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MECHANICAL PROPERTIES OF ALUMINIUM 6061 CENOSPHERE COMPOSITES

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ABSTRACT

Aluminium based metal matrix composites (MMC) are being considered as good candidates for replacing conventional alloys in many industries such as aerospace, automotive, and sport due to their potential engineered properties. They can be tailored to have superior properties such as high specific strength and stiffness, increased wear resistance, enhanced high temperature performance better thermal and mechanical fatigue and creep resistance than those of monolithic alloys. In the light of the above, the paper focusses on development and characterization of aluminiun Cenosphere composite and evaluate its properties such as hardness, density, porosity and its tensileproperties. It is observed that the density, porosity and ductility decrease with an increase in the percentage of reinforcement and a considerable increase in hardness and tensile strength.

***Key words**: Aluminium 6061, fly ash cenospheres, density, porosity, tensile strength, ductility*

1. Introduction

Metal-matrix composites (MMCs) are engineered combinations of two or more materials (one of which is a metal) where tailored properties are achieved by systematic combinations of different constituents. Composite materials are attractive since they offer the possibility of attaining property combinations which are not obtained in monolithic materials and which can result in a number of significant service benefits. These could include increased strength, decreased weight, higher service temperature, improved wear resistance, higher elastic modulus, controlled coefficients of thermal expansion and improved fatigue properties. The quest for improved performance has resulted in a number of developments in the area of MMC fabrication technology .These includes both the preparation of the reinforcing phases and the development of fabrication techniques [1]. Cenospheres are lightweight, inert, and hollow spheres mainly consisting of silica and alumina, are filled with air or gases, and are by-products of the combustion of pulverized coal at the thermal power plants. These ash particles get their hollow spherical shape as a result of cooling and solidifying around a trapped gas (generally CO_2 and N_2 bubble) from the molten droplets of inorganic coal residue. Another variety of the particles, present in the coal ash, is the particle containing included spheres (hollow or solid) and is called `plerosphere'[2].

In general, addition of hard reinforcement in the matrix alloy results in improved hardness of the composites. However, presence of soft reinforcement in the matrix alloy reduces the hardness of the obtained composites. The type and extent of incorporation of the reinforcement has a profound influence on the hardness of the composite [3]. A higher hardness was also associated with a lower porosity. The porosity of the composite increased with increasing SiC volume fraction. The most common particulate composite system is aluminum reinforced with silicon carbide. However, within this system, there are many microstructural variables which can affect mechanical properties [3-4]. It is also reported that the tensile strength tends to increase while toughness and ductility of composites decreases with increased volume fraction of particulates [6]. Niranjan*et al.* [6] have reported that dispersion of hard ceramic particles in a soft ductile matrix results in improvement in strength. This has been attributed to large residual stress developed during solidification and to the generation of density of dislocation due to mismatch of thermal expansion between hard ceramic particles and soft aluminum matrix [7-8].

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2. Experimental Procedure

A batch of 3.5kgs of Aluminum 6061 alloy was melted using a 6KW electric furnace. The melt was degassed using commercially available chlorine based tablets (Hexachloroethane). The molten metal was agitated by use of mechanical stirrer rotating at a speed of 300 rpm to create afine vortex. Preheated cenospheres (preheated to 200^{o}C for 2 hrs) were added slowly in to the vortex while continuing the stirring process. The stirring duration was 10 min. The composites melt maintained at a temperature of 710ºC was then poured in to preheated metallic moulds. Thestirrer blades used were made of stainless steel and were coated with ceramic material to minimize the iron pickup by the molten metal. The amount of cenospheres was varied from 2 to 8wt%instepsof2%.

2.1 Optical Micrograph studies

The samples were ground on the Silicon carbide abrasive paper. of 300, 600, 800, 1000 and 1200 grit sizes. These samples were then ground on golden touch fine abrasive papers of 1, 2, 3, and 4 grid sizes. The grinding was done in successive steps on each abrasive paper. Care was taken while grounding the samples by polishing in only one direction (form right to left). After emery polishing the samples were thoroughly washed, dried and polished on a velvet cloth using alumina as an abrasive on a two disc polishing machine. To obtain a highly polished surface of mirror finish, quality diamond paste of grade 30 (1 microns) was used.

2.2 Density Measurement

The densities of the developed composites were determined by means of Archimedes' principle by immersing the samples in a fluid. The weight of the displaced fluid equals its volume when water is used. The volume of water displaced is equal to the volume of the body immersed. All weights were obtained by means of a 0.1mg digital balance equipped with a spring balance. The sample was suspended in air on the spring by means of a thin thread and its weight determined as w_1. It was then completely submerged in a beaker of water and the new weight recorded as w_2. Its density was then calculated from Equation

$$\text{Volume of sample} = \frac{W_1 - W_2}{W_1} \text{-------} \quad (1)$$

Where w_1 – weight of the sample in air

w_2---- weight of sample in water

2.3 Microhardness test

Hardness test was performed on polished samples of the cast alloy and its composites using Vickers micro hardness tester. Tests were performed with a load of 100g for a duration of 10 seconds. The test was carried out at five different locations in order to contradict the possible effect of indentor resting on the harder particles. The average of all the five readings was taken as hardness of sample.

2.4 Tensile test

Tensile tests were performed on both Al 6061 and developed composites using INSTRON universal testing machine.. The specimens were machined as per ASTM E 8M dimensions which was specific for the INSTRON tensile test machine A strain rate of 0.25mm/min was maintained during testing. Modulus of elasticity, ultimate tensile strength, yield strength, and percentage elongation were evaluated.

3. Results and Discussions

3.1 Reinforcement – Fly ash Cenosphere

It is seen through the optical micrographs of as cast Al 6061 alloy and Al 6061 cenosphere composites. The distribution of cenosphere particles in the matrix is related to the solidification process of the alloys. It is observed that during solidification process, the cenosphere particles are pushed onto the solidifying interface because the ratio of coefficient of thermal conductivity between the particles and aluminum is less than 1 [9] It can also be seen that there is a clear interface between the cenosphere particles and aluminium alloy matrix. Further, it is observed that the developed composites are free from common cast defects such as porosity and shrinkage cavity.

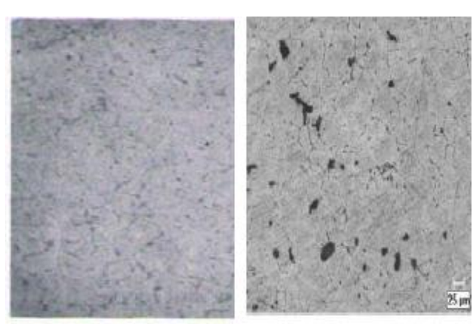


Fig 1.a.Al 6061 matrix   Fig.1.b.Al 6061 -2% Cenosphere

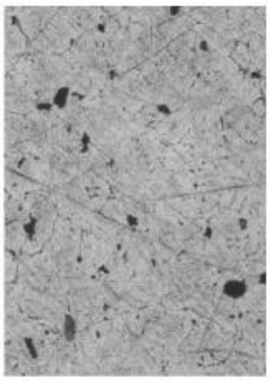


Fig. 1.c.Al 6061 -4% cenosphere

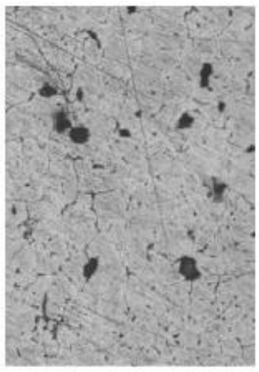


Fig.1.d. Al 6061 -6% Cenosphere

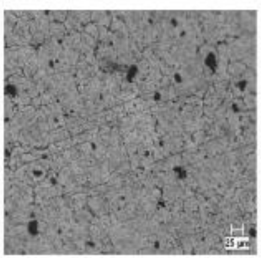


Fig. 1a-1e Microphotographs of Al 6061 cenosphere composites

3.2 Density

The graph (Fig 2) shows the variation of density of Al6061 matrix alloy and Al6061-cenosphere composites respectively. It is observed that density of composite decreases with increased content of reinforcement in the matrix alloy. Lower values of density in composites can be attributed to the fact that cenospheres has lower density.

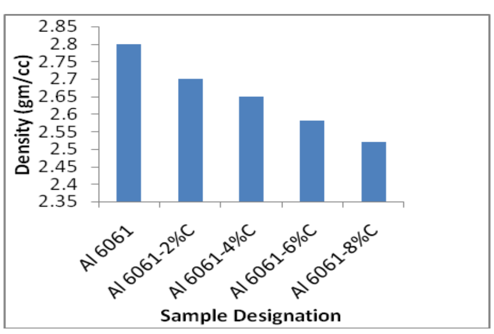


Fig.2 Variation of density of as cast Al 6061 alloy and Al6061-cenosphere composites

3.3Microhardness

The graph (Fig 3) shows the variation of microhardness with increase in percentage weight of cenosphere particles in Al6061 alloy. From the graph, it is observed that there is a significant improvement in microhardness with addition of cenosphere particles in matrix alloy. This improvement in the hardness value of matrix alloy may be attributed to facts that, cenosphere being hard reinforcement do exhibit greater resistance to indentation of hardness tester, by rendering its inherent property of hardness to matrix alloy

It is reported that addition of hard reinforcement in soft ductile matrix always enhances the bulk hardness of matrix material [10]. Further, there is a large difference in co-efficient of thermal expansion of Al6061 alloy and cenosphere particles, which will lead to thermal mismatch between matrix alloy and reinforcement. This factor increases the density of dislocations in the material resulting in higher hardness value [11]. Further, the increase in hardness value can also be attributed to the fact that higher hardness is always associated with lower porosity of metal matrix composites [12] as reported in Section 3.1

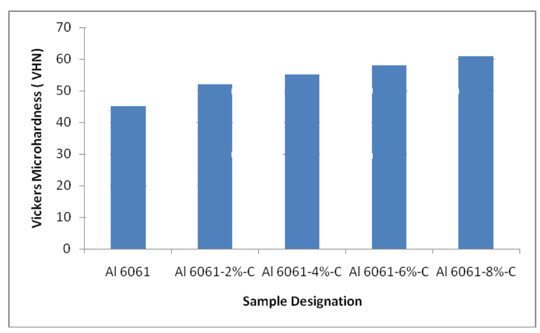


Fig.3 Variation of microhardness of Al 6061 alloy with reinforcement

3.4 Ultimate Tensile Strength

The variation of ultimate tensile strength with increase in percentage of cenosphere particles is as shown in the figure 4. It is observed that there is a linear increase in ultimate tensile strength. This increase in the ultimate tensile strength can be attributed to the fact that addition of cenosphere particles induces strength to matrix alloy there by causing increased resistance to tensile stresses resulting in enhanced ultimate tensile strength [13].

Further, the improvement in tensile strength may also be attributed to fact that there is generation of high dislocation densities in matrix material as a result of huge difference in co-efficient of thermal expansion between matrix and reinforcement [14].

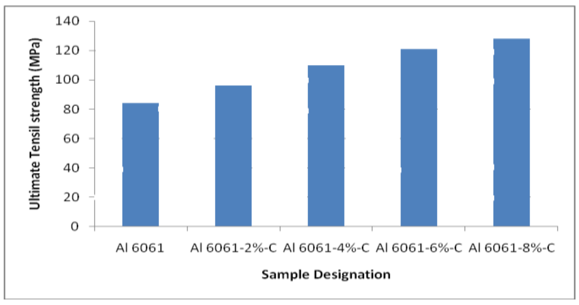


Fig.4 Variation of Ultimate Tensile strength of Al 6061 matrix - cenosphere and the developed composites.

3.5 Yield strength

The variation of yield strength of as cast Al 6061 matrix alloy and its developed cenosphere composites is as shown in Fig 5. From the figure it is evident that there is an increase in proof stress of all the composites when compared with the cast Al 6061 matrix alloy. It is clear that with the presence of cenosphere particles the yield strength increases significantly. This could be due to good interface strength between reinforcement and Al 6061 matrix alloy. Also, due to lesser pores present along the interface which will substantially lead to lesser flaws to act as crack initiating sites.

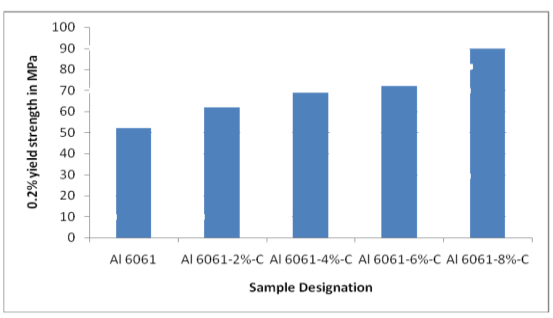


Fig.5 Variation of Yield strength of Al 6061 matrix - cenosphere and the developed composites.

3.6 Ductility

Figure 6 shows variation of ductility of Al6061 alloy Al6061-cenosphere composites. It is observed that addition of cenosphere leads to the drastic reduction in ductility of Al6061–cenosphere composites. The reduced ductility of the composites with increased content of cenosphere particles can be attributed to the stress concentration effects at the matrix and the reinforcement interface.

The presence of intrinsically brittle phases and presence of additional secondary or intermetallic phases serves as potential sites for crack nucleation resulting in reduction in ductility under static loading [15-16]. Ramachandra *et al.* [17] have reported this kind of reduction in ductility with an increased content of reinforcement in soft ductile matrix.

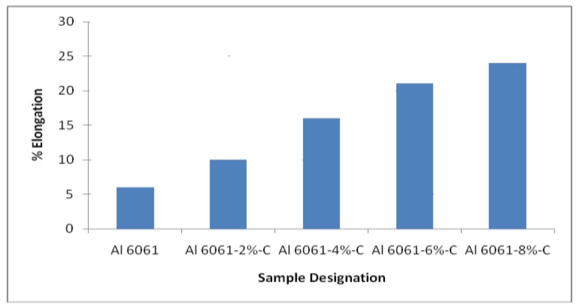
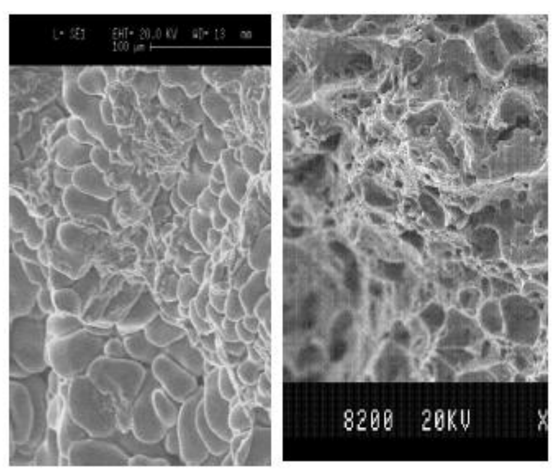


Fig.6 Variation of ductility (%age elongation) of Al 6061 matrix alloy and the developed cenosphere composites

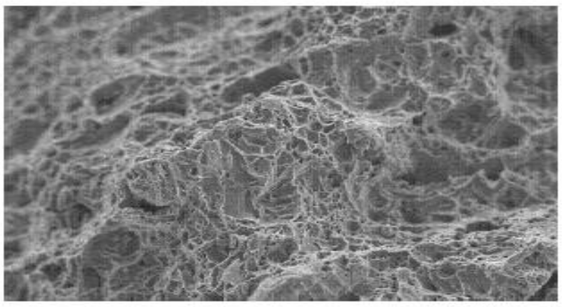
3.7 Fractography

Fig.7 shows the fractured surfaces of both the matrix Al 6061 alloy and the developed in uncoated cenosphere composites. From the micrographs it is evident that Al 6061 matrix alloy shows larger and uniform voids indicating the ductile fracture, where as all the composites show voids of size smaller than that of matrix alloy, indicating macroscopically brittle fracture and microscopically ductile fracture. These fractographs clearly indicate an evidence of good bond between matrix and the reinforcement leading to improved hardness and ultimate tensile strength of composites as discussed in the earlier sections. Further particle fragmentations at few locations have been observed.



Al 6061 matrix

Al 6061 -4 % Cenosphere



Al 6061 -8 % Cenosphere

Fig.7 Factographs of Al 6061 alloy and the developed cenosphere composites

4. Conclusion

- Al 6061-cenosphere composites have been successfully produced by liquid metallurgy route.
- Microstructure studies clearly reveal uniform distribution of cenosphere particles with good bond between the matrix and reinforcement.
- Density and porosity of the composites increases with the increased content of cenospheres as a reinforcement both.
- Microhardness, tensile strength, modulus of composites are higher when compared with that of matrix alloy. Increased content of hard reinforcement in the matrix alloy leads to enhancement in microhardness, tensile strength, modulus of the composites.
- Ductility of the composites increases with increased content of reinforcement in the matrix alloy.

References

1. *Rohatgi P K (1993), "Metal-matrix Composites", Defence Science Journal, Vol. 43(4), 323-349.*

2. *Raask E (1968), "Cenospheres in pulverized-fuel ash", J. Inst. Fuel, Vol. 41.*

3. *Anwar Khan A R Ramesh C S and Ramachandra A (2002), "Heat Treatment of Al6061-SiC composites", Proc. of the Int. Conf. on Manufacturing, ICM, Vol. 21-28.*

4. *Miller W S Lensen L A and Humphreys F J (1989), "The strength toughness and fracture behaviour in Aluminium-Lithium based metal matrix composites", Aluminium-Lithium, Vol. 5, 931-941.*

5. *Yang J Cady C Hu M S Zok F Mehrabian R and Evans A G (1990), "Effects of damage on the flow strength and ductility of a ductile Al alloy reinforced with SiC particulate", Acta Metallurgical Material, Vol. 38, 2613-2619.*

6. *Niranjan H B (1998), "Tensile and corrosive properties of Al Hematite composite", In Proc., of the First Australasian conference on Composite Materials (ACCM-1), Osaka, Japan, Vol.546.*

7. *Gurlond J (1974), "Composite Materials", In., L J Brautman (Ed.), Academic Press, New York, Vol. 4.*

8. *Clegg W J (1998), "A stress analysis of the tensile deformation of metal matrix composites", ActaMetallurgica, Vol.36, 2141-2149.*

9. *Dwivedi D K (2003), "Sliding temperature and Wear behaviour of cast Al-Si base alloy", Material Science & Technology, Vol.19, 1081-1096.*

10. *Alahelisten A Bergman F Olsson M and Hogmark S (1993), "On the wear of aluminum and magnesium metal matrix composites", Wear, Vol. 165, 221-231.*

11. *Moustafa Z F (1995), "Wear and Wear Mechanisms of Al-22%Si/Al2O3 Composite", Wear, Vol. 185, 189-195.*

12. *Zhang Z F Zhang L C and Mai Y W (1994), "Wear of ceramic particle-reinforced metal- matrix composites", Int., Wear mechanisms, Journal of Material Science, Vol. 30, 1961-1966.*

13. *Luster W Thumann M and Baumann R (1993), "Mechanical properties of Aluminium alloy 6061-Al2O3 composites", Materials science and technology, Vol. 9, 853 – 862.*

14. *Vogellany M Aersenault R J and Fisher R M (1986), "Interfaces-Metal Matrix Composites", Mat., Trans., Vol. 17, 379-389.*

15. *Chawla N and Shen Y L (2001), "Advance Engineering Mat.,", Vol. 357.*

16. *Ismail Ozdemir and KazimOnel (2004), "Thermal cycling behaviour of an extruded aluminium alloy/SiCp composites", Composites Part B: Engineering, Vol. 35, 379–384.*

17. *Ramachandra M Radhakrishna K (2007) "Effect of reinforcement of fly ash on sliding wear, Slurry Erosive wear and Corrosive behavior of Aluminum matrix Composites", Wear, Vol. 262, 1450-1462.*

