the workability behavior of Al–SiC powder metallurgy composites.

Singhal et al. [18] have fabricated Al-matrix composites reinforced with amino-functionalized carbon nanotubes by using powder metallurgy process. The tensile strength of aluminium matrix composites reinforced by carbon nanotube particles has been increased by the combination of spark plasma sintering followed by hot-extrusion processes [19]. Montealegre et al. [20] have obtained a superior mechanical and physical properties using nanosized diamond and carbon nanotubes as reinforcement in titanium matrix composites Qianqian et al. [21] have prepared CNT reinforced light metal composites by melt stirring and have showed the improved mechanical properties significantly. The hot working characteristics of extruded Mg/nano-Al_2O_3 (1 vol.%) Composite have been evaluated using a processing map and kinetic analysis [22]. SiC particles with an average size of 25 μm and Mica of 45 μm are uniformly dispersed in the aluminium matrix composites by using stir casting method [23]. Umanath et al. [24] have fabricated and conducted wear studies on Al6061/SiC/Al_2O_3. Esau et al. [25] have optimized the parameters of plasma sintering of aluminium/alumina agglomerated sludge composite by using Taguchi method for maximizing the bending strength. Dingal et al. [26] have used Taguchi method to find out the significant factors influencing density, porosity and hardness on selective laser sintering of iron powder. Siddhi Jailani et al. [27] have used grey Taguchi method to optimize the sintering process parameters of Al–Si (12%) alloy/fly ash composite.

Transition metal oxide such as copper oxide (CuO and Cu_2O), iron oxide (FeO, Fe_2O_3 or Fe_3O_4) and zinc oxide (ZnO) nanomaterials have special physicochemical properties which have arised from the quantum size effect and high specific surface area, which may be different from their atomic or bulk counterparts [28]. Zhanhu Guo et al. [29] have prepared and characterized vinyl-ester based nanocomposites reinforced with CuO nanoparticles. They have observed that, there is an increase of about 15% in the tensile modulus for CuO nanoparticles reinforced composites when compared with the cured pure resin. Rajmohan et al. [30,31] have found that the incorporation of nano Cuo particles improves the mechanical Properties in glass fiber and carbon fiber composites. Rajmohan et al. have used desirability analysis for optimization of sintering parameters in hybrid aluminium matrix reinforced with micro SiC particles, and nanocopper oxide (CuO) particles [32].

The literature has indicated that an extensive work has been carried out in the synthesis and characterization of various CNT particles reinforced aluminium matrix composites. Very limited investigations are available on transition metal oxide reinforced hybrid aluminium matrix composites. The present investigation focuses on synthesis and characterization of hybrid aluminium matrix reinforced with micro SiC particles, and nanocopper oxide (CuO) particles which have been prepared by sintering process. The mechanical behavior and microstructure of samples have been investigated and presented by scanning electron microscope (SEM), X-ray diffraction (XRD) and Atomic Force Microscope (AFM).

2. Experimental

2.1. Powders and mixtures

Atomised 99.5% purity aluminium powder manufactured by MEPCO, India and SiC, nano CuO powders manufactured by M/S US Research Nanomaterials Inc, USA are used as the initial materials for fabrication process. The chemical composition of the powders used in the investigation is presented in Table 1. Three mixtures of varying nano CuO content (0–2 wt%) are prepared. Al + 10% Sic, Al + 10% SiC + 1% nano CuO and Al + 10% SiC + 2% nano CuO powder mix are blended on a pot mill to achieve proper quality mixtures.

2.2. Compacts preparation

Powder compaction is the process of compacting metal powder in an die through the application of high pressure. The density of the compacted powder is directly proportional to the amount of pressure applied. In the present investigation, the typical pressures range used is from 55 to 66 N/m^2. The cylindricall work piece used in the work is made by single-level tooling. Green compacts of the powder blend are prepared for a 1.0 MN capacity hydraulic press by using a suitable punch and die assembly as shown in Fig. 1. The compact pressure is maintained for all composition of nano CuO composites to maintain the 90% relative density. The green compact surfaces are coated with aluminium paint and they are dried under the room-temperature conditions for a period of 7 h [17].

2.3. Sintering

The coated compacts are sintered in an electric muffle furnace in the temperature range of 580 ± 10 °C for a period of 180 min and they have allowed to be cooled at a room temperature in the furnace itself. The parameters used in compaction and sintering are presented in Table 2. The aspect ratio is maintained at 0.90 for all compositions of composites. The photograph of the sintered hybrid composites is presented in Fig. 2.

3. Results and discussion

Microstructure and mechanical characterization of sintered composites is carried out using metallographic examinations with Scanning Electron Microscopy (SEM), X-ray diffraction (XRD) analysis, Atomic force Microscope (AFM) analysis, hardness and density measurements. The sample preparation for microstructural study have been carried out first by polishing the sliced samples with emery paper up to 1200 grit size, followed by polishing with Al_2O_3 suspension on a grinding machine by using velvet cloth. Then, the samples are polished with 0.5 μm diamond paste. Metallographic specimens are prepared for microstructural observation by grinding up to 600 grits with SiC abrasive paper and then they are consecutively polished by diamond pastes of various sizes. The polished surface is etched with 10% NaOH solution and has been examined by using scanning electron microscope.

3.1. SEM analysis

The characterization of CuO nanoparticles and SiC particles dispersed in aluminium matrix composites have carried out by using Scanning electron microscopy (JEOL SEM) with EDAX energy dispersive X-ray spectroscopy (EDS) in order to evaluate the morphological changes observed in the nano Cuo powder particles and composites. The average size of CuO nanoparticles used in the present investigation ranges from 40 to 70 nm. From the Fig. 3 it has been confirmed that the average size of the dispersed nanoparticles is varying from 40 to 70 nm and further it has identified that the morphology of CuO nanoparticles are nearly spherical in shape. Fig. 4(a and b) shows the SEM micrograph of Al–10%SiC/nano Cuo composites. The distribution of the SiC and nano Cuo particles in the aluminium matrix is noticeably uniform. Homogeneous distribution of the reinforcement in the matrix is essential to form a composite with uniform mechanical properties. The produced