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EFFECTS OF PARTICULATE ADDITIVES ON THE MECHANICAL PROPERTIES OF ALUMINUM ALLOYS PRODUCED VIA SPIN CASTING

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Abstract: Industrial development is growing at a very high rate and there is need for new materials. Spin casting has emerged as one of the best casting techniques in composite production. In this study, the effect of particulate addictives on the mechanical properties of aluminium alloy produced via spin casting was investigated. The materials used for the composites production were Al 6063, pulverized laterite and titanium dioxide (TiO_2). From the results, it was discovered that the reinforcement were uniformly distributed within the Al 6063 matrix. Composition 3 has the highest hardness value of 75.7 HRC, with 8 wt% of titanium dioxide (TiO_2) to 12 wt% of laterite. As from composition 2, increase in titanium dioxide and reduction in laterite led to reduction in ultimate tensile strength as a result of reduction in dislocations barrier in the microstructure.
Keywords: spin casting, aluminium alloy, composites, mechanical properties

1. INTRODUCTION

A composite material is made by combining two or more materials to give a unique combination of properties [1]. Metal Matrix Composite (MMC) has been playing a significant role in engineering applications particularly in light weight materials. Aluminium matrix composites (AMCs) with their enhanced strength, improved stiffness, reduced density, improved abrasion and wear resistance offer better alternative to existing materials used for structural, non structural and functional applications such as aerospace, automotive engine, electronic packaging, precision instruments and sports equipment [2-4]. The development and introduction of low cost and high performance advance engineering materials for various engineering applications has continued to draw the attention of researchers in material engineering field, several authors have reported about the design of metal matrix composites.[5]. Commonly used reinforcement in AMCs are of micro level, however technological advancement in nano sciences makes it possible to use nano sized reinforcement in metal matrix composites and these are termed as Metal Matrix Nano Composites (MMNCs).

The areas of application of Al based composites is expected to continue growing, this is as a result of its the attractive property spectrum possessed by AMCs and the relative low cost of production in comparison with other competing MMCs (such as Magnesium, Copper, Titanium and Zinc) for similar applications [3]. Nigeria, as a nation is blessed with abundance of laterite and titanium dioxide which are good reinforcement materials for production of composites at lower cost. The aim of this research, therefore is to determine the effects of particulate additives on the mechanical properties of aluminum alloys produced via spin casting

2. METHODOLOGY

— Material and method

The materials used for the work were scraps of Aluminium (pure Al) purchased from Aluminum alloy 6063 from Nigalex aluminum company, Oshodi, Lagos state. Laterite soil and Titanium dioxide (locally known as Moju powder) was sourced locally from Akure, Ondo state, the laterite was grinded and pulverized using the ball mill. This was further sieved using 300µm sieve. Nigeria. Wooden patterns with diameter of 22mm by 155mm long were used. Natural sand was used to prepare the sand mould, a mixture of silica sand with considerable amount of bentonite. The addition of bentonite improved the bonding strength. The moulding of the pattern was carried out using a moulding box comprising of cope and drag that gave rigidity and strength to the sand. Parting sand was properly applied for the easy removal of the mould from the pattern. The gating system was properly designed for smooth channeling of the molten metal into the mould cavities through the sprue, runner, in-gates and riser that were perfectly placed in position. Spin casting technique was used for the casting operation. The quantity of Titanium Oxide and Laterite were determined by charge calculation to give 20 wt% reinforcement consisting of varying ratios of Titanium - Laterite in the order of 0:20, 4:16, 8:12, 10:10, 12: 8, 16:4 and 20:0 to produce the composites.

The cast aluminium scraps, titanium oxide and laterite were carefully worked out and charged into the furnace.

Table 1. Chemical composition of aluminium scraps

Si	Fe	Cu	Mn	Mg	Zn	Cr	Ti	Al
0.40	0.24	0.03	0.04	0.55	0.03	0.01	0.02	98.68

Table 2. Chemical composition of Laterite

SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
44.90	16.74	16.67	0.97	0.12	0.17	10.07	0.18	1.18	0.07

Table 3. Mass of the matrix and the reinforcement for each composition

	Mass of Al (g)	Mass of TiO_2 (g)	Laterite (g)
CONTROL	814.29	---	---
COMPOSITION 1	550.10	---	137.53
COMPOSITION 2	622.48	31.85	124.50
COMPOSITION 3	644.20	64.42	96.63
COMPOSITION 4	656.26	82.03	82.03
COMPOSITION 5	668.32	100.25	66.83
COMPOSITION 6	690.04	138.01	34.50
COMPOSITION 7	714.17	178.54	---

Crucible furnace was used for the melting of the charges. Prior to the charging, preheating of titanium oxide (TiO_2) and laterite were done at a temperature of 250°C to aid removal of moisture content and improves wettability with the molten Al. The aluminium was melted in the crucible furnace, at temperature of 700°C, the aluminium melted completely. After which the preheated titanium oxide (TiO_2) and laterite were charged into the melt while stirring was done manually for 5-10 minutes. The process continued with the superheating of the composite. The spin casting machine was switched on and set at 800 rpm, and the melted composite was poured into the mould. After 10 minutes, the spin casting machine was switched off and the cast composite was left to cool to room temperature for the cast composite to be removed.

— Microstructure

The specimens for the optical microscopy were properly polished using emery papers of various grit sizes ranging from 500μm to 50000μm. The fine polishing was equally ensured using a polycrystalline diamond suspension of particle sizes ranging from 10μm to 0.5μm with ethanol solvent, after which the specimens were etched in HNO_3. Hydrochloric acid was used to swab the surface before microstructural examination was performed using Datteng- Driven Metallurgical Software [6].

— Hardness

Hardness is the measure of a material's resistance to surface indentation. The hardness for the test samples were evaluated using a Vickers Hardness Tester (LECOAT 700 Microhardness Tester). Eight test specimens for spin casting process were polished to obtain flat and smooth surface finish after this, a direct load of 490.3 MN was applied on the specimens for 10 seconds and the hardness reading evaluated following standard procedures, the average readings were calculated and recorded as the hardness

— Tensile Strength Test

The samples were machined with universal Lathe Machine TYPE C80 to produce standard test samples [7]. Instron universal tensile testing machine of model 3369 at the speed of 0.02m/s was used to carry out the tensile test by subjecting it to 10KN load.

— Fracture Toughness (K_{ic}) Evaluation

The fracture toughness of the composites was determined using circumferential notch tensile (CNT) specimens in accordance with Alaneme, 2011[8]. The composites were machined for the CNT testing and the corresponding gauge length of 27 mm, specimen diameter of 5.11mm (D), notch diameter of 3.6mm (d), and notch angle of 60^0 were noted. An instron universal testing machine was used to test for the tensile loading to fracture. The load to fracture (Pf) was obtained from the CNT specimens and the load – extension plots were used to estimate the fracture toughness using the relations according to Dieter, 1988 [9]:

$$K_{IC} = \frac{Pf}{D^{3/2}} \left[1.72 \left(\frac{D}{d}\right) - 1.27\right]$$

where; D and d are the diameter of the specimen and the diameter of the notched section respectively. Evaluation of the fracture toughness was determined according to the relation [10]:

$$D \geq \left({}^{K_{IC}}/_{\sigma y}\right)^2$$

Using the above relation, the value of fracture toughness for each samples were determined.

Figure 12: Circumferential Notch Tensile (CNT) specimen

3. RESULT AND DISCUSSION

In Figure (1-8), it was observed that there were good bonding between the matrix and the reinforcement particulates resulting in better load transfer from the matrix to reinforcement material and also even distribution of reinforcements in the matrix as a result of rotational movement of the mould during casting [11].

Figure 9 is graph showing the effect of titanium oxide (TiO_2) and laterite on the hardness of cast composites. Figure 9 shows that there was an increase in the hardness of the composites produced with the addition of titanium oxide and laterite. With the addition of 20 wt% of laterite the hardness value increase by 14.8%, with reduction in laterite to 16 wt% and addition of 4 wt% of titanium dioxide, the hardness increased by almost 2 % in composition 1. The hardness value of composition 3 was the highest, with 8 wt% of titanium dioxide and 12 wt% of laterite. There was reduction in hardness with further increase in titanium dioxide and reduction in laterite. This is similar to the result obtained by Sharma *et al.*, 2015 [12], when he investigated the effect of microstructure on mechanical properties of aluminium alloy.

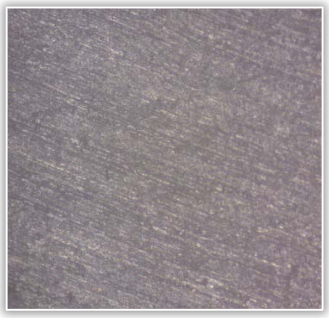

Figure 1: Control

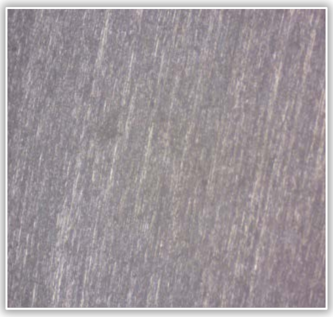

Figure 2: Composition 1

Figure 3: Composition 2

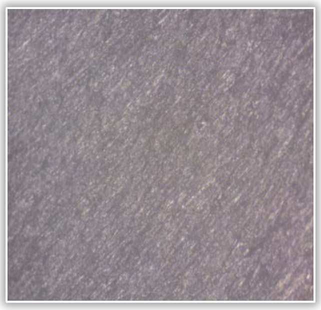

Figure 4: Composition 3

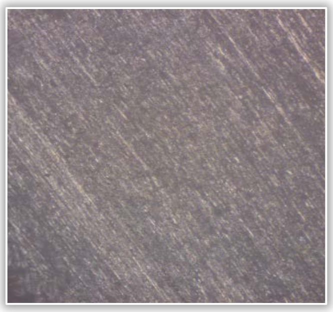

Figure 5: Composition 4

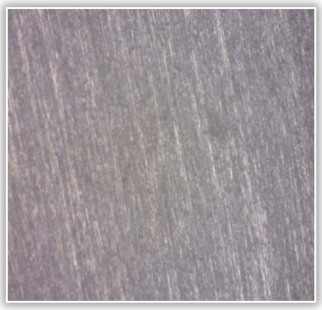

Figure 6: Composition 5

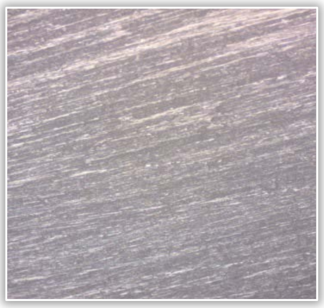

Figure 7: Composition 6

Figure 8: Composition 7

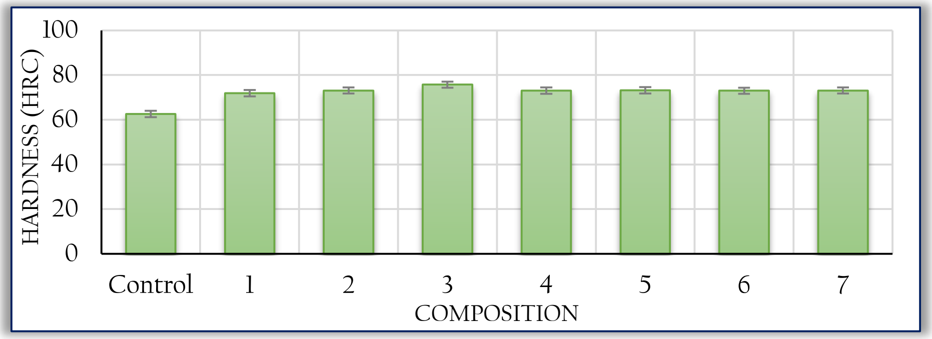

Figure 9: Effect of the titanium dioxide (TiO_2) and laterite content on Hardness

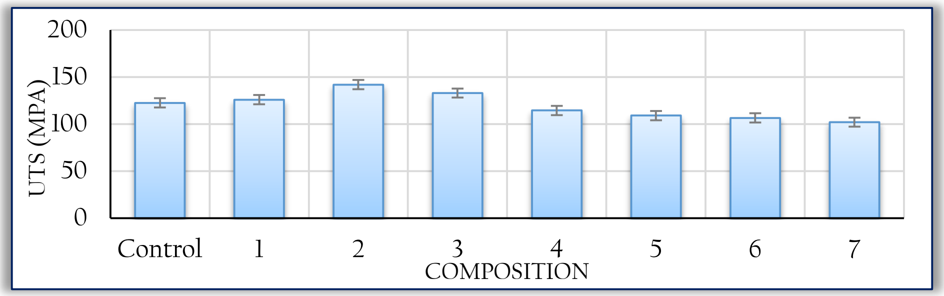

Figure 10: Effect of the titanium dioxide (TiO_2) and laterite content on Ultimate Tensile Strength

Figure 10 is a graph showing the effect of titanium dioxide and laterite content on the Ultimate Tensile Strength (UTS) of cast Al6063 particulate composites. Each value represented is an average of six measurements. The results were repeatable in the sense that each individual result did not vary more than 5% from the mean value. It can be seen that as the titanium dioxide (TiO_2) content increases, the UTS of the composite material increases up to 4 wt%. In fact, as the titanium dioxide (TiO_2) content is increased from 0% to 4%, the UTS increases by about 16%. Similar result was obtained by Pillai and Pandey, 1989 [13]. As from composition 2, increase in titanium dioxide and reduction in laterite led to reduction in ultimate tensile strength as a result of reduction in dislocations barrier in the microstructure.

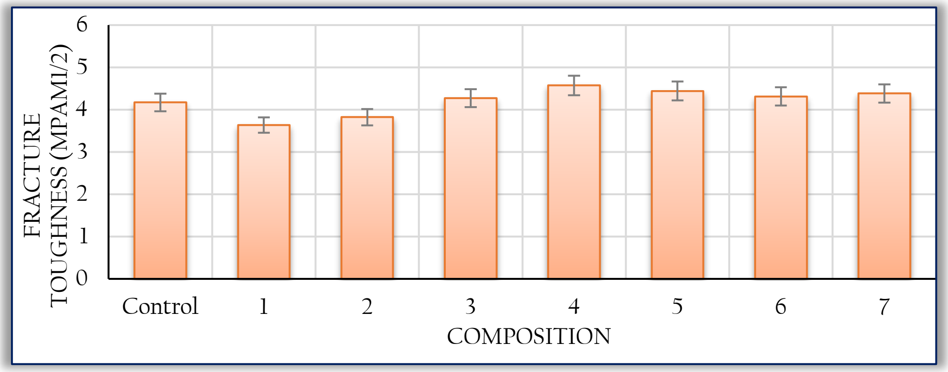

Figure 12: Effect of the titanium dioxide (TiO_2) and laterite content on Fracture Toughness

The fracture toughness values of the control and composites produced which were of different compositions are presented in Figure 12. It was observed that fracture toughness of composition 4 has the highest value of 4.57 $MPam^{1/2}$. The fracture toughness increased by almost 10 % with 10: 10 wt% of titanium dioxide and laterite, this was followed by composition 5. These two mixed ratio formed a good cohesion, thereby increased their resistance to crack propagation.

4. CONCLUSION

In the research work, the effect of titanium dioxide and laterite on Al6063 using spin casting technique was investigated. From the results presented, the following conclusions were drawn:

- Composition 3 has the highest hardness value of 75.7 HRC, with 8 wt% of titanium dioxide (TiO_2) to 12 wt% of laterite.
- As from composition 2, increase in titanium dioxide and reduction in laterite led to reduction in ultimate tensile strength as a result of reduction in dislocations barrier in the microstructure.
- It was discovered that the reinforcement were uniformly distributed within the Al 6063 matrix

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