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Synthesizing a Metal Matrix Composite (Al- Al_2O_3) from Aluminium (AA1237) Reinforced with Alumina (Al_2O_3) Particulates

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Abstract. Developing new materials with sophisticated material properties has been one of man's greatest achievement in recent times. Composite has been helping the aerospace, automobile and marine industries where weight shedding is an added advantage. New materials like carbon fibres and carbon nanotubes are now being used extensively in the manufacture of certain vehicles parts and components. This research project dealt with the synthesis of a metal matrix composite using aluminium (AA1237) as the base matrix and reinforcing it with alumina particulate (5% and 10%); a ceramic material of both 80nm and 500nm sizes. The composites were developed using the stir casting method and the casted samples were prepared and subjected to various material testing. For hardness test, the specimen C1 (reinforced with 10% of alumina 80nm) has the highest value with 14.9HB, for electrical test, it was seen that an increase in the amount of reinforcement further reduces the electrical properties such as conductivity. Other tests that could not be carried were predicted using the Rule of Mixture concept.
Keywords: Materials, composite, rule of mixture, properties

1. Introduction

Composite is made up of two major constituents, the matrix and the reinforcement. The main purpose of the matrix is to transfer and distribute the load to the reinforcement. Reinforcement takes different forms of fibres, particles, whiskers, and sheets. The composite load-carrying capacity depends majorly on the bonding type between the matrix and reinforcement and the fabrication route [1]. For example, in reinforced concrete, the matrix is the concrete (sand, cement, stone) mixture while the reinforcement is the steel bars. The reinforcement gives the matrix additional strength since concrete is weak in tensile but strong for compressive stress. Composite are classified based on the matrix material and they include metal matrix composite (MMC), ceramic matrix composite (CMC), polymer metal matrix (PMC) and carbon/graphite metal matrix (CGMC). In this work, metal matrix composite was synthesized using aluminium matrix (AA1237) and alumina particulates using stir casting method. Other processing routes are squeeze casting method, vapour deposition, powder metallurgy, vacuum hot pressing, and co-spray deposition process. Stir casting method is preferred to other methods because it is cost effective and processing parameters could be readily varied and monitored [2,3,5]. Below is a flowchart that describes the steps taken in the research.

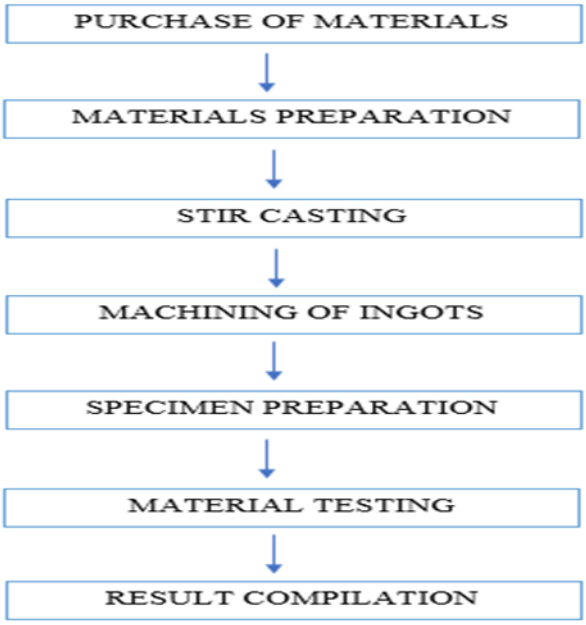

Figure 1: Show research flow chart timeline.

2. Material Preparation

Materials needed were sourced both locally and international, the aluminium ingot of 8.4kg was purchased from the local market here in Nigeria while the alumina particulate of two different grain sizes (80nm and 500nm) 100g each were purchased from US Research Materials, an American company that specialises in the processing, treatment and sales of chemical elements and compounds in the nanoscale. The weight percentage of reinforcement were at 5%, and 10% respectively. Using the volume fraction formula (Equation 1), the mass of alumina particulate required were calculated.

$$\frac{R_m}{M_m + R_m} = \%R_m \quad (1)$$

Where,
Rm = Mass of Reinforcement
Mm = Mass of Matrix

After calculating the required mass of reinforcement needed to achieve 5% and 10% mass fraction for both grain size (80nm and 500nm), the required mass was measured using a digital chemical balance, the result is populated below in the material table;

Table 1: Materials Preparation

S/N	SPECIMEN	SUB SPECIMEN	ALUMINIUM %	ALUMINA %
1.	**A**	-	100	-
	MASS	660g	660g	-
2.	**B (500nm)**	**B1**	95	5
		MASS	450g	23.69g
		B2	90	10
		MASS	430g	47.78g
3.	**C (80nm)**	**C1**	95	5
		MASS	510g	26.84g
		C2	90	10
		MASS	450g	50g

3. Stir Casting

Stir casting is one of the novel methods to produce metal matrix composites with more uniform distribution of matrix and reinforcement constituents. This approach involves mechanical mixing of the reinforcement particulates/particles into a molten metal bath [4]. The stir casting was done using an oil-fired furnace with graphite crucible to melt aluminium to 750^{0}C [5] with subsequent mechanical stirring. Many factors affect the final properties of the composite like how the variation in the geometry of the stirrer and the feeding mechanism affects the homogeneity of the material.

Figure 2: Showing the casted samples (A, B1, B2, C1 and C2)

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4. Testing

Previous researcher [6] have shown that there was significant improvement in material properties after the addition of such reinforcement. The tensile strength of Aluminium metal matrix composite was improved by the addition of the Al_2O_3 particles, the tensile strength and porosity of 6% vol of Al- Al_2O_3 composite decreased with increasing reinforcement. Percentage elongation of the composite decreased with increase in Al_2O_3 content which confirms that alumina increases brittleness. Increasing of hardness with increasing weight percentage of Al_2O_3 particles is mainly due to grain reinforcement and particle strengthen effects.

4.1 Hardness Test

The Brinell hardness test was done using a TQ SM1000 Universal Testing Machine with a steel ball of 10mm diameter indenter, the small circular samples were placed in a cavity aligned to the axis as the steel ball indenter, a lever is pushed dropping the steel ball on the sample using some form of hydraulic power, count for 15secs and then take the reading of the applied force on the digital readout display. Using a granule (magnifying glass with a measuring scale), the diameter of the indentation on the samples were measured. The Brinell hardness value was calculated using the Brinell scale formula.

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

Where,
HBS = H(Hardness), B(Brinell), S(Steel)
F = Applied force
D = Indenter diameter
d = Indentation diameter

Table 2: The Brinell Hardness Result

SAMPLE	APPLIED FORCE (N)	IDENTER DIAMETER(D) (mm)	IDENTATION DIAMETER(d) (mm)	HB (ROM PREDICTIED)	HB (ACTUAL)
A	6628	10	7.5	-	12.7
B1	6432	10	7.3	17.3	13.6
B2	6631	10	7.0	20.6	14.6
C1	6424	10	7.0	17.3	14.6
C2	6570	10	7.0	20.6	14.9

4.2 Electrical Test

For the electrical test, this was carried out in the Physics department of Covenant University, the aim was to determine the resistance offered by each of the five samples, then use the value to calculate conductance, conductivity and resistivity.

SAMPLE	VOLTAGE (V)	CURRENT (A)	RESISTANCE($\frac{V}{I}$) (Ω)	CONDUCTANCE($\frac{1}{R}$) (S)	CONDUCTIVITY ($\frac{1}{\rho}$) (S/m)	RESISTIVITY($\frac{RA}{L}$) (Ω*m) X 10^{-3}
A	0.38	2.17	0.175	5.714	94.876	10.54
B1	0.10	2.05	0.049	8	75.1	6.24
B2	0.62	2.17	0.03	3.5	40.16	10
C1	0.34	2.18	0.05	6.41	81.96	9.5
C2	0.10	2.13	0.047	5.13	78.1	4.03

Table 3: Electrical Result

4.3 Elemental Analysis

The spectrometer analysis was done at Aluminium Rolling Mills, Ota Ogun State. The elemental analysis was done using a Metavision 108N+ spark spectrometer for all samples. This was done to determine the exact sub-series of the 1000 series which contain the aluminium we used, from the analysis it was since that the aluminium was AA1237.

5. Results and Discussion

Rule of mixture is a predictive tool used to speculate some specific material properties of discontinuous and continuous composite using the volume fraction of both the matrix and reinforcement. The only hindrance to the rule of mixture concept is that it does not take in consideration the grain size of reinforcement used like the Hall – Petch model relation. The rule of mixture formula can be used to speculate properties like elastic modulus, ultimate tensile strength, mass density, thermal conductivity and electrical conductivity is given as:

$$E_c = ME_m + (1 - M)E_f \tag{3}$$

Where,
Ec = Designated material property of composite
Em = Designated material property of the matrix
Ef = Designated material property of the fibres
M = Mass fraction of the matrix in percentage = $\frac{M_m}{M_m + M_f}$

Using the rule of mixture concept, we were able to predict some important material properties.

5.1 Predicted Properties

Table 4: Predicted Brinell Hardness

S/N	VOLUME FRACTION (MATRIX) %	VOLUME FRACTION (REINFORCEMENT) %	MATERIAL PROPERTY (MATRIX) Mpa	MATERIAL PROPERTY (REINFORCEMENT) Mpa	COMPOSITE MATERIAL PROPERTY Mpa
1.	0.90	0.10	20	80	26
2.	0.95	0.05	20	80	23

Table 5: Predicted Young's Modulus

S/N	VOLUME FRACTION (MATRIX) %	VOLUME FRACTION (REINFORCEMENT) %	MATERIAL PROPERTY (MATRIX) Mpa	MATERIAL PROPERTY (REINFORCEMENT) Mpa	COMPOSITE MATERIAL PROPERTY Mpa
1.	0.90	0.10	68.5	375	99.15
2.	0.95	0.05	68.5	375	83.83

Table 6: Predicted Density

S/N	VOLUME FRACTION (MATRIX) %	VOLUME FRACTION (REINFORCEMENT) %	MATERIAL PROPERTY (MATRIX) kg/m³	MATERIAL PROPERTY (REINFORCEMENT) kg/m³	COMPOSITE MATERIAL PROPERTY kg/m³
1.	0.90	0.10	2700	3960	2826
2.	0.95	0.05	2700	3960	2763

5.2 Hardness Result

From the graph below, it is seen that the sample C2 has the highest hardness value with a value of 14.9 MPa. It is also seen that there is a positive trend to the graph which suggests that an increase in the volume fraction of reinforcement leads to an increase in hardness value of samples and C2 having the highest value means that nanocomposite have better hardness value than micro composites with the same volume fraction of reinforcement.

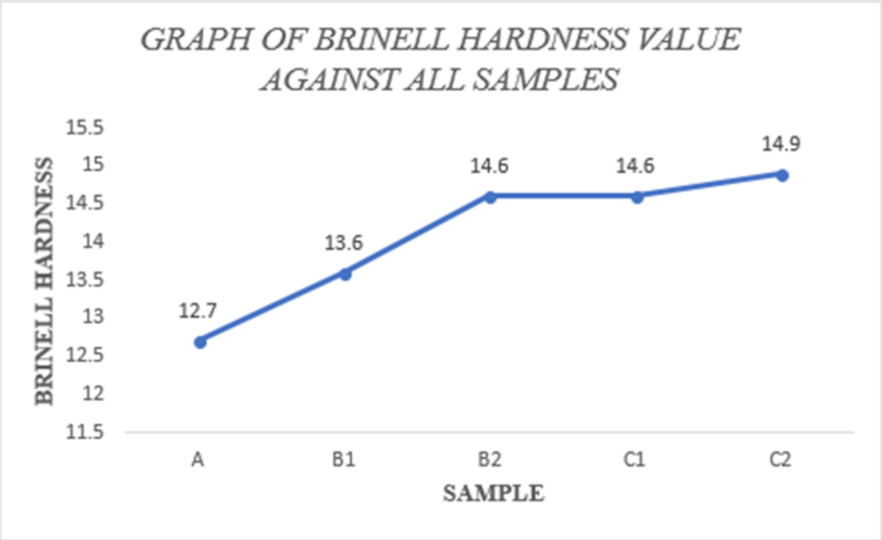

Figure 3: A graph of Brinell Hardness against all samples

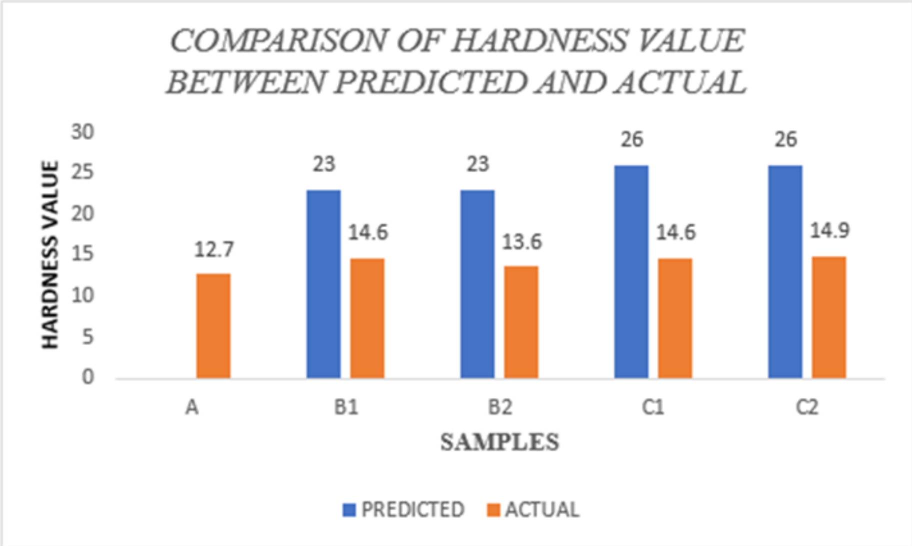

Figure 4: A comparative graph between ROM and actual Brinell Hardness value.

From graph, it is seen that the predicted value for hardness exceeds the actual for both the 5% and 10% reinforcement of both sizes, this is not questionable or strange because the rule of mixture does not take into consideration factors that can affect the final properties of the composite such as grain size, type of matrix and reinforcement used, processing route, physical and chemical properties of both matrix and reinforcement.

5.3 Electrical Result

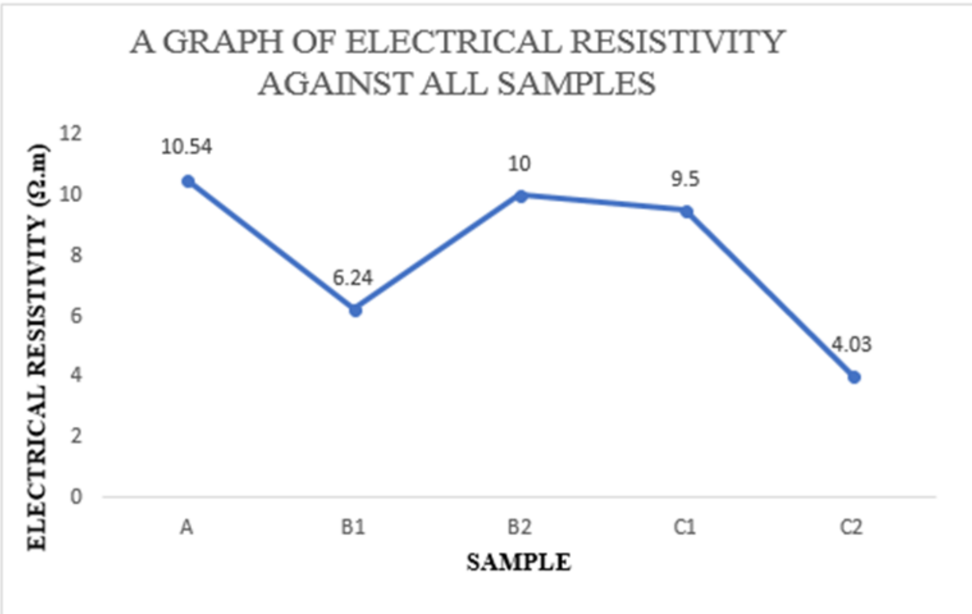

Figure 5: A graph of Electrical Resistivity against all samples.

From the graph above, it is seen that the sample with the highest value for electrical resistivity is sample A (pure aluminium AA1237) and the lowest value was sample C2 (reinforced with 10% of 80nm). Ideally, electrical resistivity is meant to be either sample C2 or B2 because alumina is a ceramic material and also an electrical insulator and an increase in volume fraction used should increase the electrical resistance of the composite.

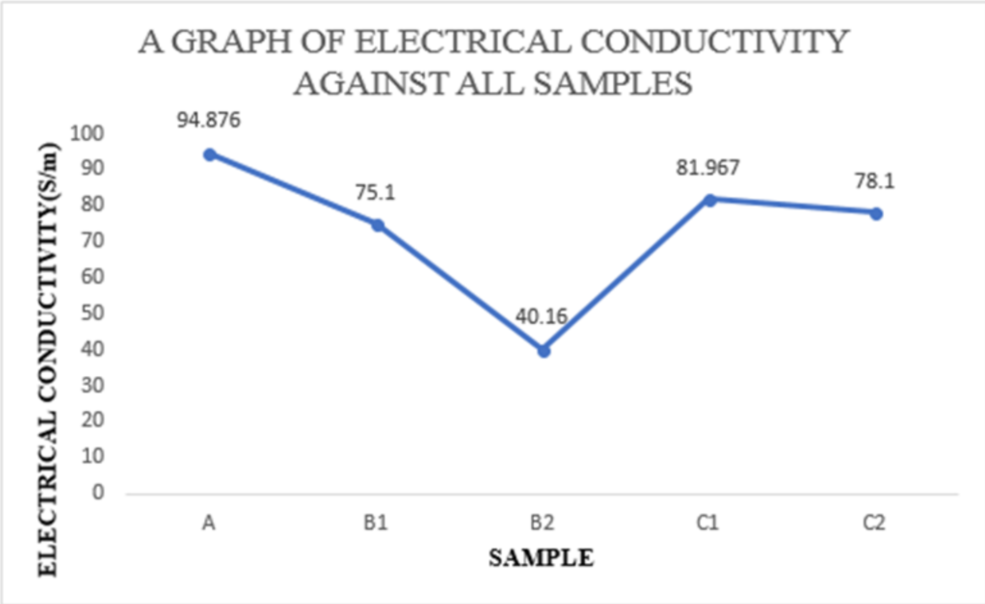

Figure 6: A graph of Electrical Conductivity against all samples

6 Conclusion and Recommendations

6.1 Conclusion

For this research work, a metal matrix composite was developed form aluminium (AA1237) reinforced with alumina particulate (80nm and 500nm) sizes, using various material testing method and from the experiments carried out in line with experimental results, it can be seen that specific material properties like hardness, conductivity and resistivity was improved and was also better than the monolithic material. Specific material properties like hardness was seen to improve by a large margin, suggest that it can be used for an application requiring high hardness. Other material test that could not be done was estimated using rule of mixture concept.

6.2 Recommendations

- All casting should be carried out the same day to avoid variance in various properties of composites.
- When quenching the casted sample, it is advisable to allow the samples to cool down in air.
- More test such as wear test, thermal conductivity test and mechanical test should be carried out for further verification of improvement in material properties.
- More focus on developing bio-composites using biological materials like fly ash, rice husk, and animal bones as reinforcement. These are not expensive, easily accessed and available in large quantities.

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