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Spark plasma sintering of graphite–aluminum powder reinforced with SiC/Si particles

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ABSTRACT

The growing demand for lightweight materials for a variety of engineering applications has led to increased researches on graphite and graphite aluminum composites. An attempt is made in this work to investigate the electrical conductivity of unreinforced graphite aluminum (Gr–Al) powder and graphite aluminum (Gr–Al) powder reinforced with 10 wt.% SiC and 10 wt.% Si using the spark plasma sintering techniques. In addition, a study of the microstructure and hardness of the resulting composite was done after full sintering at a pressure of 50 MPa and temperature of 550 °C. It was observed that the addition of 10 wt.% SiC and 10 wt.% Si improved the electrical conductivity of Gr–Al powder between 18.9 °C and 287 °C. The results of the composites showed that a relative density of 97.1% was achieved for Gr–Al sample sintered at 550 °C while 96.1 and 95.4% were obtained for Gr–Al 10 wt.% Si and Gr–Al 10 wt.% SiC respectively. The micro-hardness values are 26 ± 5, 26 ± 4 and 20 ± 3 $HV_{1.0}$ for Gr–Al (550 °C), Gr–Al 10 wt.% Si and Gr–Al 10 wt.% SiC respectively. The peak ratio values are very much improved in the hybrid composites produced. The study has shown that hybrid Gr–Al composite is a promising material for improved peak ratio and electrical conductivity.

1. Introduction

The high demand for lighter materials to replace aluminum and its alloys, particularly in the automobile and aerospace industries [1,2], has led to various researches and each of these efforts has produced one product or the other with various advantages and shortcomings [3]. Graphite (Gr) is known to be a material with high thermal conductivity, low coefficient of thermal expansion, low density and having a self-lubricating ability [4,5]. This has made it find applications in electronics as heat sinks [6,7], as die materials in sintering furnaces and recently, in the production of carbon pistons and engine block cylinder liners [8,9]. Despite all the interesting properties of graphite which make it useful in a wide range of engineering applications, it is however very difficult to consolidate [5]. Thus there has been a proposal for a graphite–particle dispersed composite produced by compacting graphite particles coated with a high thermal conductivity metal such as copper, silver or aluminum [3,10–15]. However, due to the problem of having good wettability between graphite and metal in the production of dense, high thermal conductivity composites, different efforts have been adopted to improve wettability and adhesion of graphite with the metal [16–18].

Studies have been reported on coating carbon fibers with silicon dioxide layers as well as using low melting point metals (Te, Bi, Pb, Sn, etc.) to improve wettability of graphite [3,16]. Zoltan et al. [16] observed that better performance of hybrid composites can be obtained if porosity is eliminated by improving the wettability of the reinforcing particles. Landry et al. [18] found that for graphite at temperatures less than 1273 K, aluminum and aluminum alloys do not wet graphite whatever the microstructure and texture of graphite materials.

A number of studies have been reported on varying fabrication techniques to improve the tribological properties [19–21], thermal properties [22,23], seizure resistance [24], and machinability [25] of graphite–aluminum composite. Most of these studies are however observed to be focused on casting, vacuum hot pressing, and pressure infiltration methods which have been reported to be hindered by three well known facts:(i) gasification of graphite, which initiates below the melting point of aluminum (ii) reaction between aluminum and graphite to form aluminum carbide, an unstable compound with very poor mechanical and thermal properties and (iii) poor wettability of the Al/Gr interface [4]. Little or nothing has been reported on the use of spark plasma sintering (SPS) techniques, which has recently been found to be an effective technique for fabrication of metallic and ceramic-based composites.

The advantages of SPS over other production methods include fast sintering, lower sintering temperatures, avoidance of grain coarsening, prevention of unwanted reactions among the different phases, effective consolidation and production of near net shape materials [26–29]. As there were limited reports in the literature on the spark plasma sintering of graphite–aluminum powder [3] as well as on the electrical resistivity during spark plasma sintering [30], it was decided in this

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Table 1
Elemental composition of the as-received Gr–Al powder.

Elements	C	O	Al	Si	Fe	Cu
wt.%	77.98	12.86	6.95	1.47	0.60	0.14

study, to investigate the spark plasma sintering behavior of graphite–aluminum powders and their electrical resistivity during sintering. It is conceptualized that the additions of SiC and Si particles as reinforcement are expected to improve the wettability and the infiltration of the metal into the graphite matrix, while information on densification behavior of the powders during sintering will be useful in understanding the electrical conductivity (inverse of electrical resistivity) and will also serve as data base for the use of graphite–aluminum in sintering furnaces and in electronics. Attention was focused on investigating the effect of the sintering temperature on densification process, porosity, microhardness, sintering, resulting microstructures and peak intensity ratio.

2. Experimental procedure

The starting powders used in this experiment are graphite–aluminum (Element Six Production, PTY Ltd. Company) Si (Alfa Aesar) and SiC (Carborundum Co. Ltd., Trafford Park, Manchester) powders with particle size of 80 μm, 45 μm, and 50 μm, respectively. The mixing of the powders in the pre-determined compositions (Table 1) was done using a T2F tubular mixer using a plastic bottle containing tungsten carbide balls, at a ball to powder ratio of 5:2 for 1 h at a speed of 101 rpm. The blended powders were sintered to discs of 30 mm in diameter using spark plasma sintering system model HHPD 25 manufactured by FCT Germany. The pressure in the chamber of the furnace was maintained at 1 mbar during consolidation while uni-axial compression was done throughout the sintering process with 50 MPa. Sintering was performed at a dwell time of 10 min at temperatures of 500, 550 and 580 °C using

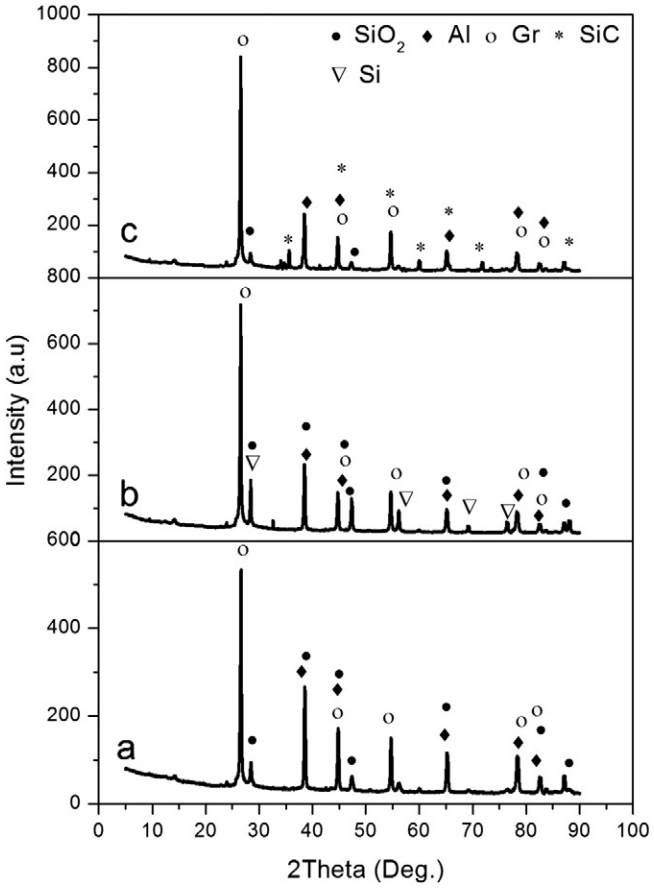

Fig. 2. XRD patterns of initial powders (a) Gr–Al, (b) Gr–Al 10 wt.% SiC and (c) Gr–Al 10 wt.% Si.

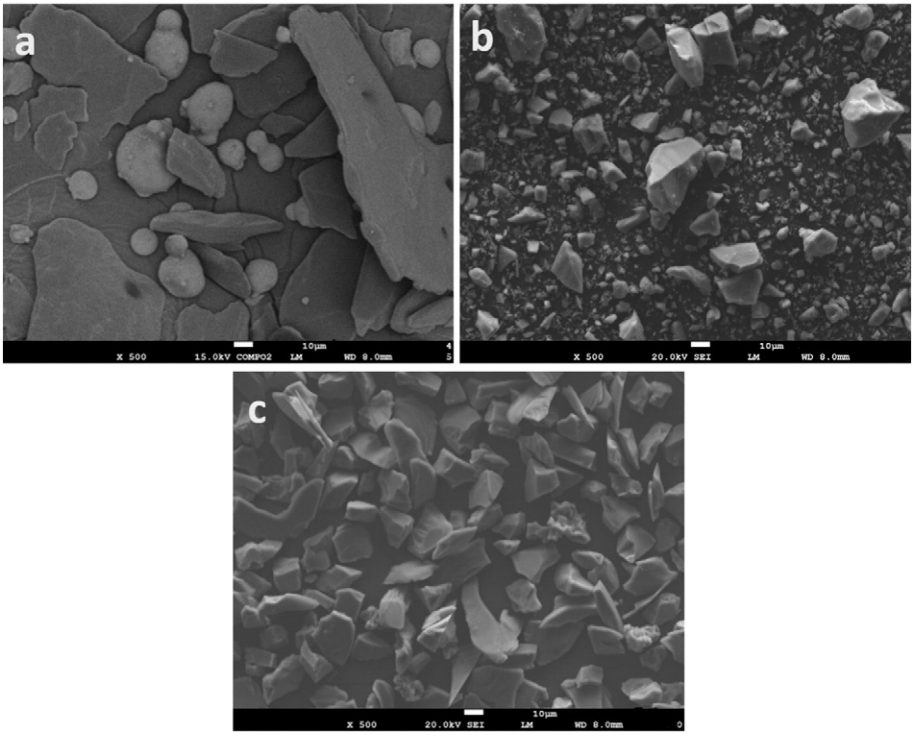

Fig. 1. SEM micrographs of initial powders (a) Gr–Al, (b) SiC and (c) Si.