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Evaluation of Corrosion Properties of Cenosphere Aluminium Composites

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Industrial processes generate certain solid by-products, the disposal of which is of serious environmental concern. The solid by-products are mainly fly ash from the power generation industry, metallurgical ore residues and slag, slurry from the mining industry, etc. Among these, fly-ash utilization continues to be an important area of national concern due to India's dependence on thermal power generation for its energy supply. Particle reinforced Al matrix composites are emerging out as potential materials to replace conventional alloys/metals. These metal matrix composites (MMCs) find extensive applications in many engineering activities because of their lightweight, high stiffness and high specific strength. This paper discusses the manufacture of cenosphere-aluminium composites. Based on varied ratios of the reinforcement phase, fly-ash cenospheres – 6061 aluminium composite with better features in terms of strength, corrosion resistance and hardness and has been developed. The current work also brings out the structure – property correlation of cenosphere-aluminium metal matrix composite. It is found from the microstructure studies that there is a homogeneous distribution of the cenospheres in the matrix of Al 6061. The corrosion studies show that there is an increase in the corrosion pitting of the cenosphere-aluminium composite.

Keywords: *Aluminium 6061 composites, Cenospheres and Corrosion resistance.*

1.0 INTRODUCTION

Aluminium alloy 6061 is widely used in numerous engineering applications including transport and construction where superior mechanical properties such as tensile strength, hardness etc., are essentially required. Aluminium based metal-matrix composites (MMCs) reinforced with alumina particles or fibers possess enhanced physical and mechanical properties. Their lightweight, high stiffness, high fatigue strength and abrasion resistance, as well as their excellent performance at high temperatures make alumina-reinforced MMCs ideal for applications in aerospace, power utility, automotive, and military sectors [1, 2]. MMCs reinforced with continuous fibers offer outstanding specific strength and stiffness along the fibre direction when compared to those with particulate reinforcements that have more isotropic properties. Most research on alumina-reinforced MMCs has focused on their manufacturing and mechanical properties [3–7]. Fly ash is a particulate waste material formed as a result of coal combustion in power plants. The use of fly ash as a filler or reinforcement for aluminum alloys, called Metal Matrix Composites (MMC's), is, therefore, very desirable from an environmental standpoint. Fly-ash forms at temperatures in the range of 920–1200º C and is collected as precipitator ash (solid particles) and cenospheres (hollow microspheres) that float on collection ponds. Cenosphere has a low density of about 0.6 gcm^{-3}, and can be used for the synthesis of ultra-light composites materials, whereas precipitator fly ash has a density in the range of 2.0–2.5 gcm^{-3}. It can improve various properties

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of selected matrix materials, including stiffness, strength, and wear resistance. Incorporation of a second phase into a matrix material can enhance the physical and mechanical properties of the latter, thereby significantly changing its corrosion behaviour. The corrosion behaviour of metal-matrix composite is determined by several factors such as the composition of the alloy, the matrix microstructure, the dispersoid and the matrix, and the technique adopted for preparing the composite. A very small change in any one of these factors can seriously affect the corrosion characteristics of the metal [8]. It is reported that the properties of the composite increases with an increasing percentage of Silicon carbide used as a reinforcement with Al6061 composites [9]. From both an economical and environmental standpoint the use of fly-ash for reinforcing aluminum alloys is extremely attractive due to its waste material character and expected low costs of production. [8]

The published literature on advanced materials, such as Aluminium Fly Ash composites, is rather limited and is primarily concerned with applications of fly ash particles for synthesis of these materials. There is also a lack of information on the influence of cenosphere particles on the susceptibility of composites to wear resistance. Therefore, it was thought worthwhile to study:

(1) the microstructural characteristics of aluminium composites reinforced with cenosphere particles, and

(2) the relationships between the composite microstructure and corrosion behaviour. The present work is dedicated to such an investigation.

2.0 EXPERIMENTAL DETAILS

2.1 Melting Procedure

The cleaned metal ingots are heated to a temperature of 800-850^{0}C by placing in a graphite crucible. A filament winding type of induction furnace is used. A degassing agent in the form of Hexamethyelene di-amine is added during the melting period. Magnesium is added in small quantities to improve the wet ability of the reinforcement particles with the base matrix. Cenosphere particles are then preheated and added to the molten metal and then continuously stirred by using a mechanical stirrer for a duration of 10 minutes. The cleaned metal moulds are then prepared by bolting together each part tightly so that no leakage of aluminium takes place. The melt with the reinforcement was then poured into the preheated metal moulds. The pouring temperature was maintained at 520^0 C. The melt was then allowed to solidify in the moulds. To compare the properties the base alloy was then cast in the same procedure.

2.2 Hardness Test

Brinnel hardness test was conducted on the specimen using a standard Brinnel hardness tester. A load of 500 kgf was applied on the specimen for 30 seconds using a 10mm ball indenter and the indentation diameter was measured using a micrometer microscope. The hardness tests on the samples were conducted as per ASTM E-10-08.

2.3 Corrosion Test

The corrosion behaviour of the cast samples were studied by static immersion corrosion test to measure the weight loss. Cylindrical specimens of the composites and the pure metal were weighed before and after immersion in 3.5% sodium chloride solution. The immersion corrosion test was conducted as per standards ASTM D-6943-10 on the samples and weight loss for thirty five days were estimated. After the time duration of thirty five days the samples were cleaned with distilled water, rinsed with acetone , dried and weighed. Corrosion rates were computed using the equation

Corrosion rate = 534 W/DATmpy

Where W is the weight loss in mg, D is the density of the specimen in gm/cm^3, A is the area of the specimen in sq-inch and T is the exposure time in hours [10].

2.4 Microstructural Analysis

Test specimens were cut from the castings obtained to a size of 10 × 10 mm were metallographically ground using different emery papers of 220, 400 and 600 grit. These specimens were then polished using diamond paste. After polishing the specimens etching was carried out with Keller's reagent. Microstructures were taken using metallurgical microscope.

3.0 RESULTS AND DISCUSSIONS

After the samples are cast and then machined, the sample designations have been assigned.

3.1 Hardness Measurement

It is seen from the graph (Figure 1) that the hardness values have shown a significant increase. This is largely due to the fact that the cenosphere forms a hard reinforcement in the aluminum matrix. Addition of a hard phase to a soft ductile matrix leads to improved hardness [11]. This is the primary reason for the gradual increase in hardness when compared to the pure aluminium samples. This fact is also attributed to the homogeneous distribution of the cenospheres in the matrix as seen in the microstructure (Figures 2–7).

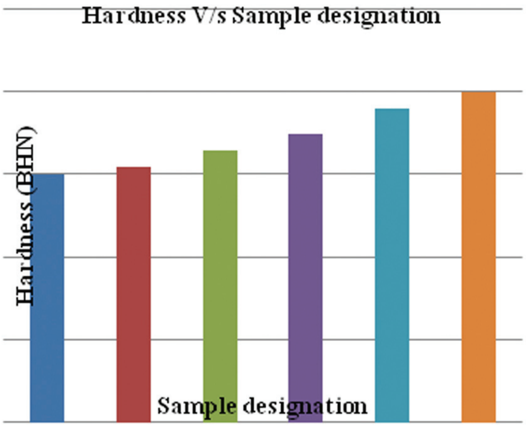

FIG 1. BHN V/S SAMPLE DESIGNATION.

Figures 2–7 are presented with optical microstructure photographs of pure aluminum 6061 and the samples with varying percentages of cenospheres as the reinforcement. It can be observed that the distribution of cenospheres (reinforcement) in the respective matrix is fairly uniform. The micrographs also clearly indicate the evidence of minimal porosity in both the pure aluminium as well as the composites.

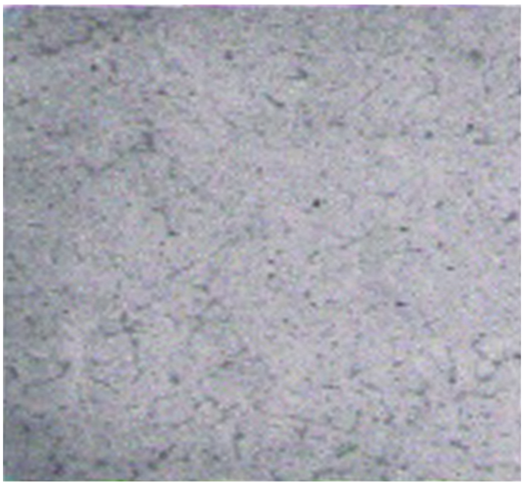

FIG. 2 MICROSTRUCTURE OF AL 6061 CE-0 (200X).

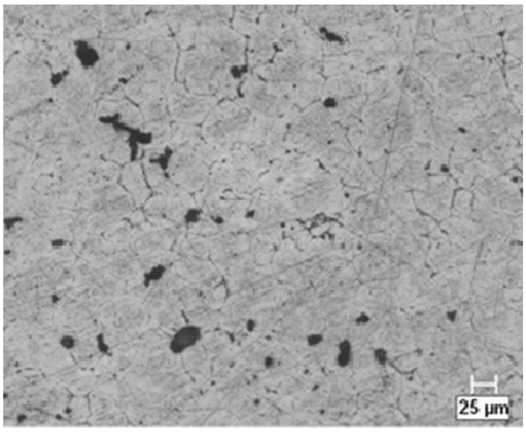

FIG. 3 AL 6061 2% CENOSPHERE (200X).

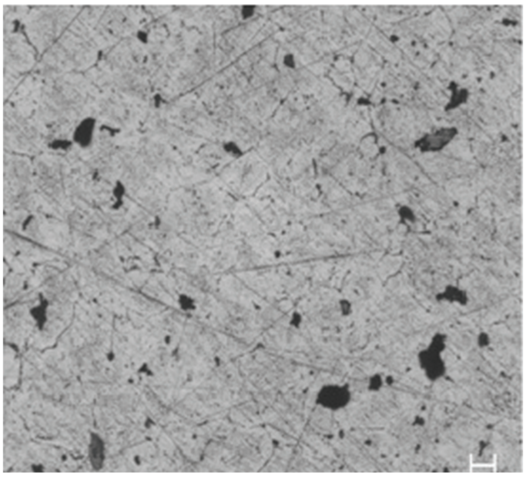

FIG. 4 AL 6061 4% CENOSPHERE (200X).

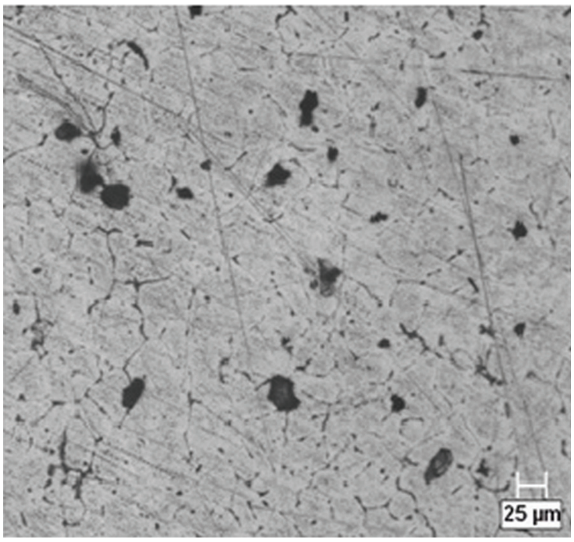

FIG. 5 AL 6061 6% CENOSPHERE (200X).

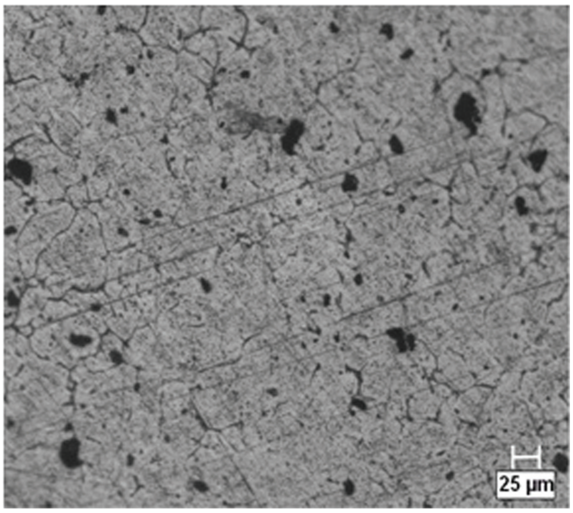

FIG. 6 AL 6061 8% CENOSPHERE (200X).

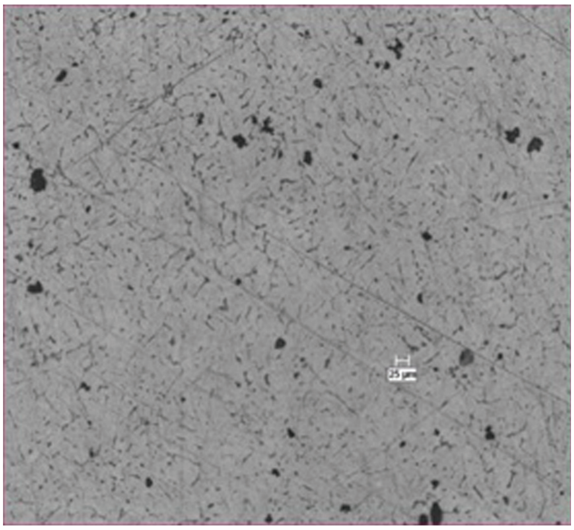

FIG. 7 AL 6061 10% CENOSPHERE (200X).

3.2 Corrosion Kinetics (Immersion Corrosion test)

Immersion test was conducted on all the samples as designated in Table 1. The samples were immersed in a solution of 3.5% sodium chloride for thirty five days and the weight loss was measured. The results of the weight loss experiments as a function of corrosion time *t* are shown in Table 1. It is seen from the table that the samples with increasing percentage of cenospheres have poor corrosion resistance as compared to the unreinforced counterparts. Cenosphere particles lead to an enhanced pitting corrosion of the cenosphere composite in comparison with unreinforced matrix. The enhanced pitting corrosion of cenosphere composite is associated with the introduction of nobler second phase of cenosphere particles and higher silicon content formed as a result of reaction between aluminium and silica. The same factors (i.e. fly-ash particles and higher silicon content) also determine the properties of oxide film forming on the corroding surface [8].

TABLE 1

IMMERSION CORROSION TEST RESULTS

Sl. No.	**Sample designation**	**Corrosion rate (mills /year)**
1	Al 6061 Ce-0	6.01×10^{-3}
2	Al 6061 Ce-2	5.4×10^{-3}
3	Al 6061 Ce-4	3.4×10^{-3}
4	Al 6061 Ce-6	2.42×10^{-3}
5	Al 6061 Ce-8	2.05×10^{-3}
6	Al 6061 Ce-10	1.8×10^{-3}

4.0 CONCLUSIONS

1. Samples having 10% of cenospheres have shown good improvement in hardness due to the presence of a hard reinforcement of cenospheres.
2. The increase in hardness has been attributed to the presence of hard reinforcement in the form of cenospheres,
3. The microstructure studies also confirm the presence of a cenospheres homogeneously distributed in the matrix.

4. Fly-ash cenosphere particles leads to enhanced pitting corrosion when compared to unreinforced samples as well as with an increase in the percentage of the cenospheres.
5. The increase in the pitting corrosion is attributed to the presence of a nobler second phase of fly ash particles.

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