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Technical Report

Evaluation of mechanical properties of aluminium alloy–alumina–boron carbide metal matrix composites

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ABSTRACT

This paper deals with the fabrication and mechanical investigation of aluminium alloy, alumina (Al_2O_3) and boron carbide metal matrix composites. Aluminium is the matrix metal having properties like light weight, high strength and ease of machinability. Alumina which has better wear resistance, high strength, hardness and boron carbide which has excellent hardness and fracture toughness are added as reinforcements. Here, the fabrication is done by stir casting which involves mixing the required quantities of additives into stirred molten aluminium. After solidification, the samples are prepared and tested to find the various mechanical properties like tensile, flexural, impact and hardness. The internal structure of the composite is observed using Scanning Electron Microscope (SEM).

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1. Introduction

Nowadays, Metal Matrix Composites (MMCs) are under serious consideration to replace conventional materials for a large number of structural applications such as those in the aeronautical/aerospace, transportation, defence and sports industries because of their superior properties. The excellent mechanical properties and the comparatively low cost make them as an attractive option [1,2]. A large number of fabrication techniques are currently used to manufacture the MMC materials according to the type of reinforcement used like stir casting (or compocasting) [3], liquid metal infiltration [4], squeeze casting [5] and spray co-deposition [6]. Compocasting process involves the agitation of particulate reinforcement and semisolid metal (SSM). Rajan et al. [7] studied the effect of three different stir casting routes on the structure and properties of fine fly ash particles in reinforced aluminium silicon alloy composite and found that the separation of fly ash particles and its dispersion are more effective in compocasting method than in liquid metal stir casting due to the shearing of fly ash particles. Similarly, Rosso presented a paper on ceramic and metal matrix composites which focussed on different technologies involved, applications and future of advanced ceramics, metal matrix and ceramic matrix composites [8].

High homogeneity is required to attain optimum mechanical properties for the composite material. Therefore, the important parameters controlling the process must be identified and corrected in order to achieve a good quality composite. Tzamtzis et al. [9] worked on processing of advanced Al/SiC particulate metal matrix composites under intensive shearing and found that the distribution of the SiC particles in the metal matrix was improved significantly when the composites were produced using the Rheo-process. CFD with finite element analysis is also used to improve the distribution of the reinforcement in the matrix. Hashim et al. [10] investigated the effect of stirrer position in the crucible and stirring speed, on the flow pattern of particles using computer simulation and compared it with visualisation experiment results using glycerol and polystyrene particles in order to disperse reinforcement particles in the molten matrix as uniformly as possible. However, there are some problems associated with the fabrication of reinforced composites like the uneven distribution of the reinforcement in the matrix. The current processing methods often produce agglomerated particles in the ductile matrix and thus they exhibit extremely low ductility [11,12].

The microstructure is also a very important parameter which influences the properties of the composite. It was done earlier by trial and error methods which were later replaced by scientific based techniques. One such trial and error method was used by Rabiei et al. [13], who experimentally tested aluminium matrix composites with various particle reinforcements, to evaluate their fracture toughness and compare the experimental results with the

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fracture toughness estimates using the Hahn–Rosenfield model and found that there was a close agreement between the experimental results and the predicted toughness using the modified fracture model. Similarly, Narayana Murty et al. [14], worked on the hot working characteristics of 6061Al–SiC and 6061–Al_2O_3 particulate reinforced metal matrix composites for the development of processing maps. A simple instability condition for assessing the extent of plastic deformation in a work piece is derived based on the Ziegler's continuum principles. Raj [15] developed Ashby's concept of maps to construct a processing map, which represent the limiting for cavity formation at hard particles in a soft matrix occurring at lower temperatures and higher strain rates and vice versa.

Fly ash can also be combined with aluminium and magnesium alloys to produce a new type of MMCs called syntactic foams or Ash alloys [16–18]. The use of fly ash reduces the amount of waste product that would normally need to be disposed by the electrical industry in MMCs since the manufacture of aluminium and magnesium is energy-intensive. The replacement of a part of aluminium or magnesium by fly ash provides significant energy savings [19,20]. Its feasibility was studied by Rohatgi et al. [21] and it was found that the process of incorporating fly ash cenospheres in die cast magnesium alloy showed refinement in microstructure.

The agglomeration, non-uniform distribution and poor wettability of reinforcement used in squeeze or stir casting, spray forming and powder metallurgy techniques diminish the mechanical and electrical properties of the fabricated composites. Also, manufacturing cost of MMCs produced by the above method is high due to expensive equipment and complex processing routes. In order to overcome the above problems, Accumulative Roll Bonding (ARB) process is used to develop Al/B_4C composites, in which the particles were distributed evenly throughout the matrix; in addition particles agglomeration did not exist in their final composite [22].

Sharifi et al. [23] mixed B_4C nanoparticles with pure Al powder by ball milling to produce Al–B_4C powder. Al–B_4C powders containing different amounts of B_4C were subsequently hot pressed to produce bulk nanocomposite samples. The hardness, ultimate compressive strength and wear resistance, of the nanocomposites increased significantly by increasing the B_4C content in pure Al powder. Different techniques have been used for fabrication of Al–B_4C composites such as liquid phase methods [25] and solid-state consolidation (powder metallurgy).

A decrease in the reinforcement particle size to the nanometer range can improve mechanical and tribological properties of the aluminium matrix composites [26]. The formation of a mechanically mixed layer (MML) can act as an effective insulation layer that prevents metal to metal contact. Higher reinforcement content in the nanocomposite promotes stronger material transfer from the counterface and oxidation reaction, and consequently causes faster formation of more protective MML with higher thickness and higher amount of oxide compounds content on the worn surface, leading to the lower wear rate. This has also been confirmed by research findings [27].

2. Experimental details

2.1. Materials

In this work for preparing metal–matrix composite, aluminium alloy (LM 25) is used as base material; alumina and boron carbide in powder form are used as the reinforcements. Boron carbide having 220 mesh size, aluminium oxide and aluminium alloy ingot are required for the preparation. Aluminium alloy ingot is cut into small pieces of 1 cm × 1 cm × 3 mm, so that it can be easily placed in graphite crucible for melting.

2.1.1. Aluminium alloy (LM 25)

The tensile properties of aluminium alloy (LM 25) at elevated temperatures are influenced by the condition (heat treatment) of the castings and the duration at the elevated temperatures. The heat treated alloy has fairly good machining properties. They are of high resistance to corrosive attack by sea water and marine atmospheres.

2.1.2. Aluminium oxide or alumina

Aluminium oxide is a chemical compound of aluminium and oxygen having chemical formula Al_2O_3. It is commonly called alumina. Al_2O_3 is an electrical insulator but has a relatively high thermal conductivity ($30\ W\ m^{-1}\ K^{-1}$) like ceramic material. Its hardness makes it suitable for use as an abrasive and also as a cutting tool.

2.1.3. Boron carbide

Boron carbide is one of the most promising ceramic materials due to its attractive properties, including high strength, low density, extremely high hardness (the third hardest material after diamond and boron nitride), good chemical stability and neutron absorption capability [24]. Boron carbide has stability to ionizing radiation. It has toughness similar to diamond. It is difficult to sinter to high relative densities without the use of sintering aids. It has good nuclear properties. The properties of aluminium alloy (LM 25), alumina and boron carbide are shown in Table 1.

2.2. Fabrication procedure

The schematic diagram of stir casting for production of MMC is shown in Fig. 1. Stir casting is a primary process of composite production in which continuous stirring of molten base metal is done followed by introduction of reinforcements. The resulting mixture is poured into the die and allowed to solidify. In stir-casting, the particles often tend to form agglomerates, which can be only dissolved by vigorous stirring at high temperature. The various advantages of stir casting are simplicity, flexibility, applicability to large quantity, near net shaping, lower cost of processing and easier control of matrix structure. In this work, stir-casting method is used for preparing aluminium metal–matrix composite. This whirlpool technique provides high strength and homogeneous set of aluminium composite materials.

3. Experimentation

The experimental arrangement consists of the main furnace and components along with four mild steel stirrer blades. The first process in the experiment is preheating. Here, the empty crucible and the reinforcement powders, namely boron carbide and alumina powders are heated separately to a temperature close to that of the main process temperature. The melting of the aluminium alloy (95%) ingot is carried out in the graphite crucible inside the

Table 1
Properties of material used.

Material	Tensile strength (MPa)	Density (g/cm^3)	Coefficient of thermal expansion (10^{-6}/°C)	Modulus of elasticity (GPa)
Aluminium alloy LM 25 grade	190–250	2.68	2.2	71
Al_2O_3	255.2	3.98	7.4	380
B_4C	261	2.3–2.55	3.2	362

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