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Reinforcement of AA1237 with Al₂O₃ to form Metal Matrix Composite

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Abstract-

The fabrication of advanced materials which possess an array of desired properties is a significant accomplishment of humanity. Composites are described as enhanced materials as they possess various advantages over conventional materials, which is why these composite materials are seen as viable alternatives in diverse engineering fields such as the aerospace, electronics and automobile industries. This work involved the fabrication of a metallic composite with the use of aluminium (AA1237) and crushed Al₂O₃ ceramic particles of 150nm and 600nm sizes as the reinforcement. The manufacturing of these composite samples was accomplished using the liquid phase process of stir casting, and they were subjected to various mechanical and electrical tests. For both hardness and tensile tests, the specimen Al/Al₂O₃/10p/150nm (10 per cent) had the highest values with 14.9 HBS and 124.41 MPa respectively. The electrical conductivity test affirmed the presence of non-conductive ceramic particles in the composite samples as the control (AA1237) had the highest conductivity value.

Key words: Aluminium, ceramic, aluminium matrix composite, hardness, tensile properties, electrical conductivity

1. Introduction

The sole aim of composite creation is to achieve a blend of properties which are not possessed by an individual material. Another objective of composites is to amalgamate the most desired features of the different components of the composite. The primary resolution is to enable transmission and allocation of the load to the reinforcement in the base matrix. The bonding and manufacturing technique governs the transmission of stress in the composite. Matrix selection transpires based on some properties such as corrosion resilience and oxidization, amongst others [1]. According to Yang et al. (2012), there are three major categories of composite materials which are extensively utilized in various forms of engineering practices: metal–matrix composites (MMC), ceramic–matrix composites (CMC)



and polymer–matrix composites (PMC) [2]. On the forms of reinforcement, composite constituents can be categorized into three types: particulate composites, structural composites and fibre-reinforced composites. For this study, metal matrix composites were produced using aluminium (AA1237) matrix and crushed ceramic particles as reinforcement. The stir casting technique is employed due to its numerous advantages over other methods. Such benefits include economic advantage over other techniques, flexibility in control and ability to cast large shapes in bulk. Figure 1 is a flowchart illustrating the stages involved in this research work [3].



Figure 1: A flowchart showing the systematic stages involved in the research project

2. Material Preparation

The materials used in this project were sourced locally as the A1237 aluminium (99.66%) was obtained from the Aluminium Rolling Mills in Ota in a block form. In contrast, the particulate alumina (Al_2O_3 -96% pure) according to American National Standards Institute (ANSI) A112.19.2 was obtained from the Civil Engineering Department in Covenant University. The ceramic alumina is in two different sizes; 150 nm and 600 nm respectively. The weight percentages of the reinforcement particles added to the aluminium matrix were 5% and 10%. With the use of the volume fraction formula, the mass of the ceramic appropriate from each composite sample was determined using equations 1-3. The developed aluminium metal composites are named using the modified nomenclature for metal matrix composite [4].

$$\%Rm = \frac{Rm}{Mm+Rm} \quad (1)$$

$$\%Mm = \frac{Mm}{Mm+Rm} \quad (2)$$

$$\%Rm + \%Mm = 1 \quad (3)$$

where:

R_m = Reinforcement mass

M_m = Matrix mass

% = Percentage

After deriving the reinforcement mass required for the 5% and 10% mass proportion for the two distinct grain sizes, the weight needed was measured with the use of electronic weighing scale (Figure 2). The naming of the composites is according to the standard stipulated by the Aluminium Association (AA) and are listed in Table 1.



Figure 2: Electronic Weighing Scale (Ohaus Model PA114)

Table 1: Materials preparation and designation

S/N	Sample	Composite designation (4)	Weight fraction of reinforcement(%wt)	The weight fraction of aluminium matrix (%wt)
1	A	Al	-	100
2	B1	Al/Al ₂ O ₃ /5p/150nm	5	95
3	B2	Al/Al ₂ O ₃ /5p/600nm	5	95
4	B3	Al/Al ₂ O ₃ /10p/150nm	10	90
5	B4	Al/Al ₂ O ₃ /10p/600nm	10	90

3. Stir casting technique

In the process of stir casting, the particulate reinforcement is introduced and blended with the metal in liquid form then the mixture is allowed to solidified [5,6]. In this work, the aluminium metal block was melted in oil-fired graphite crucible (Figure 3), followed by the introduction of pre-processed Al₂O₃ particles into the whirlpool of the metal matrix generated

by the rotary motion of the impeller [7]. One major shortcoming of the stir casting process is its inability to uniformly disperse the reinforcements, which leads to the formation of sediments in the matrix [8]. To minimize this, motorized impeller at a speed of 500 revolutions per minute was used during mixing before pouring to circular mould for solidification. The solidified samples are shown in Figure 4. The samples were machined in the machine shop at the department of Mechanical Engineering, Covenant University using power arc saw and lathe machine to obtain the specimen for tensile, electrical conductivity and hardness test (Figure 5 and 6).



Figure 3: Oil –fired Tilting Furnace



Figure 4: The fabricated composite samples



Figure 5: Circular shapes cut using a power hacksaw



Figure 6: Machining the tensile shape with the lathe machine

4. Material testing process

After machining the samples into the required shapes for the appropriate tests, hardness and tensile tests were conducted in the Department of Civil Engineering. At the same time, electrical conductivity was done in the Physics department.

Tensile test

With the use of a TQSM1000 Hydraulic Universal Testing Machine of mass 200kg and limit of 100KN force, the tensile test was conducted as all the samples. The tensile specimen was positioned employing gripping jaws at both ends of the sample one after the other and as the

actuator handle was pulled, the sample was stretched slowly at a constant rate to the point of failure, and the peak force was read via the display unit and recorded.

Hardness Test

The hardness test was conducted using the same TQSM1000 Hydraulic Universal Testing Machine in the Civil Engineering Department in Covenant University using a 10mm steel ball to create an indentation in the circular samples of varied thicknesses. The samples were first placed in the cavity of the machine and aligned with the steel ball, and then as the actuating lever was pulled, the peak force was recorded utilizing the display unit after a 15 seconds countdown. After the peak force had been recorded, with the aid of a magnifying glass possessing a measuring scale (granule), the diameter of the indentation was recorded for each of the samples.

In order to quantify the value of the Brinell hardness of each sample, the Brinell scale formula (Equation) was employed.

$$HBS = 0.102 \frac{2F}{\pi D (D - \sqrt{D^2 - d^2})} \quad (4)$$

Where,

HBS = H(Hardness), B(Brinell), S(Steel)

F = Force applied

D = Diameter of indenter

d = Diameter indented

Electrical testing

The electrical test was conducted in the Physics Department at Covenant University. The electrical test was used to obtain the values for the resistivity, conductance and conductivity of each sample by first getting the resistance of each sample. The simple circuit below drawn online on Autodesk tinkerCAD describes the circuit setup (Figure 7) used in the determination of resistance for each specimen.

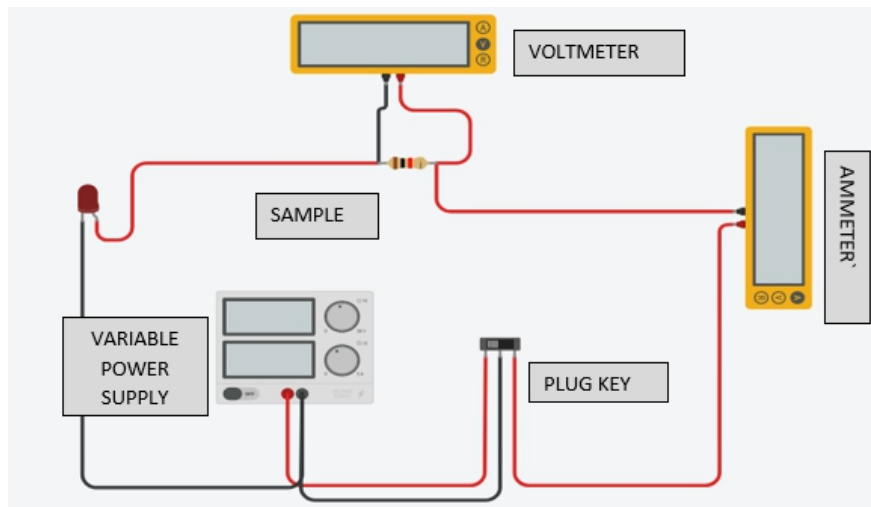


Figure7: Circuit used to determine the resistance of each sample drawn on Tinker CAD

5. Results and discussion

The values of the tensile, hardness and electrical conductivity tests on the base aluminium and four aluminium metal matrix composites (AMMC) which are Al/Al₂O₃/5p/150nm, Al/Al₂O₃/5p/600nm, Al/Al₂O₃/10p/150nm and Al/Al₂O₃/10p/600nm are presented and discussed below.

5.1 Tensile test results

From the graph in Figure 8, it can be deduced that there is higher ultimate tensile strength (UTS) for the composite samples in comparison with the control sample (AA1237). The composite which possessed the highest UTS value was sample Al/Al₂O₃/10p/150nm. This is due to the presence of hard ceramic alumina that acts as a stress barrier. Incoming stress formed successive Orowan loops round the hard-ceramic alumina in the aluminium matrix. The Orowan strengthening is also called dislocation loop (bowing). It is noted that all the composites with ceramic particles have better results for the UTS.

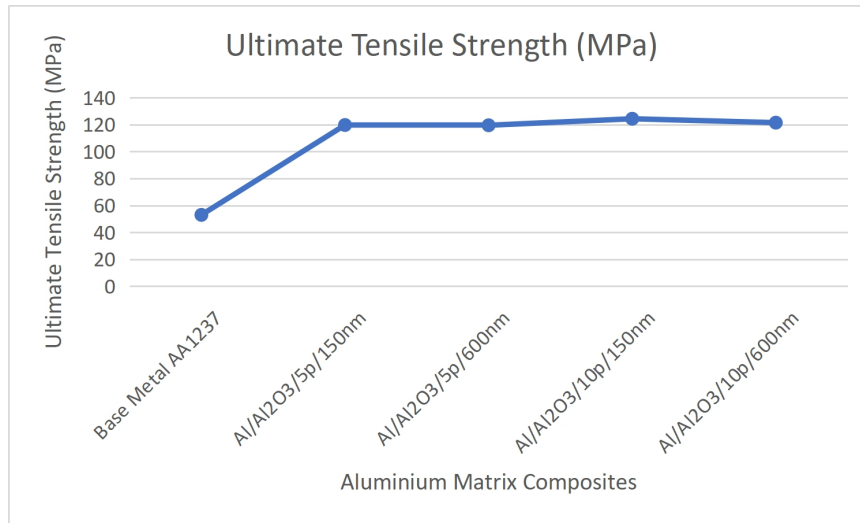


Figure 8: Graph for the Ultimate Tensile Strength test

5.2 Hardness test result

The result of the hardness test is shown in Figure 9. The addition of alumina, a ceramic material resulted in higher hardness value above the base aluminium metal in all the composites. However, hardness value for alumina with an average size of 150 nm is higher than that of 600nm counterpart for the same composition.

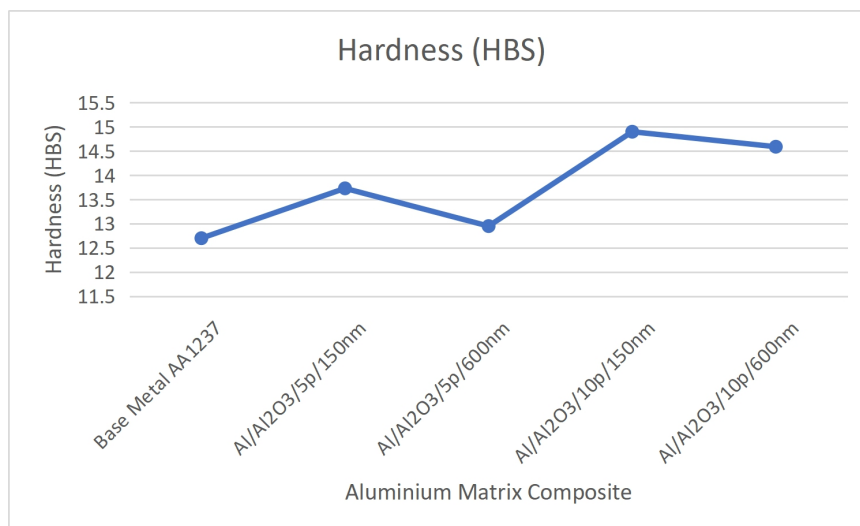


Figure 9: Graph for the Brinell Hardness Test

5.3 Electrical test results

The base metal (AA1237) possesses the maximum electrical conductivity value because it is pure aluminium. In contrast, the other samples possess much lower amounts of electrical conductivity arising from the non-conducting Al_2O_3 reinforcement material in each composite sample (Figure 10). The reduction of conductivity is not desirable in some applications; however, the presence of hard ceramic alumina ensure structural stability of the composite when used in the heat-sensitive environment. One application of this is heat sink in electronic circuits where they are attached to a heat-generating integrated circuit (IC) or diode.

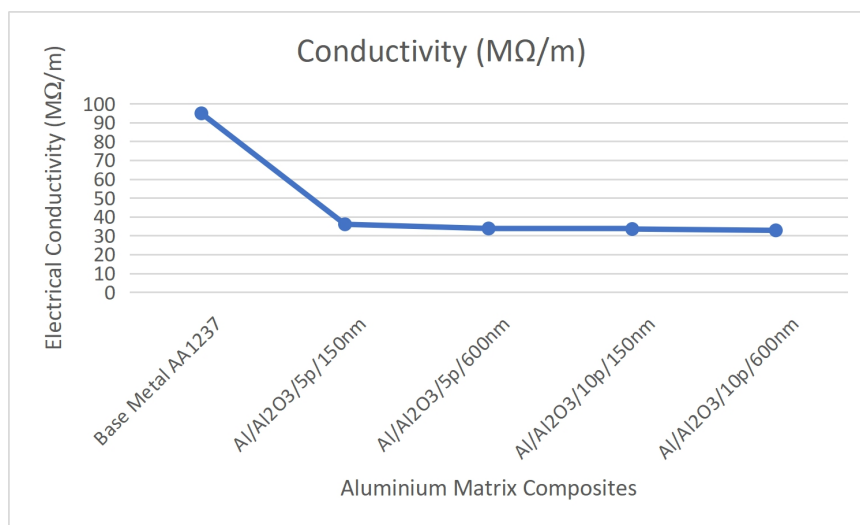


Figure 10: Graph for the electrical conductivity of each sample

6. Conclusion and recommendations

In this work, aluminium MMCs were fabricated from aluminium reinforced with ceramic particulates of 150nm and 600nm average sizes. Tensile, hardness and electrical conductivity experiments were conducted on the samples, and it was observed that specific material characteristics such as hardness and tensile strength were improved better than the monolithic material. The composites can be used for applications that require high hardness and tensile properties or heat dissipator in electronic industries.

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