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EVALUATION OF HARDNESS AND DENSITY OF AL 6061 NICKEL COATED CENOSPHERE COMPOSITES

Singh R.P[1], *Prashanth. T[2], Abrar Ahamed[3], Ani Daniel[4] and Vilas K. Bhosle[5]

[1, 2, 3, 4, 5] Department of Mechanical Engineering, Birla Institute of Technology, Offshore campus, Ras-Al- Khaimah, UAE

ABSTRACT

In recent years, among all the aluminium alloys, Al6061 is gaining much popularity as a matrix material to prepare metal matrix composites owing to its excellent mechanical properties and good corrosion resistance. Fly ash cenospheres are primarily a by-product in power generation plants. Research is in progress to effectively use this by-product to produce new usable and profitable materials as they pose major disposal and environmental problems. The present investigation is aimed at development of metal coated cenosphere reinforced Al6061 composites and to characterize their mechanical properties. Al6061 nickel coated composites have been prepared by liquid metallurgy route by varying percentage of nickel coated cenospheres between 2-10% by weight in steps of 2%. Microstructural studies, density and hardness evaluation of the composites is carried out. It is observed that there is an increase in the values of hardness and density of the composites with an increasing percentage of the nickel coated cenosphere reinforcements.

Keywords: *Nickel coated cenospheres, Electroless nickel coating, Aluminium 6061, Composites.*

1. Introduction

Ceramic reinforcements are subjected to metallic coatings to improve the wet-ability between the reinforcements and the molten metal during the processing of composites by liquid metallurgy route. Further these treatments of ceramic surfaces also decreases the interfacial reactivity which otherwise will lead to the formation of interfacial products resulting in inferior mechanical properties. Several techniques of deposition of thin layers of various metals have been successfully adopted [1]. In recent years, nickel and copper films have been effectively deposited on the ceramic reinforcements both whiskers and particulates. Nickel and copper coated reinforcements have produced beneficial effects in particular to reduction in porosity level and reduce interfacial reactions during processing of metal matrix composites [2]. Currently, electroless deposition of metallic coatings on the ceramic reinforcement is gaining popularity owing to its advantages such as uniformity in coatings over the surfaces regardless of size and shape. Further this technique is an autocatalytic which means no conduction surfaces. In general, addition of hard reinforcement in the matrix alloy results in improved hardness of the composites. The type and extent of incorporation of the reinforcement has a profound influence on the hardness of the composite [3].

Ceramic reinforcements are subjected to metallic coatings to improve the wetting between the reinforcements and the molten metal during the processing of composites by liquid metallurgy route. Further these treatments of ceramic surfaces also decreases the interfacial reactivity which otherwise will lead to the formation of interfacial products resulting in inferior mechanical properties. Several techniques of deposition of thin layers of various metals have been successfully adopted [1]. In recent years, nickel and copper films have been effectively deposited on the ceramic reinforcements both whiskers and particulates. Nickel and copper coated reinforcements have produced beneficial effects in particular to reduction in porosity level and reduce interfacial reactions during processing of metal matrix composites [2-4]. Currently, electroless deposition of metallic coatings on the ceramic reinforcement is gaining popularity owing to its advantages such as uniformity in coatings over the

*Corresponding Author - E- mail: trprashanth1977@gmail.com

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The current work comprises of evaluation of the hardness and the density evaluation the composites. The research work is dedicated to such an investigation.

2. Experimental Procedure

2.1 Electroless Nickel Coating of cenosphere Particles

A single step activation and sensitization step was carried out. Sodium Hypophosphite was used to reduce Nickel in presence of $PdCl_2$. The composition of the chemicals used for the coating process is as shown in Table 1.

$$NiSO_4+2NaH_2PO_2+2H_2O \rightarrow Ni+2NaH_2PO^{3-}+H_2+H_2SO_4 \quad (1)$$

Table 1. Bath composition for electroless nickel deposition.

Sl.No	Bath constituents	Quantity (g/ltr)
1	Nickel Chloride,	30
2	Sodium acetate	10
3	Sodium Hypophosphite, monohydrate(NaH_2PO_2, H_2O)	20
4	Glycin (H_2NCH_2COOH)	10
5	Sodium hydroxide	0.02

The nickel reduction only takes place on specific catalytic surfaces including nickel itself, which makes the reduction process autocatalytic. The reducing agent ($PdCl_2$) used for electroless plating not only supplies the electrons for the reduction, but some elements in the reducing agent can be incorporated into the nickel deposit improving its properties e.g. when sodium hypophosphite is used as a reducing agent the resultant deposit is a nickel phosphorus alloy. During the plating process, the nickel sulfate and sodium hypophosphite raw materials are continuously depleted and must be replenished in order to maintain the chemical balance of the bath and addition of either ammonia or sodium hydroxide is necessary to keep the pH within the preferred range. This results in an accumulation of sodium and sulfate ions, along with orthophosphite, as the electroless nickel bath ages and consequently the plating rate can decrease from 18 mm hr-1 to less than 10 mm hr^{-1}.

A batch of 3.5kg 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 using a mechanical stirrer rotating at a speed of 300 rpm to create a fine vortex. Preheated coated cenospheres (preheated to 200°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 molds. The stirrer 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 - 8 wt. % in steps of 2%. [8].

2.2 SEM Studies

Scanning electron microscope studies were carried out using JSM 840a Joel scanning electron microscope on Aluminium 6061, Aluminium cenosphere composite and aluminium nickel coated cenosphere composite at Indian Institute of Science (IISc), Bangalore. The sizes of the specimens were machined to 20mm (diameter).

2.2 Density and Porosity 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 using Eq. 2.

$$\text{Volume of sample} = \frac{W_1 - W_2}{W_1} \quad (2)$$

The apparent porosity of both as cast and hot extruded alloy and their in situ composites was estimated using Eq. 3 [9]

$$\text{Porosity} = \frac{W - W_1}{W - W_2} * 100 \quad (3)$$

W = Constant weight (obtained after heating the specimen in an oven for a duration of 4 hours at a temperature of 100°C).

W_1 = Weight of sample in hot water
W_2 = Weight of sample in cold water.

Fig 1(a). Al 6061.

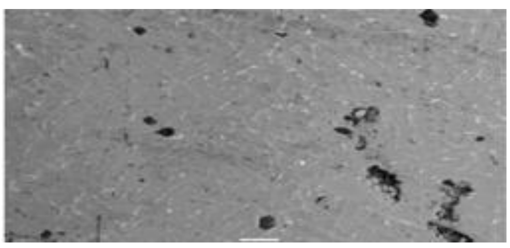

Fig 1(b). Al 6061- 2% nickel coated cenosphere.

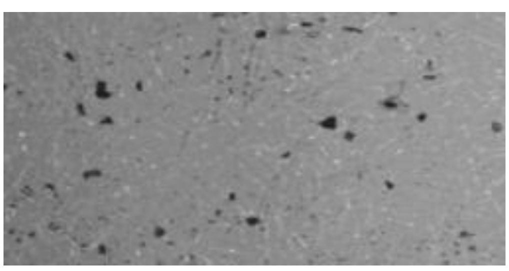

Fig 1(c). Al 6061- 4% nickel coated cenosphere.

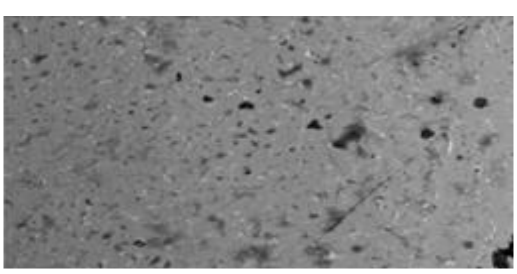

Fig 1(d). Al 6061- 6% nickel coated cenosphere.

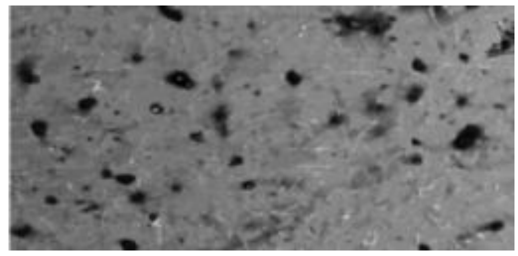

Fig 1(e). Al 6061- 8% nickel coated cenosphere.

2.3 Micro-hardness test

Hardness test was performed on polished samples of cast and hot extruded alloy and its composites using Vickers micro-hardness tester. Tests were performed with a load of 100g for 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 were taken as a measure of hardness .

3. Results and Discussions

Figs 1(a to e) shows the SEM micrographs of nickel coated cenosphere Al 6061 composites. From the micrographs, it is observed that the nickel coated cenosphere particles are dispersed uniformly throughout the matrix. Further, SEM images clearly indicate that reinforcement particulates are well bonded to the aluminum matrix and that there exists very minimum micro porosities in all the composites. This fact supports good bond between matrix and reinforcement [9]. The few pores observed in the as cast composite were mostly associated with the reinforcement particles and particle clusters. The latter feature was especially pronounced in the composite with higher weight fraction of the reinforcement in the composites. The extent of distribution of reinforcement particle in the composites is more homogeneous when compared with cast composites, suggesting that rearrangement and re-crystallization had taken place.

3.1 Evaluation of Density and Micro-hardness

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 thatcenospheres has lower density. Further, coating of the reinforcement has a significant effect on density. It is seen that on nickel coating, there is an increase in density for all the composites studied. These results are in good co-relationto other researchers [10].

Fig 3 shows the variation of micro-hardness with increase in percentage weight of cenosphere particles in Al6061 alloy. From the graph, it is observed that there is a significant improvement in micro-hardness with addition of cenosphere particles in matrix alloy.

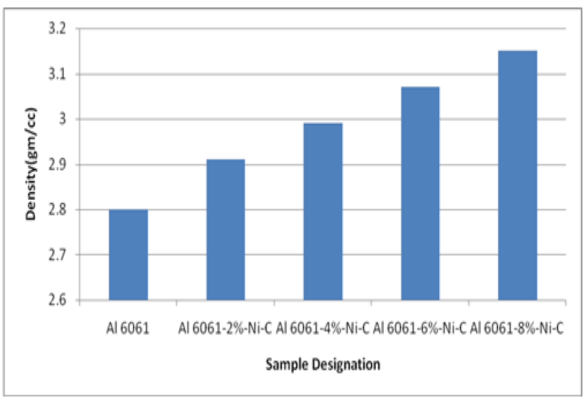

Fig 2. Variation of density of nickel coated cenosphere composites.

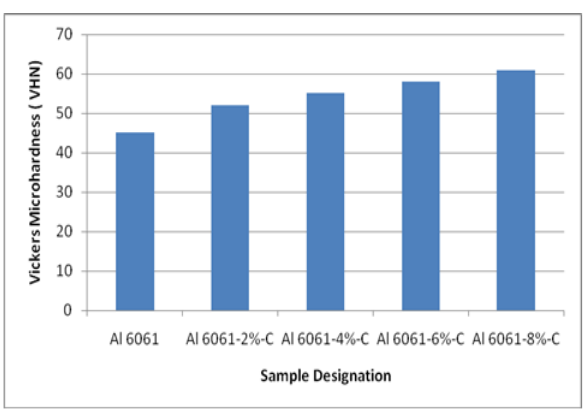

Fig 3. Variation of micro-hardness of Al 6061 alloy with reinforcement.

This significant improvement in the hardness value of matrix alloy may be attributed to facts that, cenosphere being hard reinforcement do exhibit great resistance to indentation of hardness tester, by rendering its inherent property of hardness to matrix alloy. It is also reported that addition of hard reinforcement in soft ductile matrix always enhances the bulk hardness of matrix material [11]. 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 [12].

It is also evident from both Optical and SEM microphotographs that lesser extent of porosity is observed. It is reported that higher hardness is always associated with lower porosity of metal matrix composites [13]. Further, cenosphere particles are Ni-P coated prior to addition in molten metal, as a beneficial result of it, the interface is free and even good bond exists between matrix alloy and reinforcement. Thus, the load transfer capability of matrix to the reinforcement is expected to be more which may be another reason for higher hardness value. Increased percentage weight of Ni-P coated cenosphere particles in matrix alloy leads to increase in hardness value which may be due to fact that, during hardness test of the composite, the indentation pressure is partially accommodated by plastic flow of material and largely by localized increase in concentration of Ni-P coated cenosphere particles.

3.2 Brinell hardness

The variation of Brinell hardness number (BHN) of Al 6061 cenosphere composites and Al 6061 nickel coated cenosphere composites is shown in Fig 4 and Fig 5. The introduction of nickel coated alloy results in improved BHN values of cast matrix cenospheres as a

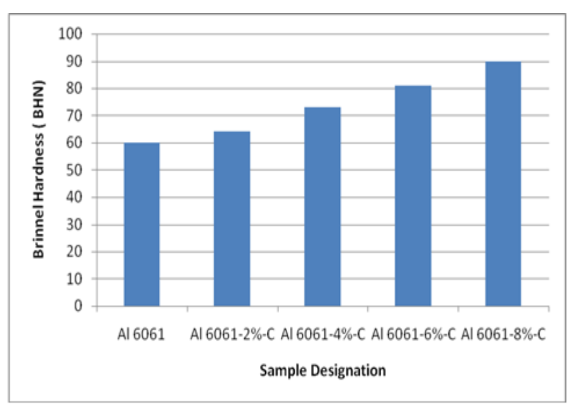

Fig 4. Comparison of Brinell hardness of Al 6061 alloy and Al 6061-cenosphere composites.

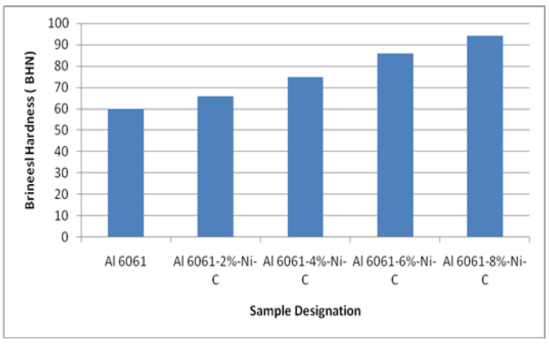

Fig 5. Comparison of Brinell hardness of Al 6061 alloy and Al 6061-nickel coated cenosphere composites.

reinforcement in the Al 6061 matrix alloy and its composites. This improvement in the hardness value of matrix alloy may be attributed to facts that, coated cenosphere being hard reinforcement do exhibit greater resistance to indentation of hardness tester, by rendering its inherent property of hardness to matrix alloy. Further, there is a large difference in co-efficient of thermal expansion of Al 6061alloy and coated 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 [14]. Thus, the load transfer capability of matrix to the reinforcement is expected to be more which may be another reason for higher hardness value. It has been reported that the Brinell hardness of the matrix alloy increases with incorporation of Al_2O_3 reinforcement in Al 6061 matrix alloy. It is reported that higher hardness is always associated with lower porosity of metal matrix composites [14].

4. Conclusions

1. Al 6061-cenosphere composites have been successfully produced by liquid metallurgy route.
2. Cenosphere particles were coated with nickel successfully
3. SEM and EDAX confirm the presence of nickel coating on cenospheres.
4. Microstructure studies clearly reveal uniform distribution of cenosphere particles with good bond between the matrix and reinforcement.
5. Density and porosity of the composites increases with the increased content of cenospheres as a reinforcement both. However, nickel coated cenospheres composites exhibits higher density and lower porosity when compared with uncoated cenospheres ones.
6. Micro hardness, of composites is higher when compared with that of matrix alloy. Increased content of hard reinforcement in the matrix alloy leads to enhancement in mechanical properties.

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