AJMC-P49

ARTICLE

# Producing AA1170 Based Silicon Carbide Particulate Composite through Stir Casting Method

P.O. Babalola[1,✉], C.A Bolu[1], A.O. Inegbenebor[1], O. Kilanko[1], S.O. Oyedepo[1] and K.M. Odunfa[2]

Asian Pub. Corp.

www.asianpubs.org

Asian Journal of Materials Chemistry

Volume: 2 Year: 2017
Issue: 3 Month: July-September
pp:
DOI: https://doi.org/10.14233/ajmc.2017.AJMC-P49

Received:
Accepted:
Published:

*Author affiliations:*

[1]Department of Mechanical Engineering, Covenant University, Ota, Nigeria
[2]Department of Mechanical Engineering, University of Ibadan, Ibadan, Nigeria

✉To whom correspondence to be addressed:

Tel: +234 80 34843286
E-mail: phillip.babalola@covenantuniversity.edu.ng

Available online at: http://ajmc.asianpubs.org

## ABSTRACT

Metal matrix composite (MMC) with improved thermal conductivity, abrasion resistance, tribology, creep resistance, dimensional stability, good stiffness-to-weight and strength-to-weight ratio will find application in the aerospace, automobile, mechatronics components (such as sensor) and other engineering outfits. In the present work, the aim is to develop aluminum (AA1170) based silicon carbide particulate metal matrix composites with an objective to develop a conventional low-cost method of producing MMC's, and to obtain homogenous dispersion of silicon carbide. To achieve these objectives two step-mixing methods of stir casting technique has been used. AA1170 and SiC (3, 9, 29 and 45 µm grit sizes) have been chosen as matrix and reinforcement materials respectively. Experiments have been conducted by varying weight fraction of SiC (2.5, 5.0, 7.5 and 10 %). The results indicated that the stir casting method is quite successful in obtaining uniform dispersion of reinforcement in the matrix. Measured properties of aluminium silicon carbide (composite) showed increase in young's modulus (E) and hardness above the unreinforced aluminium, however, there was marginal reduction of electrical conductivity in the composite

## KEYWORDS

Aluminium, Metal matrix composites, Silicon carbide, Stir casting, Mechanical properties.

## INTRODUCTION

Composites, in the broadest sense are materials comprising at least two distinct intended materials, providing superior performance or lower cost than that of the constituent materials alone (Fig. 1) [1]. The term was established in the aerospace industry and caught on elsewhere, perhaps because it became sort of a specialist word symbolic of high performance. Composites have come to be categorized by the matrix material, which contains the reinforcing elements.

Thus, there are many polymer-matrix composites (PMCs) *e.g.*, the most mature and widely used are the emerging metal-matrix composites (MMCs), ceramic-matrix composites (CMCs) and intermetallic-matrix composites (IMCs). There are also carbon-carbon composites (CCCs), containing the same basic material for both reinforcement and matrix. These are sometimes referred to as graphite-graphite composites. The matrix material

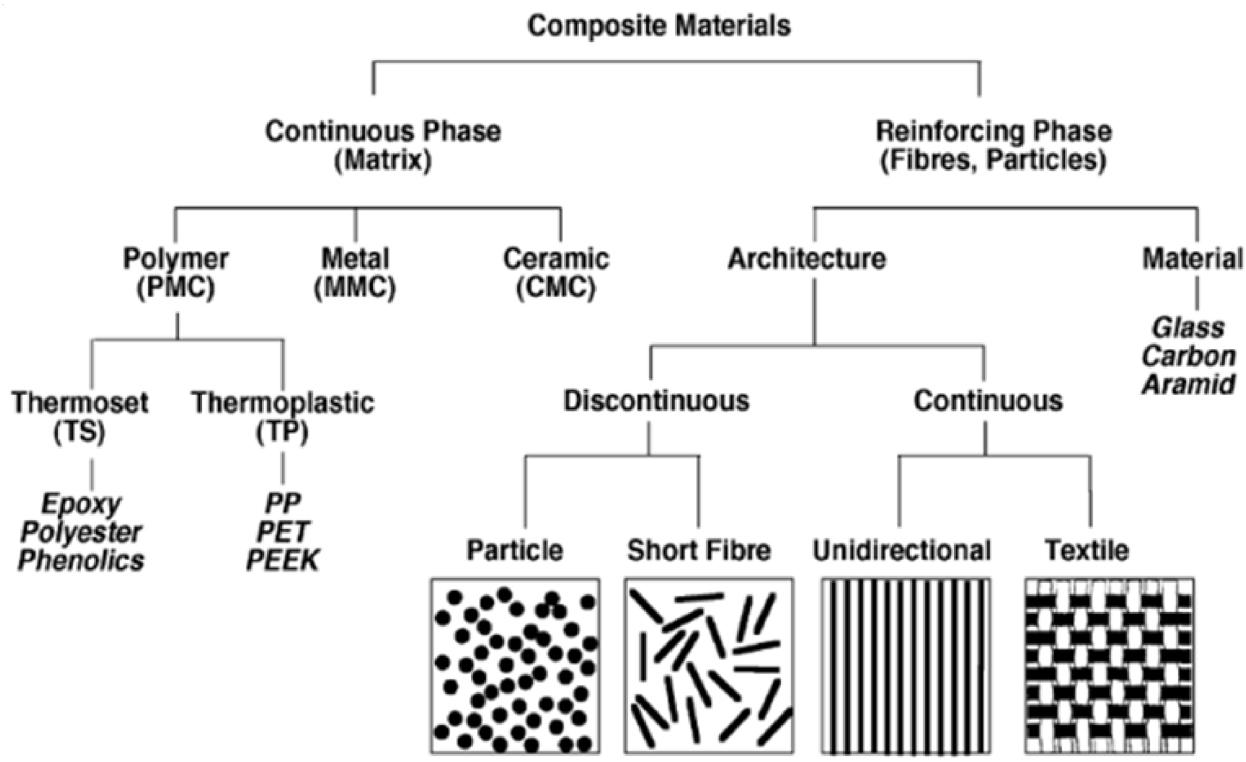


Fig. 1. Systematic illustration of the structural components of composite materials [Ref. 2]

generally governs the service temperature [1]. Metal-matrix composites (MMCs) as a class are far more heat-resistance than polymer-matrix composites and not as brittle like ceramic-matrix composites is a double advantage. Among the metal-matrix composites that have been made are aluminum, copper, cobalt, lead and magnesium reinforced with graphite. Boron has served as a reinforcement for aluminum, magnesium and titanium; silicon carbide for aluminum, titanium, and tungsten; and alumina for aluminum. Compared with polymer-matrix composites, applications so far have been limited and these are largely limited to aluminum.

**Aluminium matrix composites:** Aluminium matrix composites (AMCs) consist of a non-metallic reinforcement incorporated into aluminium matrix which provides advantageous properties over base metal (aluminium). These include improved thermal conductivity, abrasion resistance, creep resistance, dimensional stability, exceptionally good stiffness-to-weight and strength-to-weight ratios. They also have 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 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 [3-6]. Today, there is increasing use of metal matrix composites in the aerospace, automotive and bio-medical industries which resulted in the abundance of literature concerned with the processing, material characterization, properties and manufacturing of these composites [7].

**Aluminium matrix composite processing:** Particle reinforced metal matrix composites have already found commercial use on account of the fact that conventional 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 [8]. However, stir casting method is preferred to other methods because it is cost effective and processing parameters could be readily varied and monitored [6,9,10].

## EXPERIMENTAL

In this work, stir casting method was used to produce samples of aluminium matrix composites (AMCs) using 1170Al mixed with silicon carbide (SiC) particulates of 3, 9, 29 and 45 μm sizes, respectively. The chemical composition of aluminium and silicon carbide are given in Tables 1 and 2 , respectively.

TABLE-1
COMPOSITIONS IN PERCENTAGE OF ALUMINIUM INGOT 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-2
CHEMICAL COMPOSITION IN PERCENTAGE OF SILICON CARBIDE (SiC)

| C | Al | Fe | Si | $SiO_2$ | Magnetic iron | SiC |
|---|---|---|---|---|---|---|
| 0.50 | 0.30 | 0.20 | 0.80 | 0.60 | 0.04 | 97.60 |

The liquid metallurgy route (stir casting technique) was adopted to prepare the cast composites as described below. A batch of 5 kg of 1170Al was melted to 750 ºC in a graphite crucible using tilting furnace (Fig. 2) fired with diesel fuel. Temperature of the melt was measured using a K-type thermocouple. The molten metal was then poured into mould preheated to 450 ºC and the melt was agitated with the aid of mechanical stirrer to form a fine vortex. Silicon carbide particles of 2.5 vol. wt % preheated to a temperature of 1100 ºC was added into the vortex with mechanical stirring at 500 rpm for about 5 min [12]. Aluminium matrix composites (AMCs) having different particle sizes (3 , 9, 29 and 45 μm) and each size with different weight percentage (2.5, 5.0, 7.5 and10 wt. %) of SiC were fabricated by the same procedure.

**Tensile:** All specimens produced through stir casting method were cylindrical in shape and had dimensions of 110 mm diameter and 30 mm height. Five samples of each cast were cut out and prepared in the machine shop for tensile testing. Tensile test samples have cross sectional dimensions of 5 mm × 10 mm with a gauge length of 25 mm, were prepared for testing in Instron (Model 3369) Universal Testing Machine of 30kN load (ASTM International E8/E8M-09). Five measurements (modulus) were taken for each sample and the average taken as the parameter value.

**Microhardness:** Microhardness measurements were carried out using microhardness tester. Microhardness tester was LECO 700AT with a load of 492.3 mN and a dwell time of 10 s (ASTM Standard E 384). Before testing, specimen surfaces were polished using emery papers down to 1000 mesh. At least six measurements were taken for each sample and the average was taken as the microhardness value.

**Electrical conductivity and resistivity test:** Samples of each cast were cut out and prepared in the machine shop for electrical conductivity testing. Test samples having cross sectional dimensions of 10 mm × 10 mm with a length of 100 mm, were prepared for testing in 4 point probe set up machine. The working voltage is 20 mV. Voltage, current, resistivity and conductivity were obtained from this set up using Keithley Instruments Model 2400.

## RESULTS AND DISCUSSION

The results of experimental measurement of modulus, hardness and electrical conductivity are shown in Figs. 3-5.

The ratio of stress to strain is a constant characteristic of a material and this proportionality constant is called modulus of the material. It is a measure of the ability of a material to withstand changes in length when under lengthwise tension or compression and hence a desirable engineering property. It

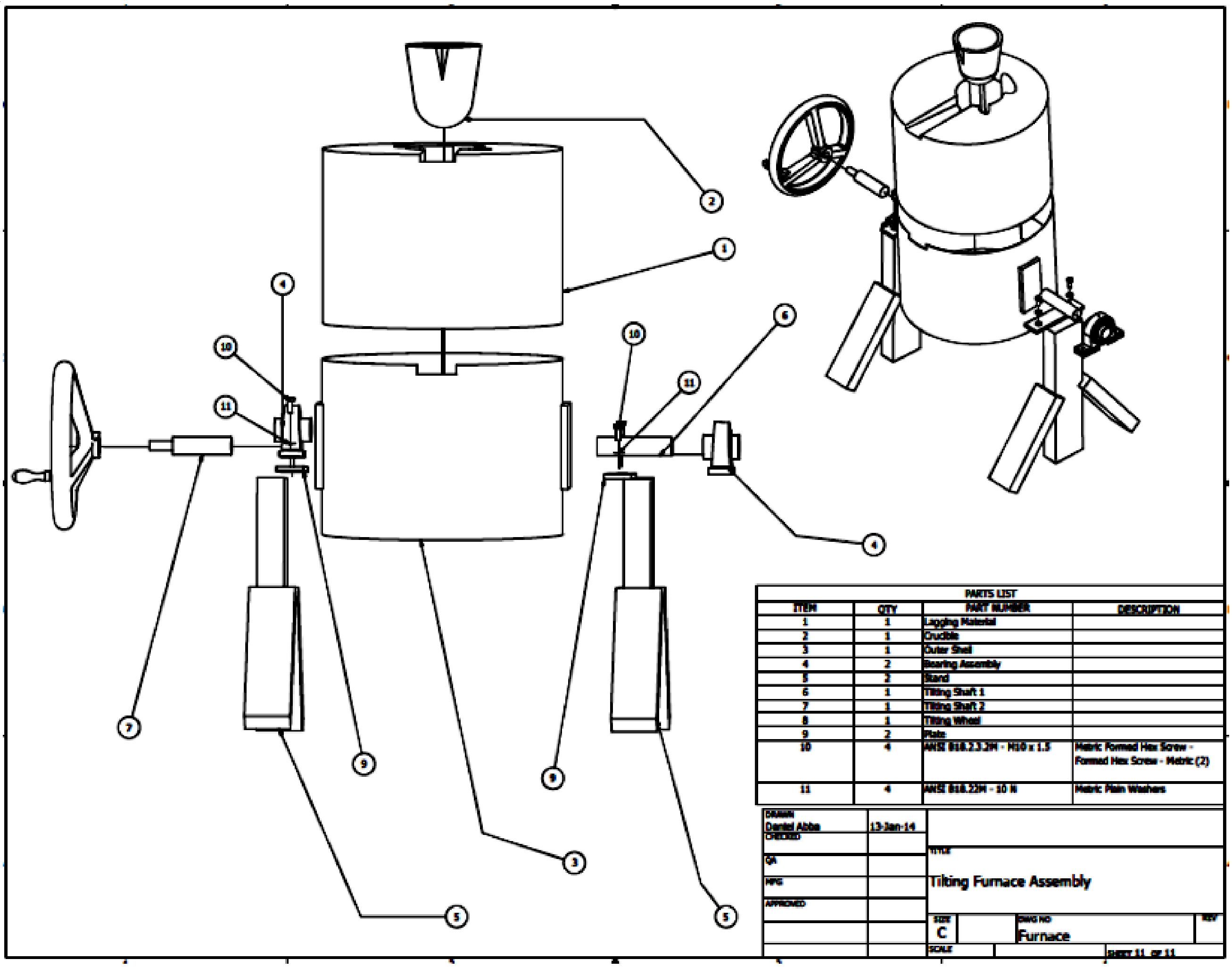


Fig. 2. Tilting furnace assembly drawing [Ref. 11]

could be seen that the modulus of the composites (after the addition of SiC to Al) are higher than the monolithic aluminium (Fig. 3). Though, aluminium is the primary load bearer, the observed increase in modulus is as a result of silicon carbide particles that served as blockage to dislocation movement and cracking in the aluminium matrix.

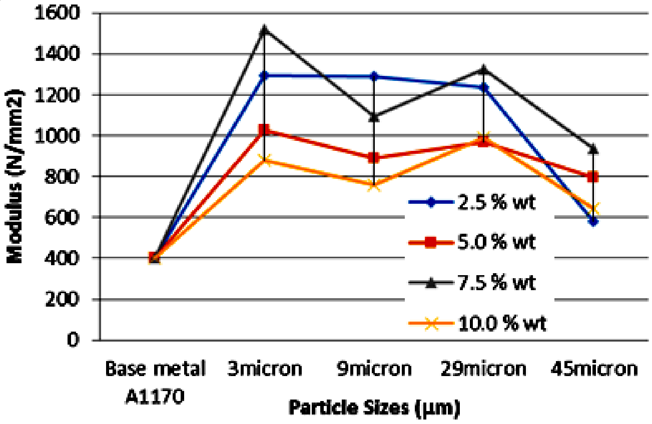


Fig. 3. Effect of particle size of silicon carbide on modulus (MPa) of AA1170/SiCp

Modulus is greatly enhanced by the addition of silicon carbide particles in all the specimens. A peak of 1517.59 MPa was recorded for 3 µm grit size composite compared with that of the base metal of 402.41 MPa. However, at higher size of 45 µm, there was reduction on modulus (935.03 MPa), although it was still higher than that of base aluminium matrix [13].

The hardness of composite was found to be considerably higher than that of the matrix alloy and increased with increasing particle size and percentage compositions of silicon carbide (Fig. 4). The higher 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.

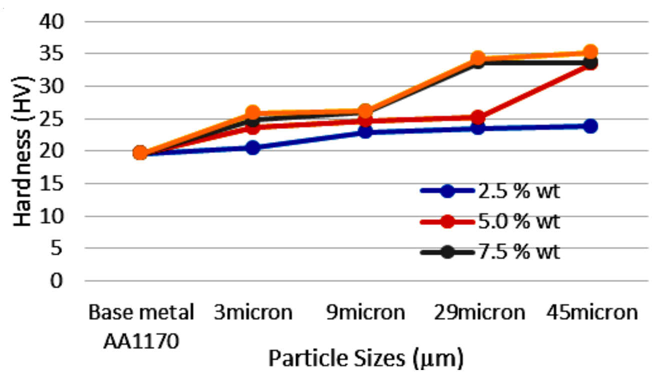


Fig. 4. Effect of particle size of silicon carbide particulates on the hardness of AA1170/SiCp

The electrical conductivity of composite materials was observed to be invariably lower than that of the monolithic aluminium-base metal. The electrical conductivity of composite materials decreases with increase in particle sizes and the volume percent of the reinforcement phase during stir casting (Fig. 5). The result is attributed to the presence of ceramic silicon carbide, a poor electrical and thermal conductor. However,

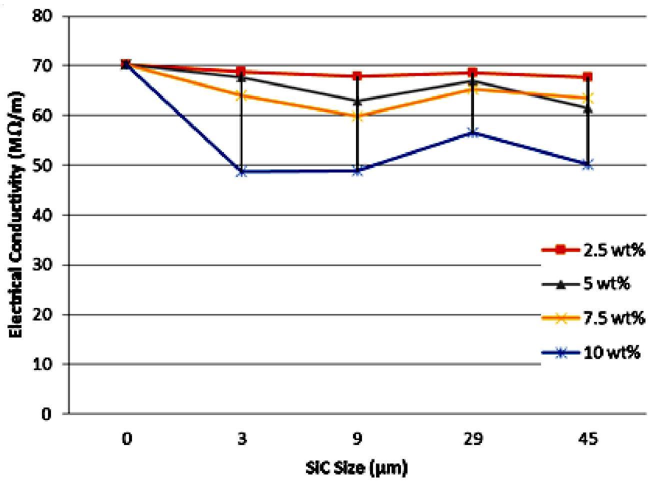


Fig. 5. Electrical conductivity of AA1170/SiCp composite samples as a function of SiCp particles sizes (2.5, 5.0, 7.5 and 10 % wt)

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$^3$) [14].

Also, the addition of silicon carbide 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

Conventional low-cost method of stir casting technique was used to produce aluminium silicon carbide (AlSiC). These metal matrix composite materials have unique set of material properties that are ideally suited for electronic, automobile, aeronautic and space machines. They have low material density (3 g/cm$^3$) when compared to traditional thermal management materials like copper molybdenum (CuMo, 10 g/cm$^3$) and copper tungsten (CuW, 16 g/cm$^3$). Structural packaging requirements are satisfied by the material strength and stiffness that are both approximately three times greater than aluminium metal. The result shows that modulus and hardness of the composite have higher value than the unreinforced aluminium.


## ACKNOWLEDGEMENTS

The authors thank Dr. S.O. Olusunle and Akinribide Ojo for their technical assistance during the mechanical and electrical tests performed at Engineering Materials Development Institute, Akure, Nigeria.


## REFERENCES


1. 1. S.G. Brady, R.C. Henry and A.V. John, "Materials, Their Properties and Uses," in *Materials Handbook*, 15th ed., New York: McGraw-Hill Handbooks, 2002, pp. 258-268.
2. Z. Zhang and K. Friedrich, *Compos. Sci. Technol.*, **63**, 2029 (2003); https://doi.org/10.1016/S0266-3538(03)00106-4.
3. 3. S.C. Tjong, "Recent advances in discontinuously reinforced aluminum based metal matrix nanocomposites," in *Composite Materials Research Progress* (ISBN: 1-60021-994-2), L.P. Durand, Ed. Nova Science Publishers, Inc., 2008, pp. 275-296.
4. E. Law, S.D. Pang and S.T. Quek, *Compos., Part B Eng.*, **42**, 92 (2011); https://doi.org/10.1016/j.compositesb.2010.08.002.

5. V. Senthilkumar and B.U. Omprakash, *J. Manuf. Process.*, **13**, 60 (2011); https://doi.org/10.1016/j.jmapro.2010.10.005.
6. B.A. Kumar and N. Murugan, *Mater. Des.*, **40**, 52 (2012); https://doi.org/10.1016/j.matdes.2012.03.038.
7. 7. O. Beffort, 'Metal Matrix Composites (MMCs) from Space to Earth" in Eiggenossische Materialprufungs-und Forschungsanstalt, EMPA, Abt. Werkstofftechnologie, Feuerwerkerstrasse 39, CH- 3602 Thun. Retrieved from http://www.empa.ch/abt126 on Oct.10, 2013.
8. B.F. Luan, N. Hansen, A. Godfrey, G.H. Wu and Q. Liu, *Mater. Des.*, **32**, 3810 (2011); https://doi.org/10.1016/j.matdes.2011.03.019.
9. 9. M.A.R. Adams, F. Kevin and A.H. Robert, "Aluminum silicon carbide (AlSiC) for advanced microelectronic packages", in *Ceramics Process Systems*, Corp. Chartley, MA 02712, 1998.
10. P.O. Babalola, C.A. Bolu, A.O. Inegbenebor and K.M. Odunfa, *Int. J. Eng. Technol. Res.*, **2**, 1 (2014).
11. P.O. Babalola, A.O. Inegbenebor and C.A. Bolu, "Design and construction of tilting furnace for producing aluminium matrix composites," Paper presented at International Conference on Clean Technology and Contemporary Engineering Management-ICCEM, Mechanical Engineering, Covenant University, Ota, Nigeria, 2012, pp. 260-271.
12. B. Abbasipour, B. Niroumand and S.M. Monir Vaghefi, *Trans. Nonferrous Met. Soc. China*, **20**, 1561 (2010); https://doi.org/10.1016/S1003-6326(09)60339-3.
13. P.O. Babalola, "*Development of Aluminium Matrix Composite (AMC) with Silicon Carbide Particles Using Stir Casting Method*". Ph.D Thesis, Covenant University, Ota, Nigeria: 2015, pp. 1-252.
14. P.O. Babalola, A.O. Inegbenebor, C.A. Bolu and A.I. Inegbenebor, *J. Minerals, Metals and Materials*, **67**, 830 (2015); https://doi.org/10.1007/s11837-015-1355-2.