International Journal of Multidisciplinary Research in Science, Engineering and Technology (IJMRSET)

Available online: www.ijmrset.com

e-ISSN: 2394-8752, p-ISSN: 2394-8791

Volume-02, Issue-11, November 2015

An Experimental Investigation on Properties of Cenosphere Reinforced Aluminium Metal Matrix Composite

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ABSTRACT: The particle reinforced aluminium based metal matrix composites are gaining importance due to their ease in manufacturing large volumes and property advantages. Cenosphere fly ash is one of the most inexpensive and low density material which is abundantly available as solid waste by-product of coal combustion in thermal power plants. Hence the present research work was undertaken with an objective to explore the utilization of low cost cenosphere as a reinforcing material in aluminium alloy (AA) 6063. The manufacturing method adopted for producing cenosphere-AA6063 was stir-casting which was customized to suit the current study. The volume percentages of cenosphere particulate considered were 5, 10, 15 and 20 used throughout the study. The composites were tested for density, hardness, compressive strength, tensile strength and Coefficient of thermal expansion as per ASTM standards and the results were compared with base alloy.

KEYWORDS: Composites, Cenosphere, Compressive strength, Tensile strength.

I. INTRODUCTION

Cenosphere, the hollow fly ash particle with low density allows to be used in the synthesis of ultra-light composite materials. The main constituents of cenosphere are oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium and titanium. The inclusion of cenosphere in aluminium alloy reduces the quantum of aluminium consumed, thereby conserving energy and reducing the cost of aluminium products [1]. Cenospheres as filler in aluminium casting reduces cost, decreases density and increases hardness, stiffness, wear and abrasion resistance [2]. The presence of cenosphere increases the damping capacity, coefficient of friction [3,4] making them suitable in industries like automotive, aerospace, etc. They are considered as potential materials for components like pulleys, oil pans, intake manifolds and valve covers [5].

II. RELATED WORK

The material content, cost and weight decreases with the incorporation of cenosphere into aluminium castings [6]. Oxy-redox reactions between aluminium and cenosphere constituents like SiO_2, Fe_2O_3, Fe_3O_4 and mullite resulted in the formation of a thick reaction product zone [7]. Cenosphere reinforced aluminium enhances the chemical stability of aluminium-cenosphere composites during synthesis and reheating [8]. The fluidity and density of the composites decreased while the hardness increased with increase in percentage of particulates. The slurry erosive wear resistance and corrosion increased with increasing cenosphere content [9]. The results of experimental investigations carried out on the distribution of cenosphere particles in AA6063, density, hardness, compressive strength, tensile strength and coefficient of thermal expansion of the composites reinforced with cenospheres of different volume percentages are discussed in this study. Revenue could be generated out of dumped waste by using it as filler and avoiding the disposal costs [10]. The use of Aluminium-fly ash composites reduce emissions like CO_2 which otherwise come from aluminum production. In transporting the components, low weight materials consume less energy benefiting the environment [6].

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III. DETERMINATION OF DENSITY

The vital criteria, uniform distribution of reinforcing particles in the molten metal greatly depends on the density of the particles. Dense particles tend to slowly settle at the base of the bath while less dense particles remove suspended on the surface. Therefore, density analysis was performed on specimens from different segments like top, middle and bottom portion of the castings. Porosity, a casting defect, causes significant reduction in mechanical properties. Proper distribution of the particles ensures good density distribution. A simple rule of mixture helps to accurately predict the theoretical density of the composite. Actual density was calculated using the Archimedes method.

Theoretical density = (Density of AA6063 X Percentage of AA6063) +(Density of cenosphere X Percentage of cenosphere)(1)

Experimental density = (Difference between apparent weight to the weightof the sample) / (Rise in water level)(2)

Percentage of porosity = (Difference between the theoretical density andactual density) / (Theoretical density) X 100 %(3)

Cenosphere has a density 700 kg/m^3, which is lower than that of aluminium alloy (2600 kg/m^3) and hence an increase in cenosphere content will decrease the density of the composite. Density of composite specimens reinforced with cenosphere particles of different volume percentages are shown in Table 1. Table 1 indicates that cenosphere reinforcement decreases the density of the composite, thereby reducing its weight [1]. This density variation can be better understood by the difference in density between the composite and aluminium alloy. This makes the composite derived most sought after in light weight applications [11].

Table 1 Influence of cenosphere on Density and Porosity

Cenosphere volume (%)	**Density of composite (g/cm^3)**		**Porosity (%)**
	Theoretical	**Experimental**	
0	2.70	2.70	0
5	2.44	2.41	1.03
10	2.14	2.11	1.36
15	1.88	1.83	2.46
20	1.67	1.62	2.97

Table 1 clearly indicates an increase in porosity with increase in cenosphere volume. The reason is that the increase in small particles always forms a cluster in the composite and the cluster regions are porosity localized region. With increasing Mg content at higher cenosphere volume of the matrix the amount of porosity can be reduced [12].

IV. DETERMINATION OF HARDNESS

Hardness of the composite depends on the hardness of the reinforcement and the matrix. Hardness is an intensive property which leads to changes in other properties. The Brinell and Vicker's hardness tests were conducted according to ASTM E10-96 and ASTM E92-82 respectively. In the present investigation it was observed that the hardness of the composite was higher than that of the unreinforced alloy. Measurement was taken at five different points of each sample to assess its reproducibility. The variation of hardness with increase in cenosphere content in the composite is shown in Fig. 1. It is clear that the hardness increases with the increase in reinforcement percentage up to 15% and for the composite containing 20% cenosphere, the hardness decreased.

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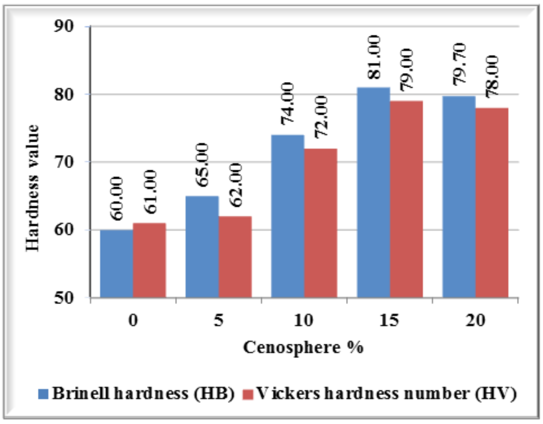

Fig. 1 Brinell and Vickers Hardness value

The hard cenosphere particles hinder the movement of dislocations within the matrix and show greater resistance to indentation thereby increasing the hardness. Beyond 15%, the slight decrease in hardness might be due to increase in porosity. Particulates that exhibited a greater resistance to indentation by the hardness tester and hence enhanced hardness which is a measure of the resistance of a material to surface indentation and is a function of the stress required to produce some specific type of surface deformation. The increased hardness was also attributed to the fact that the hard particulates act as barriers to the movement of the dislocations within the matrix [13].

V. COMPRESSION TEST

Compressive stress and strain were calculated and plotted as a stress-strain diagram which was used to determine elastic limit, proportional limit, yield strength. Compression test specimens were prepared according to the ASTM E9 standard. The compression tests were performed on a universal testing machine in a four column tool at room temperature. Total of five specimens were prepared for each volume fraction of cenosphere such as 5, 10, 15 and 20% using the stir-casting. Compression tests were conducted on the specimen fabricated and the engineering stress–strain curves were plotted during the tests. The cross head moving with a speed of 0.05 cm/min was used to apply load on the samples gradually. A chart recorder recorded the load vs. deformation values. The stress versus strain plots for specimens are displayed in Fig. 2.

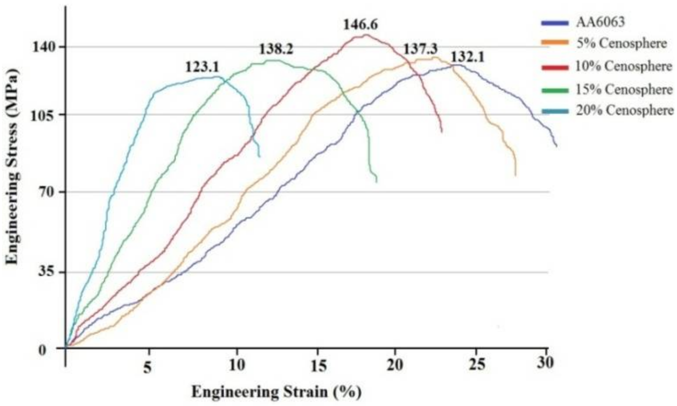

Fig. 2 Compressive Strength of Composites

Initially all the specimens showed almost linear behaviour up to a particular stress (Yield Strength) after which they deform without change in stress. Stress increases further corresponding to the additional compression of specimen until failure.

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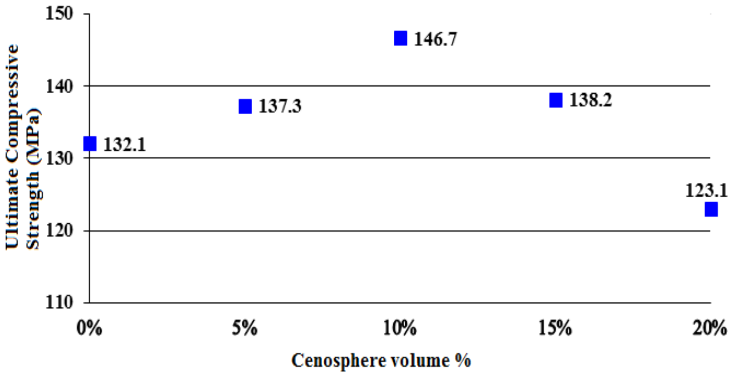

Fig. 3 Ultimate Compressive Strength of Composites

An observation of Fig. 3 which shows the influence of the volume fraction of cenosphere on the compressive strength of AA6063 reveals improved compressive strength of the composite compared to the base alloy. Increasing the volume fraction of cenosphere in the composite up to 10% was found to increase the compressive strength. Additions of 5 and 10% by volume of cenoshpere have shown to increase the compressive strength by 4 and 11% respectively.The compression modulus and the ultimate compressive strength were determined for all the specimens. The mean and standard deviation (SD) of compression test results are shown in Table 2.

Table 2 Influence of Cenosphere content on compression properties

Cenosphere volume percentage		**Yield Strength (MPa)**	**Ultimate Compressive Strength (MPa)**	**Compression (in percentage)**	**Young's Modulus (GPa)**
0	Mean	140	132.1	11	102.3
	Standard deviation	4.5	5.1	6.1	4.7
5	Mean	146	137.3	9.3	107.6
	Standard deviation	3.9	4.2	5.6	4.5
10	Mean	151	146.7	8.6	109.2
	Standard deviation	6.1	7.3	6.6	7.5
15	Mean	130	138.2	8.1	90.7
	Standard deviation	6.7	7.9	6.2	8.1
20	Mean	122	123.1	7.6	95.6
	Standard deviation	7.6	8.3	8.1	7.9

The composites containing more than 10% by volume of cenosphere were found to possess lesser compressive strength. The possibility of clustering increases with the increase in cenosphere content resulting in the degradation of the strength of composites [14]. At higher cenosphere content, the poor interfacial bonding between the cenosphereparticles and matrix material leads to decrease in compressive strength. When the composites are subjected to compressive stress, the aluminium matrix around the cenosphere particles flows away in the direction perpendicular to the applied load, which reduces the load transfer ability of the matrix [15].

VI. Tensile Test

A Universal Testing Machine (UTM) was used to conduct tensile test to determine the properties like tensile strength, yield strength and percentage elongation. The specimen for the tensile test was prepared according to the ASTM E08-8 standard. The test was carried out at room temperature. Total of five specimens were prepared for each volume fractions of cenospheres, which are, 5, 10, 15 and 20% using the stir-casting setup. The specimens were prepared and

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knurling was done at both ends for a good grip while holding in the UTM machine.The load was applied hydraulically using computer interfaced UTM. The yield and ultimate points were noted down.Stress-strain curves for all the studied composites are plotted in Fig. 5. As the reinforcement percentage increases, it was observed that the specimen required more initial loading to start elongation. Strain is found to decrease with increase in load as the addition of cenosphere imparts brittleness to the composite.

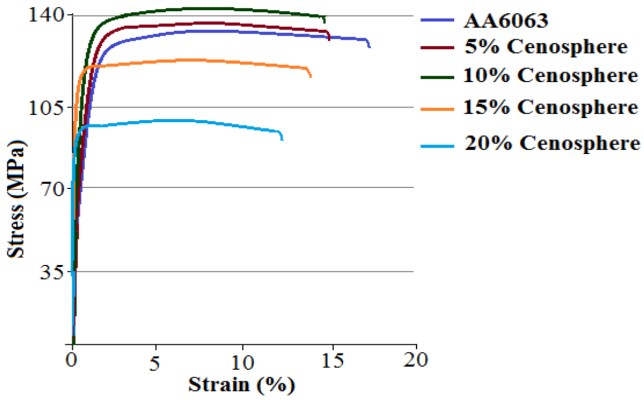

Fig. 5 Stress-Strain Curves for Specimens

A.ULTIMATE TENSILE STRENGTH

The addition of smaller quantities of cenosphere i.e., 5 and 10% by volume was found to increase the tensile strength, although marginally, by 3.5-9%. Further addition of cenosphere, i.e., 15 and 20% by volume tends to reduce the tensile strength by 10 and 25% respectively, in comparison to the unreinforced aluminium alloy. The percentage of elongation to fracture decreased with an increase in the cenosphere content and that the yield strength of the composite increased with the increase in cenosphere content up to 10% and then started to decrease. The mean and standard deviation (SD) of tensile test results are shown in Table 3.

Table 3 Influence of Cenosphere content on tensile properties

Cenosphere volume percentage		Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Elongation (in percentage)	Young's Modulus (GPa)
0	Mean	90	131	18	69.2
	Standard deviation	3.1	1.8	2.6	3.6
5	Mean	93	135.62	17.13	73.1
	Standard deviation	3.6	4.9	5.3	5.7
10	Mean	95	142.70	16.22	83.7
	Standard deviation	4.5	6.2	6.3	5.5
15	Mean	87	117.91	14.15	85.0
	Standard deviation	7.1	7.7	5.7	6.5
20	Mean	81	97.53	12.67	86.2
	Standard deviation	8.6	7.9	6.5	5.7

The UTS shows an increase until the addition of certain volume fraction of cenosphere, after which it decreases because of the weak compounds formed at the interface of the matrix and the reinforcement. The interfacial reactions should also be analysed while scrutinizing the decreased strength of high cenosphere containing composites. They

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occur during the particle incorporation process and tend to alter the matrix composition affecting the strength of composites [16].

B.PERCENTAGE OF ELONGATION

An observation of low percentage elongation of the composites indicated in Fig.6 confirms that the addition of particles lowers the ductility of the composite. The brittleness of the composite was found to increase with increase of cenosphere content. This behaviour could be attributed to the fact that the cenosphere particles and the aluminium matrix debond at higher loads leading to particle pull-out, decreasing the degree of elongation [17]. Such behaviour may be the resultant of the failure due to cumulative internal damage to particles caused by particle fracture or interfacial failure. This damage in turn leads to voids which then multiplies and reduces ductility in these composites [18]. Fig. 6 shows that the elongation of the material decreases with increase in percentage of cenosphere.

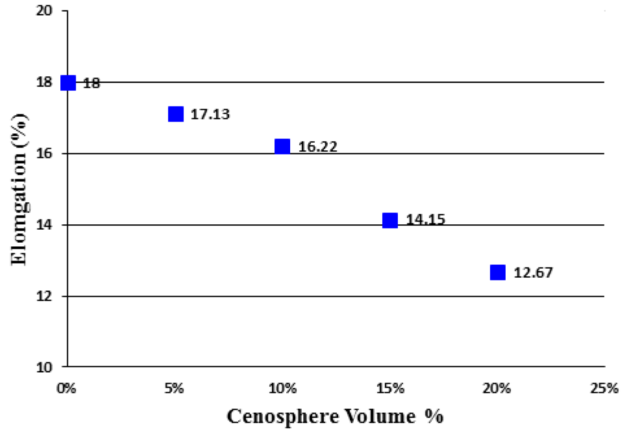
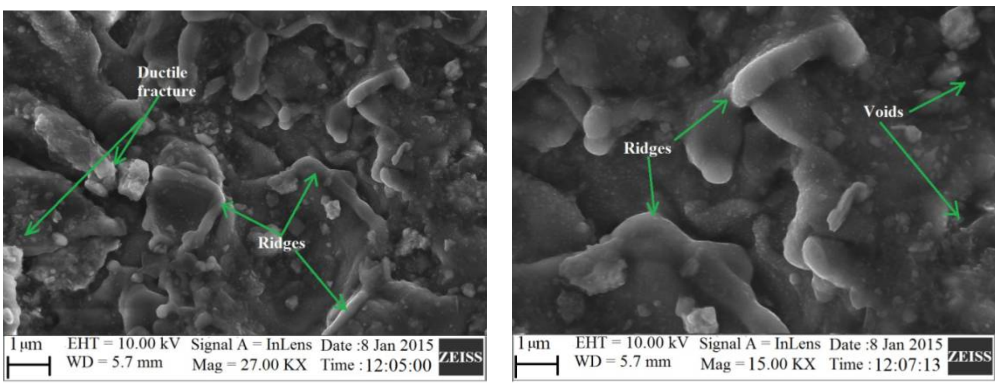


Fig. 6 Comparison of Elongation of the Specimens

C.TENSILE FRACTURE

The intrinsic micro structural effects of the tensile fracture properties of the composites can be better understood by studying the tensile fracture surfaces. The composites show the presence of both ductile and brittle mechanisms as shown in Fig. 7 (a) to (d).



(a) (b)

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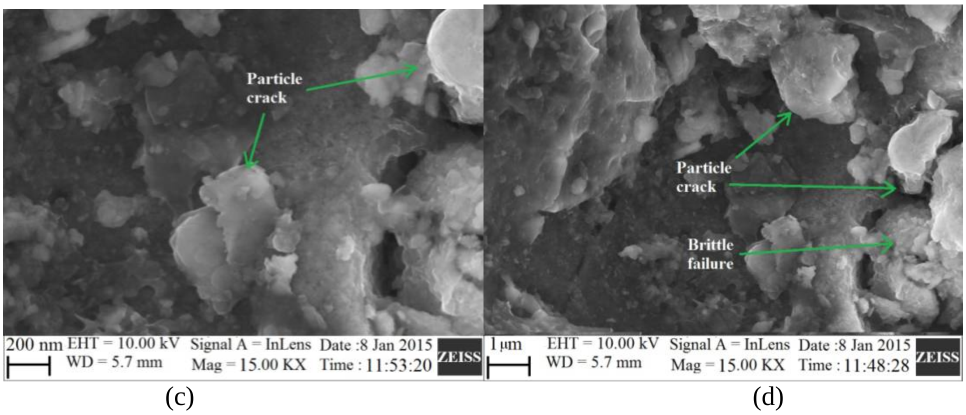

Fig. 7Tensile fractured surfaceSEM image of (a) AA6063 with 5% Cenosphere(b) AA6063 with 10% Cenosphere(c) AA6063 with 15% Cenosphere (d) AA6063 with 20% Cenosphere

A microscopic view of the fractured surfaces shows rough tensile fracture surfaces with peaks and valleys. Fig. 7 (b) and Fig. 7 (c) contain fractographs showing the tear ridges as ductile regions surrounding the fractured reinforcing cenosphere particles. The hard cenosphere particles in the AA6063 matrix cause difficulty in deformation and the key factor was the development of a tri-axial stress state in the matrix of the composite. This phenomenon contains void nucleation and growth in addition to limiting the flow of stress patterns of the discontinuously reinforced metal matrix. Higher cenosphere content reveals the brittle fracture of the particles that are responsible for the degradation in tensile elongation and the resultant failure. The presence of hard and brittle cenosphere particulates in the soft and ductile aluminium alloy metal matrix causes fine micro cracks to initiate at low values of applied stress. Examination of the tensile fracture surfaces revealed the damage associated with fracture to be highly localized at the cenosphere particle with little evidence of void formation away from the fractured cenosphere.

D.COEFFICIENT OF THERMAL EXPANSION

Ceramic particles have a lower coefficient of thermal expansion (CTE) than metallic alloys, and therefore the introduction of these particles in the matrices can reduce the CTEs of the resulting composite [19]. The primary objective of this study was to measure the reduction in CTE of aluminium due to the introduction of cenosphere particles. The reduction in CTE enhances the thermal stability of the composite. Sample of all the compositions of the composites were prepared as per ASTM D696 with a length of 46 mm and a diameter of 10 mm. The specimens placed in the dilatometer were heated at a rate of 3 ^{o}C/min for 125 minutes. The specimens were held for 10 minutes at 400 ^{o}C, and then the CTE test apparatus shut off automatically. The specimens were cooled naturally in the CTE apparatus.

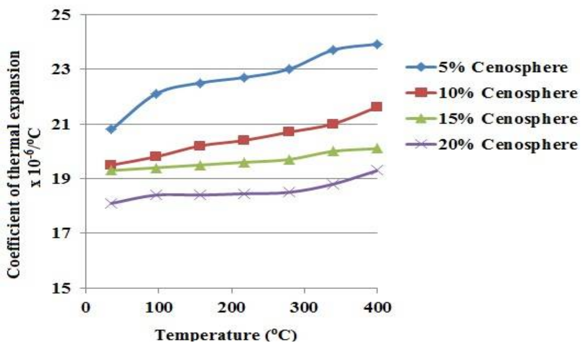

Fig.8 Variations in the CTE of Cenosphere-AA6063 Composites

The variations in the CTEs of cenosphere composites with change in temperature are shown in Fig. 8. Repetitions of measurement showed variations within only 2%, which was smaller than over 4% difference between the average CTE values for these composites. They related this trend to internal stresses that occur due to the CTE difference between the matrix and the particles. The magnitude of internal stresses decreases with increasing temperature.

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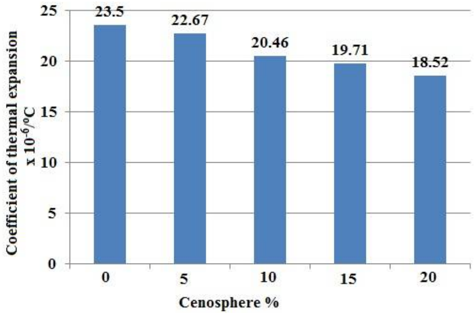

Fig.9 Variation of Composite CTEs with Cenosphere content

From Fig. 9, CTE values are 22.67 x $10^{-6}/^oC$ for 5%cenosphere, 20.46 x $10^{-6}/^oC$ for 10%cenosphere, 19.71 x $10^{-6}/^oC$for 15%cenosphere and 18.52 x $10^{-6}/^oC$ for 20%cenosphere. These values were lower than the measured average CTE of Al 6063, which is, 23.5 x $10^{-6}/^oC$. Ceramic phase formed at the cenosphere-matrix interface due to the reaction between the aluminium matrix and the silicon present in the cenospheres[21]. The difference in the average CTE of the composites suggests that the CTE was influenced by the cenosphere content.

VII. CONCLUSIONS

The density of the composite was found to decrease with increasing cenosphere content. The density was less at 20%cenosphere content but hardness was more at 15%. Optimum percent of cenosphere has to be decided after considering results of other properties like yield strength, compressive strength and tensile strength which were desirable at 10%. The presence of cenospheres in AA6063 matrix decreased its CTE and the maximum value was at 20%. Above results indicate that the composite with about 10% of cenosphere reinforcement possesses properties which are better compared to the unreinforced aluminium alloy.

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