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Mechanical Characterization of AA6061/Clay (Kaolinite) Composites for Industrial Application

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Abstract. Traditional materials have certain restrictions in an industrial application today inhibiting them from the attainment of the best blend of toughness, density and strength. The paradigm shift in the use of agro-waste products as particulate reinforcement is an excellent choice owing to the inexpensive and availability of the desired agro-waste product. This research focuses on the development of AA6061 aluminium alloy through stir casting method using kaolinite clay as the reinforcement agent in increasing weight percentages of 2.5wt %, 5wt %, 7.5wt % and 10wt %.. The use of agro-waste as reinforcements is possible as the clay kaolinite was effectively infused into the pure matrix for composites to be constructed. The tensile strength was highest at the addition of 10 wt % of clay kaolinite. Brinell's hardness test showed an increase in value with an increase in the mass fraction of clay. It was observed from the results of the tests carried out that the reinforced specimens exhibited improved hardness when analyzed using Brinell's hardness machine. Some of these properties improved with the increase in weight percentage of reinforcement particles. This research has shown the importance of agricultural waste to material engineers, material handlers and metallurgists in our society and that it is the right way to go.

Keywords. AA6061, clay kaolinite, SEM/EDS, XRD, MMCs, mechanical properties

1. Introduction

The search for better materials which have improved resistance to the harsh elements in day-to-day applications has been at the forefront of most researchers [1, 2]. The exploitation of additive-manufactured aluminium is rapidly becoming the hotspot of current research to develop products of high accuracy. However, these additive-manufactured aluminium parts have been noticed to quickly develop void defects due to their low density and poor fluidity [3, 4]. Aluminium has drawbacks, like advanced

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experimental techniques, raw materials waste and significant research costs, which restricts any additional research on additive-manufactured aluminium [5, 6]. Aluminium and its alloys can be used as materials in numerous fields of endeavour, boasting characteristics like great specific strength, toughness, low density and resistance to corrosion [7]. The surface treatment is carried out to improve functionality and long-term corrosion resistance [8]. In pursuing more robust and durable materials with enhanced properties, it would be remiss not to consider composites as they are the most profitable tool. The employment of composites and metal matrix composites (MMCs) has transformed from an abstract concept to a genuine science today [9]. This advancement is responsible for the successful and diversifying applications in this branch of practical science and engineering. Aluminium, in addition to its alloys, presents an excellent blend of properties, distinguishing it as the most economical, flexible and appealing metallic material that can be utilized for a wide variety of applications ranging from the delicate use in wrapping foil to rough engineering applications. As well as steel and iron, aluminium-based alloys are favourites for use as structural materials. [10]. In acids, salts or other electrochemically destructive media, aluminium-based alloys have often been applied as matrix materials, combined with inexpensive fortification particles to create aluminium particulate composites that last long [11]. The metal matrix's ductility and the ceramics' rigidity make for more options in industrial applications [12]. Aluminium metal matrix composites fortified with agro-based waste such as eggshell particles, breadfruit seed hull ash, and snail shell particles using the process of double stir casting are very beneficial [13]. The mechanical properties increase with the weight percentage increase [14]. Studies have shown that agro-waste products cannot completely replace synthetic ceramic composites. They can, however, be used supplementary with synthetic ceramic composites owing to its property of bio-degradability and light nature. [15]. Aluminium is a non-ferrous metal widely used in the automobile industry, aviation industry, etc., due to its lightweight property. Aluminium AA6061 is an alloy of magnesium, silicon, and smaller quantities of copper and chromium. From experimental data, clay has been found suitable and is to be used as the reinforcement element in aluminium AA6061 since it is cheaper and is available in more than 20 of the 36 states in Nigeria [16]. This research paper explores the possibility of using clay (kaolinite) as a reinforcing material in AA6061 Aluminium alloy.

2. Experiment

2.1. Materials

AA6061 was used as the matrix and clay kaolinites as the reinforcing agent. The equipment used in this research work are stir casting machine, furnace, crucible, SEM, XRD, Brinell hardness tester and Universal testing machine (UTM) SM1000. Figure 1 shows the casted moulds. Figure 2 shows the plate of reinforced aluminium matrix composites.

Figure 1. Casted Moulds.

Figure 2. Reinforced Aluminium Matrix Composite.

2.2. Experimental Set-Up

The metal matrix composite was produced using the process of stir casting. 98g of Aluminium 6061 was initially placed in a graphite crucible and was liquesced at 810°C using a pit furnace. During the liquescing of aluminium, magnesium of 2g mass was inserted into the melt for use as a wetting agent to reduce the surface tension. Upon acquiring fresh clay, it was dried in the sun to get rid of surplus water and then ground to a fine powder. This fine powder is then sieved to a particulate size of 75µm. The previously prepared clay powder was preheated to 700°C for one hour to enable the silica content to retain its amorphous characteristic below 800°C. The reinforcement was incorporated into the melt using the graphite stirrer for unvarying circulation. Table 1 shows the weight percentage of reinforcement while, table 2 shows the chemical properties of aluminium 6061. Table 3 shows the mechanical properties of aluminium AA6061.

Table 1. Reinforcement Weight Parameters.

Sample designation	Weight of Clay (%)	Weight of AA6061 (%)
AA 6061	0	100
AA 6061 + 2.5 % clay	2.5	97.5
AA 6061 + 5.0 % clay	5.0	95.0
AA 6061 + 7.5 % clay	7.5	92.5
Al 6061 + 10.0 % clay	10.0	90.0

Table 2. Chemical Properties of Aluminium 6061.

Component	**Weight (%)**
Al	97
-Si	0.5
Mg	1.0
Cu	0.3
Cr	0.25
Mn	0.14
Ti	0.13
Zn	0.22
Fe	0.5

Table 3. Mechanical Properties of Aluminium 6061.

Properties	**Metric**
Ultimate Tensile Strength	6400(kN)
Elongation at Break	2.4%
Hardness, Brinell	110.69(kN)

3. Characterization

SEM was used to study the microstructure, composition and topology of the produced composite and energy dispersive spectrograph (EDS) was used for elemental identification. A metallographic examination of the surface morphology was performed using a Scanning Electron Microscope on the pure aluminium alloy control sample as well as the specimens reinforced with clay. The specimens were primed for microstructural analysis. The specimens were ground and rubbed using emery paper. They were also polished on the fine polishing machine. The Brinell hardness tester was used to determine microhardness. The Brinell hardness tester is employed to test materials that have an appearance that is coarse or an exterior that is not polished enough to be tested using other processes of testing for the samples. This testing method often employs a high-test load of about 3000kgf and an indenter of 10mm diameter. This is done to ensure the indentation outcome exceeds that of most surface and sub-surface incompatibilities. When indentation occurs, it resists plastic deformation. The machine is hydraulically operated. The hardness was evaluated at a mass of 100g for 15 seconds; the depression observed is determined with a Brinell microscope across a minimum of two diameters, typically at right angles to each other, and the results are estimated. UTM SM1000 was utilized in determining the material tensile strength. This machine has a range of load capacities from 5kN to 2000kN. This apparatus functions when the test sample is positioned between the machine clasp. The machine records the force after the test sample has been made to undergo a tensile test; this takes place as the load is administered on the test sample. The difference in length is also measured for each sample. Its threshold is 100kN.

4. Results and Discussion

4.1. Mechanical Properties

4.1.1. Microhardness Analysis of Clay Reinforced Aluminium Alloy

Figure 3 shows the effect of the varying mass fractions of clay kaolinite particles on the AA 6061/clay composite. The Brinell hardness was evaluated for the specimens using a steel ball indenter of 10 mm diameter. There was a resistance to plastic deformation, as shown in the figure, which led to enhanced hardness. The result of the hardness test of the composite shown in figure 1 reveals that the maximum value of BHN was obtained upon the addition of 10 weight % of kaolinite. From the hardness data, the reinforced alloys increased in hardness from 15.9 BHN for the unreinforced alloy to roughly 21.1 BHN at a percentage increment of 32.7%. Therefore, there is a relationship of direct proportionality between the hardness value and the mass fraction of composite as one increases with the other. This particular specimen exhibited improved mechanical properties. It is in line with [17], as the smooth reinforcements improved its properties, especially tensile strength.

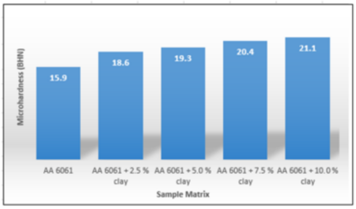

Figure 3. Effect of clay kaolinite content on Micro hardness.

4.1.2. Ultimate Tensile Strength for Clay Reinforced Aluminium Alloy

Figure 4 shows the tensile test specimen before analysis. From figure 5, it can be observed that there was a change in the tensile strength of the aluminium alloy matrix composite by the addition of kaolinite reinforcement particles when compared to the pure aluminium matrix. Furthermore, it was observed that for the reinforced composites, the values of these properties increase as the mass fraction of kaolinite added to it increases to 10wt %. In table 4 and table 5, the variation in elastic properties is seen as the values for maximum tensile stress, and the tensile stress at break varies with different mass fractions of reinforcement. As reported by [18], the trends of increase in modulus value occurred with an upsurge in the mass fraction of kaolinite added. Figures 6 and 7 show that the load-displacement curves of the AA6061 alloy matrix samples reinforced with kaolinite have higher tensile strength than the unreinforced alloy, with the alloy of 10 wt % having the highest tensile strength. The varying and shifting values and curves could also be accredited to the morphology of the clay particles. It must also be noted, however, that at a certain mass fraction of reinforcements, some of the elastic properties, which include yield stress and tensile stress, are directly proportional to the particle size [19,20]. According to the stress-strain curve, there is a notable improvement in the ductility and strength of the reinforced specimen when measured with the unreinforced base alloy.

Figure 4. Tensile Test Specimen.

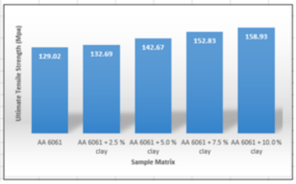

Figure 5. Effect of clay kaolinite content on ultimate Tensile Strength.

Table 4. Showing Tensile Stress at Break of the unreinforced specimen.

Specimen	Load at max tensile stress (N)	Tensile strain at max. tensile stress (mm/mm)	Tensile extension at max. tensile stress (mm)	Energy at max. tensile stress (J)	Tensile stress at Break (MPa)
1	1621.32215	0.04723	1.41687	1.02568	6.35199

Table 5. Showing Tensile Stress at Break of the reinforced specimens.

Specimen	Load at max tensile stress (N)	Tensile strain at max tensile stress(mm/mm)	Tensile at max tensile stress(mm)	Energy at max tensile stress(J)	Tensile stress at break(MPa)
1	1667.53605	0.05279	1.58362	1.34277	43.47604

2	1792.87400	0.04640	1.39200	1.37602	19.26148
3	1920.55050	0.05501	1.65025	1.59595	34.60326
4	1921.84132	0.05223	1.56694	1.54665	52.96105

In this section, red line refers to AA6061+2.5wt% C, yellow line to AA6061+5wt% C, green line to AA6061+7.5wt% C, orange line to AA6061+10wt% C.

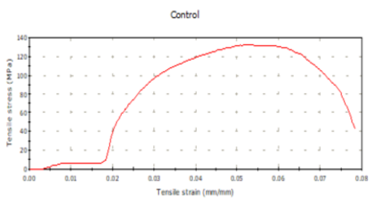

Figure 6. Tensile Strength of unreinforced AA6061 alloy.

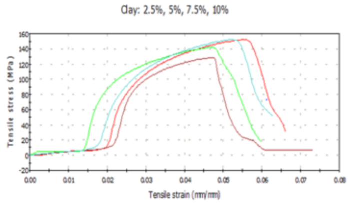

Figure 7. Showing Tensile Strength of the reinforced AA6061 alloy matrix composites.

4.2. SEM/EDS

4.2.1. SEM/EDS of Unreinforced Aluminium Specimen

Figure 8 shows a micrograph of the pure control sample. The SEM micrograph was taken at 500X magnification and a working distance of 100µm. From this image, voids are observed, and SEM revealed the crystal arrangement of aluminium alloy with other trace elements. The EDS scale showed the supremacy of aluminium and oxygen with other essential constituents. The EDS result established the basic structure of aluminium alloy, as shown in figure 5.

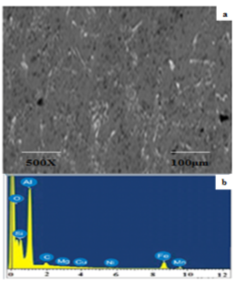

Figure 8. (a) Micrograph of Control Sample AA6061 (b) Energy Dispersive Spectra.

4.2.2. SEM/EDS of Reinforced AA6061 with Kaolinite Clay

Figures 9 - 12 (a) and (b) show the visualization of the scanning electron microscope of reinforced aluminium alloy. The specimen images were taken at 8000X magnification with an acceleration voltage of 15kV and a working distance between 200 and 500µm. It was noticed that the clay kaolinite particles were completely dispersed in the matrix for 2.5 wt% reinforcement. There is a slight orientation in the particles due to the stirring while mixing as well as handling before the mixing was concluded. Figure 6 shows the distributed clay particulates across the composite in the form of chips. The EDS inferred the elemental constituents of the developed composites in which silicate has the highest concentration and shows uniform with the images from the micrographs.

EDS revealed the peak point of the developed composites, which includes silicate, oxygen, iron, nitrogen and carbon at the interface. It was observed from the SEM images in figure 7 that there was a methodical distribution of the clay particulates in the reinforced sample. The surface morphology showed the dispersal of the clay particles in the grain boundary and the existence of composition from clay in the aluminium matrix. SEM study also shows the existence of necking indicating ductile material, and EDS revealed the existence of aluminium, silicates, oxygen, carbon, magnesium and iron at different peaks as a result of an increase in the percentage of reinforcement. From figures 11 - 12, we can observe the presence of arbitrarily shaped holes in the cross-section of the specimen.

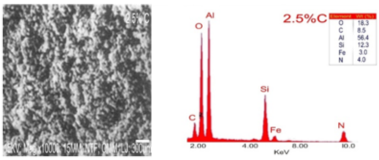

Figure 9. (a) SEM image of AA6061+2.5 wt % clay. (b) EDS of specimen.

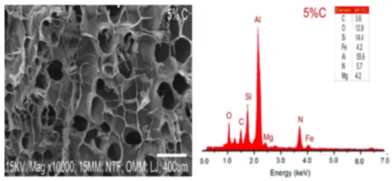

Figure 10. (a) SEM image of AA6061+ 5 wt % clay. (b) EDS of specimen.

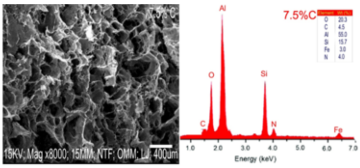

Figure 11. (a) SEM image of AA6061+ 5 wt % clay. (b) EDS of specimen.

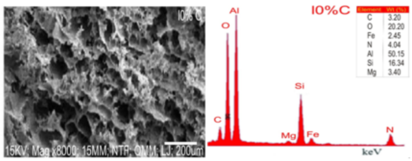

Figure 12. (a) SEM image of AA6061+ 10 wt % clay. (b) EDS of specimen.

4.3. X-Ray Diffraction Analysis of Reinforced Composites

The casted specimens were examined using x-ray diffraction analysis in order to confirm the compounds were developed in the varying weight percentages reinforcements for the composites.

Figure 13 shows the XRD analysis of the AA6061 crystalline phase at different peaks. The phases were obtained from the XRD pattern at Bragg angles of 28° at 600 intensity count. The phase shows the presence of highest peak of aluminium, with trace elements of magnesium, zinc, calcium oxide, silicon IV oxide and iron III oxide. It comprises of a single crystalline phase with a single peak except aluminium having four extra peaks.

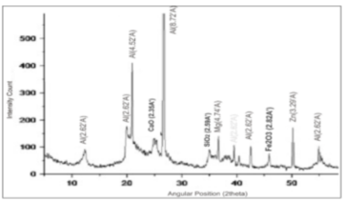

Figure 13. XRD of pure As-received Aluminium Alloy.

Figure 14 - 17 show the XRD configurations of the developed aluminium matrix composites at 75 µm. The major peaks were indexed between 2θ Bragg angle intensity of 0 and 90°, which comprise aluminium, magnesium, calcium oxide, silicon oxide and iron III oxide. The XRD patterns revealed a crystalline phase of SiO_2, and CaO at triple peaks resulting from the clay composition used in the experiment. AA6061 reinforced with kaolinite clay composites were investigated to detect the occurrence of reinforcement particles as well as the occurrence of unwanted materials. The XRD shows the peaks and phases of potential combinations of Aluminum and kaolinite clay particles. The peaks were identified by following the JCPDC manual. From the XRD results, a decrease in Mg was observed with an increase in clay particles. The phases developed can be attributed to the manufacturing method, which in this case was stir casting.

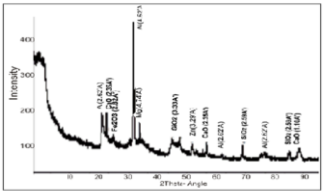

Figure 14. XRD of AA6061+2.5 wt% clay.

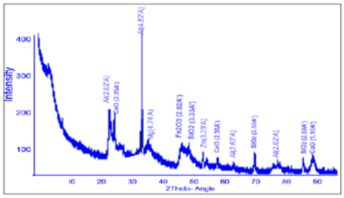

Figure 15. XRD of AA6061+5wt% clay.

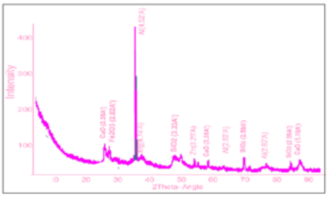

Figure 16. XRD of AA6061+7.5 wt% clay.

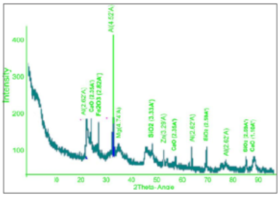

Figure 17. XRD of AA6061+10wt% clay.

5. Conclusion

In this research project, a metal matrix composite was produced by strengthening aluminium AA6061 with kaolinite clay particles through the process of stir casting. Various tests were carried out on the reinforced specimen as well as the original unreinforced sample, and from the results, which were compared and analyzed, it was discovered that the improvement of the material properties was dependent on the mass fraction of reinforcement added.

The following have been discovered from this research work.

a) The use of agro-waste as reinforcements is possible as the clay kaolinite was effectively infused into the pure matrix for composites to be constructed.

b) The XRD patterns revealed a crystalline phase of SiO_2, and CaO at triple peaks resulting from the clay composition used in the reinforcement of aluminium alloy.

c) There is a notable improvement in the ductility and strength of the stress-strain curve of the ultimate tensile strength specimen when measured with the unreinforced base alloy.

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