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Comparison of differences between agro-waste sand mold additives effects on the hardness and microstructural views of recycled aluminum alloy cooling in various coolants

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Abstract

This paper described some mechanical properties of aluminum alloy using agro-waste materials such as sawdust, groundnut shell, and eggshell. The sand-casting method was adopted to produce the alloy with 5, 15, 25, and 35% wt. additives. The microstructure of the various samples produced after quenched in water, palm oil, and engine oil was examined while hardness properties were determined. The result obtained shows that hardness values increased with an increase in the addition of sand mold Agro-waste ashes. Samples cast with eggshell ash additive and quenched in water coolant had the highest hardness value of 82.4 at 25% wt. additive when compared with sawdust ash and groundnut shell ash additives. sand-casting enhances the hardness of the specimens and thus, can be used in many engineering applications such as engine blocks and wheels in automotive parts and aerospace components.

Keywords: Agro-waste Ash; Sawdust Ash; Groundnut Shell Ash; Egg Shell Ash; Hardness; Microstructure; Sand Casting

1. Introduction

Agro waste material had created unfriendly environmental pollution in the society due to inadequate utilization or recycling. Today's world has been looking for ways of effective optimization of this waste, especially in every field and engineering. In search of this development, focuses have been made on how to recycle waste as reinforcing filler to develop composite with good mechanical properties such as rigidity, tensile strength, thermal conductivity, creep, weldability, ductility, malleability, plasticity, machinability, fatigue, hardness, toughness, corrosion resistance, electrical and conductivity (Koch, *et al., 2010*). Upon the consideration of these factors are very germane requirements for specific use in different engineering applications. Over the years some materials are found to lacking certain engineering properties such as weak strength, poor ductility, low thermal conductivity, and poor machinability (Ghasali, *et al*., 2018). Owing to the major engineering challenge in selecting appropriate material, several researchers from a different research institutes and academic institutions have worked on how to revert the problem of material failure on some selected materials. Hence, this study aimed to search for less expensive alternative materials that can replace commonly used imported (graphite, silicon nitride, titanium nitride) and compare their effectiveness on aluminum matrix composites when cooled in water, palm oil, and engine oil.

Alaneme and Olubambi 2013, investigated corrosion and wear behaviors of an Al–Mg–Si alloy matrix as a hybrid composite sublimated with alumina and rice husk ash particulate. The percentage particulate used was 2, 3, and 4 *wt.* % at a constituent to prepare 10 *wt.* % of the phase reinforcement with the AMMCs. The corrosion behavioral analysis carried out was done using a potentiodynamic polarization measurement and open circuit corrosion potential (OCP).

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Also, the wear behavioral study of the composite was tested using the coefficient of the friction parameter. The result showed superior resistance to corrosion from the reinforced composite (Al-Mg–Si) with 10% Al2O3 to that of the hybrid composite in a solution of 3.5% NaCl was recorded.

Alaneme *et al., 2018.* Carried out an experiment on mechanical, microstructure, and fracture properties of silicon carbide and groundnut shell ash particles reinforced aluminum metal matrix composites. Mixing varies of 0:10, 2.5:7.5, 5:5, 7.5:2.5, and 10:0 was used for both groundnut shell ash and silicon carbide particulate mixture. The microstructural view revealed that the phase of reinforcement was constituted by 6 and 10 wt. % of the particulate mix ratio and the characterization analysis showed that there was an improved percentage elongation, and it was constant with the increased content of the groundnut shell ash but the addition of groundnut shell ash increased the fracture toughness.

Ochieze et al., 2018. Determined wear parameters and their effects on the wear characteristics of an A356 alloy reinforced with a corn horn particulate. These particles were sourced via the sintering of the spark plasma. The experimentation technique used was Tahuchi's (L9) technique. A tribometer device was used to carry out a wear test while scanning an electron microscope device to determine the surface morphology. The result shows that the reinforced A356 alloy exhibited a better sliding resistance to the wear compared with the virgin material (as-cast A356 alloy). Investigation proved that the effect of corn horn particulate as a reinforcement material for the aluminum alloy composite immensely increases the composite's wear resistance.

Natarajan et al., 2006; Zhang et al., 2018; Ochieze *et al., 2018;* Panwar *et al., 2018.* Investigated the significant merits of aluminum matrix composites and metal matrix composites over conventional engineering materials. However, agro-waste particulates have been discovered to be a very good reinforcement constituent due to their availability and being less expensive. Many researchers have worked widely on several natural wastes from agriculture and found them to be rich in silicon and magnesium oxide constituents among others Saravanan, *et al.* Some widely recognized agro-waste are groundnut shell, coconut shell, corn cobs ash, eggshell, and cow horn. Some of the previous related researches were discussed in the review of literature below.

2. Review of Literature

(Adeleke, 2010). Among the various process variables that influence the qualities of the final casted product, the presence of additives in the sand has a considerable impact. Surface polish, dry strength, refractoriness, and cushioning qualities are all improved by adding additives to molding components

(Ikebudu *et al.,* 2021). In recent years, additives have become more widely used in the manufacture of sand molds. Aside from the inherent features of molten metal, such as composition, segregation, fluidity, and so on, which improve the soundness of the cast created mold properties are also essential in influencing the soundness of a casting. The composition of mold material, moisture content, and mold temperature are all factors that can affect the heat storage capacity of a sand mold. The advantages of sand casting over other methods include a wide variety of castable sizes, automation flexibility, ease of handling, and cost-effectiveness

(Mishra *et al.,* 2018). Fly ash, iron fillings, sea-coal, wood flour, husk, coal dust, starch, and other additions have been utilized in small amounts and have been shown to produce advantageous goods with improved resistance capabilities. Mold characteristics needed to be improved by introducing additives to molding sand to give good casting surface quality, easy casting cleaning, decreased sand adhesion to casting and reduced casting flaws. Molding sand should have properties like green strength dry strength, cohesiveness, permeability, refractoriness, collapsibility, and so on to produce defect-free castings

Adekunle *et al.* (2020) investigated the mechanical characteristics and microstructure of solution heat-treated aluminum (Al)-alloy using blended raw (BR) and blended bleached (BB) bio-quenchants. Samples quenched in blended raw melon (BRM) oil had a higher tensile strength of 151.76 N/mm2, while samples quenched in blended bleached melon (BBM) oil had a higher hardness value of 61.00 HRC. Bio-quenchants were discovered to be an appropriate substitute for PBM oil based on the results obtained.

Adebayo *et al.* (2018). The impact of local cooling media (groundnut oil, palm oil, shea butter, and air) on the mechanical characteristics of heat-treated mild steel was studied. When compared to the as-purchased specimen with 194.9 VHN, the hardness profile indicated greater values for palm oil-cooled, shea butter-cooled, and groundnut oil-cooled specimens in increasing order, whereas the air-cooled specimen exhibited a decrease in hardness. Furthermore, when comparing the as-control samples to the heat-treated specimens, the yield strength of the groundnut oil-cooled (464.4 MPa) and shear butter-cooled (412.9 MPa) samples increased, while the yield strength of the air-cooled (358.3 MPa) and palm oil-cooled (307.7 MPa) samples decreased (376.9 MPa). The ultimate tensile strength (UTS) of the specimens followed the same pattern. When compared to as-purchased specimens, the ductility improved in air-cooled samples (40.28) but declined in media-cooled specimens (34.22). The microstructural examination also demonstrated that the groundnut oil-cooled specimens had a better microstructural quality than the other heat-treated specimens.

Atuanya and Aigbodion introduced the ash from bean pods to enhance the Al–Cu–Mg alloy properties through the double layer feeding stir casting method. Mechanical properties and microstructural evaluation of a bean pod ash particulates as reinforcement on aluminum alloy is a major target for this study. The variation of 1 to 4 *wt.* % of nanoparticles was used to produce aluminum matrix composite. Hardness, tensile energy, and impact strength of the reinforced composite were evaluated with the use of SEM and XRD. The result of the experiment show robust interphase bonding was achieved with a substantial increase in the hardness and tensile strength at 4 *wt. %* by 44.1% and 35% respectively. Having considered the seemingly low or light percentage weight of the particulates, there was an improvement in the properties of aluminum matrix composites.

Further investigation by Mishra et al investigated the mechanical properties and behaviors of aluminum alloy (LM6) as a metal matrix composite material reinforced with rice husk, it ash particulate of 6wt % was used as reinforcement and an artificial aging process was adopted to vary temperatures(135 ^0C , 175 ^0C , and 225 ^0C). The stir casting method was used to develop metal matrix composites and the results revealed an improvement on the hardness value in them as-cast samples from 54.8HRB to 78.4HRB for the composite at 175 ^0C .

Saravanan and Kumar investigated Al-Si 10Mg on their mechanical properties reinforced with cheap and available local rice hush ash particulate and its constituent varied from 3%, 6%, 9%, and 12% per unit weight using liquid metallurgy to develop metal matrix composite. From the SEM (scanning electron microscope), it was observed that rice husk ash was well spread in the aluminum matrix and thus the tensile strength and hardness of the aluminum were improved. Also, area interface was increased between the rice husk ash particles and the developed metal matrix.

3. Material and methods

3.1. Materials

- Natural sand, according to Shuaib-Babata *et al.* (2019), Natural sand samples were taken from the riverbank in the Asa/Ballah area of Ilorin, Kwara state.), the sample used was sieved with a 75 μm sieve to separate the substance from deleterious substance.
- Aluminum Scrap, Al alloy scrap was obtained at Nigerian Aluminum Extrusions Limited (NIGALEX), Apapa-Oshodi Express Way, Lagos. The chemical composition of the aluminum alloy was obtained from the company. This reveals that aluminum alloy scraps have a high percentage of aluminum (89.6875%) and trace components of the other elements,
- Sawdust, Groundnut Shell, and Egg Shell were sourced from Sawmill Geri-Alimi Ilorin, Oja Gboro road, Ita Elepa, Area Ilorin, and Madi Poultry Farm Tanke Area, Ilorin respectively, these are waste materials that can generate environmental pollution therefore, they needed to be used up or recycled for other products.
- Water, Palm Oil, and Engine Oil. Were obtained from the Oja Oba market in Ilorin. This cooling media is needed due to its varied viscosity and cooling rate attributes during the quenching process.

3.2. Method

3.2.1. Method of Burning Eggshell, Sawdust, and Groundnut Shell

20kg of each additive were sun-dried for 13 days only eggshell and groundnut shell was grated into a particulate using the manual mortar method. The three materials were burned locally using a charcoal burner by a method of dry frying figure 1a to 1c, 2a to 2c, and 3a to 3c

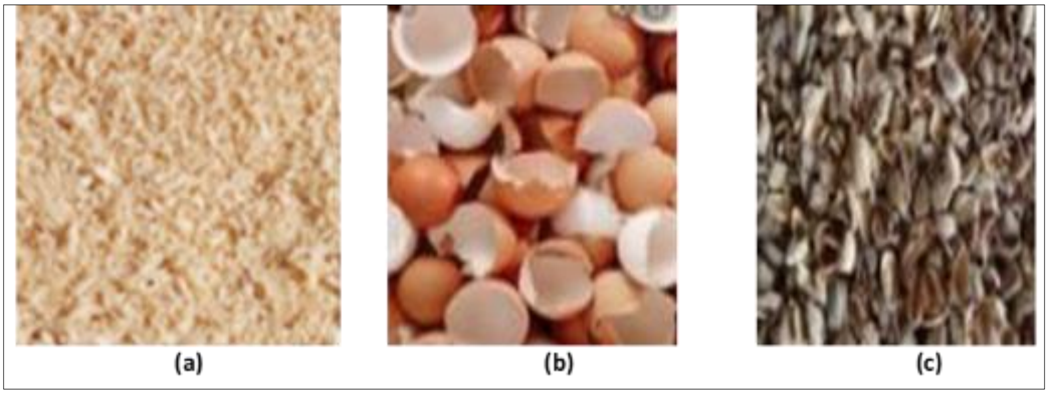

Figure 1a to 1c as sourced Agro- Wastes as Reinforcement

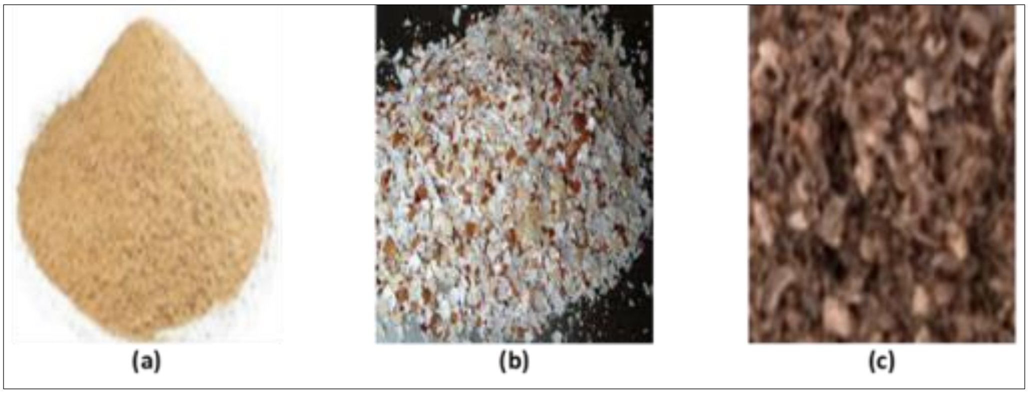

Figure 2a to 2c Ground Agro-waste particulates as reinforcement

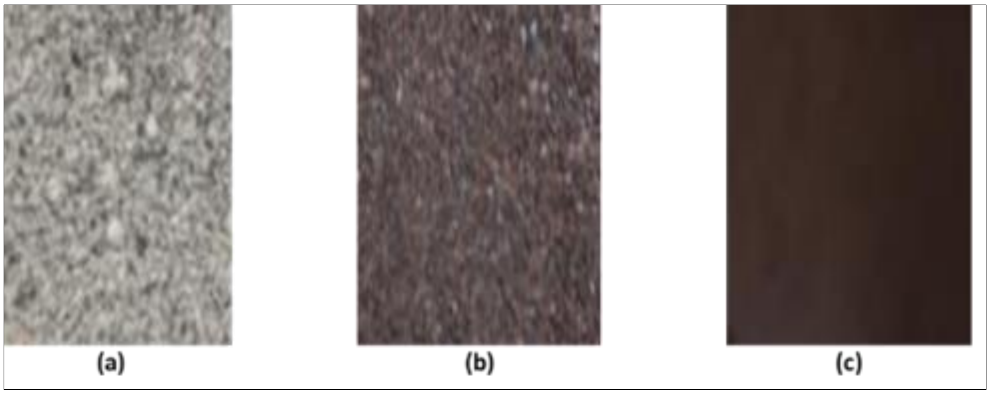

Figure 3a to 3c Agro-waste Ash particulate after burnt

The qualities of the chemo-physical properties were investigated to determine their impacts on casting, and they are listed in Table 1.

Table 1 Physico-chemical Properties of Additives used for the Casting Process

Properties	SDA (Source: Raheem and Sulaiman, 2013)	ESA (Source: Afolayan *et al.,* 2017)	GSA (Source: Okonji *et al.,* 2018)
Fineness Silica (SiO2)	76.3	0.12	79.10
Alumina (Al2O3)	5.8	0.49	5.95
Lime (CaO)	4.7	46.69	0.18
Iron Oxide (Fe2O3)	2.9	0.32	3.5
MgO	1.2	0.18	5.2
SO3	1.6	0.57	-
K2O	-	0.21	3.67
Na2O	-	0.19	0.78
Cr2O3	-	-	0.16
LOI	3.9	-	6.56
Specific Gravity	2.02	2.1	2.50
Bulk Density (Kg/m3)	834	1500	1562

3.3. Choice of Aluminium Scarp for the Project

Al 6061 alloy scrap was obtained at Nigerian Aluminum Extrusions Limited (NIGALEX), Apapa-Oshodi Express Way, Lagos. (Figure 4). The chemical composition of the aluminum alloy was obtained from the company as shown in Table 2 and this reveals that aluminum alloy scraps have a high percentage of aluminum (89.6875%) and trace components of the other elements, indicating that they belong to the heat treatable group of wrought aluminum alloys 6xxx series

Figure 4 As sourced Aluminun scrape for the experiment

Table 2 Test results for compositional analysis for the aluminum scrape

% Weight	Elements									
	Cr	Cu	Fe	Mg	Mn	Si	Zn	Ti	Others	Al
Average	0.022	0.144	0.626	2.515	2.063	4.417	0.649	0.01	0.05	89.6875

3.4. Mixing of Mould Sand and Additive

Mixing of mold sand to additives was carried out at Kwara state polytechnic foundry workshop in Ilorin Nigeria. 30kg sand was obtained for each mold during the mixing preparation and weighted while wet and dried to assess the moisture content of the sand. Table 3 shows the different quantities of prepared sand, water, and additives (groundnut shell, eggshell, and sawdust ashes) were mixed. The mixing process involved the addition of 5%, 15%, 25%, and 35% of the total weight of sand with additives which is equivalent to 1.5Kg, 4.5Kg, 7.5Kg, and 10.5Kg of additives respectively are added to the required sand as shown in Table 3. Mathematical expression for percentage by mass additives is as follows;

$$5\% \text{ additives} = \frac{5}{100} \times 30 = 1.5kg$$

$$15\% \text{ additives} = \frac{15}{100} \times 30 = 4.5kg$$

$$25\% \text{ additives} = \frac{25}{100} \times 30 = 7.5kg$$

$$35\% \text{ additives} = \frac{35}{100} \times 30 = 10.5kg$$

Table 3 Explained proportion of local additives on percentage

Additives	**Additives Percentage (%)**	**Percentage of Sand Addition (%)**	**Total Weight of Sand(w)**
Control	0	100	30kg
Groundnut shell Ash	5% 15% 25% 35%	98.5, 95.5, 92.5, 89.5	30kg
Sawdust Ash	5% 15% 25% 35%	98.5, 95.5, 92.5, 89.5	30kg
Eggshell ash	5% 15% 25% 35%	98.5, 95.5, 92.5, 89.5	30kg

3.5. Casting procedure

20kg of Aluminum scraps were melted to a standard required temperature say 1000 ^0C in a crucible furnace for 2hrs, and then introduced to the prepared mold of three hollow holes in a liquid state through a path gate, after 5 minutes of solidification inside the mold, the mold was dismantled and the specimens were quickly subjected into three different cooling medium (Water, Engine Oil, and Palm Oil) for further solidification to take place. The cast samples were labeled based on cast, different percentages of additives, and cooling media used for further preparation on hardness tests and microstructural examinations as shown in Figure 5a to 5d below.

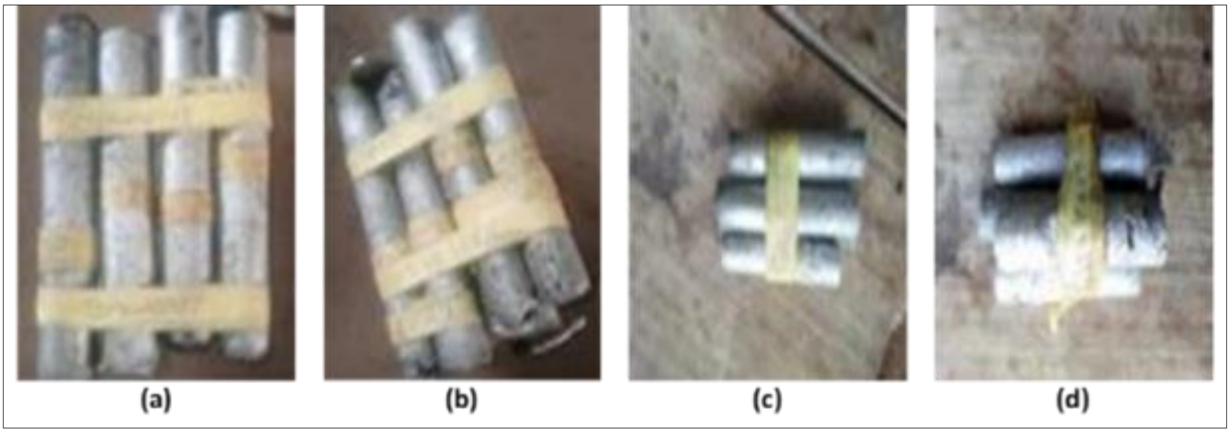

Figure 5 As-cast and as additives cast specimens cooled in different media

3.6. Mechanical testing of the cast-quenched aluminum alloy

3.6.1. Hardness test

For this project, thirty-nine samples were produced for the test. Three as cast and thirty-six additives-quenched samples. The hardness test for both as-cast and additive-quenched specimens was determined using Monsanto Testing Machine. A hardness test on the sample was carried out in the same institute and department using a hardened steel ball indenter that is pushed into the material under a specified force as shown in figure 6. The diameter of the indentation in the material's surface is measured, and the Brinell hardness number is derived using this dimension. The Brinell scale characterizes the indentation hardness of materials through the scale of penetration of an indenter loaded on a material test piece.

Figure 6 Specimen after Indentation

3.6.2. Determination of Microstructural Properties of Cast - quenched Samples

The microstructural examination was carried out by using an electron microscope. Each specimen was made by cutting a small piece of cast quenched aluminum alloy (approximately 20mm on an edge), then grinding and polishing it to a mirror shine. Wet coarse grinding was carried out using 80 to 180 grit electrically powered disks, and then all debris was washed away with tap water. Fine grinding was immediately done on increasingly finer grade emery sheets (220, 400, and 600 from course to fine). At each change of paper, the specimen was rotated through 90^o in the abrasive wheel. The very fine surface scratches were eliminated when the grinding was completed by polishing the surface to a mirror quality. This was accomplished by combining alumina polishing powder in a water suspension with a polishing cloth set on a flat rotating disc and the specimen being held against it under minimal pressure. Before polishing the item, it was properly washed.

To show the specimen's entire structure, the polished surface was etched using a chemical reagent and vigorously agitated for several seconds. The specimen was washed in running water to remove the etching reagent and then air-dried.

4. Results and discussion

4.1. Analysis of Hardness Properties

The recorded results of the hardness test for the corresponding different additives and various quenching media are shown in Table 4. The data will illustrate graphically the effect of the parameters on the cast samples as shown in figure 7 to figure 9.

Table 4 Hardness (HRB) Values

Quenching Media				
Additives		**Water**	**Palm Oil**	**Engine Oil**
	0	64.1	55.5	50.8
Sawdust Ashes				
	5%	67.7	59.9	54.1
	15%	70	64.2	60.2
	25%	74.8	68.3	65.5
	35%	74.1	67.8	64.1
Groundnut Shell Ashes				
	5%	67.7	59.2	57.2
	15%	71.4	69.4	62.7
	25%	76.8	71.4	69.1
	35%	76.2	70.8	69.6
Egg Shell Ashes				
	5%	69.6	66.1	61.5
	15%	79.2	75.7	72.3
	25%	82.4	80	76.1
	35%	81.7	81.4	75.7

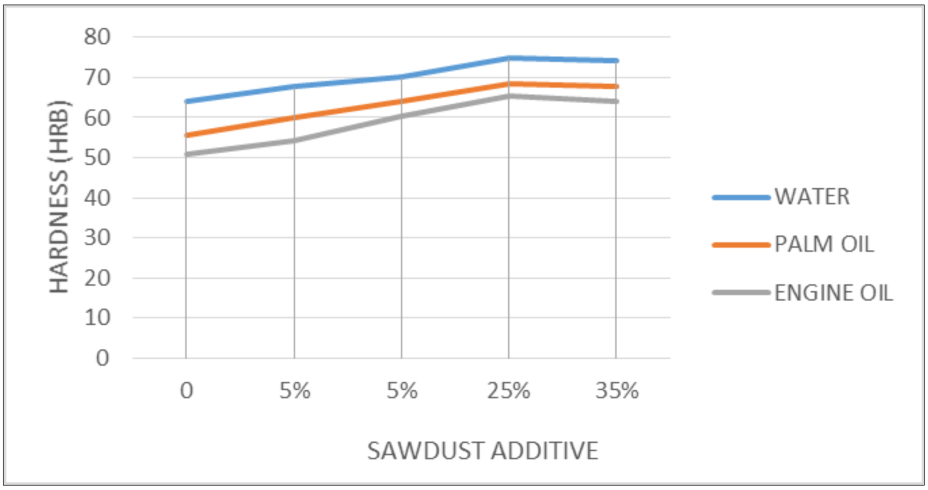

Figure 7 Hardness of Quenched Aluminum 6061 Prepared using Sand Casting with Sawdust Ash Additive

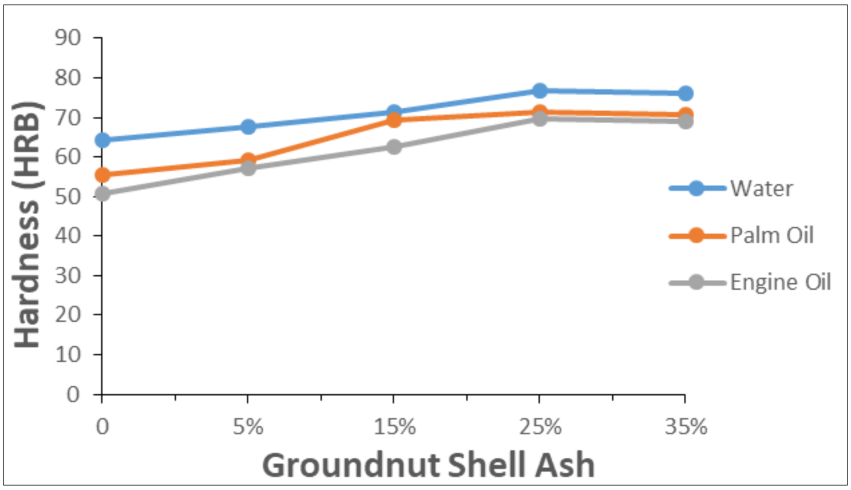

Figure 8 Hardness of Quenched Aluminium 6061 prepared using Sand Casting with Groundnut Shell Ash Additive

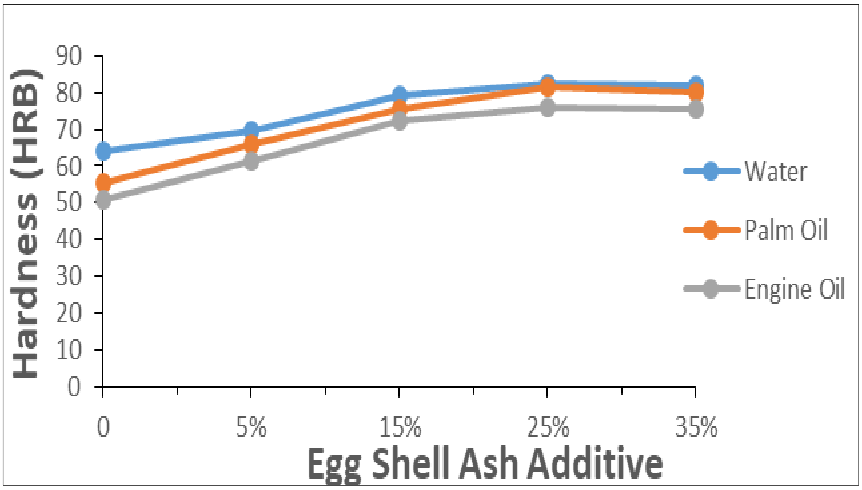

Figure 9 Hardness of Quenched Aluminium 6061 prepared using Sand Casting with Egg Shell Ash Additive

Looking at the graphical illustration in figure 7 to 9, the cast aluminum 6061 has a superior hardness property to the ESA additive, which has a hardness of 82.4 HRB when compared to samples with other additives, which could be owing to the ensuing fine grain size of the sands (Kumar et al, 2016). In comparison, alloys with the lowest hardness values in the as-cast condition show the greatest improvement in hardness after solution heat treatment. This means that the additions comprised some grain refining elements that had the best reaction to solution heat treatment of the cast Al alloy (6061) because it contained the Physico-chemical Properties of additives listed in Table 4. The peak hardness of Al alloy (6061) as shown in Figure 4. increases across the 5 percent, 15 percent, and 25 percent sand additions range, and the decrease in hardness with increasing sand additives are not as quick as the fall in hardness with increasing quenching medium. At a larger percentage of additives, the hardness begins to rapidly drop, reverting to solution heat-treated hardness levels at around 35 percent. This is due to the influence of mold additives on quenched and cast aluminum demonstrated that as the percentage of mold additives grew, the hardness of the aluminum increased. In addition, adding 35 percent mold additives to the three compounds studied in this study has little or no effect on the hardness. These signify the addition of mold additive of more than 25% has no effect and this is in line with the Okonji *et al.* (2018) findings. Low porosity, high bulk density, high compressibility strength, high shear strength, and low hardness have been linked to an increase in grain size of phases in cast aluminum from mold additives, a result that he claims allows for facile dislocation movement in the liquid metal during solidification. (Zaki, 2014). Therefore, the relatively low hardness value was a result of lumped grain size of the phases.

4.2. Microstructural Analysis

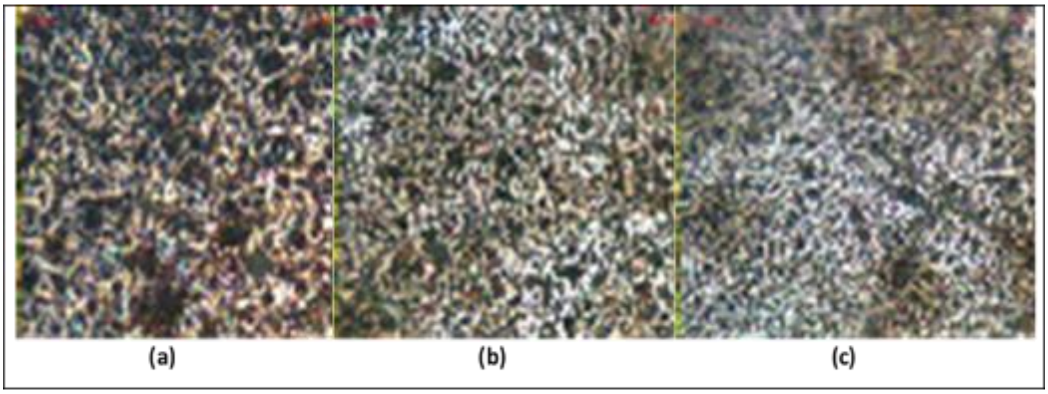

Figure 10 Microstructures for Cast Aluminium 6061 without Sand Additives

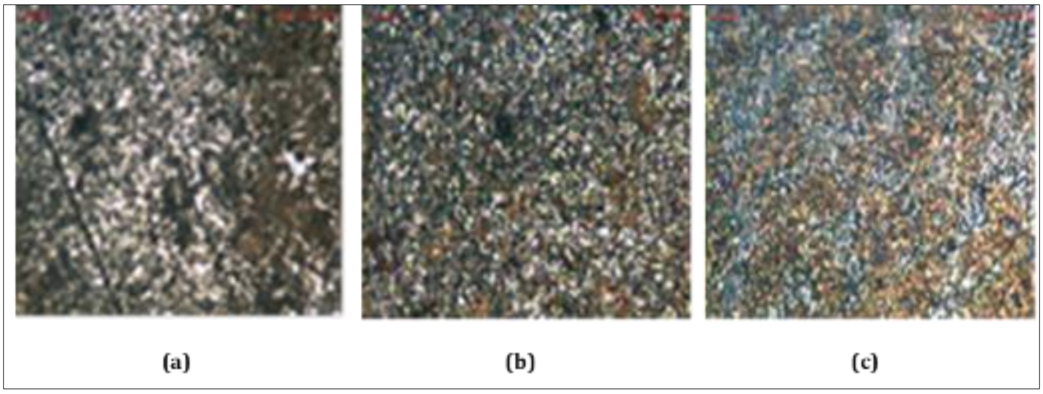

Figure 11 Microstructures for Cast Aluminium 6061 Mould with 5% SDA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

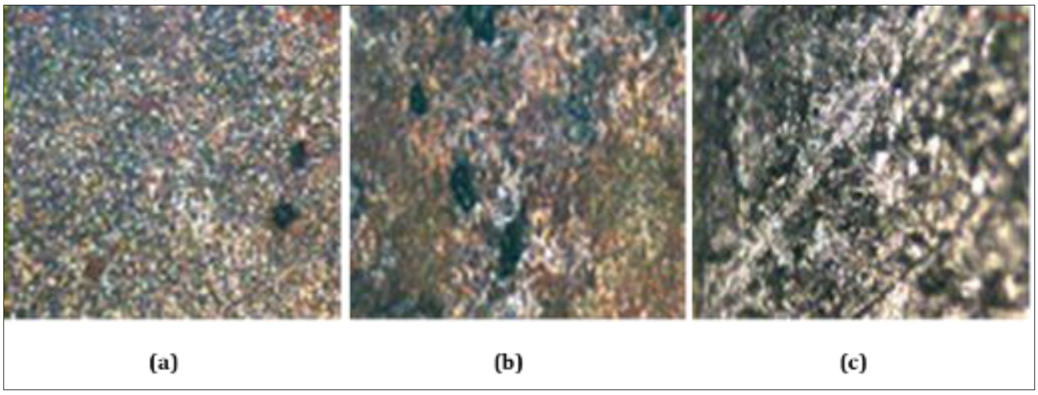

Figure 12 Microstructures for Cast Aluminium 6061 Mould with 15% SDA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

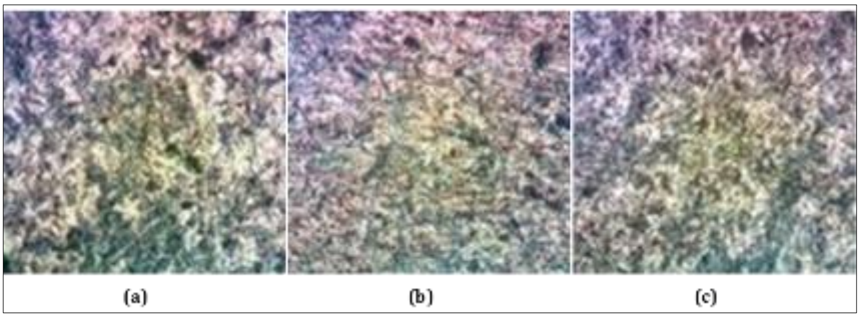

Figure 13 Microstructures for Cast Aluminium 6061 Mould with 25% SDA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

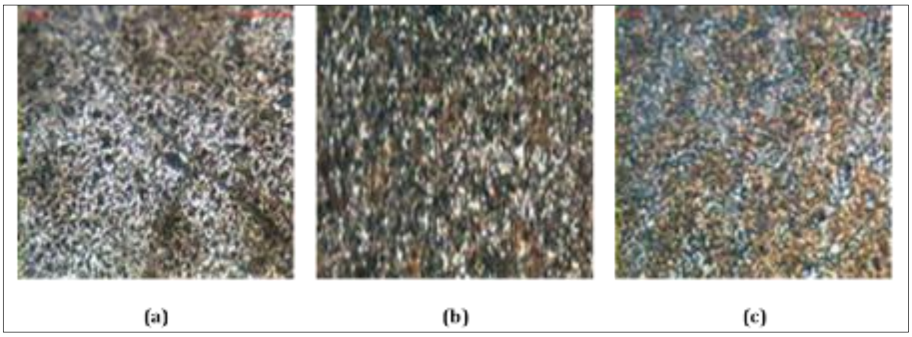

Figure 14 Microstructures for Cast Aluminium 6061 Mould with 5% GSA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

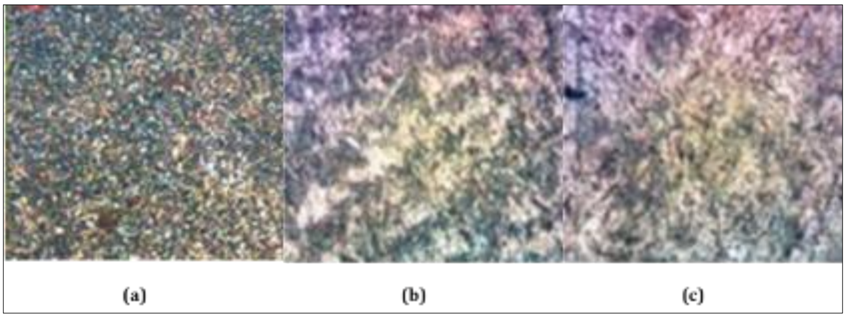

Figure 15 Microstructures for Cast Aluminium 6061 Mould with 15% GSA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

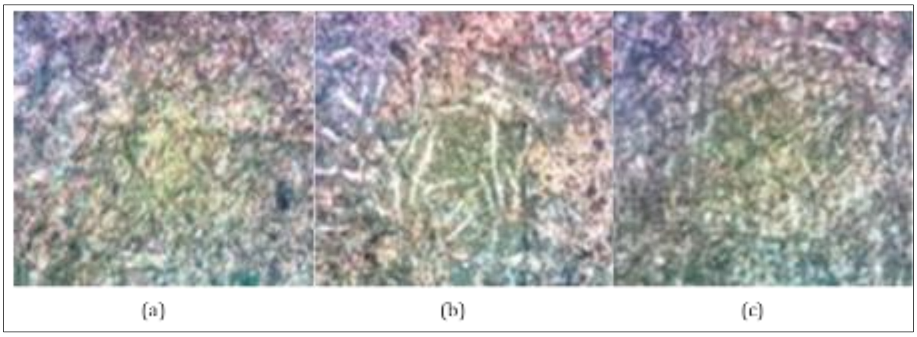

Figure 16 Microstructures for Cast Aluminium 6061 Mould with 25% GSA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

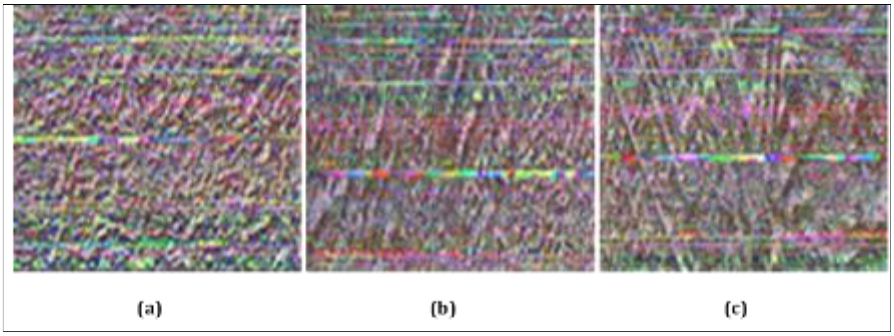

Figure 17 Microstructures for Cast Aluminium 6061 Mould with 5% ESA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

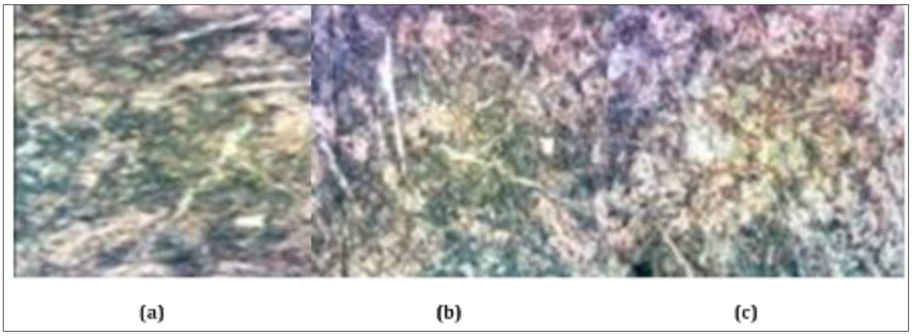

Figure 18 Microstructures for Cast Aluminium 6061 Mould with 15% ESA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

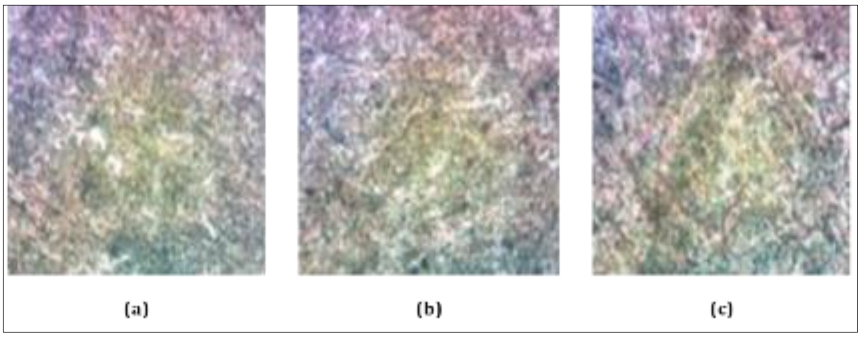

Figure 19 Microstructures for Cast Aluminium 6061 Mould with 25% ESA after quenched in (a) water, (b) Engine Oil, and (c) Palm Oil

The photomicrographs obtained from the microstructural examination of the as-cast and sand-additives cast quenched aluminum in Water. Palm oil and Engine oil using the Inverted Material Microscope were shown in Figures 10 – 19. Optical microscopes were used to investigate the microstructures of the test samples in both their as-cast and sand-additives cast. Primary alpha-aluminum dendrites, interdendritic irregular Aluminium-Silicon eutectic areas, Iron-rich intermetallics, and magnesium-silicon particles surrounding their boundaries dominated micrographs, as expected. The eutectic silicon particles in all of the micrographs had a tiny globular shape, indicating structural change caused by the addition of strontium during the casting process.

Figure 10: illustrate two major phases: primary Si-particles in the Light-Al phase (light patches) and eutectic (Si) phase (dark patches) with Si-particles as depicted in the microstructure of as-cast Al-alloy 6061 material. In the as-cast Al-alloy, the material showed a large concentration of Si particles in the Al alloy (6061) due to high grain growth in sand casting leading to lower mechanical properties like percentage elongation and hardness value and agrees with the work of Adekunle *et al.* (2020).The microstructure of cast Al-alloy materials from sand mold additives (SDA, GSA, and ESA) after quenching in water, palm oil, and engine oil as shown in Figures 11 to 19 highlighting the presence of intermetallic elements in the observed alloys and demonstrating that the grain structure was refined as the additive elements

dissolve, redistributing the elements to form different precipitates within a short quenching time, mechanical properties of the quenched materials. This could be due to enhanced grain structure re-distribution during cooling because of the relatively short solution heat treatment duration.

5. Conclusion

Experimentations were conducted on aluminum 6061 alloy by adding various percentage local additives to sand mold and quenched in different media as discussed earlier. The specimens prepared were subjected to mechanical tests like hardness test, and microstructural test. The result shows that hardness strength increased up to 25 % weight percentage of additives and then starts decreasing. The addition of additives in the sand during casting enhanced the hardness of aluminum alloy properties i.e. the higher the carbon content the higher the hardness. ESA gives the highest hardening because of its higher carbon content followed by GSA, and then SDA.

Compliance with ethical standards

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Disclosure of conflict of interest

I hereby declare that there is no conflict of interest.

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