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RECYCLED ALUMINIUM CANS/RICE HUSK ASH: EVALUATION OF PHYSICO-MECHANICAL PROPERTIES

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ABSTRACT

The need for Aluminium metal matrix composites in engineering components for automotive, aerospace and other structural applications has motivated the quest to find a cost-effective production methods and superior mechanical properties for these composites. This however, prompted an attempt to harness the huge industrial and agricultural wastes potentials to produce useful materials from wastes to wealth. Aluminium based metal matrix composites have been produced from recycled aluminium cans reinforced with rice husk ash (RHA) particles using stir casting technique. In this paper, microstructure, density and mechanical behaviours of aluminium reinforced with RHA (particle size 150 µm, 300 µm and 600 µm) have been studied by varying weight fractions (5 %, 10 %, and 15 %) at constant stirring speed of 140 rev/min and stirring time of 2 mins. Optimization was carried out using Response Surface Methodology (RSM). The effects of percent weight fraction and particle size of rice husk ash on density, hardness, ultimate tensile strength, impact strength and fatigue of the aluminum composites are reported. The prepared composites were characterized using scanning electron microscopy (SEM). The scanning electron micrographs showed a fairly homogeneous distribution of RHA particles all over the aluminum matrix. Furthermore, RHA particles were bonded well with the aluminum matrix and a clear interface existed. The reinforcement of RHA particles enhanced the physico-mechanical properties of the aluminium/rice husk ash matrix composites.

KEYWORDS: Aluminium Alloy, Metal Matrix Composite, Reinforcement, Rice Husk Ash, Stir Casting,

1.0 INTRODUCTION

In Nigeria, environmental problems that come with the transition from the traditional bottle packaging to aluminium can packaging requires urgent attention. This is because large volumes of aluminium cans drinks are consumed daily across the country and the empty cans are not being properly disposed. As a result, environmental pollution is on the increase greatly, and is becoming uncontrollable, as streets, highway and drainages are being littered by empty drink cans used in our day to day activities. Those aluminum cans wastes were dropped in drainages, preventing water from flowing therefore, leading to water logging which aids breeding of mosquitoes and disease outbreaks (Agunsoye et al, 2015).

Rice husk ash is one of the most inexpensive and low-density reinforcement, and are available in large quantities as solid waste by-product when compared with other reinforcements like SiC, Al_2O_3 etc. (Robatgi 1997; Surappa, 2003; Hague et al, 2016). According to Hague et al, (2016), rice husks contain about 75 wt.% organic volatile matter and the balance 25 wt.% of this husk which is converted into ash during the firing process, and is known as rice husk ash. This RHA is a great threat to the environment, causing damage to the land and the surrounding area in which it is dumped. Also, the disposal of rice husk also has caused various challenges which include cost and availability of disposal sites. The need to protect environment is a concern of this study to ensure the effective utilization of the agricultural waste and to reduce if not completely eliminated menaces associated with poor waste management by recycling of agricultural and industrial waste materials (Agunsoye et al, 2015; Gaustada et al, 2012; Bungardean, Sopran and Salanta, 2013).

Aluminium alloys have certain limitations which affect its use in automobile and aerospace industries. Such limitations include low temperature capability, high thermal expansion coefficient and inadequate mechanical, and tribological characteristics. As a consequence, Si-based RHA can be reinforced with aluminium alloy to produce composite materials with metal matrices a used for engine cylinders, pistons, disc and drum brakes, cardan shafts and for other elements in automotive and aviation industry. The most important type of metallic materials is composite materials with matrices of aluminium alloys due to a set of their beneficial properties (Prasad and Asthana, 2004; Miracle, 2005; Stojanovic, 2013).

The addition of hard and stiff ceramics reinforcement has been established to improve the modulus behaviour and strength properties in the metallic matrices (Usman, Raji, Hassan and Waziri, 2014; Saravanan and Kumar, 2013; Gladston et al, 2015). Reinforcing aluminium metal with rice husk ash as a source of silica particulate will yield a material that displays combination of physical and mechanical properties of both the metal matrix and the silica from the ashes.

The aim of the study is to recycle aluminium waste cans to develop aluminium metal matrix reinforced with rice husk ash to produce composites with superior mechanical properties suitable for automotive, aerospace and other industrial applications. The study shall also seek to harness the huge agricultural and industrial wastes potentials to produce useful materials, by creating new materials from wastes to wealth.

2.0 METHODOLOGY

The methodology of this research involves preparation of metal matrix (base metal) and reinforcements, preparation of composites and specimens, selection of test methods and test conditions, experimental measurement of the density and mechanical properties of the specimens, and determination of microstructures. Four process parameters were used in production of Al/RHA composites, namely: three different particle sizes (150 µm, 300 µm and 600 µm), three percentage weight fractions of RHA (5 %, 10 % and 15 %), constant stirring time of 2 minutes and stirring speed of 140 rpm.

2.1 SAMPLE PREPARATION

The matrix material and reinforcement selected for the study are aluminium alloy from waste aluminium cans obtained from local market in Ikorodu, Lagos and rice husk sourced from local rice mills in Imota town, Lagos.

2.1.1 Preparation of Aluminium Alloy (Matrix)

Compressed aluminium cans (Figure 1a) of 5 kg were packed in a crucible furnace and re-melted in a diesel fired furnace and heated to 850 ^{0}C after which the crucible containing melt of aluminium cans was removed from the furnace so that the slag floating on top of the melt due to plated paint around the cans could be screamed off the surface of the melt. The melt in the crucible was returned to the furnace and then heated to 850 ^{0}C. Then, the melt was poured into a trapezoidal shaped metal moulds to produce the billet (Figure 1b).

(a) (b)

Figure 1: (a) Aluminium Scrap (b) Aluminium alloy billet.

2.1.1 Preparation of Rice Husk Ash (Reinforcement)

The mixture was first blown manually to separate the husk from rice grains and other contaminants and then washed with tap water twice by stirring in a container to allow the sand impurity and rice particles to settle at the bottom while the powdered grains and sand mixed with the water became muddy. This muddy water was then poured away and the rice husk was manually removed from the container leaving behind the settled sand. The blown and washed rice husk was then dried under sun rays for three days on stainless steel trays. The rice husk was placed inside a crucible pot and lagged with cotton wool and then burnt at 700 ^{o}C for two hours inside the muffle furnace for pyrolysis. The ash was further burnt at 1100 ^{o}C for another two hours, sieved and graded into three different particle sizes of 150 µm, 300 µm and 600 µm (Figure 2).

Figure 2: Graded rice husk ash.

2.1.3 Preparation of composites from Aluminium alloy and rice husk ash (Al/RHA)

Monolithic trapezoidal shaped aluminium bars reinforced with rice husk ash (RHA) particles of average sizes 150 µm, 300 µm, 600 µm respectively at 5 %, 10 % and 15 % weight fraction of RHA are used for casting of Al/RHA-MMCs by melt-stir technique.

The melting was carried out in a crucible pot placed inside the crucible furnace. Each aluminium alloy billet melted was first preheated at 450 ^{o}C before melting at 750 ^{o}C and rice husk ash of the required percent weight fraction and particle size was measured and preheated to about 100 ^{o}C before incorporating into the melt which was then degassed to control the porosity.

To enhance the wettability between the rice husk particles and alloy melt, 1 wt% of magnesium is simultaneously added into the molten melt. Saravanan and Kumar (2013), stressed that particles of rice husk ash will be rejected without addition of magnesium.

The molten metal is stirred by the improvised stirrer at a speed of 140 rpm for the required time. The mixture is poured into the cylindrical and rectangular die moulds which has been preheated to about 200 ^{o}C before pouring. During pouring in the die mould, slag and any form of impurity was removed. This procedure is carried out for the control sample and nine composites according to RSM with 3-level historical data shown table 1. Samples of the rectangular and circular composite produced from the die cavity metal mould is shown in Figure 3. This is used to machine the specimens for microstructure, density measurement and mechanical properties tests.

Table 1: Design of Experiment model range for the Al/RHA composites.

Std	Run	Block 1	Weight fraction %wt	Mesh Size µm
1	3	Block 1	5	600
2	1	Block 1	5	150
3	7	Block 1	15	150
4	8	Block 1	15	300
5	6	Block 1	10	600
6	2	Block 1	5	300
7	5	Block 1	10	300
8	4	Block 1	10	150
9	9	Block 1	15	600

Figure 3: Sample of the Rectangular and Circular billet of the composite.

3.1 Density Measurement

The mass of the control sample and composite samples was determined using electric weighing balance, and the volume was obtained by Archimedes principle by immersing the sample into a measuring cylinder and the rise in volume was recorded and used together with the mass to calculate the densities.

Density of nine composite samples of Al/RHA-MMC's and unreinforced Al alloy (controlled sample) were obtained using standard specimen of dimensions 50x10x10 mm. Weight of the sample in air (w_1) was measured, and the same sample was immersed in distilled water and weight of the sample was recorded as w_2. Then the actual density was obtained using equation 1.

$$\text{Density} = \frac{W_1}{W_1 - W_2} \, x \, \rho_{water} \quad (1)$$

3.2 Tensile Test

The tensile strength was determined by first preparing the sample on a lathe machine. The tensile test was carried out at room temperature on HZ-1009 Computer Servo Universal Testing Machine, by Dongguan Lixian Instrument Scientific Company Limited. Figure 4a shows the machined specimen for the control sample and nine composites.

3.3 Hardness Test

The Vickers diamond test was done on Vickers hardness tester (LECO AT700 Micro Hardness Tester,) Each of the nine samples of Al-rice husk ash-MMC's for different sizes and weight fraction of rice husk ash and one control sample shown in Figure 4b. All samples were prepared with a fine-grained emery polishing papers. Then at any clear view of the grains the diamond indenter was then indented under an applied load of 490.3 Nm (50.03 kg) with a dwelling time of 10 secs at three different points and the depth of penetration of the indenter on the steel specimen was noted and read directly from the calibrated gauge of the machine, the average value was calculated and recorded. The hardness readings were evaluated following standard procedures.

3.4 Impact Energy Test

The impact energy test was carried out on all the ten samples of squared cross-section of size (11.4 x 11.4 x 75 mm) with V-notches 45^o and 3.3 mm depth (Figure 4c). The impact test was carried out on Izod (pendulum) Impact Testing Machine.

3.5 Fatigue Test

Fatigue specimen was first prepared on a lathe machine and the test was carried out on SM 1090 Rotating Fatigue Machine. Nine samples of Al/rice husk ash-MMC's and a control sample were prepared with ASTM standard dimensions (Figure 4d). Count to fracture for each specimen were taken and recorded at constant load.

(a) (b) (c) (d)

Figure 4: (a) Tensile specimen (b) Hardness specimen (c) Impact specimen (d) Fatigue specimen.

3.6 Microstructure test

Metallographic samples were cut from each of the specimen, filed with bastard file and then with a smooth to provide the initial flatness before subsequent surface grinding. It was mounted with Bakelite (organic material of isopine) using mounting press model Simplement 2. Preliminary machine grinding of the cut specimens surface was followed by grinding with 1000B grain sizes grade paper to achieve smooth and shining surface using metal series model 2000, Germany. Final polishing with diamond paste of grade B (3 mm) was made until smooth and mirror finished surface was obtained using a polisher machine model 900, China.

The specimens were etched in 2% HNO_3 (Nital) for 10s, dried with rectified spirit to remove moisture, and examined in direct illumination on a metallurgical microscope model DMS 557 with an in-built camera through which the resulting microstructure of the samples were all photographically recorded with magnification of 500. The procedure was carried out for composites of Al-RHA and control sample.

3.0 RESULTS AND DISCUSSION

3.1 Compositional Analysis

The elemental composition of the control sample and rice husk ash are shown in tables 2 and 3 respectively. The unreinforced Al alloy contains some residual elements in reasonable proportion that could form intermetallic compounds in the Al composites.

Table 2: The elemental composition of the as cast aluminium alloy ingot.

Al	**SI**	**Fe**	**Cu**	**Mn**	**Mg**	**Zn**	**Cr**	**Ni**	**Ti**
95.24	0.66625	›1.861	0.0953	0.8382	0.8565	0.0252	0.0168	0.1194	0.035
Sr	**Zr**	**V**	**Ca**	**Be**					
‹0.000	‹0.008	0.0153	0.0127	‹0.000					

Table 3: Percentage chemical composition of rice husk ash burnt at 700°C.

SiO_2	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_2**	**K_2O**	**Na_2O**	**Others**	**LOI**
97.095	1.135	0.316	0.073	0.825	0.146	0.181	0.092	Balance	0.965

3.2 Microstructural Analysis

Figures 5-8 show the scanning electron micrograph (magnification of 500) with attached EDS of the control sample (monolithic aluminium) and Al/RHA-MMC's samples for different sizes (150 µm, 300 µm, 600 µm) and weight fraction (5%, 10%, 15%) of RHA particles at stirring time of 2 minutes and stirring speed of 140 rpm. Casting defects such as shrinkage and porosity are minimal in the SEM micrographs. These developments demonstrate that the castings are of good quality. This can be adduced to the choice of process parameters and experimental design employed for production of the castings. The EDS analysis indicted the presence of Al with maximum peak in all castings. Other peaks around Al peak, which are minor indicate the presence of trace elements having low count score. This observation confirms the elemental composition of the control sample and the composites. The consistence presence of C, and O in Al/RHA composites are attributable to the carbonization of RHA added to aluminium alloy as reinforcement. It shows clearly from EDS that carbon increases as the percent weight fraction of the reinforcements increases. The very low count of oxygen in the EDS shows that the degree of porosity is very low. Therefore, RHA particles were bonded well with the aluminum matrix and a clear interface existed. This resulted in improved mechanical properties of the composites.

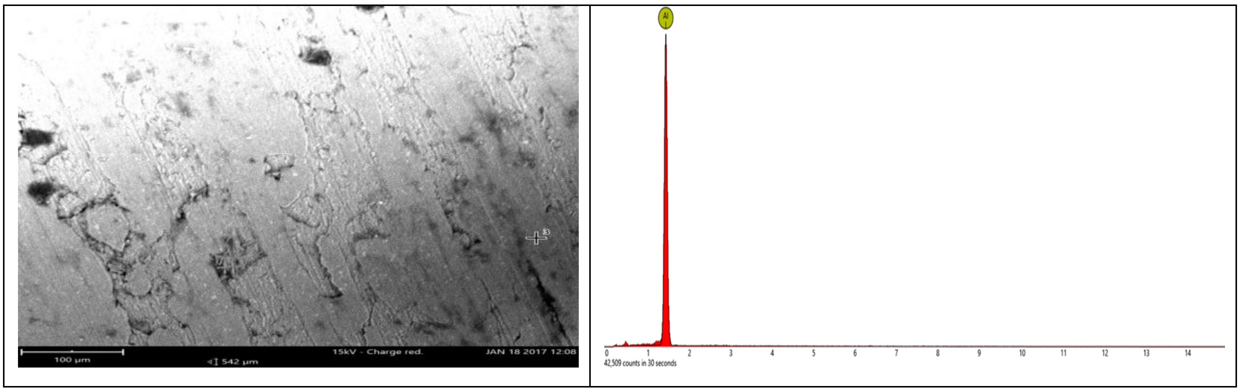
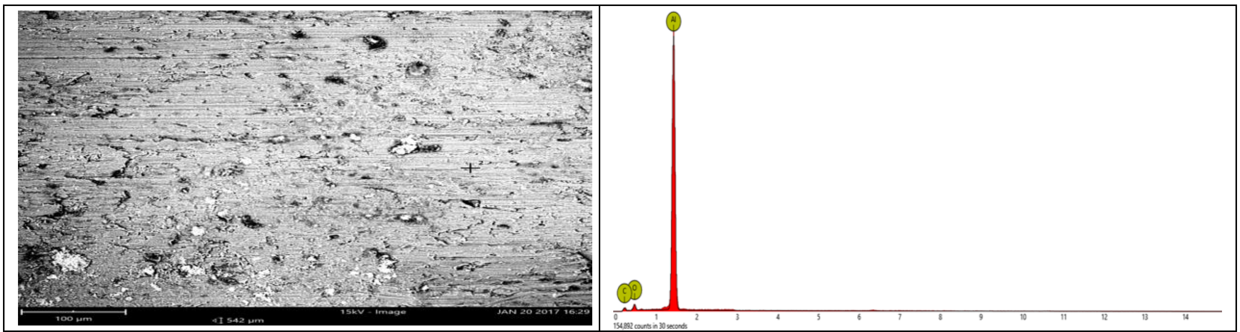
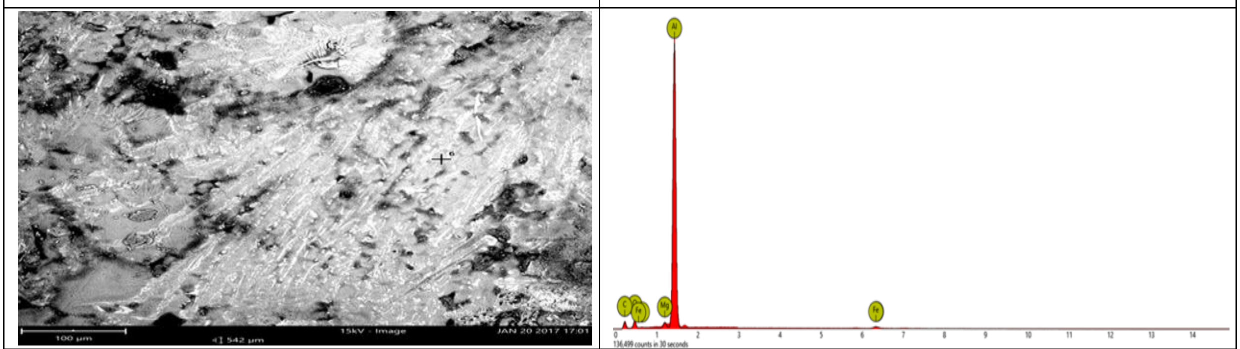


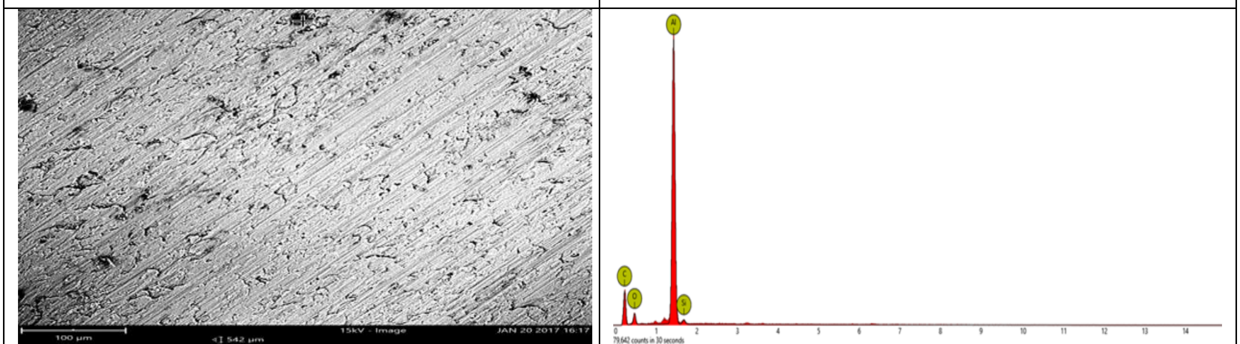
Figure 5: SEM and EDS of monolithic Al alloy (Control sample).



(a) SEM/EDS at 5 % wt. RHA



(b) SEM/EDS at 10 % wt. RHA



(c) SEM/EDS at 15 % wt. RHA

Figure 6: SEM/EDS at 150 µm of Al/RHA composites.

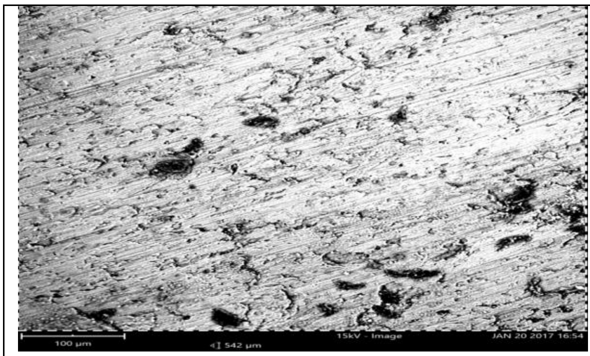
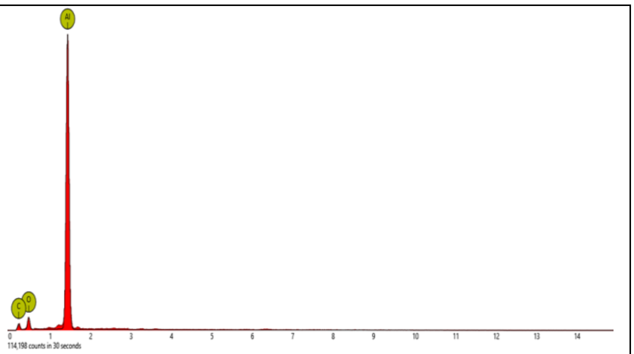
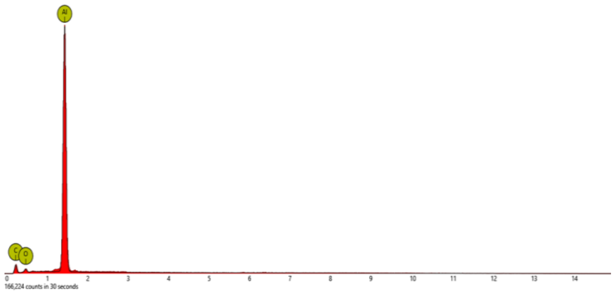
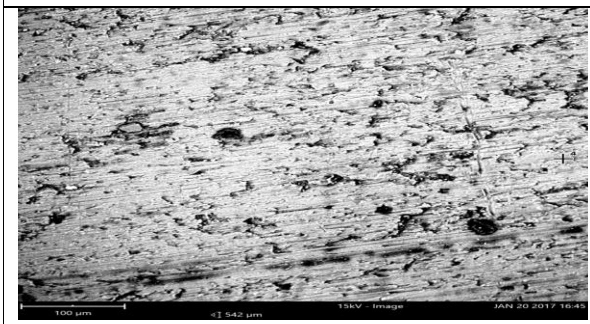
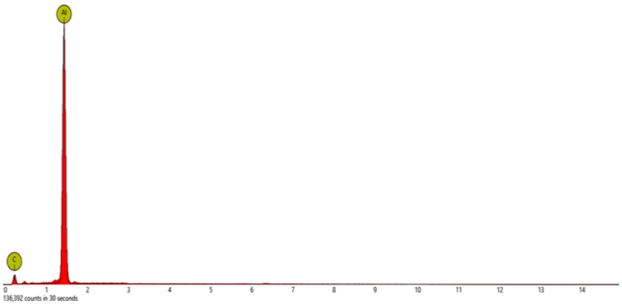
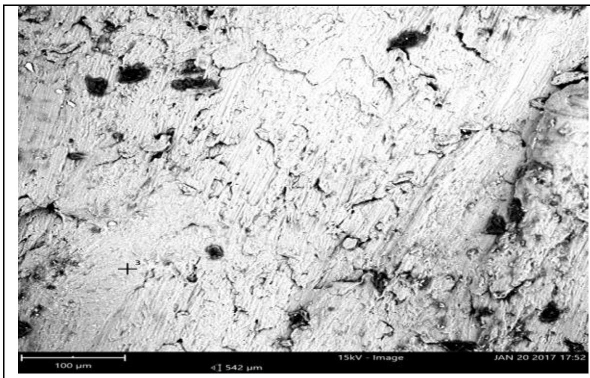
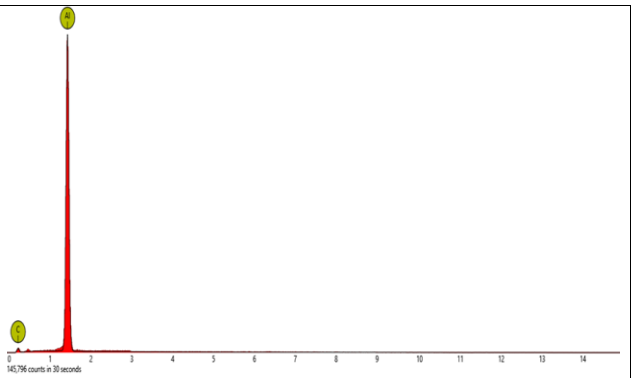
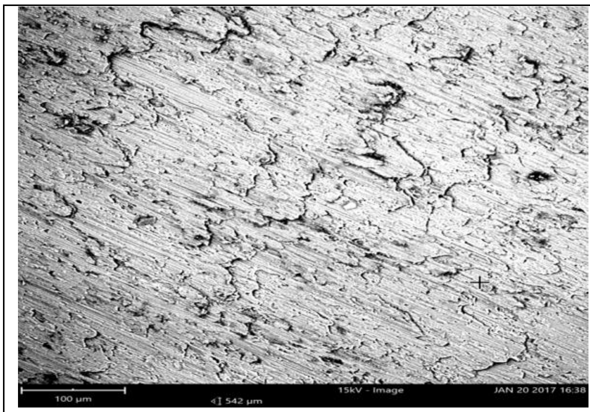
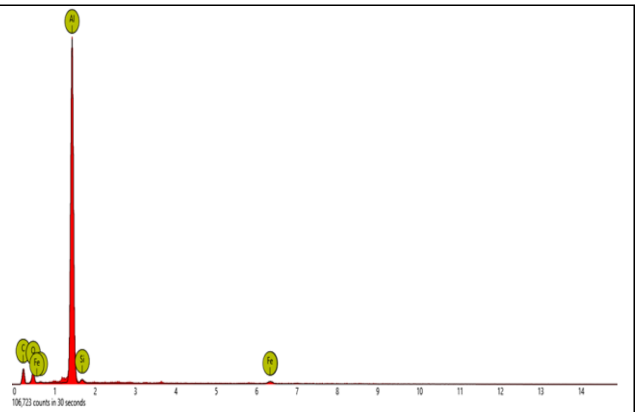
	
(a) SEM/EDS at 5 % wt. RHA	
	
(b) SEM/EDS at 10 % wt. RHA	
	
(c) SEM/EDS at 15 % wt. RHA	

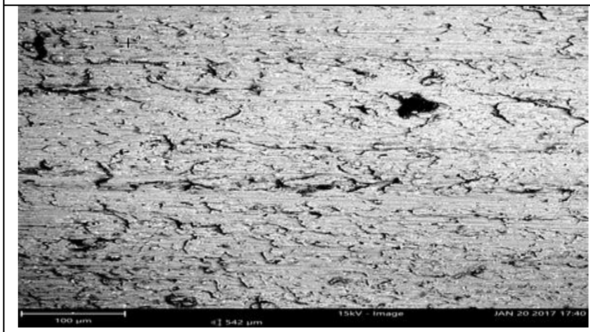
Figure 7: SEM/EDS at 300 µm of Al/RHA composites.

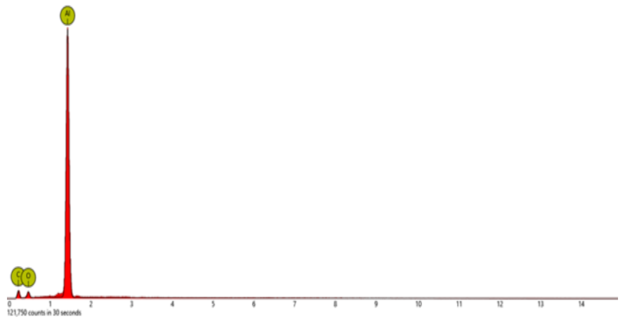
	
SEM/EDS at 5 % wt. RHA	





SEM/EDS at 10 % wt. RHA





SEM/EDS at 15 % wt. RHA

Figure 8: SEM/EDS at 600 µm of Al/RHA composites.

3.3 Physico-mechanical properties

Table 4 shows the results for mechanical properties of the control sample. Results of density and mechanical properties of Al/RHA composites are plotted in Figures 9a-e.

Table 4: Mechanical Properties for monolithic aluminum alloy (control sample).

Density X 10^3(kg/m^3)	Ultimate Tensile Strength (MPa)	Hardness (HD)	Impact Strength (KJ/m^2)	Fatigue Cycles x10^6
2.85	148	68	122	0.72

3.3.1 Effect of Weight Fraction and Particle Size on Density

From Figure 9a, the density of the composites decreased greatly with increase in weight fraction (5-15%), but a slight decrease was observed with increase in particle size as it moves from 150-600 µm. At low particle size of 150 µm, the density of the composites decreased from 2.72 x 10^3 to 2.65 x10^3 kg/m^3 as weight fraction increases. So also at 600 µm size, the same behaviour was observed but with much decrease from 2.71 x 10^3 to 2.62 x 10^3 kg/m^3.

3.3.2 Effect of Weight Fraction and Particle Size on Ultimate Tensile Strength

The ultimate tensile strenght increased with increase in weight fraction up to 10 % but decreased with increase in particle size. The interactive effect of weight fraction and particle size on the ultimate strength was shown in Figure 9b. At low particle size 150 µm, the ultimate strength of the material tends toward linearity as weight fraction increases. At 600 µm size, ultimate strength increased from 136 MPa to 151.8 MPa as weight fraction increases from 5-15 %.

3.3.3 Effect of Weight Fraction and Particle Size on Hardness

As shown in Figure 9c the Al alloy composite hardness increased with increase in weight fraction but decreased with increase in particle size. The interactive effect of weight fraction and particle size against the material hardness shows that at low particle size of 150 µm, the hardness was observed to increase from 91.49 HD to 97.52 HD as weight fraction increases. At high particle size of 600 µm, the hardness tends towards linearity with slight increase from 71.19 to 79.10 HV. The material hardness is favoured by low particle size 150 µm and high weight fraction of 15 wt%.

3.3.4 Effect Weight Fraction and Particle Size on the Impact Strength

Figure 9d revealed that the impact strength increases with increase in weight fraction and particle size. The interactive effect of weight fraction and particle size on the Al/RHA impact strength shows that at low particle size 150 µm, the impact strength of the material decreased slightly as weight fraction increases. At 600 µm size, impact strength increased as weight fraction increases from 5-15 %, therefore, higher impact was seen at 600 µm and 15 % weight fraction.

3.3.5 Effect of Weight fraction and Particle size on fatigue

Figure 9e shows that the fatigue cycles increased slightly with increase in weight fraction and stirring time but decreased greatly with increase in particle size. Also, the interactive effect of weight fraction and particle size against the material fatigue revealed that at low particle size of 150 µm mesh, the fatigue of the material increased from 2.04 to 2.25×10^6 cycles. At high particle size of 600 µm mesh, the fatigue of the material slightly decreased from 1.01 to 0.98×10^6 cycles and then increased to 1.05×10^6 cycles as weight fraction increases.

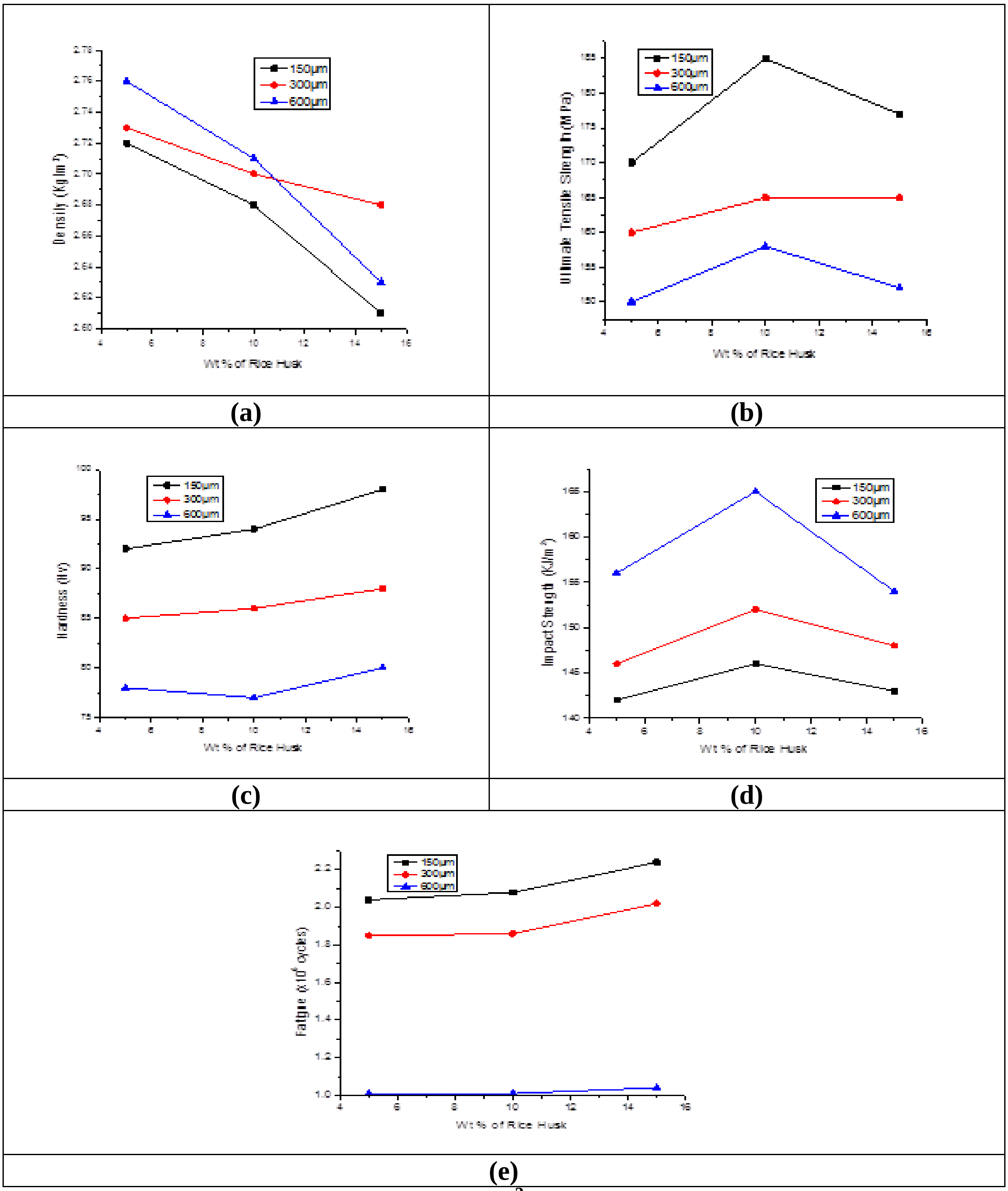


Figure 9a-e: Variation of (a) densities (at 10^3) with the percentage weight fraction and particle size of rice husk ash (b) Ultimate Tensile Strength with the percentage weight fraction and particle size of rice husk ash (c) Hardness with the percentage weight fraction and particle size of rice husk ash (d) Impact Strength with the percentage weight fraction and particle size of rice husk ash (e) Fatigue with the percentage weight fraction and particle size of rice husk ash.

4.0 CONCLUSION

The conclusions drawn from the present investigation are as follows:

- Rice Husk Ash, the agricultural waste generated from milling paddy can be successfully used as a reinforcing material while waste aluminium cans can be recycled to produce Aluminium Metal-Matrix Composite by stir casting techniques.
- Microstructure analysis shows the uniform distribution of rice husk ash particles in the aluminum alloy. The microstructure revealed good interfacial bond between matrix and rice husk ash particles. The RHA particles refined the grains of the aluminum matrix. The good dispersibility of RHA particles in aluminium matrix improves the hardness, tensile, impact and fatigue properties of the matrix material.
- The density of the composites decreases greatly with increase in weight fraction (5-15%), but a slight decrease was observed with increase in particle size as it moves from 150-600 µm.
- The ultimate tensile strenght increases with increase in weight fraction up to 10 % but decreases with increase in particle size.
- The hardness increases with increase in weight fraction but decreased with increase in particle size.
- The impact strength increases with increase in weight fraction and particle size.
- The fatigue cycles increases slightly with increase in weight fraction and stirring time but decreased greatly with increase in particle size.
- The use of RHA and waste aluminium cans for the production of Al/RHA composites can turn agricultural waste into industrial wealth. This can also solve the problem of storage and disposal of waste aluminium cans and rice husk.

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