

# THE EFFECT OF PROCESS PARAMETERS ON MECHANICAL AND WEAR PROPERTIES OF ALUMINIUM-FIRED CLAY COMPOSITES

Agbeleye A.A. \*, Hassan S.B., Esezobor D.E., Balogun S.A., Agunsoye J.O.

Metallurgical and Materials Engineering Department, University of Lagos, Lagos, Nigeria

\*Corresponding author. Tel.:+2348023165293, aagbeleye@unilag.edu.ng

## ABSTRACT

*In this paper, the mechanical and tribological behaviours of as cast and rolled samples of Aluminium AA1070/fired clay (Al-Clay) composites were studied. The composites were developed through stir casting route with 0-20 wt.% clay particles of grain sizes 250, 177 and 150  $\mu\text{m}$ . The samples were cold rolled to final reduction of 20 and 35%. Hardness, tensile, impact and wear tests were performed on the developed composite samples and their microstructure were examined to determine the phases present in the composite. The results showed improvement in the mechanical and wear properties of Al-Clay composites with increase in wt.% clay addition. Increase in percent reduction also showed a reasonable increase in the mechanical and wear properties of the rolled samples. The results obtained clearly shows that Al-clay composite can be produced by stir casting and possess superior properties to the Aluminium AA1070 in terms of wear properties, impact energy, tensile strength as well as hardness.*

**Keywords:** sliding wear, surface analysis, sliding friction, hardness, three-body abrasion

## 1.0 INTRODUCTION

The increasing demand for the use of lightweight materials with high specific strength in industries such as aerospace and automotive industries has led to the development and use of Aluminum based composite. The Metal Matrix Composite (MMCs) is slowly replacing the general light metal alloys such as aluminum alloy in different industrial applications where strength, low energy and mass savings are of utmost importance in criteria (Allison and Cole, 1993). The use of aluminum in industrial application has been a common practice over the years. Aluminum is the most abundant metal in the earth's crust and the third most abundant element we have after oxygen and silicon. The chief source of Aluminum is bauxite and aluminum is soft, durable, lightweight, ductile and malleable which makes it suitable for machining operations and various industrial applications. Aluminum alloy are alloys in which aluminum is the predominant metal. Aluminum 1000 series which is the metal matrix to be used for this project is essentially pure aluminum with a minimum 99% aluminum content by weight

and can also be work hardened. Its high ductility increases its machinability makes it suitable to be used in wires, ships, airplanes, marine, packaging etc. One of the main drawbacks of this material system is that they exhibit poor tribological properties, hence leading to the development of new material with higher wear resistance and better tribological properties, without compromising the strength to weight ratio. (Sinclair and Gregson, 1997).

Clay minerals continue to be widely utilized in the production of traditional ceramics and other products due to their ubiquity and low cost combined with properties that include plasticity during forming, rigidity after drying, and durability after firing (Ries, 1927). For much of the twentieth century, the ceramics industry centered on the utilization of clays and other silicate minerals. Clay contains majorly reinforcing materials such as  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  with trace presence of other materials (Esezobor *et al.*, 2014) making it a potential candidate for the production of metal matrix composite for wear applications in friction related environments.

This research focuses on the use of AluminumAA1070 reinforced with 150 $\mu\text{m}$ , 177 $\mu\text{m}$  and 250 $\mu\text{m}$  of fired clay particle sizes to produce composites with composition of 0-25wt. %. The effect of cold rolling on Aluminium AA1070/fired clay (Al-Clay) composite samples were also examined. The mechanical and wear tests will be done according to ASTM E8/ESM-13 and ASTM G-99-05 specifications respectively.

## 2.0 METHODS

AluminumAA1070, billet from Aluminum rolling Mill, Otta, Ogun State, Nigeria was then melted and reinforced with 150 $\mu\text{m}$ , 177 $\mu\text{m}$  and 250 $\mu\text{m}$  of fired clay particle sizes to produce 300mm length and 18mm diameter cylindrical rod composites samples with composition of 0-20wt. % using the stir casting technique (figure 1). The composite samples were subjected to cold rolling operation with final reduction of 20 and 35%. The tensile and Brinell hardness tests of samples were conducted using respectively hydraulic universal testing machine UH-X/FX Series machine and Wolpert Testor 930 Universal Hardness Tester. Impact Test was carried out on an Avery Charpy impact-testing machine with a capacity of 298.28Nm and striking velocity of 5.03m/s. The wear characteristics of Al-clay in dry sliding conditions were subjected to a series of pin-on-disc wear tests. Cylindrical pins of 15mm diameter were made from the Al-Clay. The action of a constant load 6N on 60 grit Emory paper at a sliding speed of 1.05m/s was investigated.

Mechanical (tensile, hardness and impact) and wear tests on the composites samples were carried out according to ASTM E8/ESM-13 and ASTM G-99-05 specifications respectively.

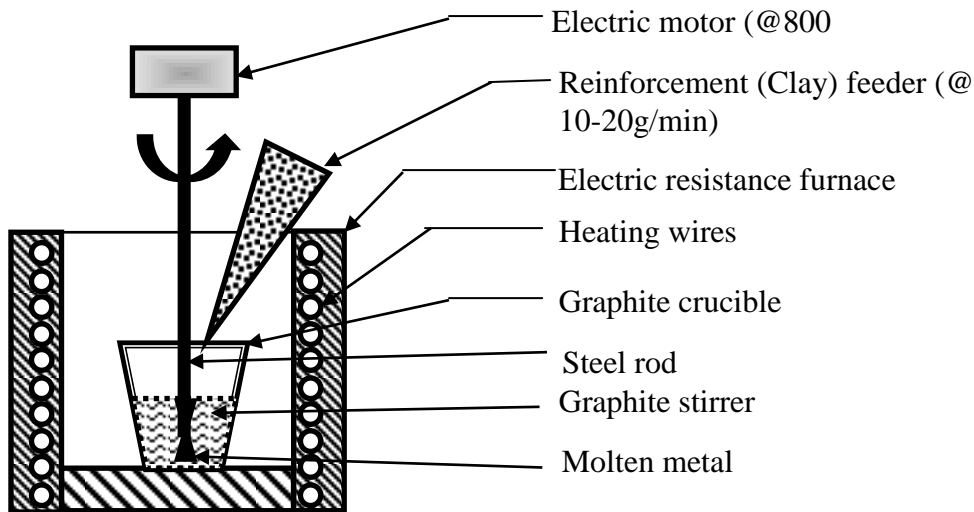


Figure 1: Graphical representation of Stir Casting process

Metallographic examinations were carried out using CETI 0703552 Metallurgical Research Optical Microscope. The samples were grinded on different grit size papers sequentially by 60, 220, 320,400, 800 and 1200. After grinding the samples were mechanically polished by alumina paste and then pre etched by 1Molar NaOH, then etched by Weck's reagent for 20 seconds to obtain a better view.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Mechanical Properties

The results of the analysis of the aluminium alloy and the clay are presented in Table-1 and Table-2 respectively.

**Table 1: Optical Emission Spectrometric analysis of Aluminium AA1070**

<b>Element</b>	Si	Mg	Fe	Cu	Mn	Zn	Pb	Na	Ti	B	Al
<b>% composition</b>	0.0914	0.0037	0.177	0.0005	0.0019	0.0035	0.0013	0.0008	0.0057	0.0003	99.72

**Table-2: Atomic Absorption Spectroscopy (AAS) analysis of clay sample**

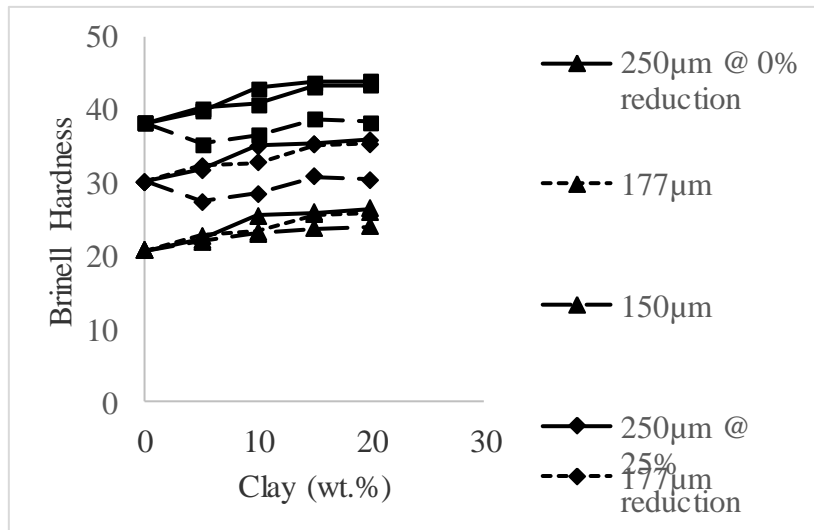
<b>Parameters</b>	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	MnO	MgO	Na <sub>2</sub> O	CaO	K <sub>2</sub> O	BaO	SO <sub>3</sub>	LOI
<b>Level detected (%)</b>	45.62	33.74	0.43	0.01	0.06	0.05	0.04	0.63	0.01	0.03	4.545

The summary of the Brinell hardness number, ultimate tensile strength (UTS), and impact energy as a function of the percentage weight addition of clay particles is presented in Figures 2, 3 and 4 respectively.

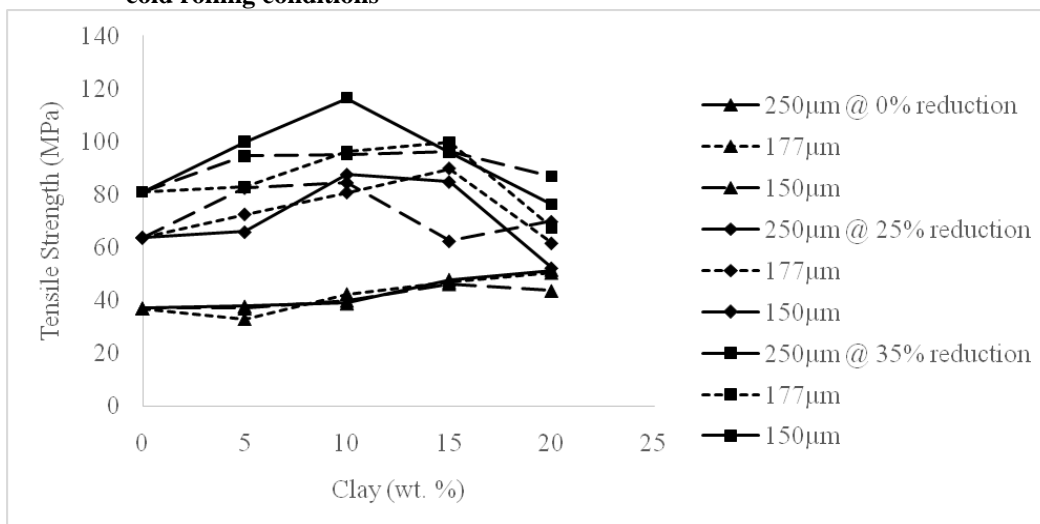
The Brinell hardness values of the Al-clay composite as presented in Figure 2 show that increase in the percentage of clay particle addition was accompanied with corresponding increase in the hardness values and it reached a maximum values of 26.4 HB at 20 wt.% fired clay with 250µm particle size, which is an increase of about 28% as compare to the control sample. The cold rolled samples were also seen to show increase in hardness values peaked at 43.9 HB at 35% reduction and 20 wt.% clay with 250µm particle size.

The UTS of the composite samples as shown in Figure 3 increases as the addition of clay increases to a peak value of 51.36 MPa at 20 wt.% clay particle addition over the conventional AA1070 of 36.91 MPa. The cold rolled samples also show considerable increase in the UTS values with the maximum value of 116.39 MPa at 35% reduction and 10 wt.% clay with 250µm particle size. Further increase in clay particle addition to 20wt.% clay resulted in a decline in the UTS values.

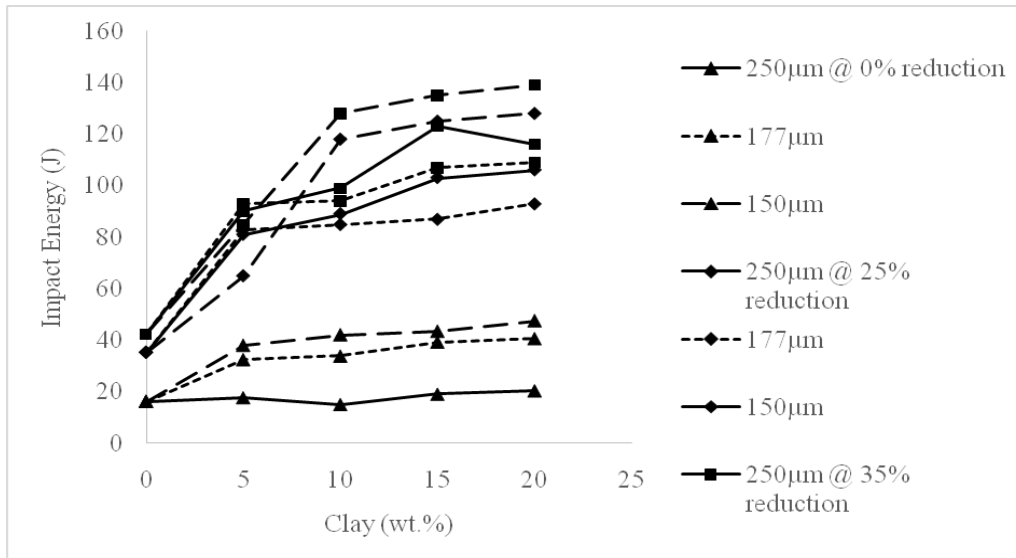
The improvement of the UTS and micro hardness with the increment in the volume fraction of clay particles may be due to the presence and pinning effect of the clay particles (Khraisat and Abu Jadayil, 2010; Essam *et al.*, 2010; Devaraju *et al.*, 2013) which serve as impingement for the movement of dislocations and as a result restrict the sliding of the grain boundaries.



**Figure 2: Brinell Hardness (HB) of Al-Clay composite samples at varying particle sizes and cold rolling conditions**



**Figure 3: Tensile strength of Al-Clay composite samples at varying particle sizes and cold rolling conditions**



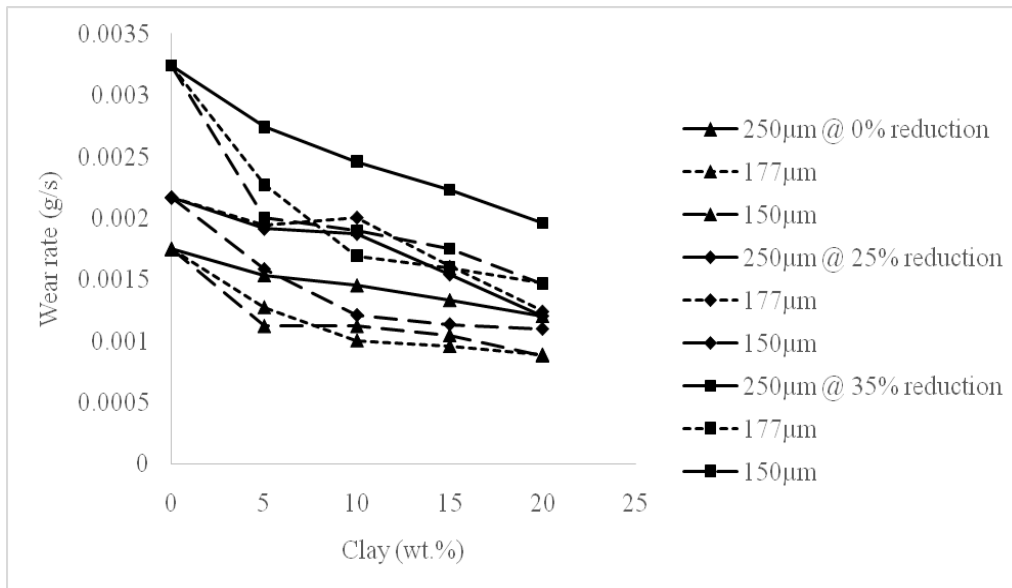
**Figure 4: Impact energy of Al-Clay composite samples at varying particle sizes and cold rolling conditions**

The results of the impact test as shown in Figure 4 revealed that an increase in the weight percent fired clay particles resulted in increase in impact energy with respect to the base metal. This is due to proper dispersion of fired clay particles into the matrix and also strong interfacial bonding between the base metal and fired clay interfaces. It was also observed that samples with 150µm particle size significantly show superior impact energy with respect to samples with 177µm and 250µm. Cold rolled samples also show considerable increase in the impact energy values with the maximum value of 139J at 35% reduction and 20 wt.% with 150µm particle size.

### 3.2 Wear characteristics

The result of the wear test of the composites with various volume fractions of Al and cold rolled conditions are displayed in Figure 5.

The wear rate decreases with increase in the volume fraction of the reinforcing agent (clay) as compared to conventional AA1070. The lower wear rate observed at optimum condition of 20 wt.% clay is due to enhanced hardness by the dispersion of the hard intermetallics over the AA1070 matrix, which acted as load supporting elements (Essam *et al.*, 2010; Devaraju *et al.*, 2013; Kumar and Balasubramanian; 2008).

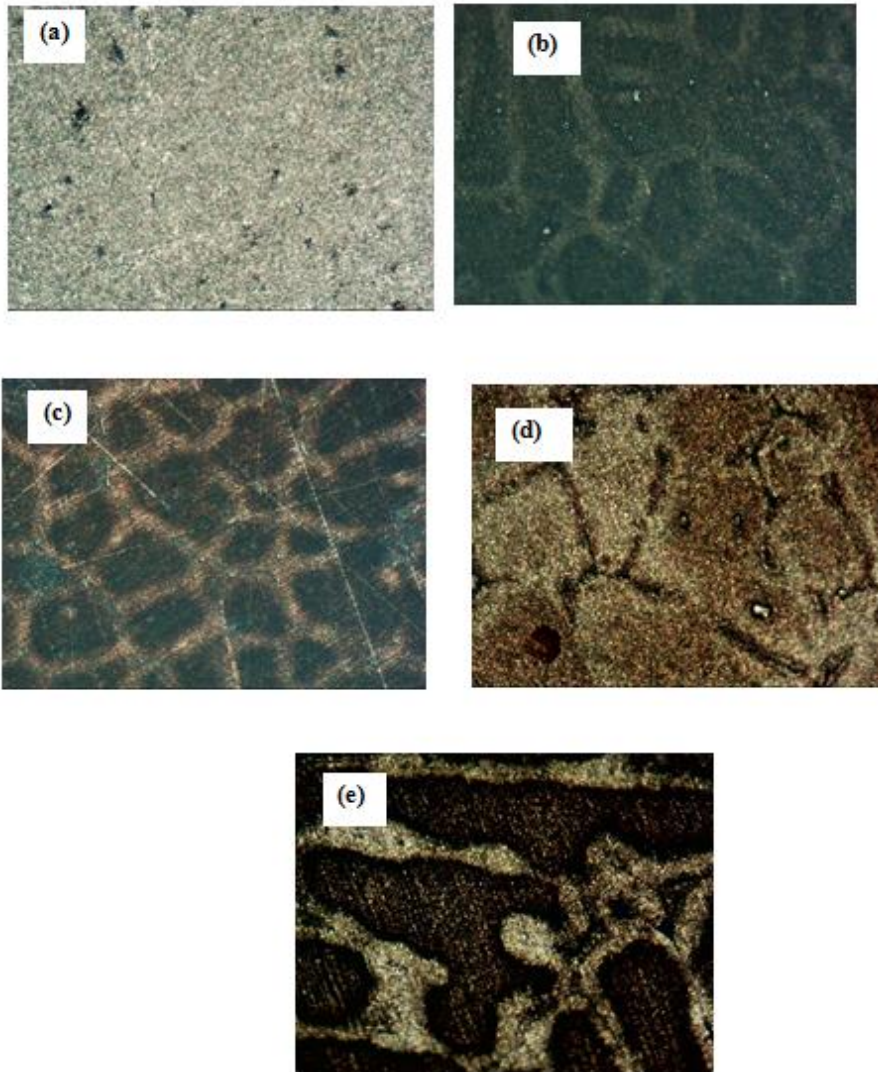


**Figure 5: Wear rate of Al-Clay composite samples at varying particle sizes and cold rolling conditions**

Material removal in a ductile material such as aluminum matrix is due to the indentation and ploughing action of the sliding disc. Incorporation of hard fired clay particles in the AluminiumAA1070 restricts such ploughing action and improves the wear resistance. The improvement in wear resistance properties of the developed composites can also be attributed to the release of the clay particles on the surface during wear process, which to an extent may prevent metal to metal contact and also serve as solid lubricants (Tjong *et al.*, 1999). On the other hand, the wear rate increases with increase in the normal load and sliding speed. This trend was also observed in the work of Devaraju *et al.*, (2013).

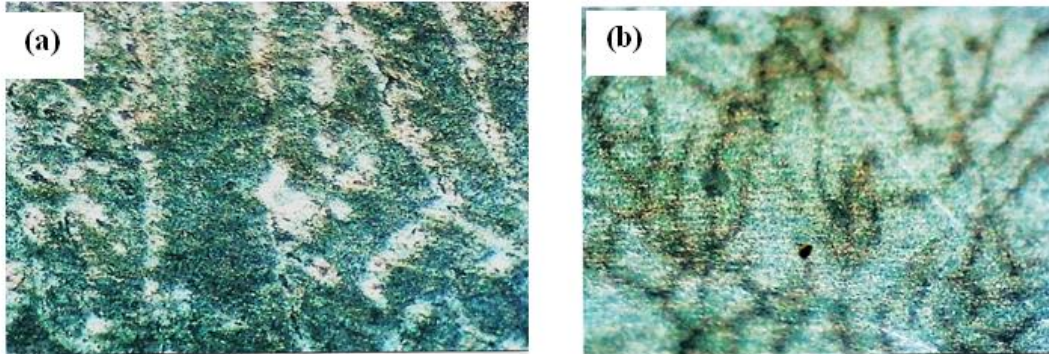
### 3.3 Microstructure

The results of the metallographic examination of all the samples are displayed in Plates1-2. The clay particles are fairly distributed along the grain boundaries of the AluminiumAA1070 matrix. The addition of the clay particles is observed to have enhanced the formation of finer grains



**Plate 1:** Optical microstructure of the Al-Clay composite samples with 250µm particle size (a) As cast Aluminium AA1070, (b) 5% clay, (c) 10% clay, (d) 15% clay, (e) 20% clay





**Plate 2: Optical micrograph of Al-Clay composite with 20% Fired clay of 250 $\mu$ m at (a) 20% reduction (b) 35% reduction**

The microstructure as revealed in Plate 2 show that increase in the percentage reduction in cold roll promotes the formation of finer grains which can be attributed to the improvement in the mechanical and wear properties of the developed composites.

#### **4.0 CONCLUSIONS**

The conclusions drawn from the present investigation are as follows:

1. The results obtained clearly shows that Al-Clay composite can be produced by stir casting and possess superior properties to the Aluminium AA1070 in terms of wear properties, impact energy, tensile strength as well as hardness.
2. Increase in fire clay additions also resulted in an increase in tensile strength, impact energy, and the hardness of the developed composite.
3. Increase in the particle size of fired clay causes a reduction in the impact energy.
4. The formation and distribution of the second phase particles is uniformed around the grain boundaries of the microstructure and generally improve the mechanical properties of the developed composite.
5. Cold worked samples show superior mechanical and wear properties as compare to as-cast samples.

## **5.0 REFERENCES**

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