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Letters

Development and characterization of AA6061 aluminium alloy /clay and rice husk ash composite

O.S. Olusesi, N.E. Udoye *

Department of Mechanical Engineering, College of Engineering, Covenant University Ota, Lagos State, Nigeria

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ABSTRACT

Reinforcement performs a dynamic function in the efficiency and durability of composite materials. In the past, various researchers have conducted studies aimed at the use of different chemical particles as reinforcement particulates for aluminium metal matrix composites, leading to progressive results for the desired properties of the reinforced composite material. This study shows the potential in harnessing agro-waste materials as reinforcement instead of the traditional synthetic reinforcements such as boron carbide, silicon carbide, etc. Rice husk ash and clay particulates are harnessed for this study due to their proven ability to improve composite features such as hardness, tensile strength, bend strength, etc. This study shows, by means of various literature reviews and tests conducted at different reinforcement wt%, the viability of agro-waste reinforcement as opposed to synthetic reinforcement. The SEM (scanning electron microscope) images show homogeneous dispersal of reinforced particulate in the produced composite and XRD (X-ray Diffraction Analysis) depicts the occurrence of various phases in the composite.

1. Introduction

The advancement in the intricacy of materials science and the application of metal matrix composites is increasing recently because of the variety of users in different sectors of the industry [1,2]. Although, the main reason for their increased use in the automobile and aviation industries is the cost. Other potential advantages such as lighter weight, better component durability, and enhanced recyclability are considered [3,4]. Aluminium is primarily applied as a material for the mechanical framework, particularly in the aviation sector because of its lightness in weight. But, the low strength and low melting point is always an issue [5]. An economical means of fixing this issue was applying ceramic reinforcing materials in the form of SIC and SIO_2 as reinforcing material. The use of ceramics and strengthening material particulates gives allowance for increasing the elastic modulus of aluminium, enhancing the temperature-based characteristics and mechanical properties [5]. Aluminium is primarily applied for base material used mostly in industries that need lightweight materials such as the aviation industry that value lightness in weight. But, the production processes involved in manufacturing aluminium AA6061 reduce some properties, e.g. strength, melting point, etc [6,7]. One of the most viable cost-effective means of fixing this issue was material reinforcement with substances like silicon oxide or in this case, clay and rice husk as an alloying element [8]. Aluminium AA6061 is gradually turning into a novel brand of material in aviation usage since the characteristics of the aluminium is custom-made by adding the preferred reinforcing particulates [9]. Metal matrix composites are metals supported or reinforced with other materials, such as metals and ceramics. Due to the need for materials with more diverse in application, metal matrix composites have come to light as promising substitutes for standard alloys in high-strength and stiffness application, e.g. the manufacturing of high strength steel [10,11]. Rice husk ash, clay, groundnut husk, palm kernel shell, sugar cane bagasse, fly-ash, fibres, and whiskers are some of the agricultural by-products found as a suitable material for metal matrix composite (MMC) reinforcements. However, research materials on the potentials of agro-waste materials or ashes being used as alloy reinforcements are relatively limited compared to their synthetic counterparts. The available research materials prove Aluminium-based composites reinforced with agro-waste products like rice husk and clay are a suitable replacement for composites with synthetic reinforcements due to their cost efficiency and mechanical property improvement [9,12].

* Corresponding author.
E-mail address: nduka.udoye@covenantuniversity.edu.ng (N.E. Udoye).

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2. Other applications of agricultural waste

2.1. Rice husk ash (RHA)

RHA is used to generate electric power. RHA can also be applied in greenhouse outcome reduction since plants absorb CO_2 as they mature, and this carbon is discharged when the renewable energy from plants and animals undergoes combustion [13,14]. Moreover, the remaining renewable energy from plants and animals after burning consists of Si and C, which can be used as ceramics reinforcement or filler in MMCs. The benefit of applying biomaterials or their by-products for ceramics are enormous. Firstly, the biomaterial is an inexpensive source of carbon, silicates and other compositions. It is environmentally friendly to refer the biomaterials as traditional wastes. The bio-materials and their by-products afford patterns for fabricating ceramics with unique structures that cannot be obtained by conventional ceramic handling practices [15].

Rice husk ash is utilized to treat effluents, and Abdelwahab et al. [16] utilized stimulated rice husk ash to take in dyes from aqueous solutions. The RHA is used as inexpensive and operational material for collecting another substance's molecule to extract direct F. Scarlet from an aqueous solution. Furthermore, aluminium hydroxide with RHA can extract fluoride from drinking water [17]. The existence of RHA in epoxy paints as steel coating improved wear susceptibility and elongation. The presence of filler in epoxy paints improves paint plasticity [18]. Moreover, RHA is applied in a normal silica source for exterior perfection of paper to obtain good printability. RHA is utilized in the production of cheaper building blocks and in the making of high-grade cement in two regions. It is also a raw material for the heat insulation in a Firebrick and construction of superior flat steel. RHA is used for lagging of liquefied metal in tundish and ladle in slab caster. It averts quick cooling of steel and safeguards equal changing to solid in casting operation [19]. Bose et al. [20] showed that magnesium silicide fabricated by alloying of 99.9% purity polycrystalline silicon sourced from RHA and super-purity magnesium powder has active applications as a semiconductor device. RHA is a renewable energy source for providing a constant supply of liquid and gaseous fuels through the thermochemical transformation procedure [21].

2.2. Breadfruit seed hull ash

It provides numerous advantages in the reduction of the discarded bulks of electric utility in the industries. It also offers super quality hull ash and introduces a quality grade of novel materials with enriched features at a cheaper rate. Researchers and scientists have studied the probability of using this reinforcement for engineering applications since breadfruit grows all over tropical Africa. Breadfruit seed hull ash can also be a suitable reinforcing agent in the fabrication of lightweight MMCs constituent with a decent thermal resistance [22].

2.3. Coconut shell

Coconut shell is an essential agro-based waste for tropical Nations utilized globally as a new method of energy-biofuel. It was burnt as a method of solid waste dispersal which added immensely to CO_2 and methane emissions. It is known as a fuel source rather than disposal as the cost of fuel oil, natural gas, and electricity supply has skyrocketed tremendously [15]. Currently, the Nigeria coconut shell is used as a fuel for the boilers, and residual coconut shell is discharged as gravel for proper roads maintenance. Blacksmiths purchase the coconut shell as a fuel source for casting and forging operations [23,24].

2.4. Bagasse

Bagasse is known as the tangled cellulose fibre residue from sugarcane. It is the alternative fuel source in place of the higher cost of conventional fuels [24]. Bagasse is used to improve the age strengthening properties of an alloy.

2.5. Eggshell

Eggshell consists of 95% of calcium trioxocarbonate and 5% of organic constituents. It is frequently changed into a low protein feeding for animal feed, transforming into a lucrative business where supply exceeds demand. Furthermore, the ES is a plentiful source of the poultry industry. It has a reasonably low density in comparison with mineral calcium. These attributes make it an exceptional material for bulk amount, cheaper and low-load bearing composite applications such as the automobile industry, domestic, offices, and factories [25,26].

3. Experimentation

3.1. Reinforced matrix material

The selected materials for this research are AA6061 reinforced with rice husk ash and clay (kaolinite) particles.

3.2. Preparation of aluminium composite material

In this study, stir casting was utilized as a means of manufacturing. The aluminium alloy was heated up to its liquefaction temperature, i.e. 660.3 °C. The reinforcing particulates, clay and rice husk ash, were dried using a rotary drier, then milled for grain smoothness. Finally, air floated to filter coarse grains. Sintering was applied for the solidification of particles at 1000 °C. Sintering is a heat treatment process utilized to increase the power and structural reliability of the developed composites. Then the aluminium alloy melt was degassed for removal of impurities. The pre-heated particles and stirring were done using a mechanical stirrer for homogeneous dispersal in the matrix. Then transferred into a pre-heated die, and the casting was allowed to solidify at room temperature, then ejected and machined for testing. Fig. 1 shows the pictures of cast aluminium matrix composites.

Fig. 1. Cast aluminium matrix composites.

3.3. Processing of the ash from rice husk and clay

The rice husk was washed to remove dust. Then, it was dried at room temperature for one day before heated to 200 °C for 1 h to eliminate moisture. It was followed by heating to 600 °C for 12 h to eradicate carbon before pulverizing to 75 μm and 150 μm mesh size.

The processing of clay involves crushing raw clay before drying it in rotary driers. It is then passed through a milling process. It is proceeded by pulverizing and air floating to remove coarse grains, Sintering at 1000 °C.

3.4. X-Ray diffraction analysis

The fabricated composite samples were studied using the x-ray diffraction technique to explore the various phase formations in the composite and observe unwanted material. The X-ray Diffractometer (XRD) is a high-speed methodical instrument generally used to identify a material's crystallographic structure. It is a conservative method that gives comprehensive information on the crystal lattice, chemical constituents, and physical attributes. A crystalline sample is fixed in the pathway of an X-ray beam. The beam and detector are revolved through a range of angles. When electrons have adequate strength to displace inner shell electrons of the target material, characteristic X-ray spectra are created. When the geometry of the incident X-rays impacting the sample satisfies the Bragg Equation, constructive interference happens, and a peak in intensity occurs. A detector reads this X-ray signal translating the signal to a count rate, which is then sent to a device such as a printer. The position of the peaks leads to the identification of the elements. The peak height helps in the identification of each element's concentration in the sample. XRD analysis produces data made up of spectra with peaks conforming to the various elements present in the sample.

3.5. Micro hardness tester

The Brinell Hardness Tester was applied for detecting the Brinell hardness values for this study. The Brinell hardness tester was utilised for testing materials that have a profile that is too irregular or a surface that isn't level to be measured using another process to examine the samples. This testing process usually uses a high test load of about 3000 kgf and an indenter of 10 mm diameter so as for the indentation result to be more accurate than the usual surface and sub-surface inconsistencies. The Hardness was tested at a mass of 100 g over 15 s, the indentation achieved was calculated with a Brinell microscope across not less than two diameters, usually at right angles to each other, the results are averaged.

3.6. Tensile testing machine

The Universal testing machine (UTM) SM1000 was applied in this study; this is applied for measuring values for the material tensile strength. It was used to perform a variety of tensile tests on constituents. This machine has various load capacities ranging from values such as 5kN to 2,000kN. This instrument works when the sample is placed in between the machine's hold. The device measures the force after the sample has been subjected to the tensile test; this happens as the load is exerted on the sample.

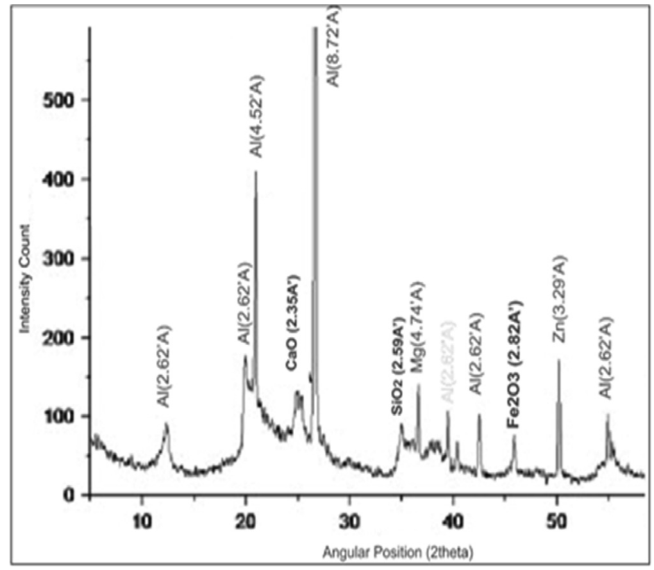

Fig. 2. XRD of AA6061.

4. Results and discussion

4.1. X-Ray diffraction analysis

Fig. 2 shows the XRD results of the unreinforced AA 6061 sample, which clearly shows the different phases in the alloy at different peaks. The dominant peaks in the unreinforced sample are calcium oxide and aluminium, proving the absence of the rice husk and clay reinforcement particulates. From Figs. 3 – 6, there is an increase in the number of phases present in the composite material with peak variations; there is an increase in the number of silicon oxide phases present and their different peak intensities due to the increase in clay and rice husk reinforcement particles. The elemental map also shows us the presence of other elements in the composite material.

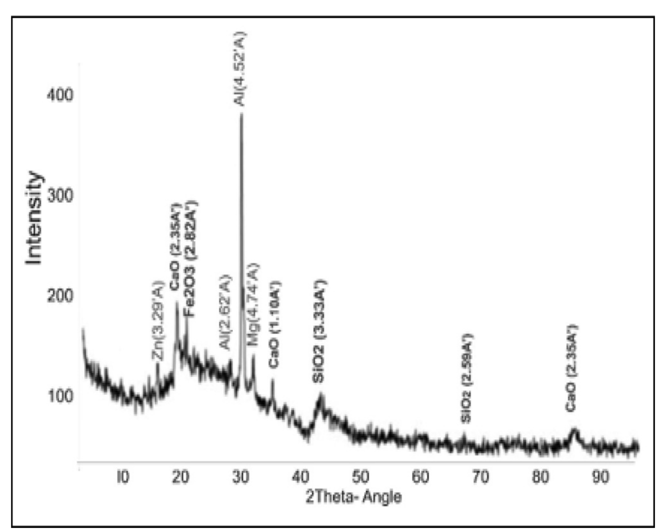

Fig. 3. XRD of 2.5% RHA + clay.

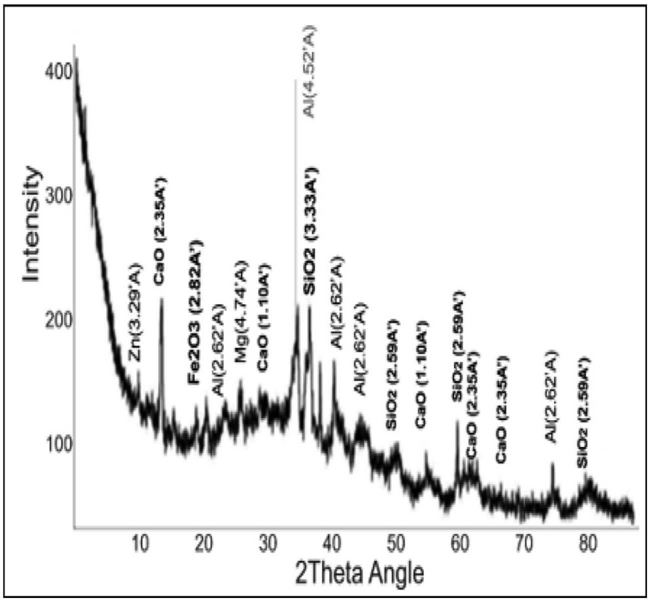

Fig. 4. XRD of 5% RHA + clay.

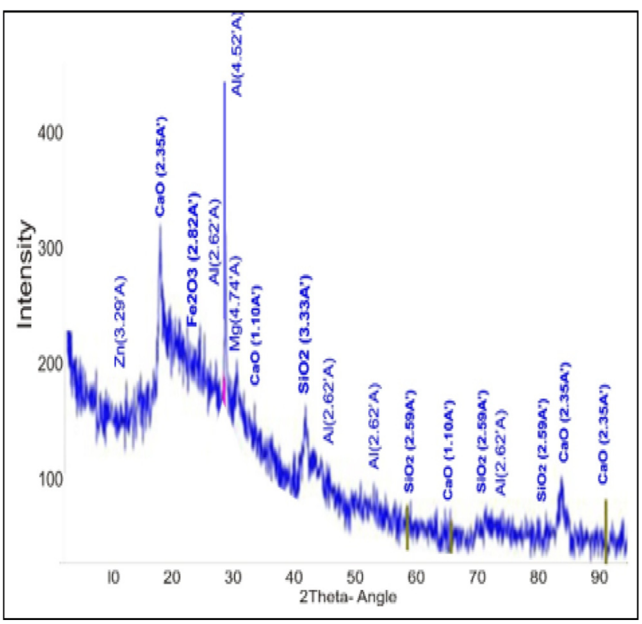

Fig. 5. XRD of 7.5% RHA + clay.

4.2. Hardness

The effect of the weight % of the clay and rice husk particles on the microhardness property of the matrix composites is shown in Fig. 7. The Brinell hardness was calculated for the samples by exerting load using a steel ball with a diameter of 10 mm. It was observed that there was an improvement in the composite's hardness at a specific reinforcement wt % relative to the AA6061. As a result of the higher Brinell hardness value of the reinforcement particulates, resistance is developed in the material to plastic deformation, which resulted in the enhancement of the composite's hardness. From this test, it was observed the highest Brinell number was gotten at 7.5% wt of RHA + C reinforcement with the AA 6061 composite matrix.

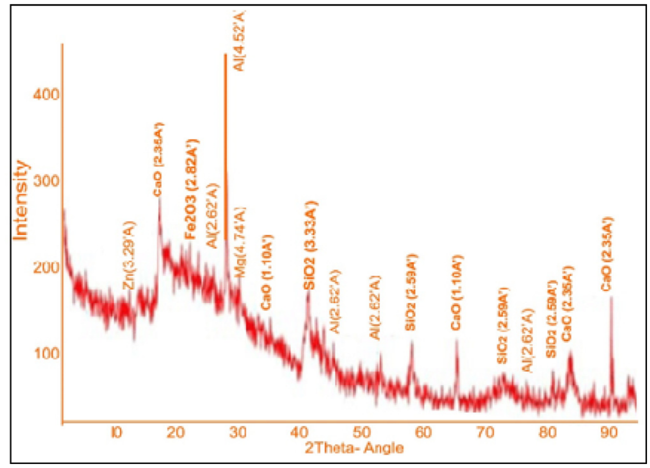

Fig. 6. XRD of 10% RHA + clay.

4.3. Tensile test

Fig. 8 shows the diagram of a tensile specimen. The result of the reinforcement with RHA + clay is shown in Fig. 9. It is visible that the tensile strength of the fabricated composite was enhanced by the adding of rice husk ash and clay as reinforcement particles relative to the base aluminium alloy. In this portion of this research, sample 1, 2, 3, 4 refers to AA6061 reinforced with 2.5% wt, 5% wt, 7.5% wt and 10% wt. respectively. The values of the tensile experiments carried out are presented in Fig. 9, which shows that the ultimate tensile strength and yield strength are heightened compared to that of pure aluminium alloy AA6061 due to the increase in the weight reinforcement of the clay and rice husk ash particles. Fig. 9 shows the tensile stress against strain for the control sample, and Fig. 10 shows the tensile stress against strain for clay + RHA reinforced sample.

4.4. SEM/EDS analysis

The composite material's microstructure was studied using an SEM equipped with an energy dispersive spectroscopy to identify the elemental composition of the control sample and reinforced sample at various wt % reinforcement. Fig. 11 shows the micrograph of the AA6061 sample and Energy Dispersive Spectra showing the mineral content of the control AA6061.

As observed from Fig. 12, the SEM images show that the clay and RHA particulates were comprehensively distributed in the continuous matrix for 2.5% wt reinforcement. Through the images, we observed there was a change in the form and the particle distribution of the sample from that portrayed in Fig. 11. The EDS results show that as a result of the clay and rice husk ash reinforcement particulates addition, there was an increase in the silicon content of the composite metal because of the high SiO_2 content in the reinforcement particles.

From Fig. 13, it can be noticed from the SEM image that there was a complete dispersion of the clay and rice husk particulates in the composite sample. A clear difference was noticed in the images of the particulates of the 5% reinforcement due to the stirring. In contrast, it is combining the components and handling before material combination takes place. As observed from the EDS analysis, there was an improvement in the silicon content of the reinforced aluminium alloy, which improves the mechanical properties of the composite sample relative to the control sample;

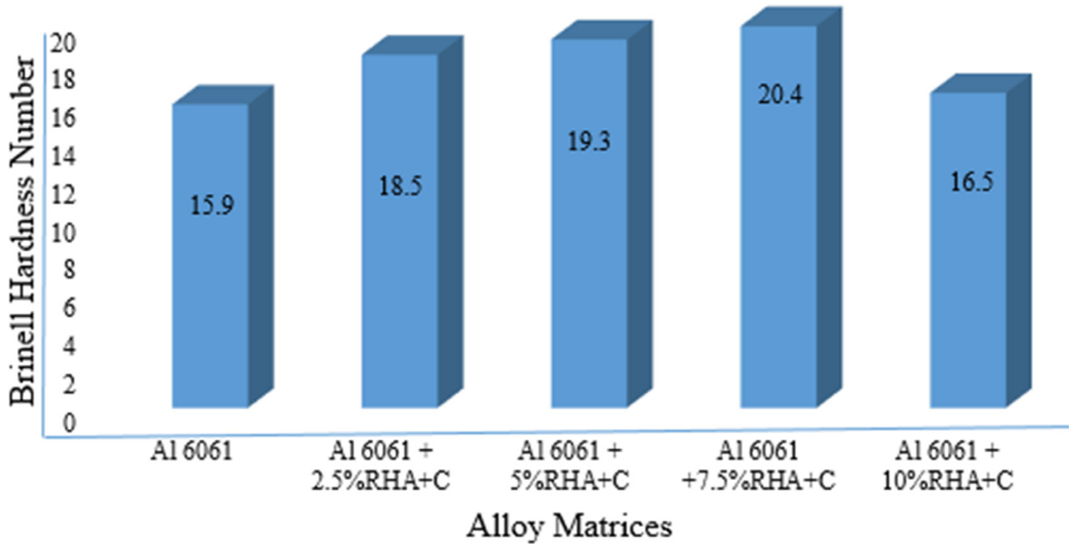

Fig. 7. Effect of RHA + clay content on Micro hardness.

Fig. 8. Tensile specimens.

there was also an increase in the elements relative to that of the reinforcement particulates.

From Fig. 14, it was observed that there was a methodical dispersal of the reinforcement particles in the continuous matrix phase. The difference in the images of the 7.5% particulates reinforcement was due to the stirring while combining the components and handling before material combination takes place. As observed from Fig. 14, there was an increase in the silicon content relative to that of AA6061 alloy which implies an addition in the SiO_2 content due to rise in the mass fractions of the clay and rice husk reinforcement particles which accounts for the enhancement of the mechanical features of the reinforced composite material.

From Fig. 15, an organized distribution of the reinforcement particulates in the continuous matrix phase was noticed. The different images of the particulates of the 10% reinforcement were due to the stirring while combining the components and handling before material combination takes place. The EDS image above

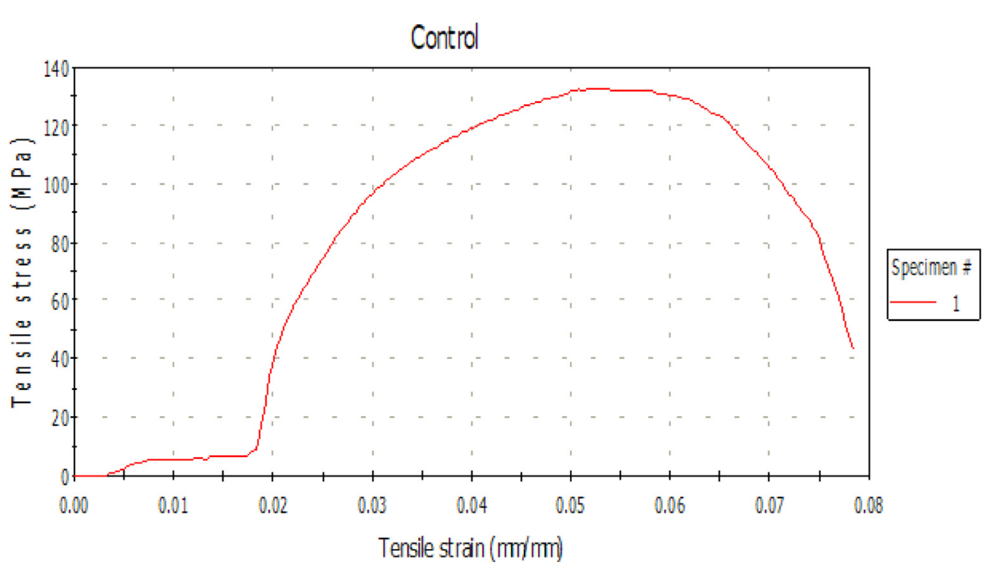

Fig. 9. Tensile stress against strain for control sample.

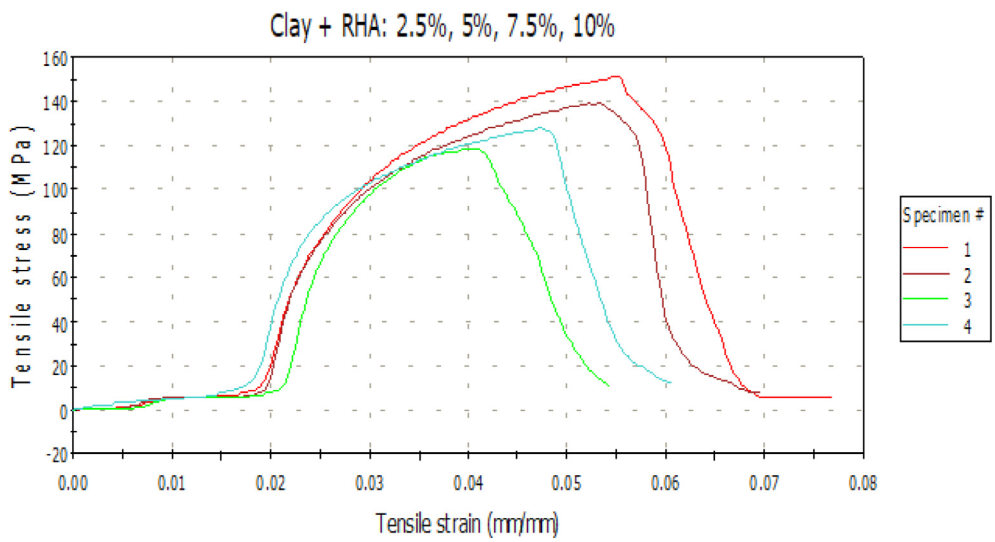

Fig. 10. Tensile stress against strain for clay + RHA reinforced sample.

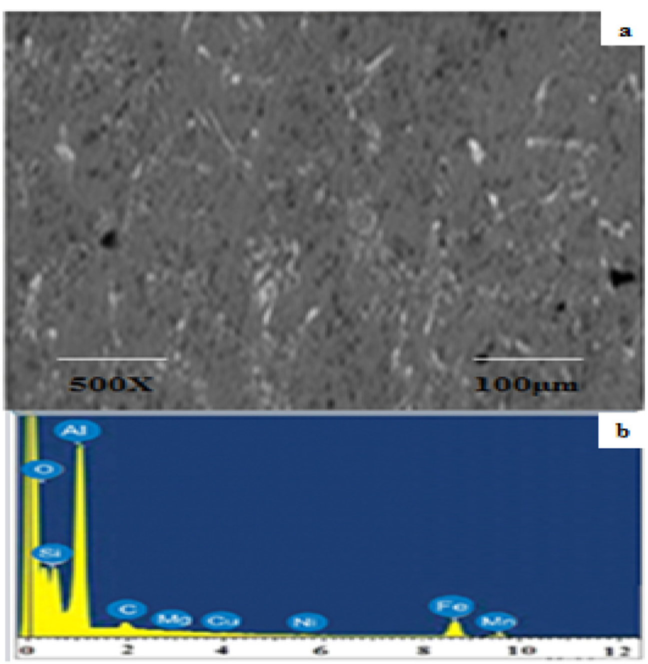

Fig. 11. (a) Micrograph of AA6061 sample (b) Energy Dispersive Spectra showing the mineral content of control AA6061.

shows the analysis of the elements present in the 10% reinforced AA 6061, which portrays the peak increase in the silicon content of the composite, which is an indicator of the presence of rich SiO_2 content, which accounts for the enhancement of the mechanical properties relative to pure aluminium alloy AA6061.

5. Conclusions

- AA6061/clay + RHA composite was adequately produced using stir casting method with various wt% reinforcements i.e. 2.5%, 5%, 7.5% and 10%.
- There was a considerable perfection in the mechanical properties of the composite relative to AA6061 aluminium alloy.
- The 7.5 wt% had better hardness property compared to other composite weight reinforcements.
- As detected from the SEM/EDS analysis, a homogeneous dispersion of reinforcement was observed in the matrix.
- The XRD analysis shows the absence of unwanted material and the possible phase combinations in the composite.

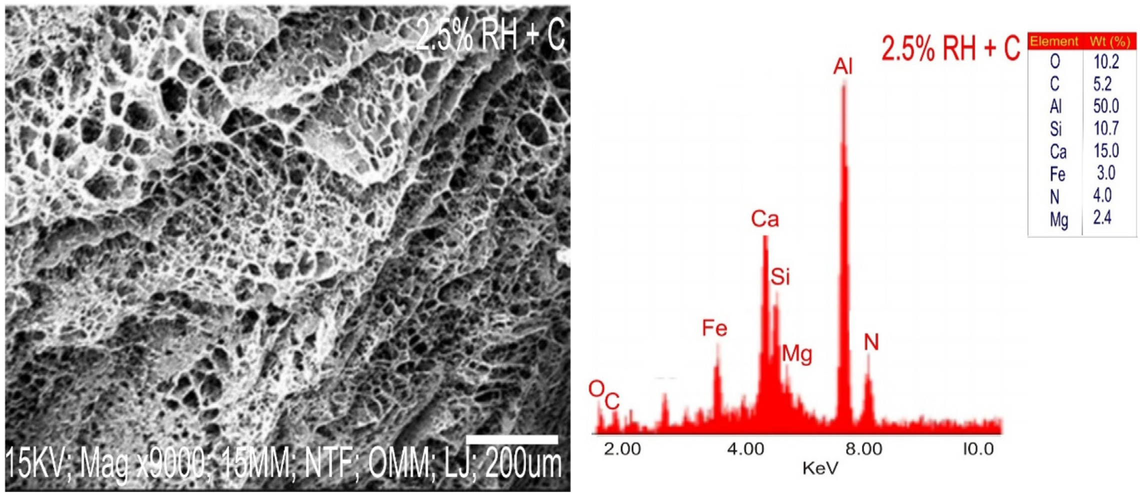

Fig. 12. (a) SEM of 2.5% clay + RHA reinforced AA 6061 sample. (b) EDS of sample.

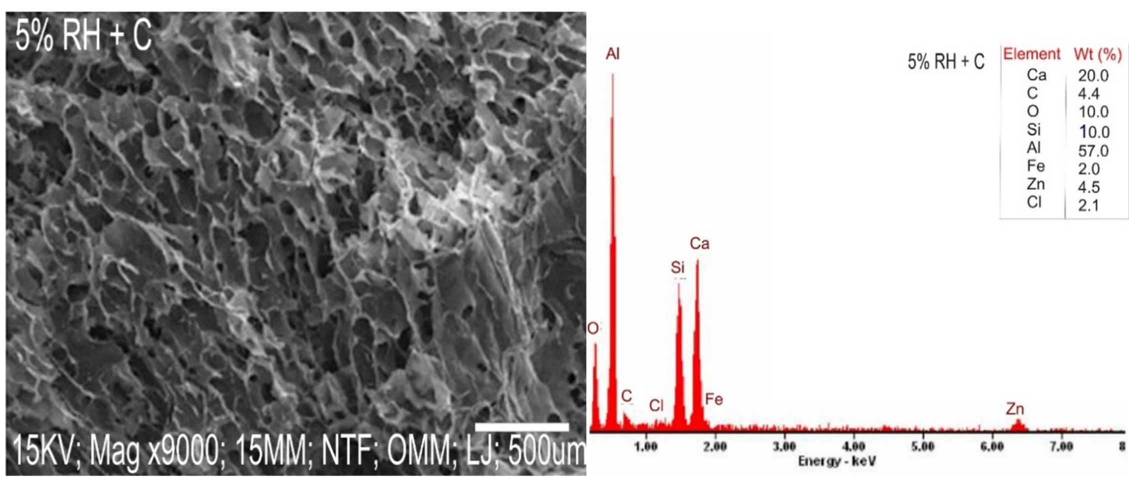

Fig. 13. SEM image of 5% clay + RHA reinforced AA 6061 sample (b) EDS of sample.

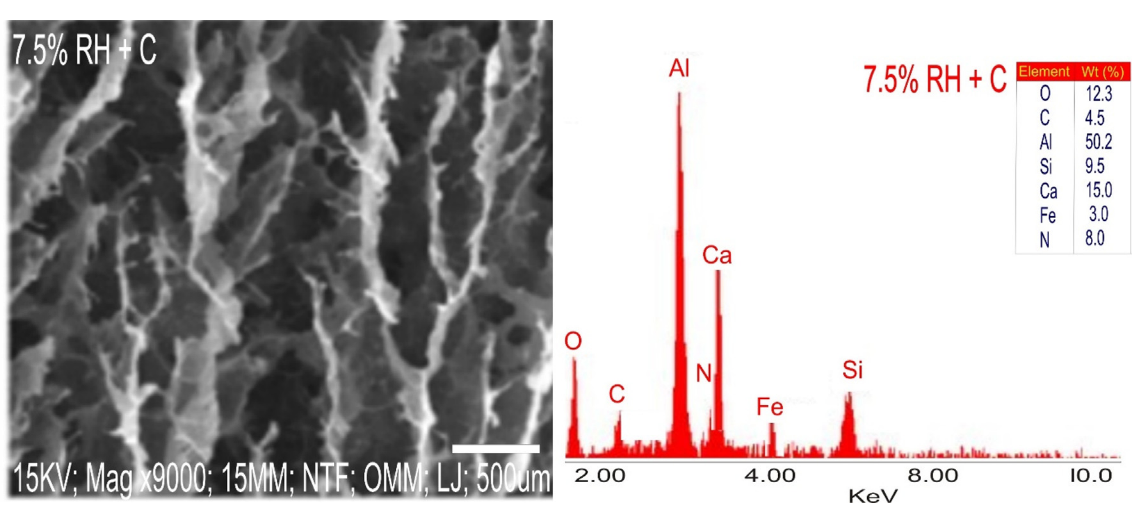

Fig. 14. SEM image of 7.5% clay + RHA reinforced AA 6061 sample (b) EDS of sample.

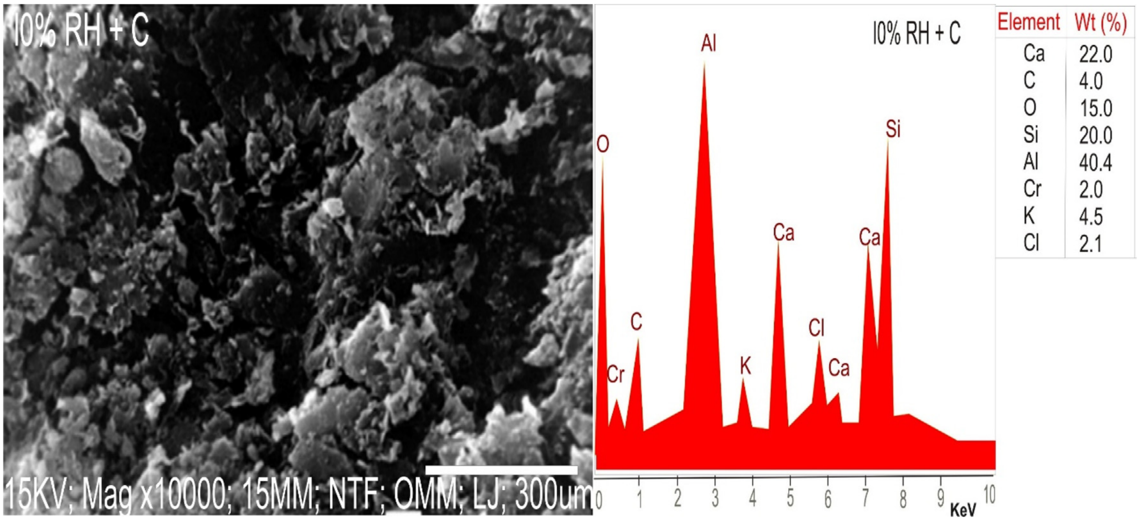

Fig. 15. SEM image of 10% clay + RHA reinforced AA 6061 sample (b) EDS of sample.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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