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Development of Al2014/Nano Carbon Black Reinforced Aluminium Metal Matrix Composites

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ABSTRACT
Nano-metal-matrix composites (NMCs) are novel composite materials in which nano-phase such as nano-particles, nano-rods, nano-structured materials are reinforced with metals or alloys to improve the physical, mechanical, wear and other properties. The results of previous works have shown that the addition of nanoclay reinforcement to aluminium alloys has improved the hardness, tensile strength and Young's modulus. Hence, the present work is focused on development and characterisation of nanoclay reinforced NMCs. Evaluating the effect of the reinforcement on the important physical properties such as corrosion properties studies were carried out. The recorded results from all tests were discussed in detail with supporting evidences. Optical microstructures confirmed the incorporation of Carbon black in Al matrix. Grain size measurement was done by two phase linear analysis method and the SEM, optical microscopy and XRD were used to observe the microstructure for CB dispersion and the particulate distribution in the composites. It was observed that the distribution of CB particles in the matrix was even without any visible accumulation. It was noticed that there was an increase in density of the MMCs with the increase in the weight percentage of the reinforcement. The corrosion by weight loss of the composite decreased with increase in the weight percentage of the reinforcement. The conclusions drawn indicate the important results and outcome of the work.

Keywords: Nano-metal-matrix composites (NMCs), Aluminium alloys, XRD.

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INTRODUCTION

As the primitive man began his life on earth, started an endless search for materials to enhance his quality of life. Initially, he explored the nature around him and started using naturally occur- ring ceramics, composites and metals. When these materials no longer satisfied his needs, his attention turned towards synthesizing new materials. In the time span of hundreds of years, man gathered lots of information and knowledge about materials, their synthesis and usage [1]. The investigation on MMCs has turned into a significant region of research in the materials world. For the most part man made materials are mixed, which may have two or more extraordinary phases those have constrained together. The preliminary phase is called the matrix material, which possess a material with lower density for example, aluminium, titanium, steel and so on. The subordinate phase is the reinforcement, which are usually particulates, whiskers and fibers. Hence the composite material has significantly better mechanical properties and higher execution than any single material from which it is framed. Aluminum alloy composites as a substitute of monolithic aluminum alloy in structural applications, is becoming gradually attractive due to their greater strength, and stiffness, which is combined with their good performance in fatigue and wear [3]. The application of aluminum reinforced with carbon black, SiC and Gr particles is in automotive industry for part like pistons, engine blocks, brake rotors, drums, calipers, connecting rods, drive shafts, where the mechanical and tribological [4].

Preparation of the test specimen

In the present research work, Al2014 /Carbon black MMCs have been prepared by liquid metallurgical technique. The furnace used for the synthesis of the Al / carbon black particulate composite is basically an electrically heated three phase resistance furnace of 12 KW capacity as in Fig. 1 with grade-heating coils and reaches maximum temperature of 1200C (5 °C accuracy). The heating rate of the furnace is 25 °C per min (See Figs. 2 and 3). Carbon black particulates were preheated to remove moisture content and minimize the thermal gradient between the matrix and reinforcement by using a muffle furnace at a temperature of 500 °C. The melting temperature of Al alloy is 670–725 °C. A known quantity of the Al alloy ingots are cleaned with NaOH (10%) solution for ten minutes at room temperature, it removes impurity, grease and dust from the surface of the ingots. The washed and dried ingots placed in the alumina crucible for melting and heated for about 700 °C. The liquid melt was degassed by passing nitrogen gas for 1 min at a rate of 1000 cc/minutes. Pre- heated carbon black was poured into the molten liquid uniformly during into the vortex and stirred using a mechanical stirrer for ten minutes. The mixture of both carbon black and Al melts was poured into the metallic die and then allowed to cool until the room temperature. Specimens of the required dimensions were machined from the prepared castings and usually the middle portion of the castings was selected for this purpose. All specimens were polished for smooth surface finish with different grits of silicon carbide papers except those required for microscopic examination, which required further polishing.

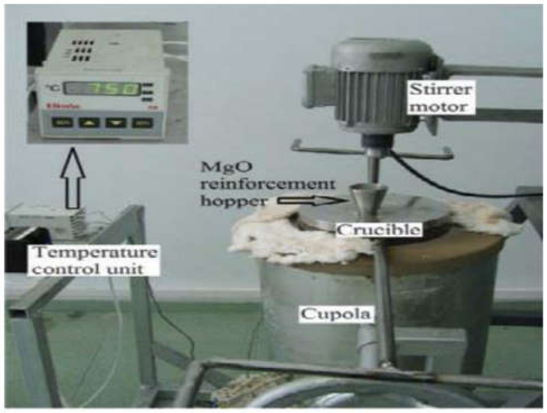

Figure 1: Furnace along with mechanical stirrer.

Characterization

In the present work, microstructural characterization of the Al- 2014 matrix alloy and Al2014/carbon black MMCs were done A detailed study in optical microscopy has been carried out using Scanning Electron Micrographs (SEM), in order to locate the particulate distribution in the composites. The specimens after sectioning were subjected to rough grinding, polishing and then with etching as per ASTM E3 standards. After usual machining and grinding, polishing was carried out by holding the specimen in hand and rubbing smoothly against the papers supported on a flat surface. As Al alloys are comparatively soft, sufficient care was taken to avoid any deep scratch being formed at the cross-section. Reflection type optical microscope fitted with a camera was used to take the micrographs of the samples. The magnification used was 250. The scanning electron micrographs (SEM) with EDS were taken for Al MMCs. The magnification used: 2000 and 2500. The composite was studied for corrosion behavior by the standard salt prays technique. It is a popular method to check the corrosion rate of metallic and coated surface specimens. The corrosion attack is checked after a specified time, as per the experimental standards. Some specimens require less or longer period of test time depending on the resistance offered by the material or coating standards. Some specimens require less or longer period of test time depending on the resistance offered by the material or coating due to corrosion. The salt spray test is one among the widely found corrosion tests. The internationally recognized standard test as per ASTM - B117 is performed using corrosion test chamber as shown in Fig. 4.

Figure 2: Pin-on-disc Wear test rig.

Figure 3: Al2014 alloy ingot.

Figure 4: Generally, the specimens are opened to fine fog of salt water at 35 °C temperature. The concentrated solution varies based on the material to be checked.

The wear and friction test was performed on all the specimens for loads of 10, 20 and 30 N and with rotational speeds of 200,300 and 400 rpm. The machine run time was set based on the speed selected. The pin weight was measured before and after each test to calculate the loss in the composite weight. The wear and friction force displayed on the monitor was noted down for further calculations. The surface morphology was studied under SEM.

RESULTS AND DISCUSSION

The prepared Al/carbon black nano-powder composites were analysed using optical microscopy for better understanding microstructural parameters, and also extended the same work corrosion studies. Analysing the composites provides a basis for comparison between matrix alloy and reinforcement in order to better understanding the effects of carbon black reinforcement on properties of the composites. Fig. 5 show the microstructure of Al/carbon black composites with different percentage of carbon black for a particle size of 60 nm. The size of the carbon black is in nanometer, it is very difficult to observe under optical microscope and even scanning electron microscope, and some voids are absorbed along with some black marks.

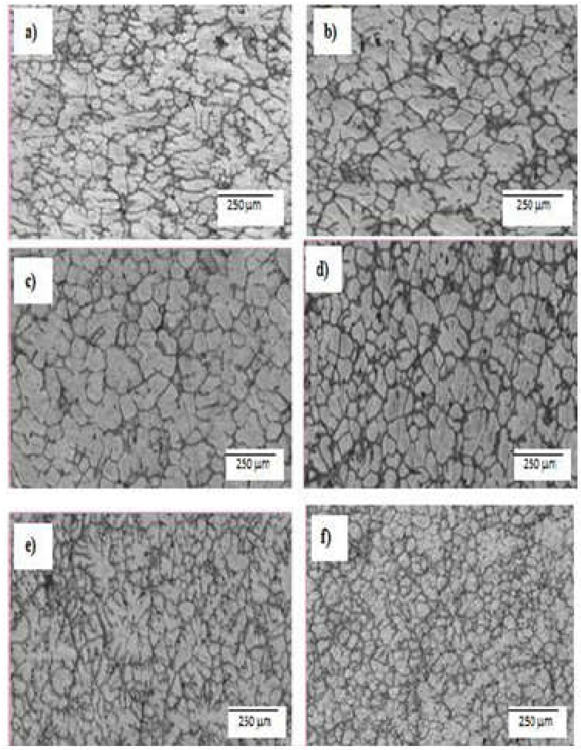

Figure 5: Micrographs of Al/ carbon black composites at different reinforcements a) as cast, b) 5%, c) 10%, d) 15%, e) 20% and f) 25% of carbon black.

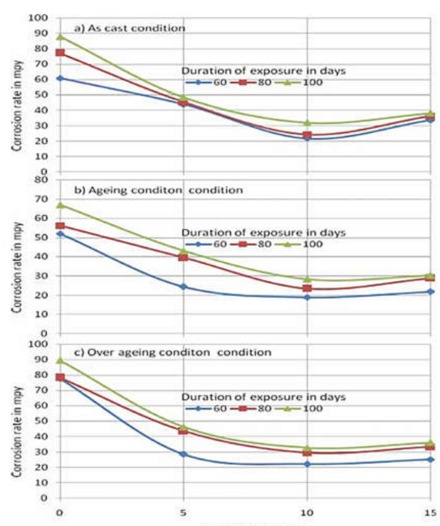

Figure 6: Effect of bath % carbon black and duration of exposure on Corrosion rate of Al/CB composites at a) as cast b) ageing and c) over ageing conditions.

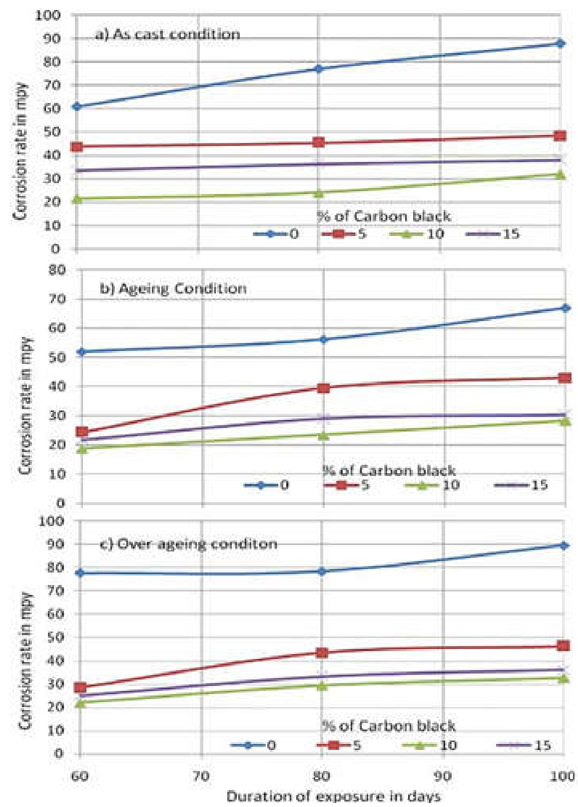

Figure 7: Effect of corrosion duration and wt% of CB in the composite on the Corrosion rate (mph) of Al/CB composites at a) as cast b) ageing and c) over ageing conditions.

Corrosion studies

The coated specimens were subjected to salt spray test i.e the corrosion test as described in the previous chapter. The corrosion rates were estimated and tabulated as in Appendix.

The corrosion rate values were plotted versus the varying% of carbon black and exposure duration to understand its behavior. The surface plots in 6 a) to c) and Fig. 7 a) to c) show the same for carbon black content of 5, 10 and 15%. It can be viewed from the graphs, that the corrosion rate has decreased when the wt.% of reinforcement is increased from 5 to 10%, but then again increased when % of carbon black is to 15%. Similar tendency can be seen even with the ageing conditions. However, the corrosion rate has decreased further for some cases like with temperature. On the whole, the corrosion rate seems to be a better value for the conditions of ageing condition and 10% carbon black.

To check the corrosion rate with weight % of carbon black in the Al matrix, two dimensional plots were graphed as shown in Figs. 7 and 8, considering the above obtained optimal coditions 10% of carbon black and medium ageing condition (See Fig. 9).

Also the corrosion rate of pure aluminium is taken for comparison. It can be understood from the graph that the corrosion rate has decreased with the addition of carbon black. For carbon black of 15%, the corrosion rate is slightly increased and with further increase in carbon black load, the corrosion rate has drastically increased.

The drastic increase in the corrosion rate may be due to the fact that with increased carbon black loading, the irregular and porous surface areas are exposed leading to higher corrosion [65]. Also, the crevice corrosion may dominate because of the more gaps formed on the porous surface.

Morphology of corroded surfaces

The morphology of the corroded specimens was captured after the weight loss test in 3.5 wt% of sodium chloride (NaCl) solution for 90 h, Fig. 9 shows the samples before and after corrosion test. It can be seen that the samples have undergone corrosion to some extent, but to understand the level of corrosion, SEM morphologies of the samples were taken. Fig. 9 a) to c) show some of the cor- roded images taken for samples under carbon black back of 5, 10 and 15% respectively. Two different magnified images are presented. In the case of 5% of carbon black (Fig. 9a), the surface mor- phology reveals small degree of corrosion containing small holes and pits due to the incorporation and uniform distribution of car- bon black particles in the composite coating. Similar trend is observed in the case of 10% carbon back loading (Fig. 9 b).

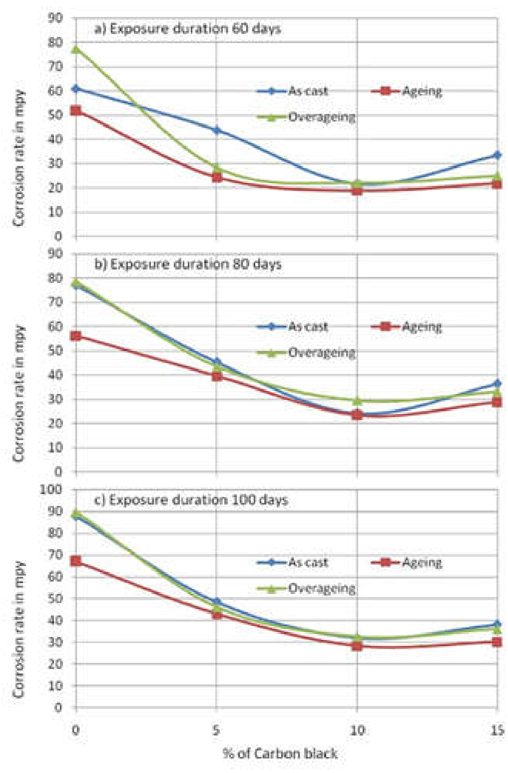

Figure 8: Effect of ageing and carbon black content on corrosion rate of Al/Carbon Black composites duration of a) 60 days, b) 80 days and c) 100 days.

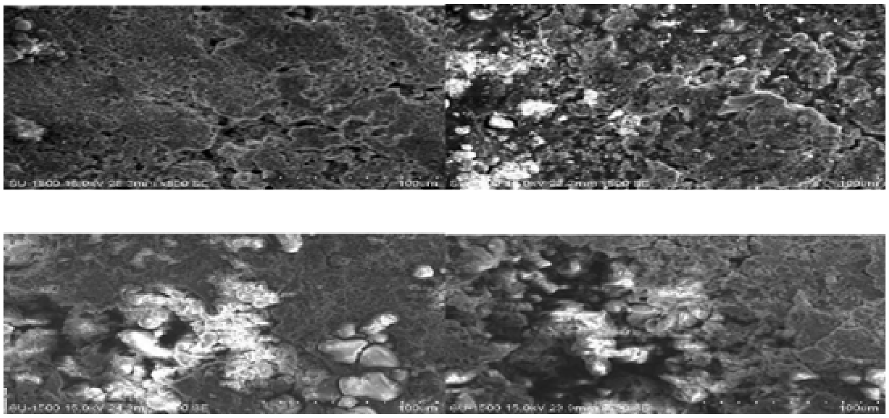

Figure 9: Corroded surface of a) Al, b) Al/5% CB c) Al/10% CB and d) Al/15% carbon black in 3.5 wt% NaCl solution for 100.

However, with higher carbon black of 15%, the surface morphology indicates more corrosion because of the non– uniformity of the reinforcement. The hydrogen bubbles that are formed at higher concentration, current density and bath temperature, hinder the carbon black particles from reaching the deposition areas and thus creating the pores. This porosity on the surface leads to more corrosion.

The reduction in corrosion rate may be due to the fact that car- bon black particles physically impede corrosion by filling the gaps and holes leading to uniform coating and so increase the corrosionpotential of the coating. Also, this avoids confined corrosion and leads to uniform corrosion, besides the increase in resistance to corrosion.

CONCLUSION

Materials selection, preparation and micro structural characterization for the Al/ carbon black nano-powder composites were studied. A homogeneous mixture of CB powder was made by mixing 0.5–15.0 wt% CB with solution by ultra sonication followed by drying using a magnetic stirrer. Grain size measurement was done by two phase linear analysis method and the SEM, optical microscopy and XRD were used to observe the microstructure for CB dispersion and the particulate distribution in the composites. It was observed that the distribution of CB particles in the matrix was even without any visible accumulation. It was noticed that there was an increase in density of the MMCs with the increase in the weight percentage of the reinforcement. Al/CB based MMCs when reinforced with garnet of weight percentage from 0 to 15% could be successfully produced by liquid melt metallurgical technique. The rate of corrosion of both the alloy and composite decreased with time duration. The corrosion rate of the composites was lower than that of the corresponding matrix alloy. The corrosion by weight loss of the composite decreased with increase in the weight percentage of the reinforcement. The corrosion rate is strongly dependent on the heat treatment conditions. By the heat treatment (T6) both matrix and composite possess greater corrosion resistance.

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