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# Mechanical Property Evaluation Aluminium 6061 Nickel Coated Cenosphere Composites

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In recent years, among all the aluminium alloys, Al6061 is gaining much popularity as a matrix material to prepare MMCs 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 byproduct to produce new usable and profitable materials as they pose major disposal and environmental problems. In the light of the above, 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%. Density, hardness and tensile behaviour of the composites is carried out. It is observed that there is an increase in the values of hardness, density of the composite with an increasing percentage of the nickel coated cenosphere reinforcements. There is also a notable increase in the tensile strength as well as reduction in ductility of the prepared composite. Fractographs to indicate the behaviour of the composites have also been depicted in the paper.

*Keywords*: nickel coated cenospheres, electroless nickel coating, aluminium 6061, composites, tensile behaviour, fractographs.

## 1. Introduction

An increased interest is observed in last few years in metal matrix composite, mostly light metal based, which have found their applications in many industry branches, among others in the aircraft industry, automotive-, and armaments ones, as well as in electrical engineering and electronics, etc. Metal matrix composites (MMCs) are gaining wide spread popularity in several technological fields owing to its improved mechanical properties when compared with conventional metals/alloys. During the last decade, fly-ash cenospheres particles have been dispersed in different matrices, such as polyester resins, cement and nickel for producing composite materials in the bulk and coating forms for variety of industrial applications. Fly-ash is a non-conducting ceramic material [1]. Cenospheres are inert hollow silicate spheres. Cenospheres are a naturally occurring by-product of the burning process at coal-fired power plants, and they have most of the same properties as manufactured hollow-sphere products. Cenospheres are primarily used to reduce the weight of plastics, rubbers, resins, cements, etc. used extensively as filler lubricants in oil drilling operations under high heat and high stress conditions down the hole. Also used as oil well cementing, mud putty and similar applications. Cenospheres were first used in the United States as an extender for plastic compounds, as they are compatible with plastisol's thermoplastics, Latex, Polyesters, Epoxies, Phenol resins and urethanes. The compatibility of Cenospheres with special cements and adhesives coating and composites have been well identified. Cenospheres are widely used in a variety of products, including sports equipments, insulation, automobile bodies, marine craft bodies, paints, and fire and heat protection devices [1].

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 [2]. 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 [3-4]. Currently, electroless deposition of metallic coatings on the ceramic reinforcement is gaining popularity owing to its advantages such as uniformity in coatings over the 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 [5]. The most common particulate composite system is aluminium reinforced with silicon carbide. However, within this system, there are many microstructural variables which can affect mechanical properties [6-7]. Such variables include matrix alloy, volume fraction of particulate and particle size. Stronger matrix alloys tend to produce stronger composites, although the increasing strength due to reinforcement tends to be less when higher strength matrix alloys are used. It is also reported that the tensile strength tends to increase while toughness and ductility of composites decreases with increased volume fraction of particulates [8]. Niranjan et al. [9] 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 aluminium matrix [10-11]. The type and extent of incorporation of the reinforcement has a profound influence on the hardness of the composite [12]. Anwar khan et al. [13] has studied the heat treatment effect on hardness of Al6061-10wt. %SiC composites. An increase in solutionizing time increases the hardness of the composites. Sahin et al. [14] has evaluated the hardness for different volume fraction of SiC with Al-Si alloy matrix. The hardness of the MMCs increased more or less linearly with the volume fraction of the SiC particles in the alloy matrix. A higher hardness was also associated with a lower porosity. The porosity of the composite increased with increasing SiC volume fraction. It is reported that the increased content of $TiO_2$ enhances the hardness of composites. This can be attributed to higher hardness of $TiO_2$. With increased content of $TiO_2$ the probable formation of Al-Ti intermetallic precipitate and alumina increases which contributes significantly to the enhancement of the hardness of composites [15].

## 2. Experimental procedure

Aluminum 6061 alloy with magnesium and silicon as the major alloying elements was selected as matrix for preparing the composites owing to its excellent casting properties, mechanical properties coupled with good formability, mass production of light weight metal castings and its wide applications in industrial area. A single step activation and sensitization step was carried out using sodium hypophosphite to reduce nickel in presence of palladium chloride. 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 in 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. The densities of the developed composites were determined by means of Archimedes' principle by immersing the samples in a fluid. All weights were obtained by means of a 0.1mg digital balance equipped with a spring balance. 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. Composites are prepared as discussed in earlier work [16].

## 3. Results and discussions

Further, coating of the reinforcement has got 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 similar to the observations of other researchers [17]. On the other hand, cenosphere particles are Ni-P coated prior to addition in molten metal, as a beneficial result of it, the interface is free from the reaction products as discussed earlier 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.

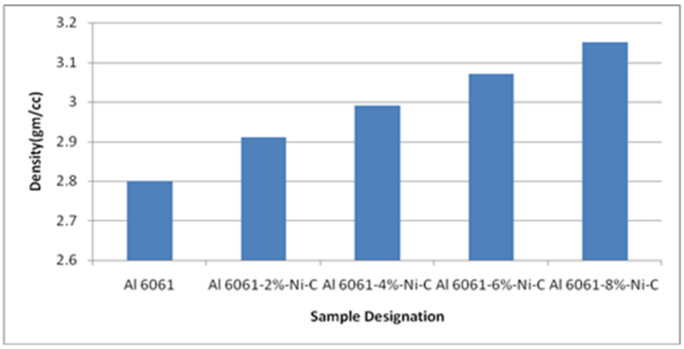


**Figure 1** Variation of density of Al 6061 alloy and Al6061-nickel coated composites

On the other hand, as the coated nickel cenosphere particles are stiffer than the aluminum matrix, a significant amount of stress is initially borne by the Ni-P coated cenosphere particles as shown in Fig. 1. In addition, incorporation of coated cenosphere particles in the matrix alloy leads to increase in work hardening of the composite owing to relatively less volume of metal and also the geometric constraints caused by the presence of reinforcement, As a result, the load required for void nucleation and its propagation is high which increases the tensile strength of the composite [18].

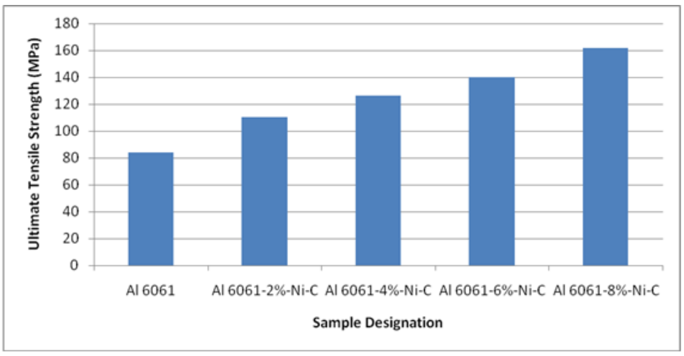


**Figure 2** Variation of Ultimate Tensile strength of Al 6061 matrix –nickel coated cenosphere and the developed composites

Since the particle size is small, the probability of having strength limiting flaws / defects in the composite is expected to be less, leading to increase in ultimate tensile strength, (Fig. 2) as stated by many researchers [19-22]. In increasing the strength of the composite material a critical role played by the clean interface that exists between matrix material and reinforcement. It is reported that the moderate interfacial reaction and enhanced interfacial bonding between matrix and reinforcement results in improved bulk mechanical properties [23]. It is also reported that, when the reaction free interface exists between matrix and reinforcement, the load transfer efficiency of matrix to the reinforcement is high. Thus, higher stress is required to initiate the crack between matrix alloy and reinforcement resulting in higher tensile strength [24].

### 3.1. *Ductility*

The ductility of Al 6061 matrix alloy and its developed nickel coated composites is measured in terms of percentage elongation of the tensile specimens. Fig. 3 shows the variation in ductility of Al 6061 matrix alloy and nickel coated cenosphere composites. It is observed that all the composite samples have higher ductility than the base Al 6061 matrix alloy as well as the cenosphere composites. The improvement in the ductility can also be attributed to porosity reduction and homogenization of reinforcement distribution, and also an extensive refined microstructure obtained. All these factors together improve the interfacial strength and ductility of the matrix and composites [25]. It is also reported that, severe plastic deformation will increase the interface bonding strength between the reinforcements and the matrix which in turn will lead to improvisation of ductility [26]. It is reported that NiAl-TiB2 composites have led to an improvement in ductility of the developed composites [27].

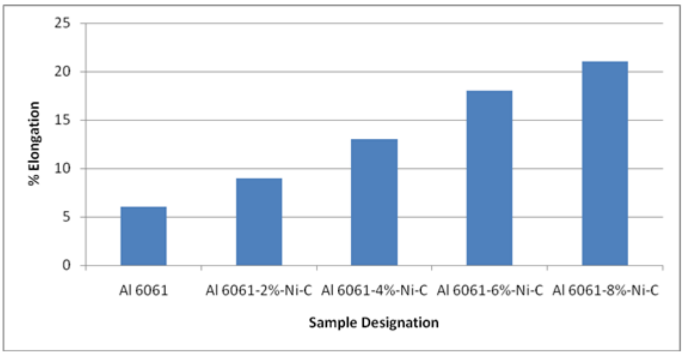


**Figure 3** Variation of ductility (%age elongation) of Al 6061 matrix alloy and the developed nickel coated cenosphere composites

### 3.2. *Fractographs*

Fig. 4 shows the SEM photographs of the fractured surface of the nickel coated ceno- sphere tensile fractured specimen. It is observed that the matrix alloy has got larger dimples with voids when compared with in situ composite systems studied. Further, fracture of reinforced phase may be due to excellent bond exist between the matrix alloy and the reinforcement as a result of metallic coating of reinforcement as discussed earlier.

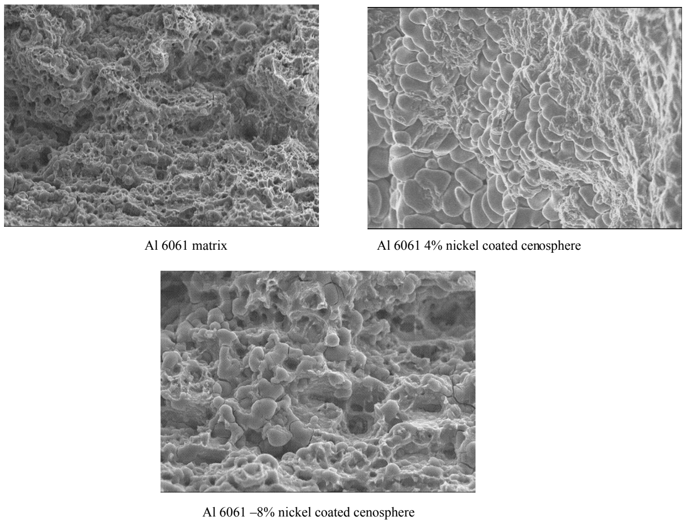


**Figure 4** Fractographs of Al 6061 alloy and the developed nickel coated cenosphere composites

With increase in load during tensile loading, the larger particles will undergo fracture first, followed by fracture of small sized particles. Further, the maximum intensity of particle fracture is observed in the region of particle clustering. It is also clear that particle fracture become dominant, with increase in the percentage of reinforcement in the matrix material. Micro voids have been observed in Al6061–coated cenosphere composites as evidenced from Fractographs. These features leads to lesser ductility when compared with matrix alloy Al6061. These observations are in close agreement with Al6061-SiC composites [28].

## 4. Conclusions

The present work has led to the following conclusions:

1. Al 6061-cenosphere composites have been successfully produced by liquid metallurgy route.

2. Cenosphere particles were coated with nickel successfully

3. Nickel coated cenospheres composites exhibits higher density and lower porosity when compared with uncoated cenospheres ones.

4. Micro-hardness, tensile strength, modulus of composites is higher when compared with that of matrix alloy. Increased content of hard reinforcement in

the matrix alloy leads to enhancement in micro-hardness, tensile strength, modulus of the composites.

5. Ductility of the composites increases with increased content of reinforcement in the matrix alloy. However, nickel coated cenosphere composites possess lower ductility when compared with the uncoated cenosphere composites.

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