American Journal of Mechanical and Industrial Engineering
2022; 7(1): 1-6
http://www.sciencepublishinggroup.com/j/ajmie
doi: 10.11648/j.ajmie.20220701.11
ISSN: 2575-6079 (Print); ISSN: 2575-6060 (Online)

Influence of Cow Horn Particles on the Hardness and Impact Properties of the Reinforced Recycled Aluminium Alloy

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To cite this article:
Adeyemi Gbenga Joshua, Oguntuase Musa, Stephen Joseph Temitope. Influence of Cow Horn Particles on the Hardness and Impact Properties of the Reinforced Recycled Aluminium Alloy. *American Journal of Mechanical and Industrial Engineering*. Vol. 7, No. 1, 2022, pp. 1-6. doi: 10.11648/j.ajmie.20220701.11

Received: April 9, 2022; **Accepted**: April 23, 2022; **Published**: May 7, 2022

Abstract: Development of low cost metal alloys reinforced with waste materials such as agro- waste and industrial waste has been one of the major innovations in the area of material engineering. This aimed at producing engineering materials with improved properties without additional cost of techniques such as annealing and normalising. In this study, aluminium scraps from automobile parts (secondary aluminium) were used as principal material and reinforced with locally available inexpensive cow horn particulate (ago-wastes) of 3, 6, 9 and 12% by weight to produce an aluminium based composite. Hardness and impact strength of the aluminium alloy reinforced cow horn particulate (CHp) were studied. The results showed that the produced composite exhibits superior hardness value compared to the alloy metal. The hardness increases from 87.7 BHN to 101.4 BHN, 132.4 BHN, 134.4 BHN and 143 BHN with addition of 3%, 6%, 9% and 12%, weight of CHp into the aluminium alloy matrix, respectively. However, the composite displayed lower impact strength than the aluminium alloy and the strength reduces as the weight percentage of CHp in the composite increases. Addition of 3%, 6%, 9% and 12%, weight of CHp into the aluminium alloy reduced the impact value from 49.4 J to 36.76 J, 35.05 J, 33.68 J and 28.53, respectively. The X-ray diffraction analysis of the reinforced aluminium alloy revealed the presence of CHp without the formation of any other intermetallic compounds, good bonding between CHp and aluminium alloy, and absence of agglomeration of CHp in the aluminium alloy matrix.

Keywords: Aluminium Alloy, Cow Horn Particles, Hardness, Impact Strength, X-Ray Diffraction

1. Introduction

Aluminium has been identified as the most abundant metal earth crust [1]. Aluminium and its alloys are increasingly use of for engineering applications due to their many favourable technical properties [1, 2], and they possessed recycling tendency (i.e., end-of-life aluminium, also known as secondary aluminium, can be melted and used to reproduce a new useful material). Therefore, recycling of aluminium scraps is of good economic value and it is also a major way of preventing end-of-life aluminium materials from littering the environment.

Conventional engineering materials are sometimes reinforced with particles to produce composite materials with unique properties such as high strength, wear resistance, light weight and dimensional stability at high temperature [3]. In the past few years, a lot of researches have been carried out in the field of material engineering using agro-wastes to reinforce aluminium alloy in order to develop new useful materials with better mechanical properties such as hardness and impact strength (Obi et al., 2016) (Joseph et al., 2019). Reinforced aluminium alloys are recognized to be useful in many areas such as aerospace, electronics, automotive, thermal and wear applications [4, 5]. Some of the agro wastes used in literature include rice husk ash [4, 6, 7], groundnut shell ash [8], bean pod ash [9] and cow horn particulate [10, 11]. Aluminium alloys are used as matrix in these composite due to their low density, good casting abilities and high corrosion resistance [2, 12, 13].

Prasad and Krishna investigated the effects of rice husk ash (RHA) on the mechanical properties and wear characteristics of A356.2 alloy [14, 15]. The constituent of the RHA used was in varying fractions of 4%, 6% and 8% per unit weight of the reinforced aluminium alloy. The study showed that the hardness and strengths of the reinforced A356.2/RHA composites improved when compared with unreinforced alloy. However, wear rate and friction coefficient of the composites decrease with increasing RHA particles content. They concluded that A356.2 alloy reinforced with rice husk improved hardness and strength can find applications where lightweight materials are required with good stiffness and strength.

Furthermore, the research conducted by Ghosh et al. [16] to study the mechanical and tribological properties of the aluminium alloy (Al6061) reinforced with rice husk ash in varying fractions of 4%, 8% and 12% per unit weight and fabricated by through stir casting process showed improvement in tensile strength, micro-hardness, coefficient of friction and wear depth on the samples. Reinforcing aluminium alloy (Al6061) rice husk ash (RHA) and fly ash particles in varying contents of 5%, 10% and 15% each by weight produced aluminium composites with better mechanical properties and machinability when compared to the pure alloy, and less percentage of fly ash in the composite gave strength and machinability to the composite Al6061 [7].

Saravanan and Kumar [6] performed an experiment to know the possibility of improving the mechanical properties of AlSi10Mg through reinforcement with RHA. The results of mechanical tests on the reinforced alloy showed that tensile strength, compressive strength and hardness of the composite improve as percentage of RHA increase while the ductility of the composite decrease as RHA fraction increase in the AlSi10Mg/RHA composite. Muni et al. [4] reinforced Al 6061 alloy with rice husk ash, copper and magnesium in 6, 8 and 10wt.% RHA, 3wt.% Cu and 1 wt.% Mg to produce hybrid composites. The hardness, impact strength and ultimate tensile strength of the composite were found to increase slightly with the increase in wt.% of RHA content.

Literatures have also shown that agro wastes of animal origin have been used to reinforce aluminium alloys during production of aluminium based composites with better mechanical properties. Ochieze *et al*. investigated the wear characteristics of aluminium alloy (A356) reinforced with cow horn particulates produced via the sintering of the spark plasma [10]. It was found that the reinforced A356 alloy exhibited a superior sliding resistance to the wear when compared with unreinforced A356 alloy. Asafa et al. studied the possibilities of using snail shell as a reinforcement for scrap aluminium based materials from roofing sheet and automobile piston using stir casting technique [17]. Snail shell particles of weight fraction of 16 to 48 wt.% and size of 200, 400 and 600 μm were used to reinforced aluminium scraps. Results of tests conducted on the produced aluminium based composite showed that tensile strength of 236 MPa and hardness of 48.3 HRF were achieved at 48wt.% and 600 μm particle size when compared to 92.4 MPa and hardness of 29.2 HRF for the unalloyed samples, respectively.

The effects of eggshell particles on Al–Cu–Mg/eggshell particulate composites was investigated by Hassan and Aigbodion [18]. The Al–Cu–Mg alloy based composites containing 2-12 wt. % irregular shaped carbonized and uncarbonized eggshell particles were produced through stir technique. It was found that Al–Cu–Mg alloy reinforced with carbonized eggshell possessed superior physical and mechanical properties than composite with uncarbonized eggshell particles. Also, density was found to reduce by 7.4%, impact energy decreased by approximately 24.67% whereas tensile strength and hardness were enhanced by 14.28% and 25.4%, respectively, at 12% wt. carbonized eggshell when compared to unreinforced alloy. In addition, Kolawole et al. [19] studied recycled aluminium alloy reinforced with different quantities of calcinated snail shell particles. Their results showed that uniform distribution of snail shell particles with good wettability and interfacial bonding improved hardness and tensile strength by 50%.

Consequently, this present study aimed at producing reinforced aluminium alloy composites using agricultural waste (cow horn particulates) and also to investigate effects of the cow horn particulates on the mechanical properties of the composite with focus on hardness and impact strength while X-ray diffraction analysis would also be conducted on the composite.

2. Material and Experimental Methodology

2.1. Aluminium Alloy and Cow Horn

Aluminium scraps consisting of automobile parts was the major material used in this work. It was purchased from Aluminium scraps merchant in Ado-Ekiti, Nigeria. Cow horn particulate used as reinforcing material was sourced locally from an abattoir also in Ado-Ekiti, Nigeria. Both materials are readily available and main advantage of using these materials is that it helps in controlling environmental pollution that these end-of-life materials would have constituted. Table 1 presents the results of chemical analysis carried out at Obafemi Awolowo University, Ile-Ife, Nigeria on the pure aluminium specimen to determine its chemical compositions.

Table 1. *Chemical composition of aluminium alloy from automobile parts (secondary aluminium).*

Element	Composition	Element	Composition
Si	4.42	Ni	0.02
Fe	0.77	Zn	0.59
Cu	0.66	Ti	0.03
Mn	0.09	Pb	0.02
Mg	0.36	Al	Bal.
Cr	0.02		

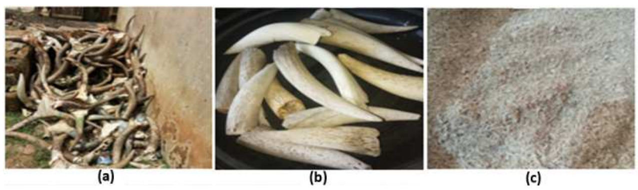


Figure 1. *(a) Raw cow horns, (b) washed and sun-dried cow horns and (c) grinded cow horns particulates.*

2.2. Preparation of Reinforce Material

The cow horns littering abattoir is shown in Figure 1(a). The preparation CHp starts with removing of the bony core of the cow horns from the keratin sheath and washed thoroughly with water and detergent so as to remove any trace of marrow, blood and other substances that can hinder proper bonding between aluminium alloys and the reinforcement and thereafter, sun dried for a month (Figure 1(b)). The bony core was then crushed into smaller pieces with hammer and grinded with a grinding machine to cow horn particulates (CHp) shown in Figure 1(c). The chemical composition of cow horn particulates (CHp) as was presented by the Ochieze et al., is shown in Table 2. The chemical composition of the cow horn used in the present study was assumed to be of the same with the cow horn applied in their research work.

Table 2. *Chemical composition of cow horn.*

Constituents	Composition (%)	Constituents	Composition (%)
CaO	76.09	Al_2O_3	0.10
SiO_2	11.79	Fe_2O_3	0.09
MgO	3.54	MnO	0.06
K_2O	0.52	Na_2O	0.003

2.3. Casting of Specimen

Moulds were prepared and labelled A to E as shown in Figure 2. The compositions of the intended aluminium alloy-CHp composite by weight proportions of CHp were prepared as shown in Table 3. The sample labelled A, which was the control sample, did not contain reinforcement, whereas samples B, C, D and E were aluminium alloy reinforced with various weight contents of CHp. Then aluminium scraps was heated to 660°C in crucible place inside furnace to have molten aluminium at Foundry Workshop, Obafemi Awolowo University, Ile-Ife. Molten aluminium without reinforcement was poured into the mould labelled A. For sample B, the first fraction of CHp was added into molten aluminium and thoroughly stirred. The molten metal with CHp was reheated to 750°C for proper mixture of the constituents in the melt. It was then poured into the mould labelled B for casting purpose. Similar procedure was repeated for each specimen according to weight volume fraction of CHp reinforcements as shown in Table 3.

Table 3. *Percentage weight composition of samples.*

Sample	Composition
A	Al + 0% CHp (control sample)
B	Al+3%CHp
C	Al+6%CHp
D	Al+9%CHp
E	Al+12%CHp

The samples were casted with compositions as specified in Table 3 and allowed to solidify in the moulds as shown in Figure 2. These samples were then ejected from the mould after they had been to cool to room temperature. Subsequently, fettling and cleaning of the cast samples were then carried out to remove protrusion and obtain clean surface. They were finally machined into specimens for x-ray diffraction analysis, hardness and impact strength tests.

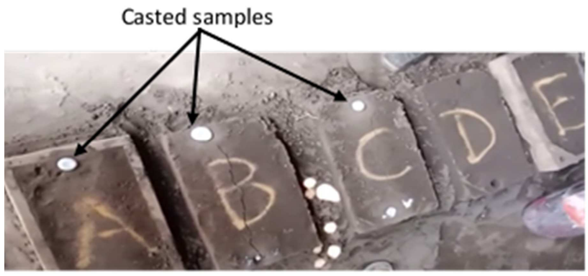


Figure 2. *Solidified specimens inside moulds.*

2.4. Specimen Preparation

The casted samples produced were machined on lathe machine to hardness and ASM standards impact test specimens. The hardness test specimens were machined to rectangular prism of 10 mm × 10 mm × 15 mm shown in Figure 3(a), while the impact specimens were machined to lengths of 60 mm, width of 10 mm and V notched angle of 450 to a depth of 2 mm as shown Figure 3(b).

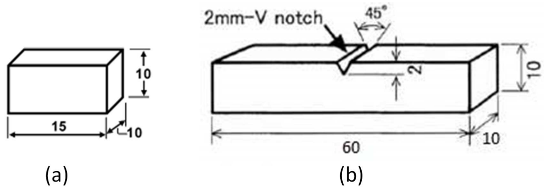


Figure 3. *Samples of the machined (a) hardness and (b) impact test specimens.*

2.5. Hardness Test

Hardness test was carried out on Brinell Hardness Testing Machine according to ASTM E10-14 standard. The test was conducted on flat, stage-grinded and polished surface of the test specimens. During each test, a hard, spherical indenter was pressed into the sample by a load of 250 kg and maintained for dwell period of 15 seconds. The diameter of spherical indentation produced on the specimen after the indenter was removed was then was measured with an optical scanning systems on the machine and converted to Brinell hardness value. The mean value of three measurements taken at different positions on the specimen was used to evaluate the hardness value of the specimen. The procedure was repeated for all the samples of the composite with various percentages of CHp.

2.6. Impact Test

Impact test is used to determine the ability of a material specimen to withstand sudden load. The impact test of the specimens was conducted using Izod impact tester (Figures 4) according to ASTM E602-91 standard.

The impact strength of a sample was evaluated from the energy absorbed when an arm of the tester (striking hammer at constant potential energy) was released from a specific height to break the sample. The specimen was held in the machine with the notch facing the hammer, and hammer positioned half inside and half above the top surface of the vice was brought and locked at its top most striking position at the position. The hammer was then released, fell due to gravity and broke the specimen through its momentum. The indicator at the topmost final position was subsequently read and recorded. The steps were repeated for all the samples.

Figure 4. *Izod impact testing machine.*

2.7. X-Ray Diffraction Analysis

As the understanding of the lattice parameters of a new material is necessary for development of this material, X-ray diffraction (XRD) is one of the quickest ways to test for lattice parameters in a material. Each sample was run through the Rigaku D/Max-lllC X-ray diffractometer developed by the Rigaku Int. Corp. Tokyo, Japan shown in Figure 5. It was set to produce diffractions at scanning rate of 2 o/min in the 2 o to 50 o at room temperature with a CuKa radiation set at 40 kV and 20 mA. The X-ray on passing through the samples gave peaks that was typical of each type of diffracted along a group of planes and the way they were diffracted was characteristics of the arrangement of the atoms within the element.

Figure 5. *XRD Rigaku diffractometer machine.*

3. Result and Discussion

3.1. Effect of Cow Horn Particulate on Hardness Properties

The results of hardness test performed on the aluminium alloy-CHp composite with various percentage by weight of CHp is presented in Figure 6.

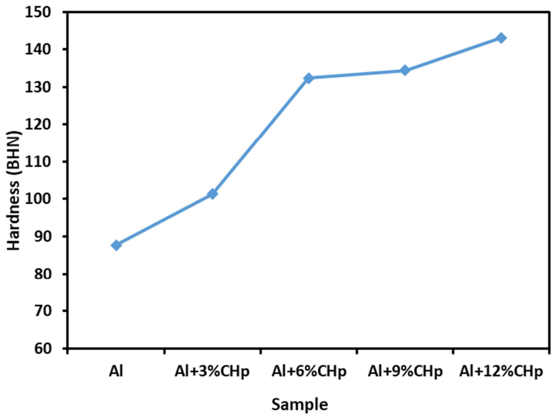


Figure 6. *Effect of CHp on hardness properties of the composite.*

It is evident from Figure 6 that the values of the hardness significantly increase from 87.7 BHN to 101.4 BHN with 3% weight of CHp in the aluminium alloy matrix. It was also observed that the value of the hardness increases as the weight fraction cow horn in the composite increases. Increasing the weight of CHp to 6%, 9% and 12% in the aluminium alloy matrix increases the hardness by 51%, 53% and 63%, respectively. The improvement in hardness can be attributed to presence of the harder and stiffer cow horn reinforcement and grain size transformation of the metal matrix. The transformation in the metal matrix composites due to addition of reinforcements is reduction in grain size which is as a result of reinforcement placing itself in the grain of the matrix thereby increasing the grain boundaries [20]. As the weight ration of reinforcement increases the hard surface increases and the grain size of the matrix reduces thereby causing more resistance to plastic deformation and hence, increase in hardness of the composite. This was similarly observed by Saravanana and Kumarb, and Abbas Y. Awad et al. in their studies of Aluminium alloy matrix reinforced with rice husk ash [6, 21].

3.2. Effect of Cow Horn Particulate on Impact Energy

Impact test was carried to evaluate the toughness of the composite to sudden load. Figure 7 shows the recorded impact energy absorbed (work done to fracture of a test specimen) against the composites compositions during the test. The results shows that the values of the impact energy decrease as the weight fraction of cow horn particles in the reinforced composite increases. Addition of 3% CHp to the metal alloy decreased the absorbed impact energy from 49.4 J to 36.76 J, and further increase in the percentages of CHp in the composite from 3%, 6%, 9% and 12% additionally reduced the impact value by 4.7%, 8.4% and 22.4%, respectively. The observed dropping in the impact energy of the composites could be attributed to the brittle nature of the CHp when compare to the ductile metal matrix. As the weight ratio of aluminium alloy matrix decreases in respect to the increasing weight percentage CHp in the composite, the toughness of the composites decline and thus, its ability to absorb impact load decreases.

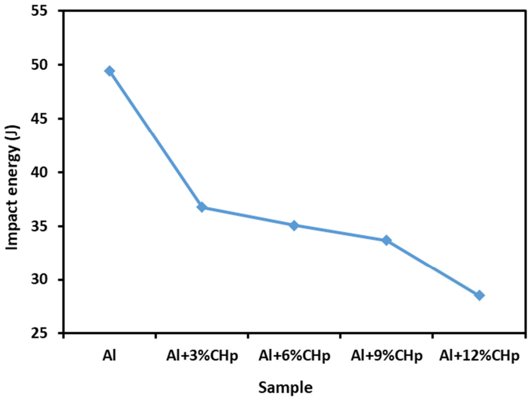
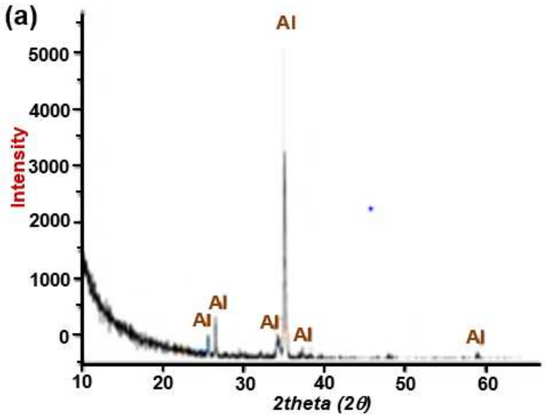
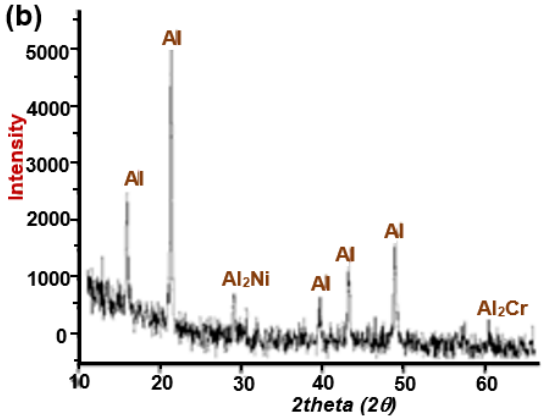
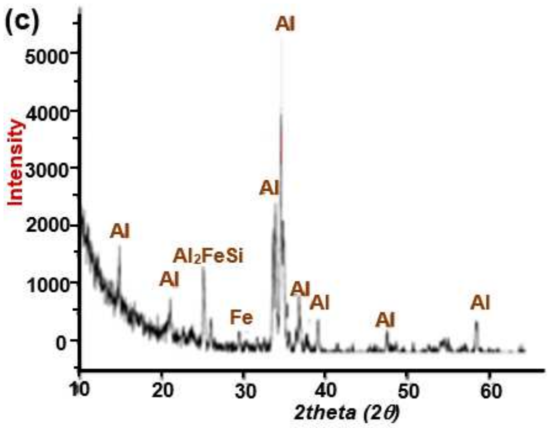
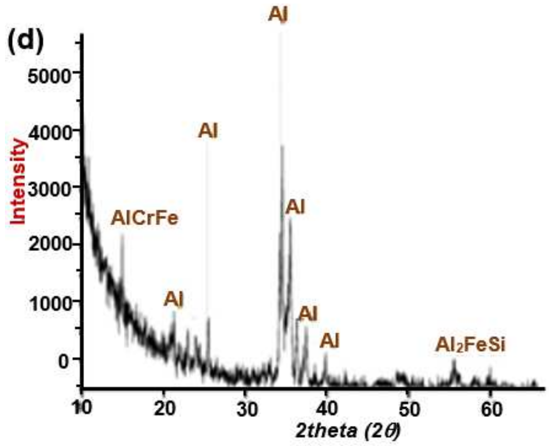


Figure 7. *Effect of CHp on Impact strength of the composite.*









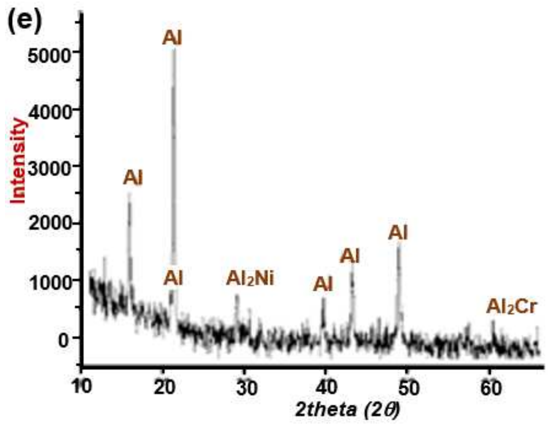


Figure 8. *XRD graphs of (a) 0% CHp (b) 3% CHp (c) 6%CHp (d) 9% CHp and (f) 12 CHp.*

3.3. Effect of Cow Horn Particulate on X-Ray Diffraction

The images of the chemical compositions of the samples of the aluminium alloy reinforced with various percentages of the cow horn particles captured with XRD Rigaku Diffractometer machine are presented in Figures 8(a) to 8(e).

The sharp peaks in the XRD patterns appeared in the graphs denote that the samples material tested is crystalline, and the highest peaks in the graphs indicate main element (Al as the main phase) from the aluminium alloy which is the major percentage of the composite whereas the low peaks revealed the presence of CHp without the formation of any other intermetallic compounds. XRD patterns also display various additional elements to major phase after the alloy was reinforced with cow horn particles, and intensity of these elements (e.g., Al_2FeSi) from CHp in the composition varies with samples as indicated by distinct small peaks. The addition of these elements from the CHp played some essential roles in the mechanical properties (hardness and impact values) exhibited by the composite samples as discussed. Furthermore, the presence of small peaks shows good wettability which in an indication of good bonding between CHp and the aluminium alloy matrix [18, 22], and multiple small peaks confirm the absence of agglomeration of CHp in the matrix [20].

4. Conclusion

Cow horn (agro-waste) littering abattoirs has been to reinforced aluminium scraps (end-of-life material) to produce aluminium based composite. The following conclusions were drawn from the results for the hardness and impact tests, and X-ray diffraction analysis performed on the composite:

1) Cow horn particulate, an agricultural waste, can be used to reinforce scraps aluminium alloy thereby turning wastes into industrial benefits and reduce environmental pollution.
2) The results show that the hardness strength of reinforced aluminium alloy increase with addition of cow horn particles and the hardness increases with the increase in the weight fraction of CHp in the composite.
3) The reinforced aluminium alloy exhibits inferior impact strength compared to the aluminium alloy.
4) The impact strength of the reinforced aluminium alloy decreases with the increase in the weight fraction of CHp in the composite.
5) The XRD analysis reveals the presence of CHp without the formation of any other intermetallic compounds, absence of agglomeration of CHp in the metal matrix and good bonding between CHp and the aluminium alloy matrix.

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