Research on Engineering Structures & Materials

www.jresm.org

MIM Research Group

Research Article

Influence of melon shell ash reinforcement on the mechanical and microstructural characteristics of recycled aluminium matrix composites

Olatunji P Abolusoro*[1,2,a], Moshibudi Caroline Khoathane[1,b], Washington Mhike[1,c]

[1]*Dept. of Chemical, Metallurgical and Materials Eng., Tshwane University of Technology, South Africa*
[2]*Dept. of Mechanical and Mechatronics Engineering, Landmark University, Omu-Aran, Nigeria*

Article Info

Article history:

Received 14 June 2024
Accepted 15 Aug 2024

Keywords:

Melon shell ash;
Aluminum cans;
Composite;
Microstructure;
Mechanical properties

Abstract

This study produced a composite using melon shell ash as reinforcement on recycled Aluminium waste cans matrix. The melon shell particulate additions to the matrix were done in wt.% of 0, 10, 5, 15 and 20. The mechanical behaviour of the composite demonstrates that the tensile values increased as the particulate addition increased to 15% wt. to reach a maximum of 113MPa but dropped at the 20% addition. The impact energy on the other hand increases marginally at 5% particulate addition and increases slightly higher with the addition of reinforcement of 10% wt to attain a maximum value of 77J. However, a further increase in the melon shell ash to 15% wt and 20% wt reduced the impact energy. The hardness values of the composites at all the % wt. additions were generally higher than that of the unreinforced Aluminium with the peak hardness value of 57.2BHN obtained at 10% wt. addition. The density of the composites decreases as the % wt. of the melon shell ash particles increases. The improved mechanical properties and lower density of the composites achieved in this study are significant factors in developing strong and lightweight engineering materials for industrial applications.

1. Introduction

Aluminium alloy is a lightweight, malleable, durable and corrosion-resistant metal. It is highly recyclable and has found wide uses in automobile, construction, building, food and beverage industries [1]. As a result of the expansion in the use of Aluminium alloys, there is a need for improvement in some of its properties through modification of its constituent elements. One of the ways this has been achieved is through the reinforcement of the aluminium matrix with suitable substances to form composites [2–4]. The use of Aluminium composites has expanded tremendously as a result of the increase in demand for efficient, lightweight and low-cost materials for industrial applications. Aluminium matrix composites (AMC) have gained wide attention from scientists and researchers own to their simpler production methods, economic feasibility and homogenous structure of the particulate reinforcements. AMC also demonstrate higher stiffness, low density and thermal expansion coefficient, good wear resistance and specific strength [5, 6] Reports have shown that the type and fractions of reinforcements on the Aluminium composites influenced the behaviour of the composites. Significant improvements have been achieved in aluminium composites through the introduction of little ceramic-containing particulates such as, Titanium carbide (TiC), Boron carbide (B_4C), Silicon carbide (SiC), and Silica oxides (SiO_2) [7–13]. However, the economic and environmental challenges involved in the

*Corresponding author: abolusoroop@tut.ac.za
[a] orcid.org/0000-0003-1493-3445; [b] orcid.org/0000-0002-5328-2721; [c] orcid.org/0000-0003-4670-1171
DOI: http://dx.doi.org/10.17515/resm2024.320me0614rs

production of these ceramics have led to the exploration of the potential of agricultural waste-based reinforcements [14, 15] Agricultural waste emanates from remnants of crops after the edible parts have been consumed. The abundance and availability of these wastes coupled with low cost and sustainability have endeared them to researchers as reinforcement materials [16,17]. In addition, Agrowastes are usually dumped indiscriminately in the open land giving rise to environmental pollution. Ashes from Agrowastes such as rice husk, groundnut shells, sugar cane bagasse, palm kernel shells, coconut shells and melon shells have been utilized as reinforcement materials in Aluminium matrix composites as a result of their constituents [16], [18–21] Rice husk ash (RHA) possess high percentages of Silicon oxides together with other compounds such as MgO, Fe_2O_3 and Al_2O_3 [22–25]. Tensile strength, toughness, and hardness improvement have been reported in RHA and mica as reinforcement in A7075 matrix composites [26]. SiC extracted from RHA has also been utilized as reinforcement [27, 28]. Joharudin et al [29]. reinforced recycled A7075 chip with silica extracted from RHA. His result showed improvement in the hardness values of the composites. Coconut shell ash (CSA) is another agro-waste that has found application as reinforcement in composite production. It has also been reported to contain SiO_2, MgO, Fe_2O_3 and Al_2O_3 [30]. The addition of CSA as reinforcement to the aluminium matrix of A6082 has been reported to enhance the properties of the composites [30]. Using the stir casting method, Kaladgi et al [31] reinforced 6061 with coconut shell microparticles and Al_2O_3. His result revealed a boost in the hardness and tensile strength of the composites as the percentage of reinforcements increased. Bello et al [32] utilized coconut shell microparticles to reinforce Aluminium alloy using the compo-casting method. An increase in tensile properties was observed due to appreciable interfacial adhesion between the aluminium matrix and the particulate reinforcement. Palm kernel shell ash (PKA) is also an agricultural waste which contains abundant siliceous materials. SiO_2 is a major constituent of PKA mostly up to 40%. Other constituents present include metallic oxides such as aluminium oxide, magnesium oxide, Potassium oxides, and calcium oxide [33, 34]. The addition of PKA as reinforcement on the aluminium matrix was found to improve the wear resistance and the mechanical behaviour of the developed composites [35]. Sugar cane bagasse (SCB), a waste from sugar cane has also been explored for reinforcement purposes. The main constituents are cellulose, hemicellulose, wax lignin and ash [36, 37]. The presence of these elements makes SCB a suitable reinforcement fibre material for the development of composites with outstanding physical and chemical characteristics [38, 39]. Chandla et al [40] employed bagasse ash to reinforce the aluminium alloy 6061 matrices via stir casting technique and observed an increase in the hardness and tensile strength of the composite as the bagasse ash content increased. Ashes from other agricultural wastes and organic materials such as Aloe vera, pine leaf and lemon grass have equally been explored as reinforcement materials on Aluminium alloy matrix [41–43]. The potential of melon shell ash as reinforcement on aluminium matrix has also been explored [44, 45]. A study by Abdulwahab et al [46] on an Al-Si-Mg matrix reinforced with melon shell ash revealed improvement in the mechanical property of the Al-Si-Mg alloy up to a maximum of 20% wt addition of the melon reinforcement. However, better thermal conductivity was achieved in the composite with the 5%wt addition of reinforcement than the other proportions (10 wt%, 15 wt%, and 20 wt%). Suleiman et al [47] also employed melon shell ash as a reinforcement on the Al-Si alloy matrix. Their result showed that the hardness and the tensile strength of the composite increased while the impact energy and the percentage elongation decreased. From the foregoing literature review, it is evident that studies on the use of agricultural waste as reinforcement on recycled aluminium alloys are scarce in the literature. Although there has been reported use of melon shell ash reinforcement on a certain grade of aluminium alloy (Al-12%Si), however, research on the use of melon shell ash to develop composites with other aluminium grades and especially aluminium waste cans has not been reported. Therefore, this study focuses on developing and exploring the potential of recycled aluminium waste cans matrix reinforced with melon shell ash for lightweight engineering applications in automobiles.

This study attempts to reduce the challenges posed by the indiscriminate disposal of agricultural and aluminium wastes and its environmental consequences. Most agro wastes and waste aluminium cans especially in developing countries are usually burnt or buried. This method of disposal constitutes a health risk for both plants and animals. The utilization of the melon ash and the aluminium waste cans to produce composites will help in turning the wastes into useful engineering materials that will help minimize the risk involved in the improper disposal of the wastes thereby promoting good health and a safe environment which is vital to the attainment of the Sustainable Development Goals (SDG) 3 which is good health and well-being. The impact of composite production also extends beyond this goal, with implications for other SDGs such as SDG 12 (responsible consumption and production), SDG 9 (Industry, innovation and infrastructure) and SDG 2 (Zero hunger) as more production of the crops will be encouraged thereby making more food available for consumption as a result of the innovative use of the wastes from the crops.

In this research, the aluminium waste cans were recycled as the matrix material while the melon shell ash was used as the reinforcement via the stir casting technique. The main objectives of the study include burning the melon shell and investigating the chemical compositions of the produced ash, production of the composites via stir casting method, and characterization of the composites to obtain the mechanical properties and the microstructures.

2. Materials and Methods

2.1. Preparation of The Melon Shell Ash

The melon shell (Figure 1) was sourced from a market in Omu-Aran, Kwara state, Nigeria. They were thoroughly washed to eliminate dirt, sun-dried and then burnt into ashes and sieved with a 38 µm sieve size. Figure 2.

2.2. Aluminum Waste Cans Preparation

The Aluminum waste cans were picked from different dumping sites in Omu-Aran, Kwara state, Nigeria. Figure 3. A compositional analysis was carried out on the Aluminium alloy using the theoretical density of 2.7 g/cm3. Table 1.

Table 1. Aluminium waste cans chemical composition (weight %) [2]

Element	Fe	Mn	Ti	K	Si	Cu	Zn	Mg	Cr	Al	Others
% Wt	0.431	0.388	0.006	0.013	0.59	0.074	0.194	2.143	0.008	96.043	0.11

2.3 Analysis of The Produced Melon Shell Ash

X-ray fluorescent (XRF) was employed for the elemental analysis of the melon shell ash. The analysis was carried out using the Thermo Fisher ARL PERFORM’X Sequential XRF equipment with Uniquant software. Table 2.

Table 2. Melon shell ash composition

Oxides	SiO_2	K_2O	SO_3	P_2O_5	FeO_3	TiO_5	Al_2O_3	MnO
Weight %	75.11	4,59	0.62	9,77	1,31	0.16	2,67	0.457
Oxides	CaO	ZnO	BaO	Na_2O	MgO	V_2O_5	LiO	ZrO_2
Weight %	2,12	0.476	0.089	0.53	0.36	0.006	1,42	0.01

Fig. 1. Melon shell

Fig. 2. Melon shell ash

Fig. 3. Waste Aluminium cans

Fig. 4. Sand mould with the composites

2.4 Composite Production

The aluminium cans were crushed and weighed on a weighing scale before being loaded into a mild steel container and charged into the blast furnace, which was preheated to 500 degrees Celsius. The furnace temperature was raised to 800°C, which is higher than the melting point of the aluminium waste cans, which is about 660°C The charged Aluminium was left for about forty-five minutes in the furnace and stirred at 450 rpm to allow proper and complete melting. Following this, the molten aluminium was removed from the furnace and the impurities/ slag were separated from the molten Aluminium. The prepared melon shell ash powder was introduced into the molten metal as the reinforcement in percentage by weight to produce the composites. The mixture was stirred for 1 minute, returned to the furnace, and left for about 15 minutes. After this, the molten composite was removed from the furnace, gently poured into the prepared sand mould (Figure 4) and left to cool naturally. The composite rods (Figure 5) were removed from the sand mould after 24 hours. The reinforcement was added in percentage by weight according to Table 3 to produce five distinct combinations. The samples without reinforcement were the control samples i.e. 0% wt. The percentage weight additions were selected based on literature reports on related studies [2, 22, 46, 47].

Table 3. Various % wt additions of melon shell ash to the Aluminium matrix

S/N	Al alloy (% wt.)	Melon ash (% wt.)
1	100	0
2	95	5
3	90	10
4	85	15
5	80	20

2.5. Characterization

2.5.1. Mechanical Properties

Three specimens were machined into B557M ASTM standard [48] for each percentage reinforcement used (Figure 6). The mean values of the ultimate tensile strength were recorded. The tensile strength was carried out using the INSTRON universal testing machine. The Brinell hardness testing was performed following ASTM E10-18 2017 [49] using a universal testing machine with an indenter of 10mm at 500kgf for 10s. About five indentations were made on each sample and the average was evaluated. Two impact test samples cut to ASTM standard E23 of the year 2007 [50] were evaluated for all the composites. The test was performed on the notched rectangular samples of dimensions 75 x 10 mm using the Avery-Denison Universal Impact-Testing Machine. The impact strength measured in joules (J) was recorded for the test specimens.

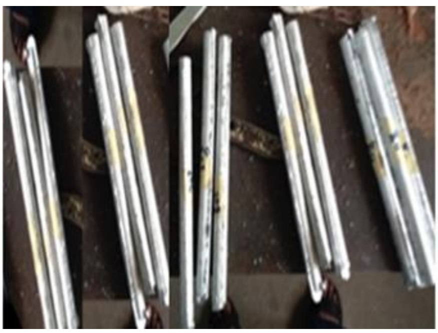

Fig. 5. The composites before machining

Fig. 6. Tensile samples

2.5.2 Density

The density of the composites was measured using Archimedes's principle and equation 1 [2].

$$\rho c = \left(\frac{Wc}{Wc - Ww} \right) \times \rho w \tag{1}$$

Where; ρc = density of the composite; ρw = density of water at room temperature ($1000kg/m^3$ or $1g/cm^3$); *W*c = weight of composite in air and *W*w = weight of composite immersed in water

2.5.3 Surface Morphology Examination

Samples of 6mm each were cut from the composites, mounted, grinded, polished, and etched with Weck's reagent for the microstructural study. This was performed with an optical microscope set at a magnification of 50. Three samples at different percentage reinforcement additions i.e., 0% wt, 5% wt, and 15% wt. were selected for SEM and EDS analysis based on their mechanical behaviour.

2.6 Challenges

The main challenge encountered during the composite preparation was the melted aluminium cans carrying lots of impurities and slags which increases the melting time of the aluminium in the furnace. Frequent efforts were made to remove the slags on the molten aluminium before adding the reinforcements. The thermal instability resulting from the temperature difference between the sand mould and the molten composites causes sparking of the molten metal during pouring. However, preheating the mould before pouring the molten metal was helpful. The limitation of the stir casting method which includes particle agglomeration at higher volumes of reinforcement additions was another challenge. The stirring time at the higher percentages of reinforcement additions was increased for more even distributions of the melon shell ash.

3. Results and Discussion

3.1 Tensile Test

The tensile result as shown in Figure 7 indicates that the melon shell ash particulate addition has a significant influence on the tensile properties of the Aluminium alloy. At 5% weight addition of the melon shell ash to the Aluminium matrix, the tensile strength increases by 7.5% and increases by 16.1% at 10% weight addition. The highest tensile strength of 113MPa was obtained at the 20% weight addition of the melon shell ash reinforcement representing about 23.7% increase from the unreinforced alloy. However, at 20% reinforcement addition to the matrix, the ultimate tensile strength decreases.

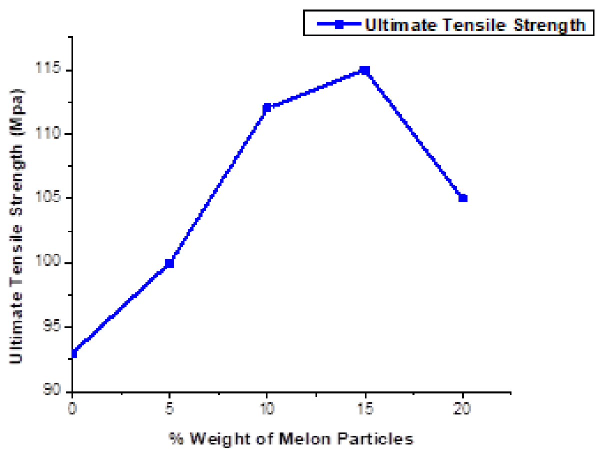

Fig. 7. Ultimate tensile strength of the composites at different weight additions

The increase in tensile strength of the composites up to the 15% weight addition of the melon shell ash could be ascribed to the ability of the melon shell ash particulates to act as a hindrance to dislocations when subjected to loading during the tensile test. The high silicon content of the melon ash which has been known to promote grain boundary strength and other hard compounds such as Fe_2O_3, Al_2O_3, MgO, TiO_2 and CaO present in the melon shell ash have played a significant role in the strength improvement of the composites [46, 47]. The decrease in the composite strength at 20% weight addition could be due to the influence of the segregation of the oxide particles which weakens the strengthening precipitates of the composites [47].

3.2 Hardness

The hardness values of all the composites at different percentage weight additions (Figure 8) were significantly greater than that of the unreinforced Aluminum. The hardness value increased from 48.5 HBN for unreinforced Aluminium to 55.5 BHN at 5% wt melon shell ash addition. This value further increased to 57.2 at 10% wt particulate addition to give the maximum value. Thereafter, the hardness value dropped at 15% wt and reduced a bit further at 20% wt addition. The uniform dispersion of the melon ash particles along the grain boundaries of the composites, as observed in the microstructures, improved its resistance to plastic deformation thereby impacting hardness to the composites. The decrease in hardness values as observed at 15% wt. and 20% wt. melon shell ash additions could be attributed to the increase in the weight of the melon shell ash in the Aluminium matrix which advanced the coarsening of the precipitates and weakened the intermetal-particulate bonding of the composites [2, 34, 44].

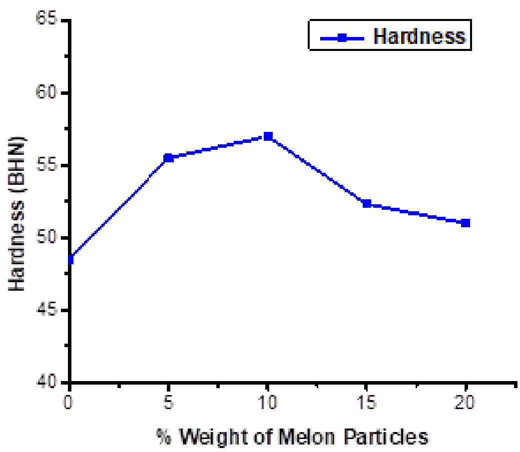

Fig. 8. The hardness of the composites at different weight additions

3.3 Impact

The impact test results vary across the different percentage compositions of the reinforcement (Figure 9). At 5% particulate addition, a marginal increase in impact toughness from that of the Aluminium matrix was observed. Further addition of reinforcement to 10% increases the impact energy slightly higher. However, as the addition of the particulate reinforcement increases further, the impact energy reduces. The highest impact energy of 77J obtained at 10% represents a moderate addition of reinforcements. At this stage, the melon shell ash blends with the Aluminium matrix to enhance interfacial adhesion and maximum absorption of energy with adequate toughness and strength to tolerate the impact force [2, 46]. The impact energy reduces as the melon shell ash addition increases to 15% wt and reduces further at 20% wt. This could be linked to the high volume of melon shell ash present in the composite which could lead to segregation by the ductile Aluminium matrix making it prone to crack propagation. Also, the thermal differences set up between the melon shell ash particles and the Aluminium matrix generate elastic stresses which put the melon shell ash into compression and the matrix into tension, consequently advancing the brittleness which probably lowers the impact strength and could also be responsible for the lower hardness and tensile strength trend observed at the 20% wt addition [51].

Generally, all the mechanical properties of the composite were observed to decrease at the highest percentage of reinforcement. In addition to the explanations already given on this in sections 3.1, 3.2, and 3.3, one of the factors that could be responsible for the lower mechanical properties at this weight fraction addition is the agglomeration of the reinforcements as evidenced in the microstructures in Figures 11 (c) and (d). The clustering of the melon shell particles could lead to stress concentration and nonuniformity in the reinforcement orientation, thereby initiating cracks and failures that could lower the composite strength. Also, insufficient matrix material due to the high volume of reinforcements could lead to reinforcement wetting, causing a reduction in the mechanical properties. Another possible factor is the thermal expansion mismatch resulting from differences in the thermal expansion coefficients of the aluminium matrix and the high volume of melon shell ash which could induce internal stresses in the composite, reducing the mechanical properties.

The factors given above as possible causes of the observed reduction in the mechanical properties of the composites at the 20% wt. could be mitigated by optimizing the melon shell ash processing to enhance the fibre quality. Interfacial modification of the melon shell ash to improve bonding with the Aluminium matrix at higher percentages of weight addition may also be helpful. Other natural fibres could be incorporated into the melon shell ash to form a hybrid reinforcement. However, the compatibility of such hybrid reinforcement with the matrix must be ascertained.

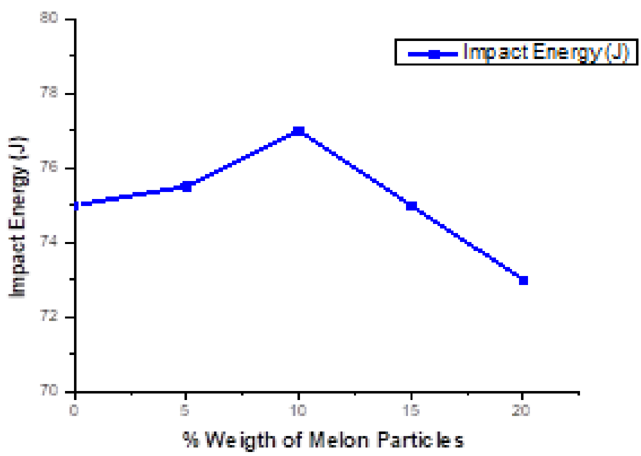

Fig. 9. Impact toughness of the composites at different weight additions

3.4 Density

The densities of the composites, as shown in Figure 10 decreased as the % weight addition of the melon ash increased. The density of the control sample i.e., the unreinforced aluminium is 2.8 g/cm^3. This density decreases to 2.49 g/cm^3 at 20% wt. The implication of this is that the greater the weight of the reinforcement, the lower the weight of the composites. This could be ascribed to the lower density of the melon ash in comparison to that of the Aluminium. This led to the reduction in the weight of the composites' matrix-reinforcement particles, thereby lowering the composites' density [2, 22]. The reduction in the density of the composites observed at all the different % wt additions of the melon ash revealed that Aluminium lightweight composites are achievable with considerable additions of melon shell ash as reinforcement**.**

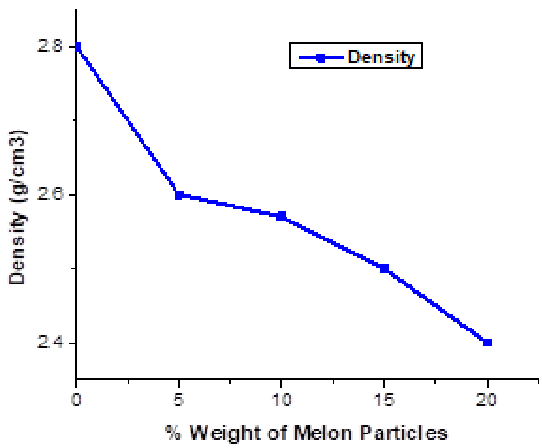

Fig. 10. Density variation of the composites at different weight additions

3.5 Surface Morphology Examination

Optical microstructures of the composites at different % wt reinforcements are presented in Figures 11 a, b, c and d while Figure 11 e is the microstructure of the unreinforced Aluminium alloy. The microstructures generally revealed uniform spread of the melon ash in the aluminium matrix. This further attests to the effectiveness of the stir casting method employed for the composite production, despite a tiny micropore that could be spotted at a point in Figure 11 (b). The melon shell ash particulates were considerably spread along the grain boundaries of all the microstructures although slight clustering of the ash particles could be noticed at some point in some of the samples. Figure 11 (c). Particulate agglomeration could be observed at some points in the composite at the highest reinforcement volume of 20% wt. Figure 11 (d). The homogenous distribution of the melon ash reinforcement in all the composite structures is accountable for the good result in the mechanical behaviour of the composites. The structural Modification due to the addition of the reinforcement as evidenced in the microstructure, promotes strong interfacial bonding within the aluminium grain boundaries. This impact strength to the composites and enhanced its resistance to deformations thereby improving the mechanical properties as recorded in the tensile, impact and hardness results obtained from the composites [2, 34, 44]. However, slight agglomeration and non-uniformity in the dispersion of the melon ash particles at higher volumes of reinforcement caused the observed drop in the mechanical strength of the composites.

The SEM and EDS analysis presented in Figures 12 a, b and c for 0% wt, 5%wt. and 15%wt. melon shell ash addition respectively show distinct features. These features emanate from the mixing of the melon shell ash with the Aluminium matrix. The EDS at the 5% wt. composition of reinforcement as shown in Figure 12 (b) reveals the presence of O, Mn, and Mg among others which are key components of the melon shell ash.

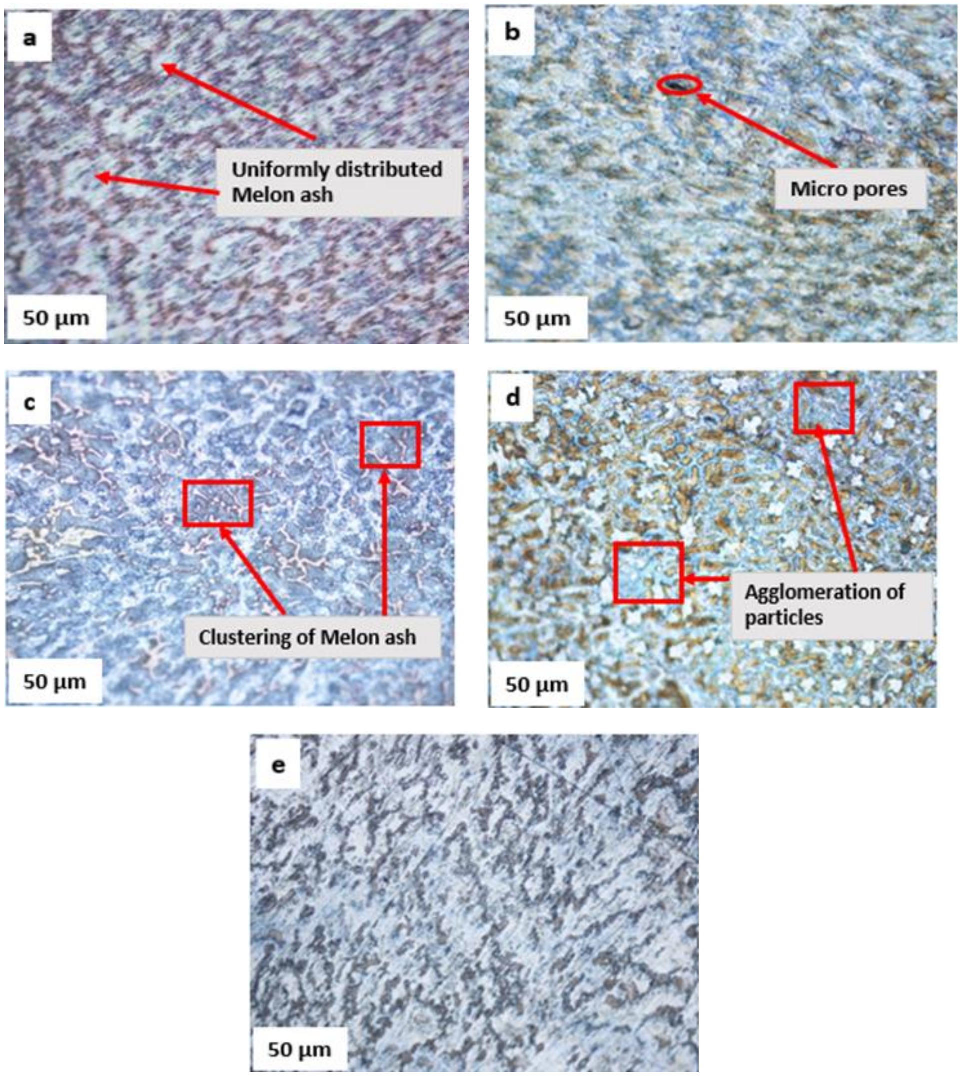

Fig. 11. Microstructures of the composites (a) 5% wt. (b) 10% wt (c) 15% wt (d) 20% wt (e) 0% wt

However, at the 15% wt addition of the melon shell ash, the percentage compositions of the elements changed with silicon having the highest composition after Aluminum. The high-volume addition of the melon shell ash to the aluminum matrix increased the silicon content of the composite since SiO_2 is the major component of the melon shell ash as given in Table 2. The addition of Si to metals has been reported to impart strength to it [46, 47]. This also explains the improvement in the mechanical behavior of the composites as compared with the unreinforced Aluminum alloys.

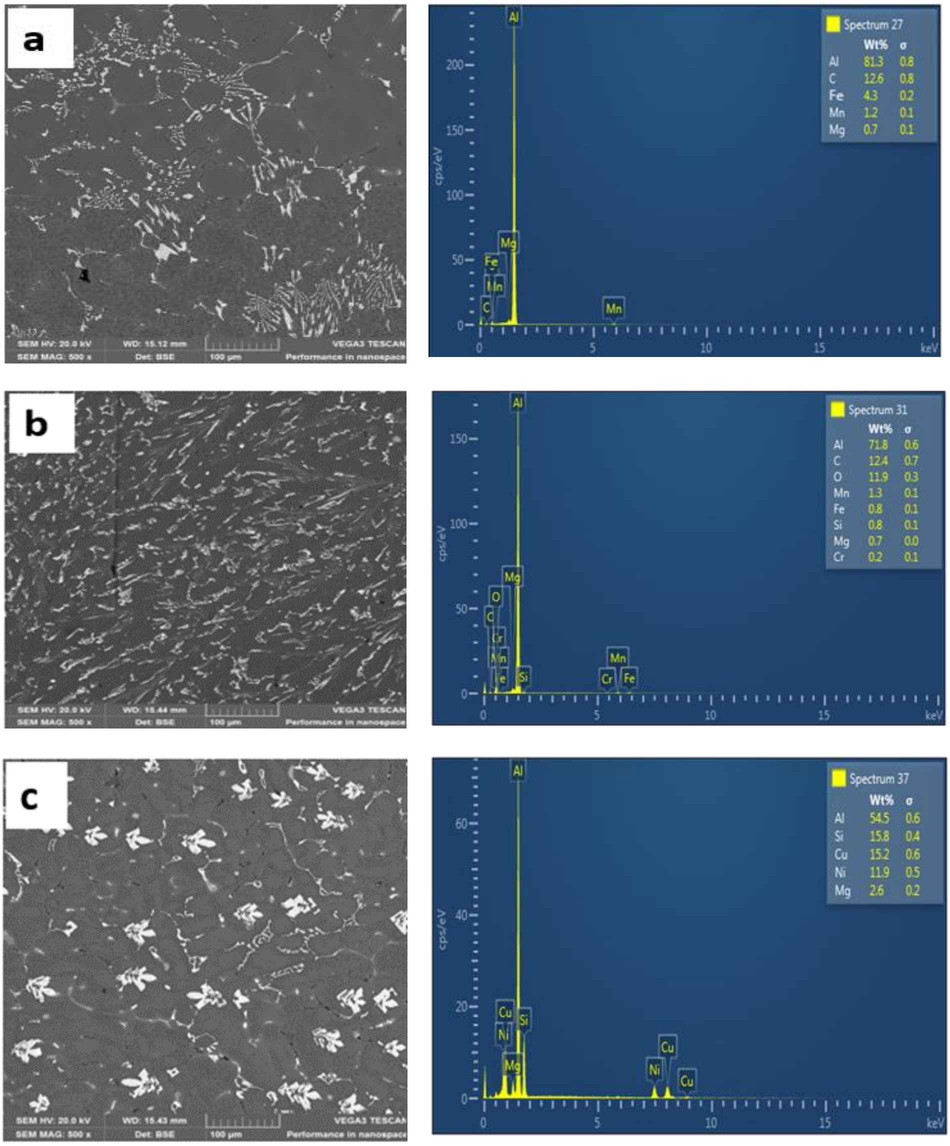

Fig. 12. SEM images and EDS analysis of the Aluminium matrix and the composites (a) 0% wt. (b) 5% wt. (c) 15% wt.

4. Conclusions

Recycled aluminium waste cans have been reinforced with melon shell ash to produce composites. The conclusions that could be drawn from the mechanical and microstructural characterizations carried out on the composites are as follows:

- Melon shell ash reinforcement could be successfully incorporated into a recycled aluminium waste cans matrix through the stir casting method.
- There is an enhancement in the ultimate tensile strength (UTS) of the composites over the unreinforced aluminium. The UTS increases as the percentage

reinforcement increases up to 15% wt particulate addition but drops a little at 20% wt addition. The maximum UTS of 113 MPa was obtained at 15%wt. addition representing about 23.7% increase above the unreinforced alloy. This improvement in the tensile behaviour could be linked to the homogenous dispersion of the melon ash particulates in the Aluminium matrix which act as a barrier to dislocations during the tensile test. The high presence of silicon and other hard compounds in the melon ash also contributed to the observed high tensile strength [46,47]. Segregations of oxide particles occurred at 20% addition which declined the strengthening precipitates of the composites leading to the observed reduction in the tensile strength at that 20% [47].

- There was an improvement in the impact energy up to the 10% wt. reinforcement. However, the toughness energy dropped at 15% wt. and dropped further at 20% wt addition. The highest impact energy of 77J was obtained at 10% wt. At this point, there was an enhancement in the interfacial adhesion between the matrix and the melon which promotes energy absorption with considerable toughness and strength to withstand the impact force [2, 47].
- The hardness values of the composites at all the % wt additions were generally higher than that of the unreinforced Aluminium. The maximum hardness was obtained at 10% wt. addition. The uniform distribution of the melon shell ash along the grain boundaries of the composites promotes its resistance to plastic deformation leading to the rise in hardness of the composites [2, 44].
- The microstructures demonstrate that melon ash particles were homogeneously distributed in all the composites although little clustering and particle agglomeration were noticed at higher % wt. reinforcement.
- Additions of the different weight fractions of the melon ash particles lower the density of the composites. This is evident from the fact that the density of the ash was lower than that of the Aluminium. This implies that lightweight Aluminium composites can be achieved with moderate additions of melon ash to the matrix.
- Generally, the produced composite possesses better mechanical properties and lower density than the unreinforced alloys. These two factors achieved in this study are very significant to Engineering materials design and selection making this study a significant contribution towards the quest for lighter-weight engineering materials with uncompromising strength.
- The enhanced mechanical properties and the reduced density of the composites have numerous potential applications in the development of lightweight engineering materials in industries such as aerospace, automobile, marine, medical, construction, sports, and energy. Many industries today are utilizing composite materials own to their benefits, especially their low weight and high strength ability. The aerospace and automobile industries are taking these advantages to produce lighter parts with high strength. The weight savings and dimensional stability offered by composite materials have reduced fuel consumption and enhanced the performance and efficiency of aircraft and automobile engines. Although carbon fibre-reinforced composites and polymer matrix composites have gained wide uses in the aerospace and automobile industries, the availability of materials, ease and cheaper production, and sustainability of melon shell ash reinforced composites could also be of tremendous advantage to the industries. The sports industries have also leveraged the merits of composites in the production of many sports equipment such as bicycles, tennis rackets, and golf clubs to ease sporting. Aluminium-melon shell ash composite does not produce any harmful emissions, this could also enhance its potential uses in the manufacturing of sport equipment. In the marine industries, lightweight composites have found applications in making boats, hulls, and propellers. Glass, carbon, and vinyl fibre-

reinforced composites with epoxy resin matrix are some of the common composites in marine applications. These composites are expected to have good strength, durability, and corrosion resistance ability. Since aluminium generally offers considerable resistance to corrosion the presence of an optimized quantity of melon shell ash as reinforcement in the aluminium matrix may likely not reduce its corrosion resistance when used in the marine environment. Composites such as natural and synthetic fibre-reinforced polymers, metal matrix composites, and carbon fibre-reinforced composites have also been utilized in building development, bridge components, long-span roofs, water storage tanks etc. Properties such as high strength-to-stiffness ratio, low density and low stress are some of the requirements for the composites employed in the construction industries. The aluminium-melon shell ash composites possess some of these qualities making it a viable option for the construction industries. The low density and the improved strength-to-weight ratios achieved in this study are desirable material properties for lightweight applications in many industries especially where cheaper, durable, available and sustainable composite materials are required.

5. Future Perspectives

The mechanical behaviour of the composites produced from the melon shell ash has shown that the properties can be controlled by varying the percentage composition of the reinforcements. This study suggests and encourages further exploration of the potential of other agricultural wastes in the environment in the field of materials, manufacturing and production engineering. In the future, agro wastes possess the potential to replace some hazardous and environmentally unfriendly reinforcements such as asbestos fibre employed in automobiles. Although the stir casting technique has been extensively utilized for composite production, however, its deficiencies such as non-uniform distributions of reinforcements and wettability call for explorations of other techniques such as compocasting, friction stir casting and powder metallurgy. Future research works could also encompass the optimization of both the composite production processes and the agro-waste composition in the metal matrix.

Acknowledgement

The authors acknowledged the following from the Department of Mechanical Engineering, Landmark University for their assistance during the composite preparations. J.I. Agaja, G.O. Omebije, M.A. Johnson, M.J. Fayose, C. Ezeobuka, A. D. Adeshina, C.C.Ekwijuru, O. Olanrewaju, K. Ekande, P.Okonkwo , J. Ogbonna and O. Kuforiji.

References

[1] Shoag MD and Rahman MF. IOP Conf. Ser. Earth Environ. Sci. 943 012028 (2021). Using Recycling Aluminum Cans as Composite Materials Aluminum Fiber Using Recycling Aluminum Cans as Composite Materials Aluminum Fiber. 2021; 943 012028. https://doi.org/10.1088/1755-1315/943/1/012028

[2] Omoniyi P, Adekunle A, Ibitoye S, Olorunpomi O, Abolusoro O. Mechanical and microstructural evaluation of aluminium matrix composite reinforced with wood particles. Journal of King Saud University - Engineering Sciences. 2022; 34:445-450. https://doi.org/10.1016/j.jksues.2021.01.006

[3] Omoniyi P, Abolusoro O, Olorunpomi O, Ajiboye T, Adewuyi O, Aransiola O, Akinlabi E Corrosion Properties of Aluminum Alloy Reinforced with Wood Particles. Journal of Composites Science. 2022;2022, 6(7):189. https://doi.org/10.3390/jcs6070189

[4] Abolusoro OP, Akinlabi ET. Wear and corrosion behaviour of friction stir welded aluminium alloys- An overview. International Journal of Mechanical and Production Engineering Research and Development. 2019; 9:967-982.
[5] Parveez B, Maleque A. Influence of agro-based reinforcements on the properties of aluminum matrix composites: a systematic review. J Mater Sci. 2021; 56:16195-16222. https://doi.org/10.1007/s10853-021-06305-2
[6] Ramanathan A, Krishnan P.K, Muraliraja R. A review on the production of metal matrix composites through stir casting-Furnace design, properties, challenges, and research opportunities. J. Manuf Processes. 2019;.42:213-245. https://doi.org/10.1016/j.jmapro.2019.04.017
[7] Baisane VP, Sable YS, Dhobe MM, Sonawane PM. Recent development and challenges in processing of ceramics reinforced Al matrix composite through stir casting process. Int J Eng Appl Sci. 2015; 2:2394-3661
[8] Ikubanni PP, Oki M, Adeleke AA. A review of ceramic/bio-based hybrid rein-forced aluminum matrix composites. Cogent Eng. 2020; 7:1-19
[9] Senthilvelan T, Gopalakannan S, Vishnuvarthan S, Keerthivaran K. Fabrication and characterization of SiC, Al2O3 and B4C reinforced Al-Zn-Mg-Cu alloy (AA 7075) metal matrix composites: a study. Adv Mater Res. 2013; 622:1295-1299. https://doi.org/10.4028/www.scientific.net/AMR.622-623.1295
[10] Bandil K, Vashisth H, Kumar S, Verma L, Jamwal A, Kumar D, Singh N, Sadasivuni KK, Gupta P. Microstructural, mechanical and corrosion behaviour of Al-Si alloy reinforced with SiC metal matrix composite. 2019; 53:4215-4223. https://doi.org/10.1177/0021998319856679
[11] Karthikeyan A, Nallusamy S. Investigation on mechanical properties and wear behavior of Al-Si-SiC-graphite composite using SEM and EDAX. In: IOP Conference Series: Materials Science and Engineering, IOP Publishing. 2017; p 012281. https://doi.org/10.1088/1757-899X/225/1/012281
[12] Alaneme KK, Aluko AO. Production and age-hardening behaviour of borax premixed SiC reinforced Al-Mg-Si alloy composites developed by double stir-casting technique. West Indian J Eng. 2012; 34:2
[13] Dwivedi SP, Sharma S, Mishra RK. Microstructure and mechanical behavior of A356/SiC/Fly-ash hybrid composites produced by electromagnetic stir casting. J Braz Soc Mech Sci Eng. 2019; 37:57-67. https://doi.org/10.1007/s40430-014-0138-y
[14] Osunmakinde L, Asafa TB, Agboola PO, Durowoju MO. Development of aluminum composite reinforced with selected agricultural residues. Discov Mater. 2023; 3:33. https://doi.org/10.1007/s43939-023-00069-z
[15] Abolusoro OP, Orah AM, Yusuf AS, Ayandotun WB, Ibrahim W (2023) Investigation of the Energy Capabilities of Selected Agricultural Wastes in a Fluidized-Bed Combustor. In: 2023 International Conference on Science, Engineering and Business for Sustainable Development Goals, SEB-SDG 2023. Institute of Electrical and Electronics Engineers Inc. 2023. https://doi.org/10.1109/SEB-SDG57117.2023.10124555
[16]Taylor P. Development of metal-matrix composites from industrial/agricultural waste materials and their derivatives. Crit Rev Environ Sci Technol. 2016; 46:143-208. https://doi.org/10.1080/10643389.2015.1077067
[17] Kandpal BC, Johri N, Kumar N, Srivastava A. Effect of industrial/ agricultural waste materials as reinforcement on properties of metal matrix composites. In: Materials Today: Proceedings. Elsevier Ltd, 2021; pp 10736-10740. https://doi.org/10.1016/j.matpr.2021.01.575
[18] Kulkarni PP, Siddeswarappa B, Kumar KSH. A survey on effect of agro-waste ash as reinforcement on aluminum base metal matrix composites. Open J Compos Mater. 2019; 9:12-26

[19] Joseph OO, Babremu KO. Agricultural waste as a reinforcement particulate for Al metal matrix composites (AMMCs). Rev MDPI Fibers. 2019; 7:7-33. https://doi.org/10.3390/fib7040033
[20] Saravanan SD, Kumar MS. Effect of mechanical properties on rice husk ash reinforced aluminum alloy (AlSi10Mg) matrix composites. Proc Eng. 2013; 64:1505-1513. https://doi.org/10.1016/j.proeng.2013.09.232
[21] Olorunmota RT, Ofuya TI, Idoko JE, Ogundeji BA. Effect of rice husk and melon shell wastes as possible grain protectants in cowpea storage. J Adv Biol Biotechnol. 2017; 1-9. https://doi.org/10.9734/JABB/2017/37114
[22] Usman AM, Raji A, Waziri N, Hassan MA. Aluminium alloy - rice husk ash composites production and analysis. Leonardo Electron J Pract Technol. 2014; 25:84-98.
[23] De SC, Khosrow R. Rice Husk Ash as a supplementary raw material for the production of cellulose-cement composites with improved performance. Waste Biomass Valor. 2010; 1:241-249. https://doi.org/10.1007/s12649-010-9017-7
[24] Tiwari S, Pradhan MK. Effect of rice husk ash on properties of Al-alloys. A[review. In: Mater Today Proc. 2017; pp 486-495. https://doi.org/10.1016/j.matpr.2017.01.049
[25] Dinaharan I, Kalaiselvan K, Murugan N. Influence of rice husk ash particles on microstructure and tensile behaviour of AA6061 Al matrix composites produced using friction stir processing. Comp Commun. 2017; 3:42-46. https://doi.org/10.1016/j.coco.2017.02.001
[26] Sathiesh Kumar N. Fabrication and characterization of Al7075 / RHA /Mica composite by squeeze casting. Mater Today Proc. 2020. https://doi.org/10.1016/j.matpr.2020.05.769
[27] Bakar RA, Yahya R, Gan SN. Production of high purity amorphous silica from rice husk. Procedia Chem. 2016; 19:189-195. https://doi.org/10.1016/j.proche.2016.03.092
[28] Verma N, Vettivel SC. Characterization and experimental analysis of boron carbide and rice husk ash reinforced AA7075 aluminium alloy hybrid composite. J Alloys Compd 2018; 741:981-998. https://doi.org/10.1016/j.jallcom.2018.01.185
[29] Joharudin NFM, Latif NA, Mustapa MS, Badarulzaman NA, Mahmod MF. Effect of burning temperature on rice husk silica as reinforcement of recycled aluminium chip AA7075. J Adv Res Fluid Mech Therm Sci. 2020; 68. https://doi.org/10.37934/arfmts.68.1.125132
[30] Ravi Kumar K, Pridhar T, Sree Balaji VS. Mechanical properties and characterization of zirconium oxide (ZrO2) and coconut shell ash(CSA) reinforced aluminium (Al 6082) matrix hybrid composite. J Alloys Compd. 2018; 756:171-179 . https://doi.org/10.1016/j.jallcom.2018.06.177
[31] Kaladgi ARR, Rehman KF, Afzal A, Baig MA, Soudagar MEM, Bhattacharyya S. Fabrication characteristics and mechanical behaviour of aluminium alloy reinforced with Al2O3 and coconut shell particles synthesized by stir casting. IOP Conf Ser Mater Sci Eng. 2021; 1057:12017. https://doi.org/10.1088/1757-899X/1057/1/012017
[32] Bello SA, Raheem IA, Raji NK. Study of tensile properties, fractography and morphology of aluminium (1xxx)/coconut shell microparticle composites. J King Saud Univ - Eng Sci. 2017; 29:269-277. https://doi.org/10.1016/j.jksues.2015.10.001
[33] Zainudin NF, Lee KT, Kamaruddin AH, Bhatia S, Mohamed AR. Study of adsorbent prepared from oil palm ash (OPA) for flue gas desulfurization. Sep Purif Technol. 2005; 45:50-60. https://doi.org/10.1016/j.seppur.2005.02.008
[34] Aigbodion VS, Ezema IC. Multifunctional A365 alloy/PKSAnp composites: microstructure and mechanical properties. Defense Technol. 2020; 16:731-736. https://doi.org/10.1016/j.dt.2019.05.017
[35] Hashimah N, Mohamad B. The utilization of Palm Oil Fuel Ash in Aluminium Metal Matrix Composites. Materials. 2019
[36] Sn W. Sugarcane bagasse: how easy is it to measure it's constituents? . Proc S Afr Sug Technol Ass. 2008; 81:266-273

[37] Thirugnanasambandham T, Chandradass J. Fabrication and Characteristization of Bagasse Ash Particle (BAP) Reinforced Magnesium (AZ91E) Alloy Composite by Vacuum Stir Casting. In: IOP Conf. Ser. Mater. Sci. Eng. 2020; 993 012133. https://doi.org/10.1088/1757-899X/993/1/012133
[38] Usman AM, Raji A, Hassan MA, Waziri NH. A comparative study on the properties of Al-7%Si-rice husk ash and Al-7%Si-bagasse ash composites produced by stir casting. Int J Eng Sci. 2014; 3:1-7
[39] Kamble A, Kulkarni SG. Microstructural examination of bagasse ash reinforced waste aluminium alloy matrix composite. AIP Conf Proc. 2019; 2105. 1-8. https://doi.org/10.1063/1.5100696
[40] Chandla NK, Yashpal, Kant S, Goud MM, Jawalkar CS. Experimental analysis and mechanical characterization of Al 6061/alumina/bagasse ash hybrid reinforced metal matrix composite using vacuum-assisted stir casting method. J Compos Mater. 2020; 54:4283-4297. https://doi.org/10.1177/0021998320929417
[41] Tyagi L, Butola R, Jha AK. Mechanical and tribological properties of AA7075-T6 metal matrix composite reinforced with ceramic particles and aloevera ash via Friction stir processing. Mater Res Express. 2020; 7:1-13. https://doi.org/10.1088/2053-1591/ab9c5e
[42] Jose J, Christy TV, Peter PE, Feby JA, George AJ, Joseph J, Chandra RG, Benjie NM. Manufacture and characterization of a novel agro-waste based low cost metal matrix composite (MMC) by compocasting. Mater Res Express. 2018; 5:1-32. https://doi.org/10.1088/2053-1591/aac803
[43] Gupta MK. Effects of tool pin profile and feed rate on wear performance of pine leaf ash / Al composite prepared by friction stir processing. J Adhes Sci Technol. 2020. https://doi.org/10.1080/01694243.2020.1800290
[44] Nagpal Y, Sharma P, Sharma R. A Study on Characterization of Green Metal Matrix Composites Reinforced with Melon Shell Ash Particulates. In: Lecture Notes on Multidisciplinary Industrial Engineering. Springer Nature, 2022; pp 141-152. https://doi.org/10.1007/978-3-030-73495-4_10
[45] Aigbodion VS, Atuanya CU. Improving the properties of epoxy/melon shell bio-composites: effect weight percentage and form of melon shell particles. Polymer Bulletin. 2016; 73:3305-3317. https://doi.org/10.1007/s00289-016-1657-8
[46] Abdulwahab M, Umaru OB, Bawa MA, Jibo HA. Microstructural and thermal study of Al-Si-Mg/melon shell ash particulate composite. Results Phys. 2017; 7:947-954. https://doi.org/10.1016/j.rinp.2017.02.016
[47] Suleiman IY, Salihu SA, Mohammed TA. Investigation of mechanical, microstructure, and wear behaviors of Al-12%Si/reinforced with melon shell ash particulates. International Journal of Advanced Manufacturing Technology. 2018; 97:4137-4144. https://doi.org/10.1007/s00170-018-2157-9
[48] ASTM International, B557-15 standard test methods for tension testing wrought and cast Aluminium. ASTM Int. 2015; 1-16. https://doi.org/10.1520/B0557- 15.2
[49] ASTM E10-18 2017. Standard Test Method for Brinell Hardness of Metallic Materials.
[50] ASTM International Standard E23 of the year 2007. Test Methods for Notched Bar Impact Testing of Metallic Materials.
[51] Hamouda AMS, Sulaiman S, Vijayaram TR, Sayuti M, Ahmad MHM (2007) Processing and characterization of particulate reinforced aluminium silicon matrix composite. Journal of achievements in materials and manufacturing engineering 2:11-16