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Fabrication and Mechanical Testing of Egg Shell Particles Reinforced Al-Si Composites

Anjali, Razia Malik, Shivani Bhandari, Ankur Pant, Arpit Saxena, Seema, Nitin Kumar, Nikhil Chotrani, Dheeraj Gunwant*, P. L. Sah

Department of Mechanical Engineering
Govind Ballabh Pant University of Agriculture & Technology, Pantnagar-263145, Uttarakhand, India
**Corresponding author*: mailto.dheerajgunwant@gmail.com

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Abstract
The production of chicken eggs on a widespread industrial level has led to the generation of a large amount of egg shells. These egg shells are considered to be bio-hazardous waste materials although they are a rich source of amino acids and minerals. In the present investigation, effort has been made to incorporate waste poultry egg shell particles (ESP) both in carbonized (C) as well as uncarbonized (UC) form into the matrix of an Aluminum-Silicon (Al-Si) alloy to improve its mechanical properties. Various mechanical properties of the resulting composites such as tensile strength, modulus of elasticity, hardness, toughness, impact and compressive strengths have been determined and found to increase after the addition of the ESPs confirming that the incorporation of waste ESPs in the Al-Si matrix serve as reinforcements. The increase in mechanical properties such as the hardness (10.2% - UC, 19% - C), tensile (6.61% - UC, 10.61% - C), compressive (9.12% - UC, 63.94% - C) and impact strengths (30.07% - UC, 302.35% - C) is more pronounced in the case of carbonized ESPs. Field-Emission Scanning Electron Microscopy (FE-SEM) has been conducted to determine the compositions of the matrix materials as well as the composites.

Keywords: Egg shell, Metal matrix composites, Chemical and physical properties

1. Introduction

The need of materials with optimum properties and cost for various engineering applications has paced research in area of metal matrix composites for the past three decades. Aluminium, both in pure and alloy form is a suitable material for many engineering and industrial applications. Thus, the physical, chemical and mechanical properties of aluminium have fascinated researchers to explore its potential. In aluminium matrix composites, the extensively used reinforcement is in particulate form and is widely employed in automotive and aerospace industries (Surappa, 2003).

Poultry is an influential sector in agriculture in India and has an average growth rate of 6% in egg production per annum (Karthikeyan and Nedunchezhian, 2013). The poultry population of India is 489 million that produces 47 billion eggs per year and ranks third highest among egg producing countries in the world (Anon., 2009). Thus egg shell may be utilized as a biodegradable waste as a low cost material for reinforcement in the matrix and it may be utilized as a low cost reinforcement in the matrix for composites (Yasothai and Kavithaa, 2014).

Paul et al. (2013) evaluated the possibility of egg shell as a rich source of calcium carbonate that can be utilized as enhancer in carburization of mild steel. They studied hardness values of mild steel after it was carburized with various wastes at 920°C for 5 hours. The hardness values remarkably increased when egg shells were mixed with sugar cane, melon shell waste and arecaceae flower waste.

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Hassan and Aigbodion (2015) studied the effects of eggshell particles on the microstructures and properties of Al–Cu–Mg/ES particulate composites with different weight percentage in both carbonized and uncarbonized form. It was concluded that values of hardness and tensile strength improved notably but a decreasing trend in impact energy was observed when carbonized egg shell particles were used as reinforcement. Agunsoye et al. (2015) investigated the mechanical and wear resistance properties of recycled aluminium can/egg shell composite at different weight percentage. An increase in wear resistance, hardness and yield stress was observed with increasing weight percentage of egg shells. The prospective of egg shell particles as reinforcement in aluminium matrix is yet to be inspected (Hunton, 2005). Inadequate study in this area motivates further work in development of an ecofriendly, cost effective and superior metal matrix composite for industrial and engineering applications.

2. Materials and Methods

2.1 Preparation of Egg Shell Particles

The Al-Si alloy used in the present investigation was obtained from the Department of Mechanical Engineering Department of GBPUAT, Pantnagar, India and was used without further purification. The Egg shells (Fig. 1) were collected from local households; they were then washed with demineralized water to remove any foreign objects and the thin outer membrane. The egg shells were then sun dried for duration of 48 hours. The dried egg shells were then pulverized to obtain fine powder (Fig. 2) with the help of a grain miller at 250 rpm. To obtain carbonized ESPs, the egg shells were first kept in a furnace preheated to a temperature of 1000 ℃ for a period of 1 hour and then converted to powder using the grain miller after cooling to room temperature. The obtained powder was passed through sieves of required size so as to obtain particles with uniform size distribution. The procedure is depicted diagrammatically in Fig. 3(b).

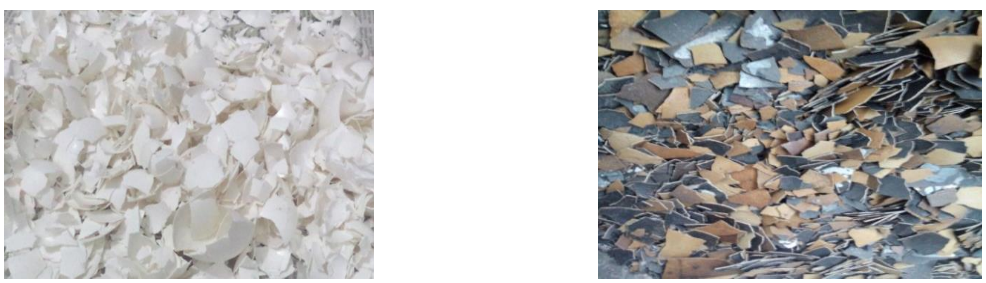


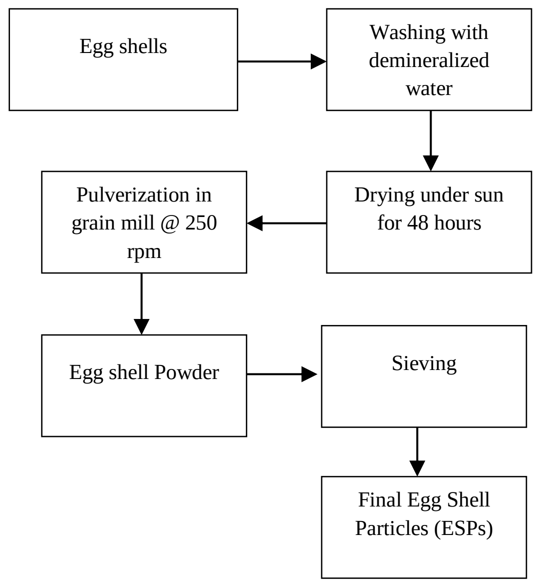
Fig.1. Uncarbonized and carbonized egg shells

Fig. 2. Uncarbonized and carbonized egg shell powder.

2.2 Preparation of Castings

The stir casting procedure was used for the fabrication of ESP-AL-Si composite as well as the control castings. Stir casting process has been so far reported to be the most viable option of fabricating Metal Matrix Composites (MMCs). Its simplicity and applicability for large scale industrial production has superseded other fabrication options such as powder metallurgy, infiltration techniques and squeeze casting etc.

Required amount of Al-Si alloy is kept in an electric furnace (Fig. 3(a)) preheated to a red hot condition and subsequently the temperature of the furnace is increased to a temperature of 750℃. The ESPs in both carbonized and uncarbonized form (10wt %) were added to molten metal. Prior to this, magnesium powder (2%) was added to the molten metal to improve wettability of the metal by increasing its surface energy, reducing the surface tension and reducing the matrix-reinforcement interface energy. During the addition of magnesium, the mixture was continuously stirred at 350-500 rpm. The mixture is stirred for further 5 minutes to ensure homogenous mixture. The mixture was then poured into sand moulds and allowed to solidify to obtain sound castings. Control castings were also fabricated in similar manner.



(a) (b)

Fig.3. (a) Electric furnace and (b) Process flow diagram

Specimens for various mechanical tests were subsequently machined from the resulting castings according to the ASTM standards or machine specifications. Three specimens for each type of test were prepared to account for the statistical analysis.

2.3 Mechanical and FE-SEM Testing

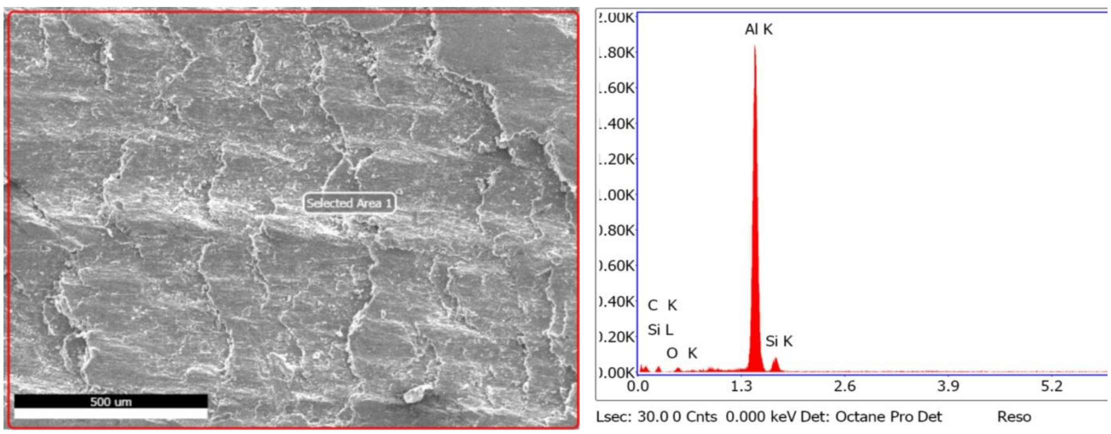
Tension and compression tests were conducted on 25 KN servo hydraulic UTM machine (model 2008, ADMET, made) according to ASTM E8 and E9 respectively. Izod impact tests were conducted according to ASTM E23 and hardness tests were performed according to ASTM E18 with a digital Rockwell hardness testing machine on H scale.

Study of morphology chemical composition of the control sample and the two composites was done using FE-SEM QUANTA 200 FEG.

3. Results and Discussion

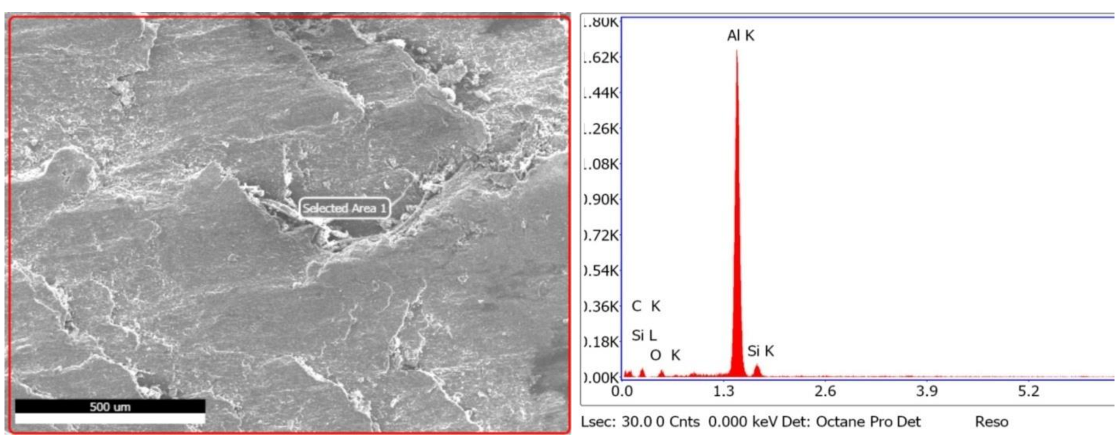
3.1 Morphology and Chemical Composition

The FE-SEM analysis of Al-Si alloy reveals chemical presence of aluminium, silicon, oxygen and carbon (Fig. 4, 5, 6). The results of Al-Si/UC-ES composite show increase in the oxygen and carbon content. This increase may be due to possible chemical reaction between the composition of egg shell powder and the Al-Si matrix. The carbon and oxygen contents are further increased by the use of carbonized egg shell powder.



(a) (b)

Fig. 4.(a) FE-SEM analysis of Al-Si alloy and (b) EDX spectra of Al-Si alloy



(a) (b)

Fig. 5(a) FE-SEM analysis 10% by weight of uncarbonized egg shell powder with Al-Si alloy and (b) EDX spectra for composite

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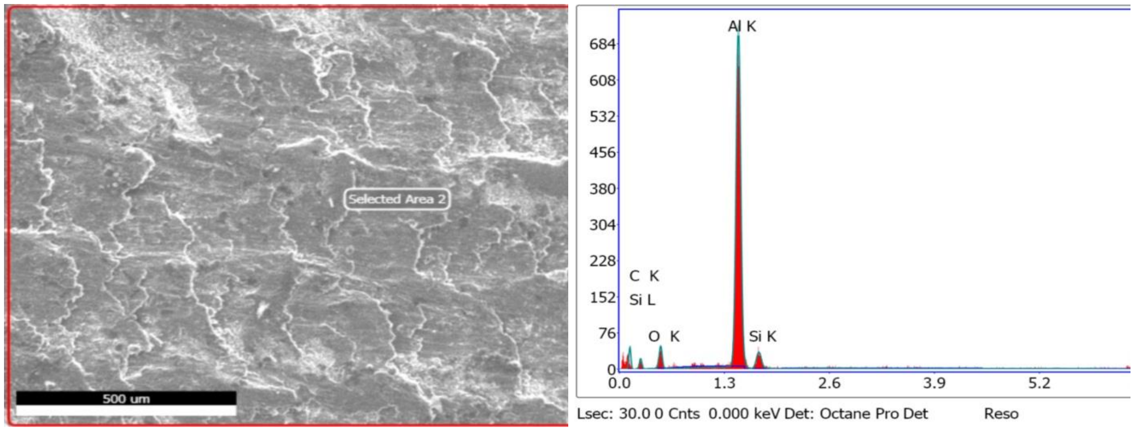

(a) (b)

Fig. 6. (a) FE-SEM analysis 10% by weight of carbonized egg shell powder with Al-Si alloy and (b) EDX spectra of composite

3.2 Hardness Test

The Rockwell hardness test is generally employed to obtain a quick and direct reading of hardness. Rockwell scale H with a steel ball indenter of ${}^{1}/_{16}{}''$ was used for determining the hardness of composites. Fig. 8 shows the average hardness values for Al-Si alloy, Al-Si-UC and Al-Si-C composites. The hardness value for Al-Si alloy is 85.30 HRH which has increased to 94 HRH (10.2%) in case of Al-Si-UC and 101.67 HRH (19.19%) in case of Al-Si-C composites (Fig. 7). This can be attributed to the fact that after carbonization, the ESPs become more rigid due to the removal of moisture thus enhancing the hardness of composite to a level higher than the uncarbonized one. Similar trend in hardness has been observed by other researchers also. The calcium carbonate present in the ESPs on the surface of composites act as rigid particles resisting the surface plastic deformation and resulting in an increase in the hardness values.

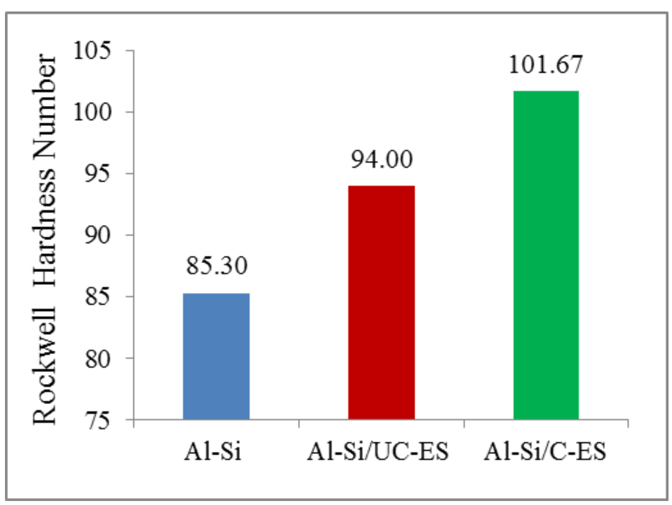

Fig. 7. Variation hardness of control sample and the two composites

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3.3 Tensile Test

The tensile test is performed to determine various mechanical properties such as tensile strength, modulus of elasticity and toughness etc. In this work, the tensile properties of the developed composites were obtained using 25 kN servo-hydraulic UTM (ADMET). The tensile test specimen before and after fracture are shown in Fig. 9 and 10 below. Results indicate that ESPs increased the tensile strength of the Al-Si matrix by 6.6% in the case of uncarbonized and 10.61% in the case of carbonized particles (Fig. 8). Addition of rigid particles to relatively ductile Al-Si matrix offer resistance to the movement of dislocations which is rather easy in case of pure metal alloy matrices due to their inherent ductile nature. Another reason for the enhancement of the tensile strength of composites may be an effective transfer of load from matrix to the ESPs. Similar enhancement in the tensile strength has been reported by other researchers also.

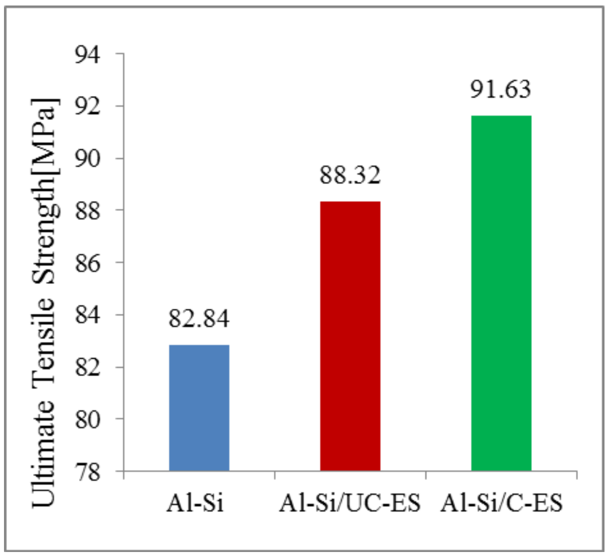

Fig. 8. Comparison of ultimate tensile strength of control sample and the two composites

There was a decrease in the modulus of elasticity values after the addition of ESPs to the Al-Si matrix. This decrease was observed to be about 4.80% below the modulus of elasticity of the pure Al-Si matrix in case of uncarbonized ESPs. Whereas the decrease was more pronounced when carbonized ESPs were added to the matrix. This decrease is obtained to be about 36.15% below the modulus of elasticity of pure Al-Si matrix (Fig. 11). The results of tensile test signify that there was a decrease in the stiffness of composites coupled to an enhancement in the tensile strength.

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Fig. 9. Tensile test specimen

Fig. 10. Tensile test specimen after testing

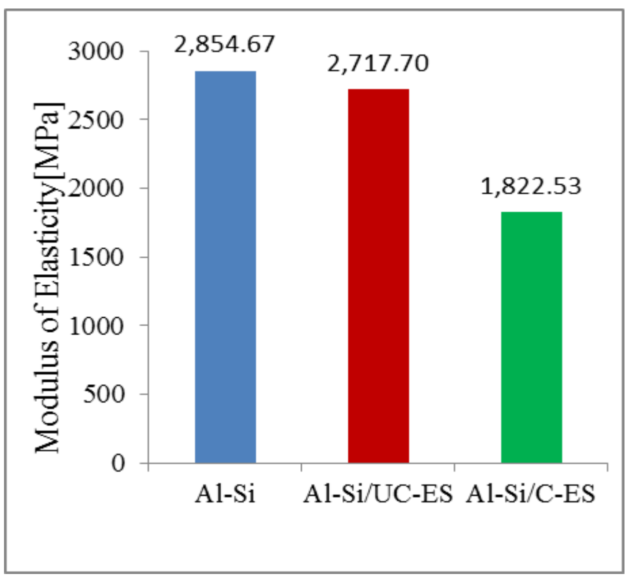

Fig. 11. Comparison of modulus of elasticity for control sample and the two composites

The toughness of any material is the area under its stress-strain curve. It is an important property of the material which has to sustain impact loads.

The toughness of the Al-Si matrix improved in the case of carbonized ESPs by 54.8%. This increase was less pronounced (30.5%) in the case of uncarbonized ESPs over the pure Al-Si matrix (Fig. 12).

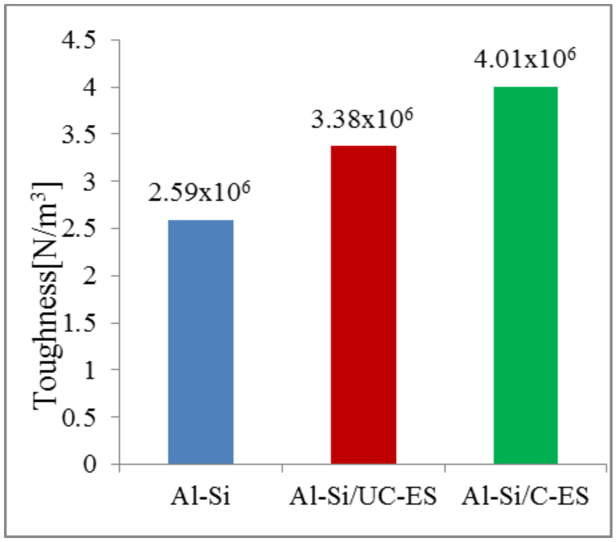

Fig. 12. Comparison of toughness for control sample and the two composites

3.4 Compression Test

Fig. 13 shows the comparison of the compressive strengths of control sample and the two composites. The compressive strength of Al-Si/UC-ES composite and Al-Si/C-ES composite increased by 9.12% and 63.94% respectively when compared with Al-Si alloy. The main reason behind It may be noted that when the composites are subjected to compressive stress, aluminium matrix around reinforcement particles flow away in the direction perpendicular to the applied load that reduces load transfer ability of the matrix and leads to material failure.

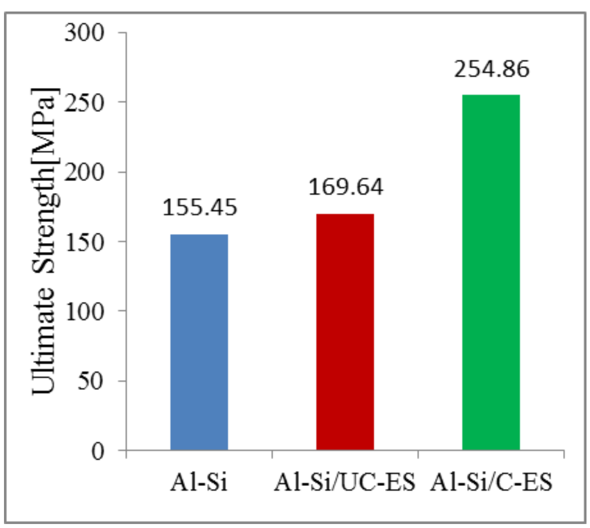

Fig. 13. Comparison of ultimate compressive strength of control sample and the two composites

3.5 Impact Test

The impact test results reveal that the impact energy of material mainly depends on the distribution of particles in matrix. As shown in the Fig. 14 below, an increase of 30.07% and 302.35% is observed when Al-Si/UC-ES and Al-Si/C-ES composites respectively are compared with Al-Si alloy. Similar results have been reported by other researchers also in the literature for Sic particles. They have concluded that the impact strength of composites improved with the increase in the weight fraction of SiC particles. Although with increase of the particle size, there was a decrease in the impact strength.

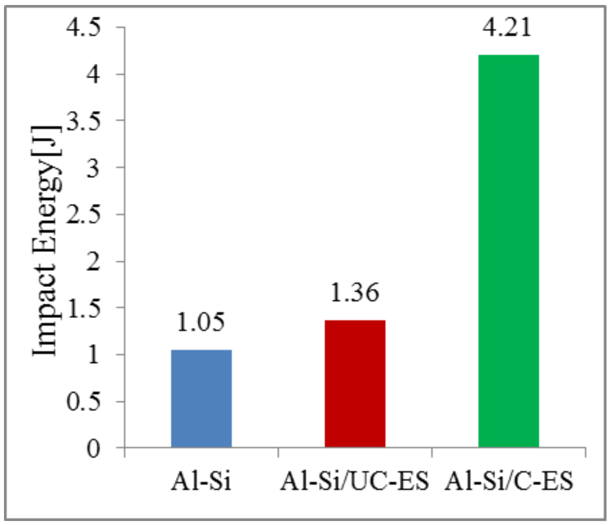

Fig. 14. Comparison of impact energy of control sample and the two composites.

4. Conclusion

The following conclusions are drawn

(a) Addition of 10% by weight of ES particles as reinforcement, both in uncarbonized and carbonized form in aluminium matrix improves the hardness, toughness, and impact energy, tensile and compressive strength of the matrix material.

(b) The value of modulus of elasticity decreased for the composites which means they are less stiff & may be used where flexibility is required.

(c) There is an increase in the impact energy absorbed by the composite with 10% loading of carbonized particles. This increase is about 4 times as compared to the pure aluminum matrix.

(d) It is observed that there is a tremendous improvement in the toughness of the material in case of carbonized ESPs again signifying an increase in the energy required for failure. These results are also reflected in the increase in the impact strength in the case of carbonized ESPs.

Acknowledgement

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