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Investigative Study of the Structure and Mechanical Behaviour of Horse Eye Bean Seed Shell Ash Reinforced Aluminium Alloy Matrix Composite

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ABSTRACT

This research investigated the structure and mechanical behaviour of horse eye bean seed shell ash reinforced aluminium alloy matrix composite. The horse eye bean seed shell ash of particle sizes (300 and 500µm) was added in concentrations of 5 and 15% by weight. The composite was developed using permanent die casting technique and machined to the required dimensions for tensile strength, hardness and impact strength. The machined samples were subjected to heat treatment at 410oC for 30 minutes, quenched in water and aged at temperatures of 100 and 300oC for 2 and 6hrs. Mechanical properties such as percentage elongation, ultimate tensile strength, Brinell hardness and impact strength were determined using a 100KN JPL tensile strength tester (Model: 130812), portable dynamic hardness testing machine (Model: DHT-6) and pendulum impact testing machine (Model: U1820) respectively. The structural analysis was conducted using an optical metallurgical microscope (Model: L2003A), scanning electron microscopy (SEM) equipped with energy dispersive spectroscopy (EDS) and X-ray diffractometer (XRD). The microstructure of the control sample revealed the presence of polyhedral-shaped primary silicon particles and needle-like precipitate of intermetallic compound. The composite showed fine intermetallic phases dispersed in the aluminium matrix. The result of the mechanical tests indicated that addition of horse eye bean seed shell ash significantly improved the ultimate tensile strength, hardness and impact strength of the aluminium alloy matrix. The ultimate tensile strength and hardness increased with decrease in reinforcement particle size and increase in percentage by weight of reinforcement and ageing temperature. Maximum ultimate tensile strength was obtained by the composite containing 5% by weight of reinforcement (500µm), aged at 300oC for 2 hrs. This was attributed to the fine intermetallic phases dispersed in the aluminium matrix. Maximum hardness was obtained by the composite containing 5% by weight of reinforcement (300µm), aged at 100oC for 2 hrs. This was linked with the presence of Al0.64Ti0.36, Al12Mg17, C0.12 Fe0.79 Si0.09, MgAl2O4, TiC, FeSi, SiC and AlMg evenly distributed in the aluminium matrix. Optimum impact strength was obtained by the composite containing 15% by weight of reinforcement (500µm) and aged at 100oC for 2 hrs.

Keywords : Composite, Particle Size, Reinforcement, Structure, Mechanical Properties

I. INTRODUCTION

Natural fiber composites have emerged as a viable alternative to glass fiber reinforced composites especially in automotive and building product applications [1]. The increased use of natural fibers as reinforcement in composites development is not only based on the strength and lightweight but also on the relative low cost and recyclability [2]. The main trends in the development of the next generation of materials, products, and processes are principally guided by sustainability, industrial ecology, eco-efficiency, and green chemistry [1]. The use of natural fibers as reinforcement for composite materials reduced the dependence on non-renewable energy/material sources, lower pollution and greenhouse emission [3].

Horse eye bean (Mucuna sloanei) is an annual leguminous climbing shrub with pods that are covered with hairs that irritate the skin when the fruit is mature and dries [4]. The constituents of horse eye bean include crude proteins, carbohydrates, fat, crude fibers, moisture, ash, phosphorus, magnesium, calcium, sodium, iron, manganese, copper, tannins, glycosides, L-Dopa and zinc [5]. The seeds are highly resistant to disease and pest and exhibit good nutritional qualities. This agricultural waste can be used to prepare fiber reinforced alloy matrix composites for commercial use.

Most common concerns about the use of these fibers are their coupling with a polymeric matrix, which need to be compatible with the cellulose contained in the fiber.

Study by [6] revealed that barley husk reinforced composites showed 10% better tensile strength than soft wood composites. The study also revealed that coconut shell and barley husk composites showed 80% and 40% better elongation at break and 20% and 35% better Charpy impact strength than soft wood composites respectively. Omole et al. [7] in their study of the mechanical properties of stir-cast aluminium matrix reinforced with African walnut kernel (Tetracarpidium Conophorum Kernel) established that the ultimate tensile strength, impact strength and hardness of the developed composite increased with increase in percentage by weight of walnut. Oghenevweta et al., [8] investigated the mechanical properties and morphological analysis of Al–Si–Mg/carbonized maize stalk particulate composites. The study indicated that the ultimate tensile strength and hardness values of the composite increased to 85.60 N/mm2 and 24HRB at 8 and 10 wt% of carbonized maize stalk addition respectively. A slight decrease in impact energy, percentage elongation and reduction in area were also noted as the reinforcement concentration increased. This mechanical behaviour was attributed to the uniform dispersion of the reinforcement along the grain boundaries of the alloy. Maleque et al., [9] developed new natural fibre reinforced aluminium composite for automotive brake pad application using coconut fibre. The study indicated that coconut fiber concentration between 5 and 10% by weight showed the higher density, lower porosity and higher compressive strength. This was attributed to the uniform distribution of resin and coconut fibre in the matrix. Zamri et al., [10] in their study of the potential of palm oil clinker as reinforcement in composite based aluminium for tribological applications established that palm oil clinker significantly improved the wear resistance of the developed composite with predominant effect obtained at applied load below 11N. A study by Alaneme et al., [11] indicated that the hardness, ultimate tensile strength, and percent elongation of the hybrid SiC and bamboo leaf ash reinforced aluminium matrix composites decreased with increase in bamboo leaf ash content. The fracture toughness of the hybrid composites were however superior to that of the single reinforced Al -10 wt.% SiC composite.

II. MATERIALS AND METHOD

Aluminium ingot containing 0.3% and 0.1% by weight of silicon and magnesium respectively were used as the matrix for this experimental study. Horse eye bean seed shell ash (HEBSSA) was used as the reinforcement. The horse eye bean seed shell was obtained from Akiyi Umulokpa in Uzo-Uwani Local Government Area, Enugu State, Nigeria. The horse eye bean seed shell was subjected to carburization in an oven at 400oC for 1 hr, ground into powder using a mechanical grinder and sieved to 300and 500μm particle sizes.

Figure 1: Horse eye bean.

For each composite formulation shown in Table 1, the required percentage by weight of aluminium ingot was melted in a bailout crucible furnace and the required percentage by weight of the reinforcement was wrapped in an aluminium foil and dipped into the melt. The mixture was stirred vigorously, reheated for 5 minutes and cast. The cast samples were machined to the required dimensions for tensile strength, hardness and impact strength tests. The machined samples were subjected to heat treatment at solutionizing temperature of 410oC for 30 minutes and quenched in water. The quenched samples were aged at different ageing temperatures (100oC and 300oC) and time (2hrs and 6hrs) and stored for mechanical tests and microstructural analysis.

Table 1: Composite formulations

Sample	R(%wt)	Ps(μm)	AT(^{o}C)	At(hr)
A	5	500	100	2
B	15	500	100	2
C	15	500	300	6
D	15	300	100	6
E	5	300	100	2
F	15	300	300	2
G	5	500	300	2
H	5	300	300	6

III. Scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS) and X-ray diffraction analysis of the studied composite

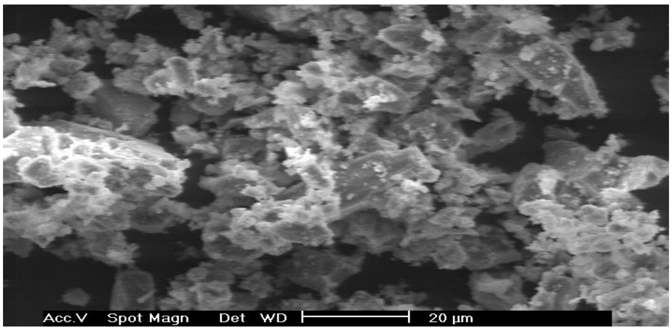

Figure 2: Micrograph (SEM) of horse eye bean seed shell ash

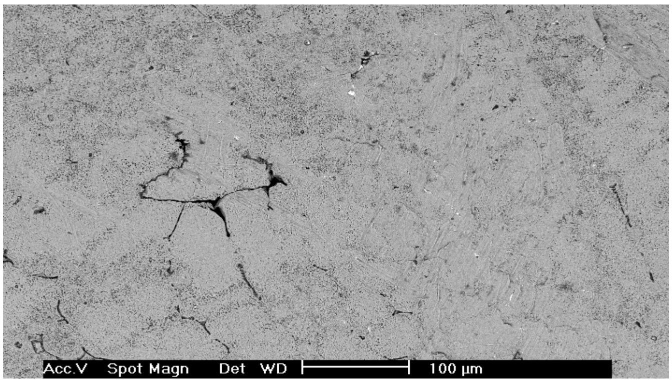

Figure 3: Scanning electron microscopy of of Al-Si-Mg alloy (control)

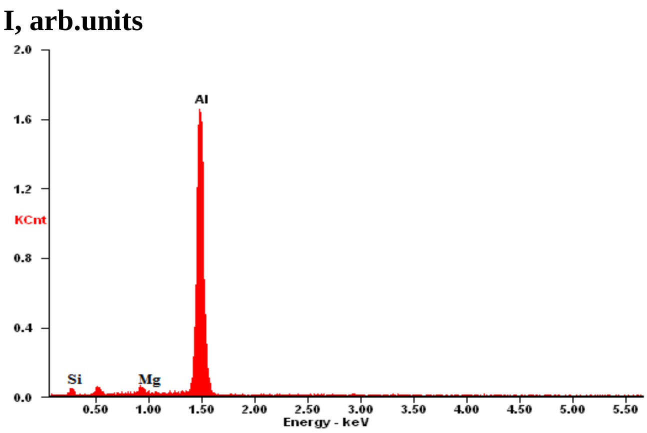

Figure 4: EDS spectrum of Al-Si-Mg alloy (control)

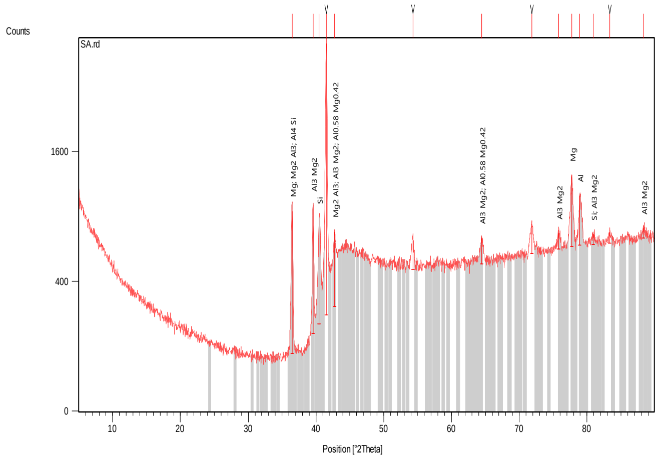

Figure 5: X-ray diffraction pattern of Al-Si-Mg alloy (control)

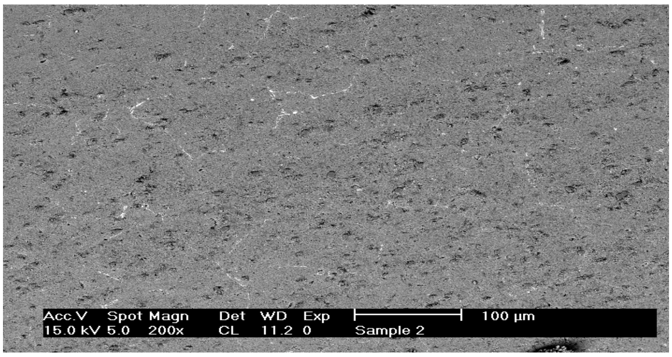

Figure 6: Scanning electron microscopy of Al-Si-Mg alloy reinforced with 15wt%HEBSSA of paricle size 500µm and aged at 100oC for 2 hours.

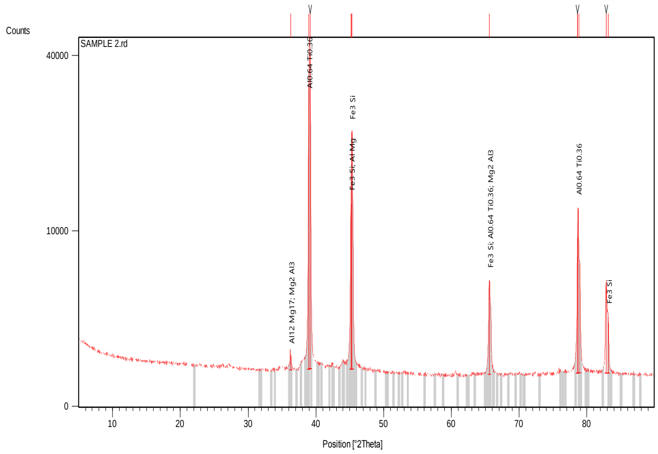

Figure 7: X-ray diffraction pattern of Al-Si-Mg alloy reinforced with 15wt%HEBSSA of paricle size 500µm and aged at 100oC for 2 hours.

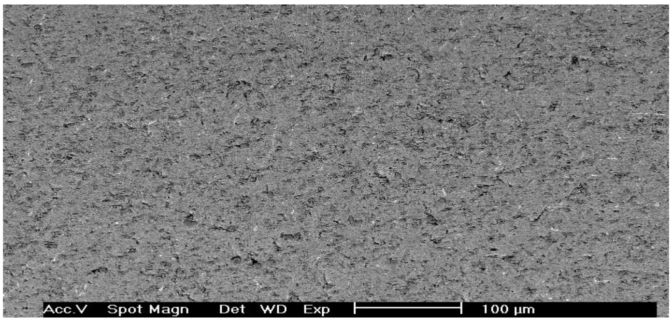

Figure 8: Scanning electron microscopy of Al-Si-Mg alloy reinforced with 5wt%HEBSSA of paricle size 300µm and aged at 100oC for 2 hours.

I, arb. units

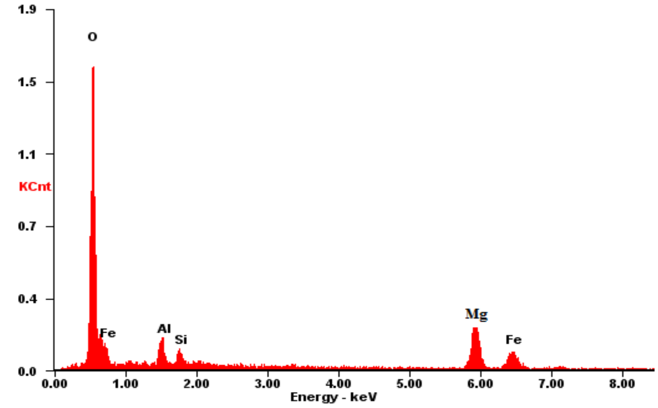

Figure 9: EDS spectrum of Al-Si-Mg alloy reinforced with 5wt%HEBSSA of paricle size 300µm and aged at 100oC for 2 hours

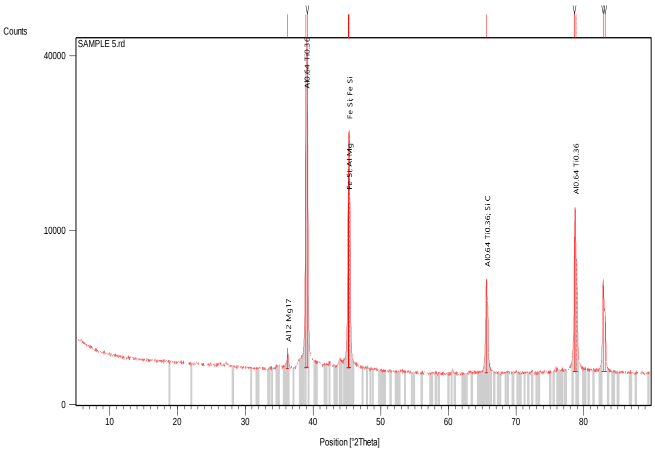

Figure 10: X-ray diffraction pattern of Al-Si-Mg alloy reinforced with 5wt%HEBSSA of paricle size 300µm and aged at 100oC for 2 hours

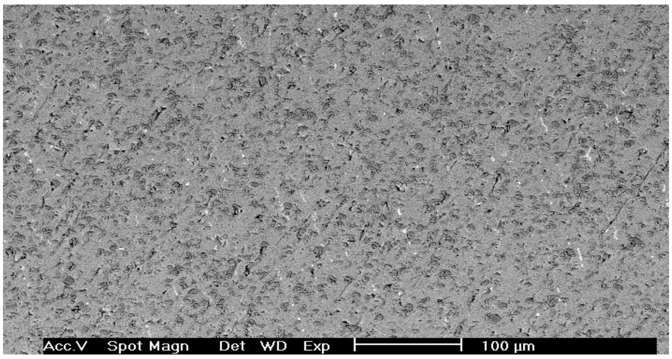

Figure 11: Scanning electron microscopy of Al-Si-Mg alloy reinforced with 5wt%HEBSSA of paricle size 500µm and aged at 300oC for 2 hours.

Figures 2-11 show the scanning electron microscopy, energy dispersive spectroscopy and X-ray diffraction pattern analysis of horse eye bean seed shell ash and the developed composites. Figure 1 indicated relatively smooth surface with a number of cracks, defects and some damage on the fiber surface. The scanning electron microscopy analysis of the control specimen revealed polyhedral-shaped primary silicon particles and needle-like precipitate of intermetallic compounds in the alloy matrix. The elemental analysis (EDS) and X-ray diffraction pattern of the control specimen indicated the presence of Al, Mg and Si and seven major phases such as: Si, Mg, Mg2Al3, Al4Si, Al12Mg17, Mg2Si and Al0.58Mg0.42 with maximum distribution of Mg2Al3 phase. More refined intermetallic compound was revealed in the composite containing 15wt%HEBSSA of paricle size 500µm and aged at 100oC for 2 hours. The X-ray diffraction pattern of the composite revealed the presence of phases such as Suessite (Fe3Si), Al0.64Ti0.36, Al12Mg17, Mg2Al3 and AlMg evenly distributed in the aluminium alloy matrix. The scanning electron and EDS analysis of the composite containing 5wt%HEBSSA of paricle size 300µm and aged at 100oC for 2 hours indicated fine particles of intermetallic compound evenly distributed in the composite structure with increased percentage of non-metallic inclusion of O and other minor elements such as Al, Si and Mg. The X-ray diffraction pattern of the composite indicated the presence of precipitate of intermetallic compounds such aluminium titanium (Al0.64Ti0.36), aluminium magnesium (Al12Mg17), carbon iron silicon (C0.12 Fe0.79 Si0.09), spinel (MgAl2O4), hongquiite (TiC), FeSi, SiC and AlMg. The EDS spectrum of Al-Si-Mg alloy reinforced with 5wt%HEBSSA of paricle size 500µm and aged at 300oC for 2 hours indicated the presence of maximum percentage of aluminium elements with minor quantity of six other elements such as C, O, K, Fe, Ti, Mg and Si.

Mechanical properties of the developed composite

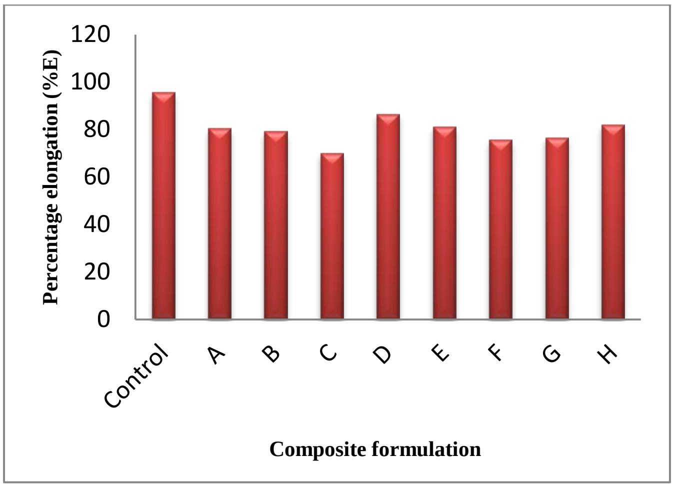

Figure 12: Percentage elongation of the developed composite

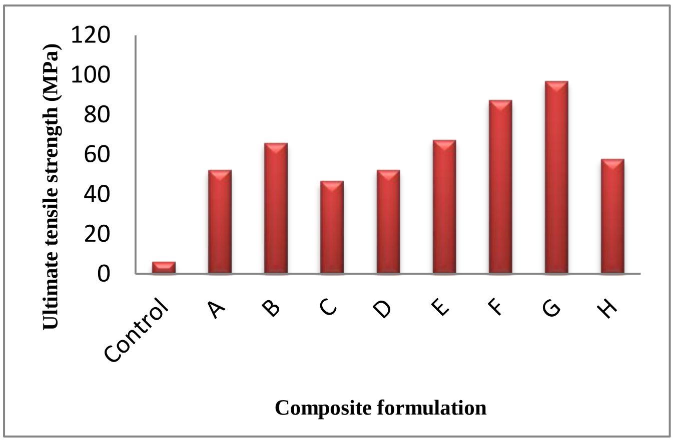

Figure 13: Ultimate tensile strength of the developed composite

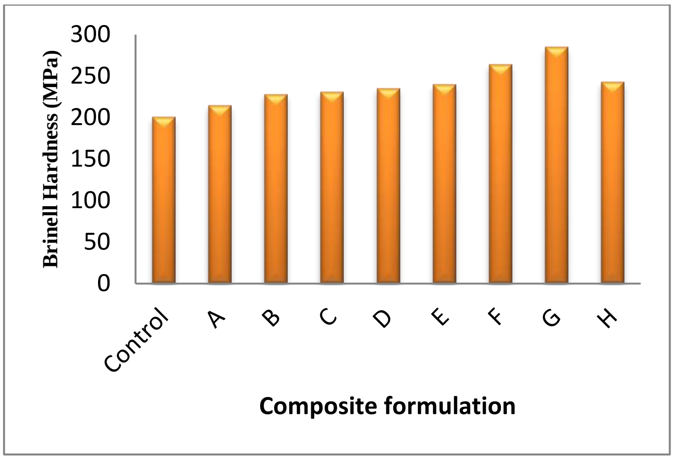

Figure 14: Brinell hardness of the developed composite

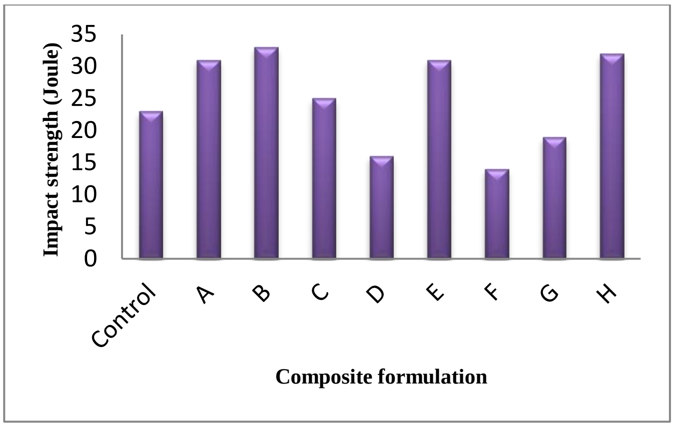

Figure 15: Impact energy of the developed composite

The effects of reinforcement concentration, particle size, ageing temperature and time on the percentage elongation, ultimate tensile strength, Brinell hardness and impact strength of aluminium alloy matrix composites are presented in Figures 12-15. Analysis of Figures 13-15 shows clearly that addition of horse eye bean seed shell ash significantly improved the ultimate tensile strength, hardness and impact strength of the developed composite. It was noted in Figure 12 that the percentage elongation decreased with increase in reinforcement composition by weight and ageing temperature. Figures 13 and 14 indicated an increase in ultimate tensile strength and hardness with decrease in reinforcement particle size and increase in percentage by weight of reinforcement and ageing temperature. Maximum ultimate tensile strength was obtained by the composite containing 5% by weight of reinforcement (500µm), aged at 300oC for 2 hrs. This can be attributed to the presence of presence of fine intermetallic compounds such as aluminium iron silicon ($Al_{0.3}Fe_3Si_{0.7}$), iron carbide ($Fe_4C_{0.63}$), carbon (C), spinel ($MgAl_2O_4$), aluminium silicon ($Al_{3.21}Si_{0.47}$) and high quartz (SiO_2) in the composite structure. Maximum Brinell hardness was obtained by the composite containing 5% by weight of reinforcement (300µm), aged at 100oC for 2 hrs. This can be attributed to the presence of precipitate of intermetallic compounds such as aluminium titanium ($Al_{0.64}Ti_{0.36}$), aluminium magnesium ($Al_{12}Mg_{17}$), carbon iron silicon ($C_{0.12}Fe_{0.79}Si_{0.09}$), spinel ($MgAl_2O_4$), hongquiite (TiC), FeSi, SiC and AlMg evenly distributed in the aluminium matrix. Optimum impact strength was obtained by the composite containing 15% by weight of reinforcement (500µm) and aged at 100oC for 2 hrs. This could be attributed to the presence of elemental carbon and phases such suessite (Fe_3Si), $Al_{0.64}Ti_{0.36}$,

$Al_{12}Mg_{17}$, Mg_2Al_3 and AlMg evenly distributed in the aluminium alloy matrix.

III. CONCLUSION

A detailed study of the structure and mechanical behaviour of horse eye bean seed shell ash reinforced aluminium alloy matrix composite has been carried out. The following conclusions were drawn from the results of the study:

1. Addition of horse eye bean seed shell ash significantly improved the ultimate tensile strength, hardness and impact strength of aluminium alloy.
2. The ultimate tensile strength and hardness increased with decrease in reinforcement particle size and increase in percentage by weight of reinforcement and ageing temperature.
3. Maximum ultimate tensile strength was obtained by the composite containing 5% by weight of reinforcement (500μm), aged at 300oC for 2 hrs. This was attributed to the fine intermetallic phases dispersed in the aluminium matrix.
4. Maximum hardness was obtained by the composite containing 5% by weight of reinforcement (300μm), aged at 100oC for 2 hrs. This was linked with the presence of $Al_{0.64}Ti_{0.36}$, $Al_{12}Mg_{17}$, $C_{0.12}$ $Fe_{0.79}$ $Si_{0.09}$, $MgAl_2O_4$, TiC, FeSi, SiC and AlMg evenly distributed in the aluminium matrix.
5. Optimum impact strength was obtained by the composite containing 15% by weight of reinforcement (500μm) and aged at 100oC for 2 hrs.

IV. ACKNOWLEDGEMENT

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V. REFERENCES

[1] Mohanty AK, Misra M, Drzal LT. Sustainable bio-composites from renewable resources: opportunity and challenges in the green materials world. J Polym Environ, vol. 10, pp. 19-26.

[2] Vishnu Prasada, Ajil Joya, G. Venkatachalama , S. Narayanana and S. Rajakumarb (2014) Finite Element Analysis of Jute and Banana Fibre Reinforced Hybrid Polymer Matrix Composite and Optimization of Design Parameters using ANOVA Technique. Procedia Engineering, vol. 97, pp. 1116-1125.

[3] Sarki, J., Hassana, S.B., Aigbodiona, V.S. and J.E. Oghenevwetaa, (2011) Potential of using coconut shell particle fillers in eco-composite materials. Journal of Alloys and Compounds, vol. 509, pp. 2381–2385.

[4] Tuleun C.D, Carew S.N, Patrick J.A (2008). Fruit characteristics and chemical composition of some varieties of velvet beans (Mucuna spp) found in Benue State of Nigeria. Livestock Res. Rural Dev., pp. 20: 10.

[5] Nwosu J. (2011) The Effect of Storage Condition on the Rheological/Functional Properties of Soup Thickner Mucuna sloanei (Ukpo). Res., vol. 3, pp. 6.

[6] Andrzej K. Bledzki, Abdullah A. Mamun, Jurgen Volk. (2010) Barley Husk and Coconut Shell Reinforced Polypropylene Composites: The Effect of Fiber Physical, Chemical and Surface Properties, Composites Science and Technology, vol. 70, pp. 840-846.

[7] Omole S. O., Akinfolarin J. F. O. and Raymond T. (2014) Assessment of Hardness and Tensile Properties of Stir-Cast Aluminium Matrix Reinforced with Tetracarpidium Conophorum Kernel. International Journal of Engineering and Applied Sciences. Vol. 4, No. 10, page: 19-22.

[8] Oghenevweta J. E., Aigbodion V. S., Nyior G. B. and Asuke F. (2016) Mechanical properties and microstructural analysis of Al–Si–Mg/carbonized maize stalk waste particulate composites. Journal of King Saud University- Engineering Sciences. 28 (2): 222–229.

[9] Maleque M.A., Atiqah A., Talib R.J. and Zahurin H. (2012) New Natural Fibre Reinforced Aluminium Composite for Automotive Brake Pad. International Journal of Mechanical and Materials Engineering (IJMME), 7 (2): 166-170.

[10] Zamri Y. B., Shamsul J. B. and Amin M. M. (2011) Potential of Palm Oil Clinker as Reinforcement in Aluminium Matrix Composites for Tribological Applications. International Journal of Mechanical and Materials Engineering (IJMME), 6 (1): 10-17.

[11] Alaneme K. K., Ademilua B. O. and Bodunrin M.O. (2013) Mechanical Properties and Corrosion Behaviour of Aluminium Hybrid Composites Reinforced with Silicon Carbide and Bamboo Leaf Ash. Tribology in Industry, 35(1): 25-35.