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The Development of Molecular-Based Materials for Electrical and Electronic Applications

P. O. BABALOLA,[1,3] A.O. INEGBENEBOR,[1] C.A. BOLU,[1] and A.I. INEGBENEBOR[2]

1.—Mechanical Engineering Department, College of Science and Technology, Covenant University, Canaan Land, Ota, Ogun-State, Nigeria. 2.—Chemistry Department, College of Science and Technology, Covenant University, Canaan Land, Ota, Ogun-State, Nigeria. 3.—e-mail: phillip.babalola@covenantuniversity.edu.ng

Aluminum silicon carbide (AlSiC) metal matrix composite materials have a unique set of material properties that are ideally suited for electronics, hence the development of molecular-based materials (MBM) for the electrical and electronic industries. The low material density of AlSiC (3 g/cm^3) makes it ideal for weight-sensitive applications such as portable devices over traditional thermal management materials like copper molybdenum (10 g/cm^3) and copper tungsten (16 g/cm^3). The aim of this work is to develop MBM for electrical and electronic industries. Aluminum (99.66% C.P.) and silicon carbide (SiC) particulates of 240 grit (45 μm), 320 grit (29 μm), 600 grit (9 μm) and 1200 grit (3 μm) at 2.5% weight fraction were used to achieve the objective. The aluminum was melted at 750°C for 25 min in a graphite crucible tilting furnace designed for this work using oil as a firing medium. After melting, a two-step mixing method of stir casting technique was adopted. The cast samples were further analyzed for mechanical and electrical properties. The electrical properties were carried out by using a 4-point probe machine. The result showed that hardness increases at lower grit level, while the electrical properties marginally increased at higher grit. It is therefore recommended that, to make AlSiC composite materials for electrical industries, the higher grit of SiC should be preferred.

INTRODUCTION

Metal matrix composites (MMCs) are a range of advanced materials that can be used for a wide range of applications within the aerospace, automotive, nuclear, biotechnology, electrical, electronic and sporting goods industries.[1] MMCs consist of a non-metallic reinforcement incorporated into a metallic matrix which can provide advantageous properties over base metal. These include improved thermal conductivity, abrasion resistance, creep resistance, dimensional stability, and exceptionally good stiffness-to-weight and strength-to-weight ratios. They also have a better high-temperature performance. Hard and strong particles in the form of particulates or fibers are added to improve the thermo-mechanical properties and performance of the lightweight but comparatively soft host metal. Common reinforcement particles include ceramics such as silicon carbide and alumina, B_4C, Si_3N_4, AlN, TiC, TiB_2, TiO_2 and hard metals such as titanium and tungsten.[1–4]

Aluminum silicon carbide (AlSiC), an example of a metal matrix composite (MMC) material, has a unique set of material properties that are ideally suited for electronics, hence the development of molecular-based materials (MBM) for the electrical and electronic industries. The low material density of AlSiC (3 g/cm^3) makes it ideal for weight-sensitive applications such as portable devices over traditional thermal management materials like copper molybdenum CuMo (10 g/cm^3) and copper tungsten CuW (16 g/cm^3).[5]

MMC Processing Routes

Particle-reinforced metal matrix composites have already found commercial use because conventional

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processing techniques, such as powder metallurgy, vacuum hot pressing, co-spray deposition process, squeeze casting, and stir casting methods, can be readily adopted for the processing of such materials.[6] However, the stir casting method is preferred to other methods because it is cost-effective and the processing parameters could be readily varied and monitored.[4,7,9]

Electronic Packaging, Substrate, Heat Sink and IC Materials

Aluminum silicon carbide (AlSiC) metal matrix composite (MMC) materials have a unique set of material properties that are ideally suited for all electronic packaging applications requiring thermal management. The AlSiC coefficient of thermal expansion (CTE) value is compatible with direct IC device attachment for the maximum thermal dissipation through the 170–200 W/mK thermal conductivity values of the material [5,7] (see Table I). The thermal conductivity (K) and electrical conductivity (σ) vary in the same fashion from one material to another.[8] Additionally, the low material density of AlSiC makes it ideal for weight-sensitive applications such as portable devices. The aim of this work is to develop MBM for the electrical and electronic industries.

MATERIALS AND METHODS

In this work, the stir casting method was used to prepare samples of AMCs using aluminium (99.66%) reinforced with silicon carbide (SiC) powder molecules of 3 μm (1200 grit), 9 μm (600 grit), 29 μm (320 grit), and 45 μm (240 grit) sizes (Table II). The chemical composition of aluminium and silicon carbide are presented in Tables III and IV, respectively.

The liquid metallurgy route (stir casting technique) was adopted to prepare the cast composites as described below. A batch of 5.0 kg of aluminium was melted to 750°C in a graphite crucible using an oil-fired tilting furnace.[11] The molten metal was then poured into a mould preheated to 450°C and the melt was agitated with the use of a stirrer to form a fine vortex. SiC particles of 2.5 vol.wt.% preheated to a temperature of 1100°C for 2 h was added into the vortex with mechanical stirring at 500 rpm according to Abbassipour et al.[10] for about 5 min. Actual mixing occurs when the slurry is at semisolid form. This experiment was repeated for particle sizes 3 μm, 9 μm, 29 μm and 45 μm all at 2.5 wt.%.

Table II. Commercially available powder of silicon carbide

S/N	Micron (μm)	Grit
1	3	1200
2	9	600
3	29	320
4	45	240

Hardness Test

Hardness measurements were carried out using a micro-hardness tester, a LECO 700AT with a load of 492.3 mN and a dwell time of 10 s. Before testing, specimen surfaces were polished using emery papers down to 1000 mesh. At least 6 measurements were taken for each sample and the average was taken as the hardness value.

Electrical Conductivity and Resistivity

Samples of each cast were cut out and prepared in the machine shop for electrical conductivity testing. Test samples, having cross-sectional dimensions of 5 mm by 10 mm with a length of 26 mm, were prepared for testing in a 4-point probe set-up machine. The working voltage was 20 mV. Voltage, current, resistivity and conductivity were obtained from this set-up (Fig. 1).

Table I. AlSiC material properties compared with common packaging, substrate and IC materials[5]

Material	Density (g/cm^3)	CTE ppm/(25–150°C)	Thermal conductivity (W/mK)	Bend strength (MPa)	Young Modulus (GPa)
Si	2.3	4.2	151		112
GaAs	5.23	6.5	54		
AlSiC (63 v% SiC)	3.0	7.5	170–200	450	175
Kovar(Ni-Fe)	8.1	5.2	11–17		131
CuW (10–20% Cu)	15.7–17.0	6.5–8.3	180–200	1172	367
CuMo (15–20% Mo)	10	7–8	160–170		313
Cu	8.96	17.8	398	330	131
Al	2.7	23.6	238	137–200	68
SiC	3.2	2.7	200–270	450	415
AlN	3.3	4.5	170–200	300	310
Alumina	3.98	6.5	20–30	300	350
Beryllia	3.9	7.6	250	250	345

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Table III. The composition in % of aluminium ingots obtained from aluminium rolling mills, Ota, Ogun State

Fe	Si	Mn	Cu	Zn	Ti	Mg	Pb	Sn	Al
0.232	0.078	0.000	0.0006	0.0016	0.006	0.0027	0.0012	0.007	99.66

Table IV. The chemical composition in % of silicon carbide (SiC)

C	Al	Fe	Si	SiO_2	Magnetic iron	SiC
0.50	0.30	0.20	0.80	0.0016	0.04	97.6

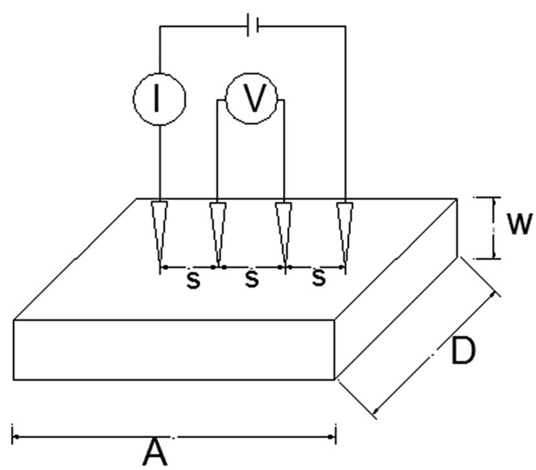

Fig. 1. Schematic illustration of the 4-point probe method.

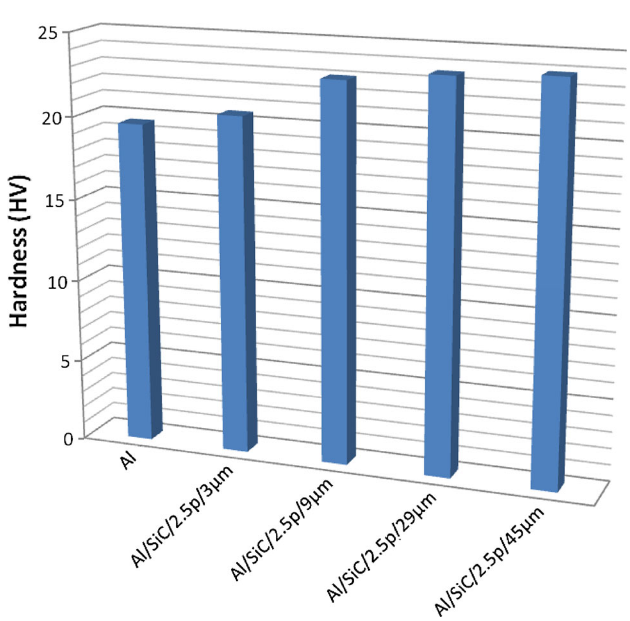

Fig. 2. Hardness of the Al/SiCp composite samples at 2.5 wt.% of SiC particles.

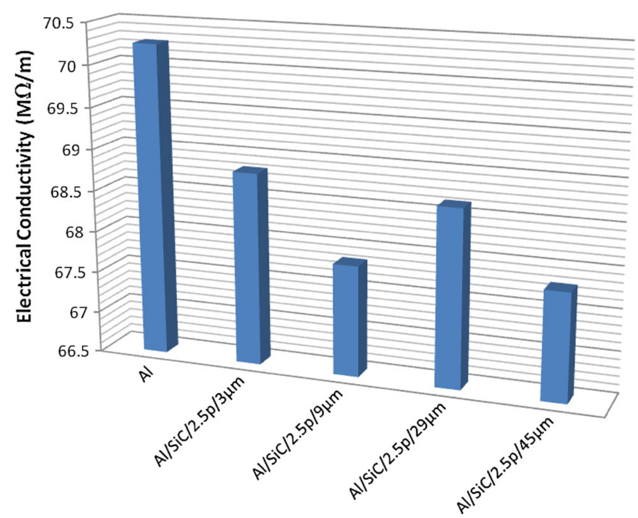

Fig. 3. Electrical conductivity of the Al/SiCp composite samples at 2.5 wt.% of SiC particles.

RESULTS AND DISCUSSION

The results of experimental measurement of hardness and electrical conductivity are shown in Figs. 2 and 3.

The hardness of the composite was found to be considerably higher than that of the matrix alloy and it increased with increasing particle size. The greater hardness of the composite samples relative to that of the matrix aluminium could be attributed to the existing hard particles (SiC) acting as obstacles to the motion of dislocation.

The electrical conductivity of composite materials was observed to be invariably lower than that of the monolithic aluminium-based metal. The electrical conductivity of the composite materials decreased with the increase in particle sizes and the volume percent of the reinforcement phase during stir casting. Non-linear behaviour between particle sizes and composite properties, as observed in Fig. 3, was also reported by Gopal et al.[12] However, the low

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material density of AlSiC (3 g/cm^3) makes it ideal for weight-sensitive applications such as portable devices over traditional thermal management materials like copper molybdenum (CuMo) (10 g/cm^3) and copper tungsten (CuW) (16 g/cm^3).

Also, the addition of SiC molecules, a ceramic powder, improved thermal stability of AlSiC material when compared to the monolithic aluminium. When this composite is attached as a heat sink to an IC device, stress failure would be avoided during service.

CONCLUSION

AlSiC metal matrix composite materials have a unique set of material properties that are ideally suited for electronics, hence the development of MBM for electrical and electronic applications. They have low material density (3 g/cm^3) when compared to traditional thermal management materials like CuMo (10 g/cm^3) and CuW (16 g/cm^3).

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