EFFECTS OF REINFORCEMENT PARTICLE SIZES ON MECHANICAL PROPERTIES OF ALUMINIUM/EGG SHELL COMPOSITES

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ABSTRACT

The 100 and 150 µm sized $CaCO_3$ particles (sourced from eggshells) from 2-12 wt.% by were used as reinforcements for the fabrication of Al ceramics composites using compo cast technique. The technique involves manual stirring of Al alloy melt-$CaCO_3$ particle mixture prior to pouring process. The morphology of the $CaCO_3$ particles and Al alloy/$CaCO_3$ composites were examined using scanning electron microscope (SEM). The mechanical properties of the fabricated Al alloy / $CaCO_3$ composites were investigated. The result obtained from SEM analysis revealed that the microstructures of Al alloy/100 µm $CaCO_3$ composites are finer than those of their counterparts. This justifies better interaction of 100 µm with Al alloy than 150 µm $CaCO_3$ particles which may be attributable to particle diffusion enhancement due to a decrease in the particle size. Al alloy/100 µm $CaCO_3$ composites displayed higher tensile strain than Al alloy/150 µm $CaCO_3$ composites. Hence the use of 100 µm sized egg shell particles for reinforcement has experimental proven advantages over 150 µm sized $CaCO_3$ particles.

Keywords: Aluminium; composite; particle; mechanical properties; diffusion

INTRODUCTION

Composites contain at least two components, one being the continuous phase (matrix) and the other(s), the discontinuous phase (s) known as reinforcement. They possess superior properties to each of its components when used alone. Composites are used in many applications ranging from domestic to industrial products because of their excellent and enhanced mechanical properties. The reinforcement in a matrix can be fibres or particles; hence the name fiber reinforced and particle reinforced composites. Fiber reinforced composites have been used in many applications. However, the difficulty in their methods of production and their anisotropic properties are major set-backs. Globally, many researches are now focusing on particle reinforced composite development in order to have replacement for anisotropic fiber reinforced composites. Report from literatures (Agunsoye *et al.*, 2015; Agunsoye *et al.*, 2016; Agunsoye *et al.*, 2015; Agunsoye *et al.*, 2014; Agunsoye *et al.*, 2014; Aigbodion *et al.*, 2012; Aigbodion *et al.*, 2010; Aigbodion *et al.*, 2010; Bello *et al.*, 2015; Hassan and Aigbodion, 2015) have shown that incorporation of particulate reinforcements in a matrix leads to improvement in strength, hardness and rigidity of the developed composites. Moreover, such enhancements in mechanical properties of particulate reinforced composites rely on wt.% or vol.% of the particulate reinforcement and their particle sizes.

Aluminium is an important non-ferrous metal among its counterparts because of its light weight, corrosion resistance, high ductility and ease of formability. However, its relatively low strength has put limit to its application. Constraint of low strength and hardness on aluminium and or its alloy can be overcome and their usages may be extended beyond low strength applications. This can be achieved either through alloying or incorporation of fillers for development of aluminium based alloy or metal matrix composites. High specific strength of aluminium metal matrix composites is attributable to their vast use in aerospace and automobile industries. Moreover, aluminium has been sourced primarily from bauxites. High energy consumption and the release of huge amount of CO_2 which accounted for 1 % of green-house gas have been linked to primary route for aluminium production (Zacune, 2000). Recycling of waste aluminium products will not only reduce power consumption but also lower environmental menaces associated with primary production of aluminium from bauxites.

Egg shells are naturally occurring structural composites which form an embryonic chamber for the developing chicks. It provides protection for egg yolk against mechanical damage and contamination (Hunton, 2005). Eggshells contain 95 % calcium carbonate in form of calcite and 5% organic matters that include polysaccharides, protein and collagens (Dhaliwal *et al.*, 2013; Hunton, 2005). Improper disposal of eggshells in the dump usually turns the ground into unpleasant smelling site. This has a high potential of health risk through disease outbreak (cholera) which is ranked as the worst environmental hazard (Hunton, 2005). Therefore, processing of eggshells for the productions of useful materials such as fertilizer, animal feed and reinforcement for composite production is imperative.

Agunsoye *et al.* (2014) studied effects of cocosnucifera (coconut shell) on the mechanical and tribological properties of recycled waste aluminium can composites. Experimental results revealed that tensile strength and wear resistance of the composites increased as volume fractions of coconut shell increased whereas there is light reduction in impact energy absorbed by the composites. Also aluminium cans reinforced with 10% volume fraction of coconut shell particles at finest size used (50 µm) displayed the highest tensile strength and optimum wear resistance. Agunsoye *et al.* (2015) studied the recycled waste aluminium can/egg shell composites, their results revealed enhancement in strength and wear resistance with increment in wt% of eggshell particle additions.

In this present work, aluminium alloy have been reinforced independently with 100 and 150 µm $CaCO_3$ particles from 2 to 12 wt.%. The aim of this work is to evaluate and compare the effects of 100 and 150 µm $CaCO_3$ particles on mechanical properties of the recycled aluminium alloy.

MATERIALS

Disposed aluminium cans were used as a source of Al alloy in this work. The cans were obtained from Waste Management Centre, University of Lagos, Nigeria while $CaCO_3$ were obtained at Jaja Hall Fast Food Centre, University of Lagos, Nigeria. Equipment used includes oil-fired pit furnace, die cavity metallic moulds, scanning electron microscope (SEM), Universal Testing Machine and Vicker hardness tester.

METHODOLOGY

Egg shells were rinsed in water to remove membranes, sundried and then pulverised to obtain egg shell particles using a ball mill. The egg shell particles (ESp) were sieved into different mesh sizes (75, 100 150, 212, 300 and 600 µm). Morphologies of 100 and 150 µm sized $CaCO_3$ (egg shell) particles were examined using SEM, ASPEX 3020.
The aluminium cans were melted at 670 ± 5^0C using a crucible furnace and cast into bars using a die cavity mould. This represented Al alloy without addition of $CaCO_3$ particles. Then, the melt of Al alloy was reinforced with 100 and 150 µm $CaCO_3$ particles (ESp). The wt.% of Eps addition to Al alloy increased from 2 to 12 % at 2 % interval. Al alloy/Eps mixtures were manually stirred prior to pouring into the mould. The cast bars were shaped into standard sizes for mechanical property test analyses. The chemical composition of the control Al alloy was determined using Hilger Analytical Direct Optical Light Emission Polyvac Spectrometer, Model E980C.

Morphology and phase identification of the produced Al alloy/Eps composites were examined using scanning electron microscope (SEM), ASPEX 3020 with attached energy dispersive X-ray spectrometer (EDX) located in the Department of Materials Science and Engineering, Kwara State University, Malete.

Samples of initial 80 mm gauge length and diameter 6 mm respectively were subjected to tensile test using Instron tensile machine. The samples were subjected to axial load at both ends. They were stressed at a strain rate of 10^{-3} s^{-1} to fracture. The impact energy absorbed by 55 x 10 x 100 mm^3 notched samples of the Al alloy/ESp composites were determined using Avery Denison Universal Impact Testing Machine. The samples were struck with pendulum hammer of 300 J released from the upper position corresponding to Charpy impact test. The hardness values were determined using square based pyramid indenter by Vickers' hardness approach.

RESULTS AND DISCUSSION

CHEMICAL COMPOSITION OF ALUMINIUM ALLOY

The percentage composition of elements present in Al alloy used as the matrix for the composite production is presented in Table 1.

Table 1: % composition of Al alloy

Element	Al	Si	Fe	Cu	Mn	Mg	Ti
%	99.10	0.33	0.21	0.03	0.27	0.02	0.04

SCANNING ELECTRON MICROGRAPHS

The scanning electron micrographs (SEM) of the $CaCO_3$ particles are presented in Fig 1a-b. EDX chemical analysis revealed the presence of Ca with the highest count score followed by O. Other elements found in the Eps are Mg and C but their intensities are very low. The presence of Ca and O are attributable to calcite which is the major component of the $CaCO_3$ (Hassan and Aigbodion, 2015).

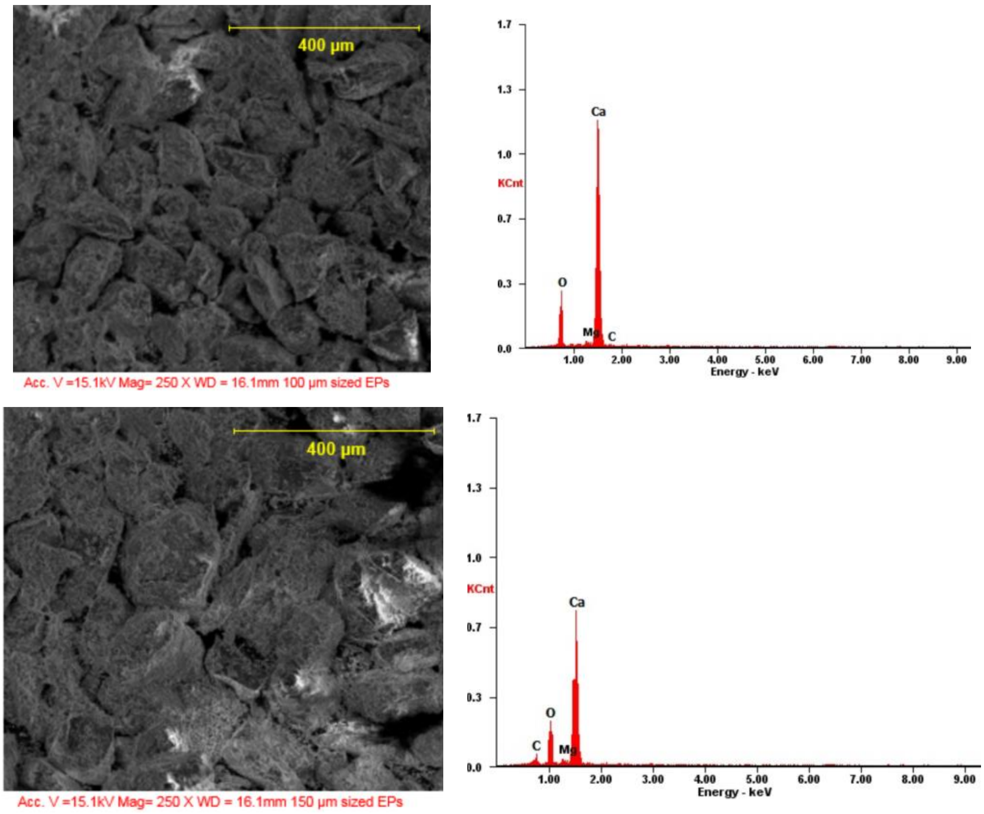
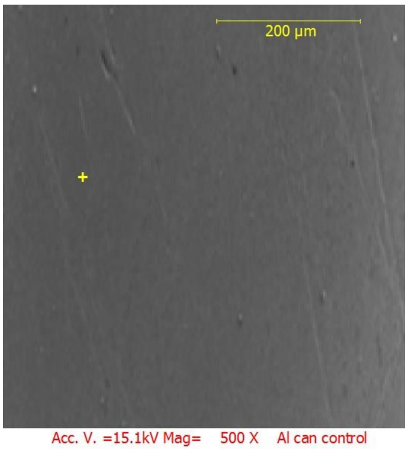


Fig 1: SEM/EDX of the $CaCO_3$ particles (a) 100 µm; (b) 150 µm

Fig 2 shows the SEM/EDX of the control cast of Al alloy. It is very homogenous and there is no presence of any second phase particles. EDX analysis indicated the presence of Al with maximum peak. Other peaks around the Al peak, which are minor indicate the presence of trace elements having very low count score. This agrees with chemical analysis in Table 1.

Figs 3-6 present the morphology and chemical composition of the produced Al alloy/Eps composites. It is observed from Figs 3-6 that the Eps dispersed evenly within the Al alloy matrix and there is a good interfacial adhesion between the matrix and reinforcement. However, grain structures of Al alloy/100 µm sized Eps composites are finer than those of their counterparts. This is an indication of better mechanical properties of the Al alloy/100 µm sized composites. The difference in chemical analysis of the composites from control Al alloy cast is attributable to Eps additions to the Al alloy. This confirmed the retention of Eps within the Al alloy matrix. Although, there might be decomposition of calcite and $MgCO_3$ on addition of Eps to the melt of Al alloy, presence of Ca, Mg and O within the Al alloy matrix is an indication of residual products such as CaO and MgO. This is in agreement with Hunton (2005). Both Ca and Mg oxides are refractory and have tendency of enhancing the strength of Al alloy.



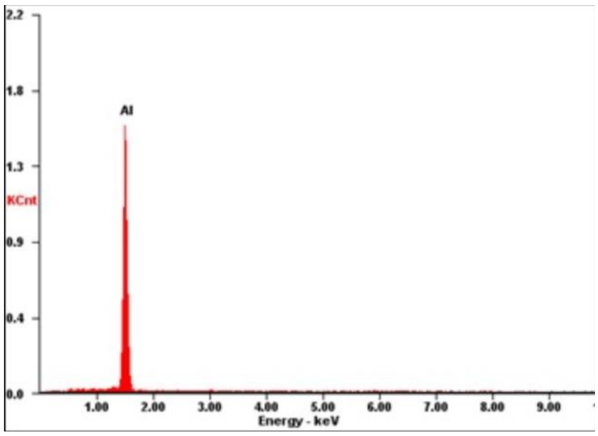


Fig 2: SEM/EDX of Al alloy (control)

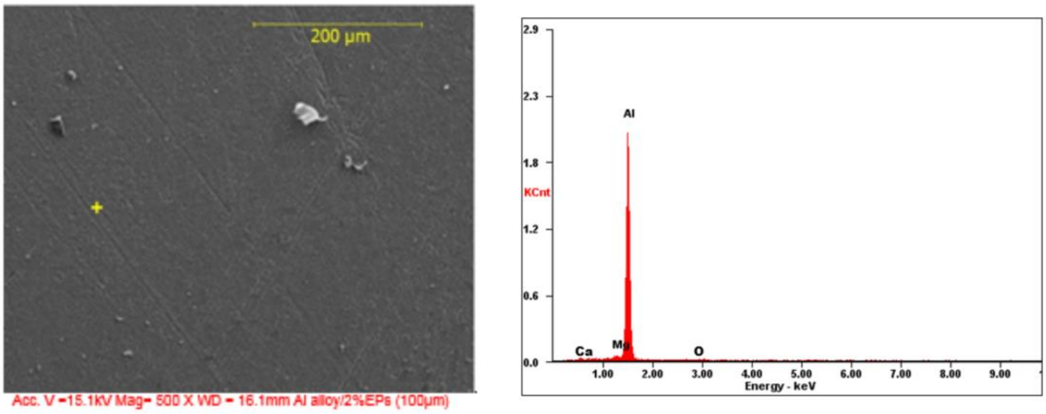


Fig 3: SEM/EDX of Al alloy/2% ESp (100µm) composites

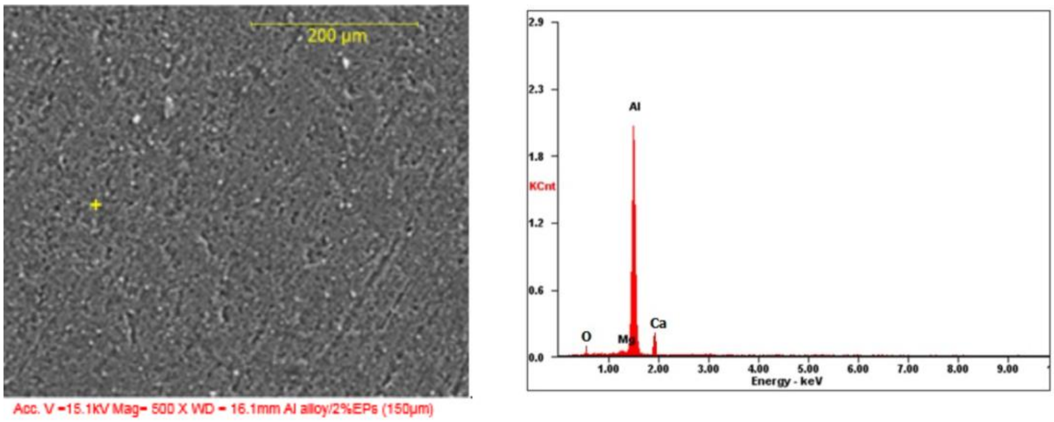


Fig 4: SEM/EDX of Al alloy/2% ESp (150µm) composites

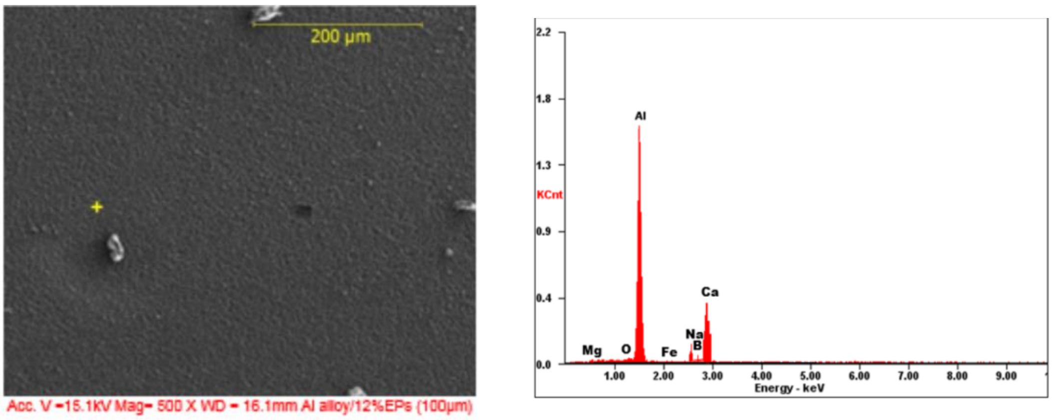


Fig 5: SEM/EDX of Al alloy/12% ESp (100µm) composites

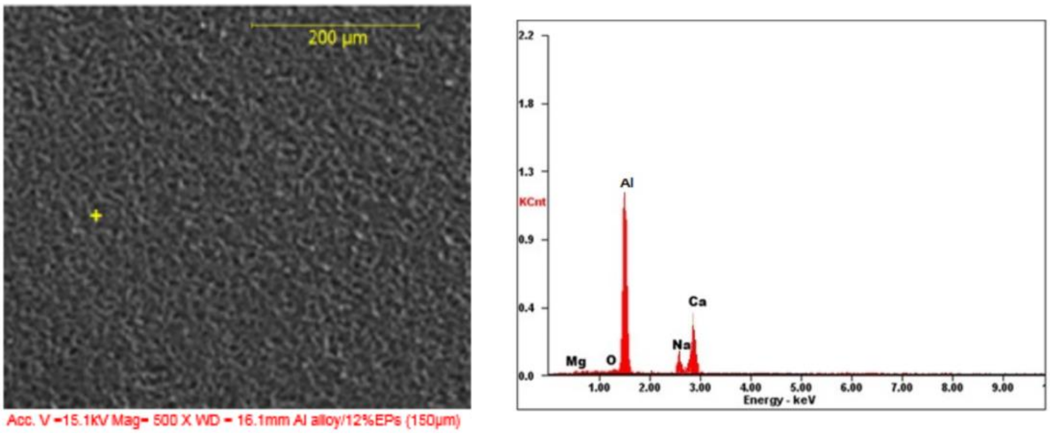


Fig 6: SEM/EDX of Al alloy/12% ESp (150µm) composites

Mechanical properties

It is observed from Figs 7-8 that the tensile stress at break and hardness values of the produced composites increased with increment in wt. % of egg shell particles additions. The marginal strength and hardness increment observed with Al alloy/100 µm Eps than those of Al alloy/100 µm Eps are attributable to influence of grain structures of the Al alloy/100 µm Eps composites (see Figs 3-6). The increment can be attributable to good interfacial bonding between the matrix and the reinforcement. The presence of refractory phase particles formed by Ca, Mg, O and Fe within Al alloy matrix is also responsible for enhancement both in tensile strength at break and hardness of the produced Al alloy/Eps composites. Finer grains, increase the number of grain boundaries and this increases the hindrance to dislocations movement (William, 2007). Figs 9-10 revealed a decrease both in tensile strain at break and impact energy of the produced Al alloy/Eps composites. This is attributed to brittle refractory filler phase particles within the Al alloy matrix (Peters, 1998). However, a slightly higher hardness and noticeable greater tensile strain of Al alloy reinforced with 100µm sized ESp can be linked to finer grain structure of the composites (see Figs 3 and 5). This is in line with literatures (Hassan and Aigbodion, 2015; Sharma *et al.*, 2015). Hence, the use of 100 µm Eps for Al alloy reinforcement proffers better enhancement in the mechanical properties such as hardness, tensile strain and impact energy (see Figs 8-10) than those of 150 µm Eps.

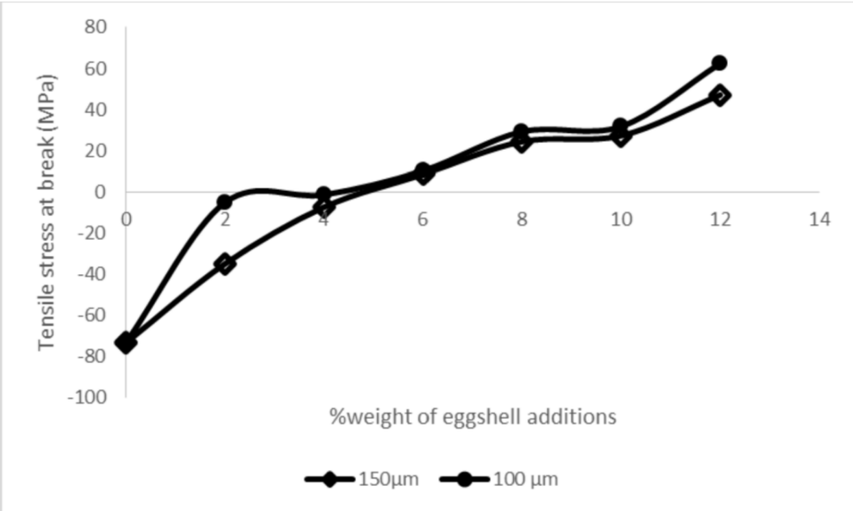


Fig 7: Fracture stress of Al alloy/ESp composites with wt. % of EPs additions

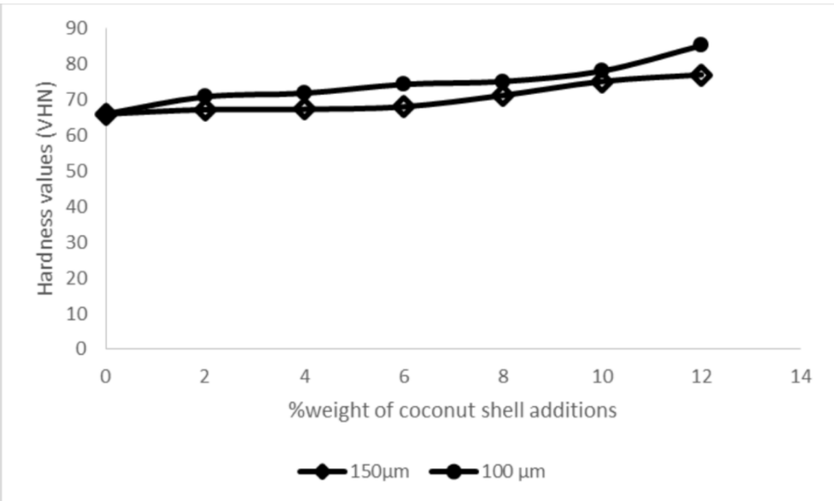


Fig 8: Hardness values of Al alloy/ESp composites with wt. % of EPs additions

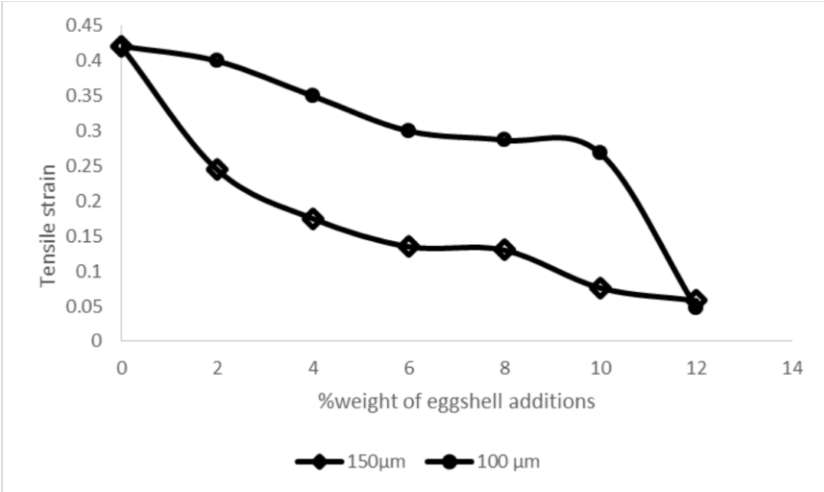


Fig 9: Tensile strain of Al alloy/ESp composites with wt. % of EPs additions

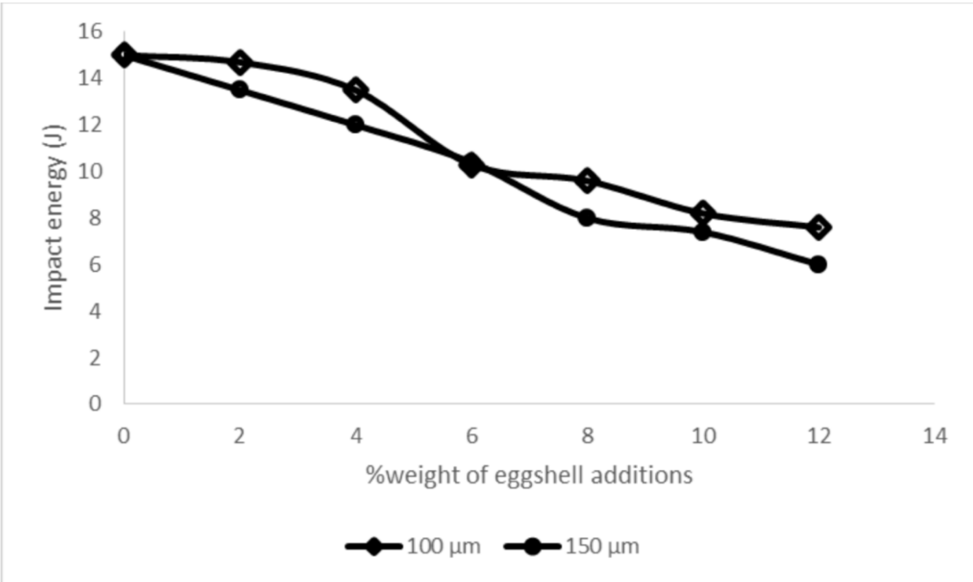


Fig 10: Impact of Al alloy/ESp composites with wt. % of ESp additions

CONCLUSIONS

From results of this research work the following conclusions can be made:

1. Fracture stress and hardness of the produced Al alloy/ESp composites increased with increment in wt. % of ESp additions.
2. There was a decrease in impact energy and tensile strain of the developed Al alloy/ESp composites as the wt.% of Eps addition increased (see Figs 9-10).

3. Al alloy/100 µm sized Eps composites displayed higher tensile strain than Al alloy/150 µm sized ESp composites.
4. Hardness of Al alloy/100 µm sized ESp composites is slightly higher than that of Al alloy/150 µm sized ESp composites.
5. Both Al alloy/100 µm sized Eps and Al alloy/150 µm sized ESp composites have comparable tensile strength.
6. Better properties of Al alloy/100 µm sized ESp composites is attributable to finer grain structure of the Al alloy/100 µm sized ESp composites.
7. Useful metal matrix composites for application requiring moderate strength and hardness have been achieved.
8. Future utilization of the developed Al alloy/ESp composites will reduce amount of egg shells dump and lower if not completely eliminate, problems associated with improper disposal of the egg shells (agro wastes).

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