Flyash and carbon fibers reinforced aluminum-based matrix composite for structural applications

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Abstract: Aluminum alloy and its composite showed excellent physical and mechanical properties. But still, there is a scope in improving the mechanical properties of the composite for the structural, automobile, and aerospace industry. The composites have been prepared to reach the needs of the industry. In this present work, micro-fillers such as fly ash, and carbon fiber reinforcements were added to the base AA7076 matrix and fabricated the composite using a motorized stir casting technique. AA7076/fly ash and AA7076/carbon fiber composites were prepared by varying wt.% percent of fly ash and carbon fiber reinforcements (0.5, 0.75, 1, and 1.25 wt.%) and results were compared. The SEM micrographs revealed the homogeneous distribution of fly ash and carbon fiber reinforcements along the grain boundaries of the AA7076 matrix material. The composites with 1 wt.% of micro-fillers showed superior hardness and tensile strength as compared to other reinforcement composite and base matrix. The experimental test results revealed that the addition of fly ash and carbon fiber reinforcements improved the mechanical properties of the AA7076/fly ash and AA7076/carbon fiber composites as compared to the AA7076 matrix material. Among them, the comparative study revealed that the AA7076/carbon fiber composite has showed homogeneous distribution of reinforcements and improved mechanical properties.

Keywords: Aluminum alloy, Composite, Carbon fiber, Homogeneous, Mechanical properties.

1. INTRODUCTION

Increased demand for lightweight enhanced performing recyclable materials is the need of the hour for industrial applications. Metal matrix composites (MMCs) have made inroads into automotive and aeronautical sectors. They have advantages over polymer matrices as they possess higher elastic modulus, higher temperature applications, resistance to moisture absorption, and higher toughness and ductility. According to the Global MMC Market Report 2019, the linear growth of the MMC product has been predicted. It has increased from 5 to 7 million kilograms after 2012, while revenue jumped from 228.80 to 400 USD Million [1].

Cast MMCs are widely fabricated in the foundry industry. Al7075 is popularly used in the aircraft industry and has a high percentage of zinc while Al7076 has higher strength and is a relatively new material in the sector of aerospace. Requirement for innovative materials with increased strength to weight ratio is increasingly being used for varied applications [2]. MMCs consist of the primary constituent as metal, and the reinforcements involve metal, ceramic, or an organic compound[3–4]. The holding material includes different alloy and their superalloys. Several reinforcements ranging from micron (Carbon fibers, Kevlar) in size to nano (MWCNTs, Graphene, Al₂O₃, ZrO₂) and their hybrid combinations were used as strength fillers. In recent years metal matrix nano-composites have been
focused on production in the foundries. In such composites, the size of the reinforcements was in the range of nanometers. Homogeneous dispersion of strength filler coupled with the consolidation process facilitates the reduction of segregation problems. Also, properties of MMCs could easily be varied with their contents for the intended application or by changing the processing technique to excel in developing materials with enhanced features. Developed MMCs possess combined properties of its constituting elements, and their subsequent use in manufacturing for new products [5-6]. Several methods for the preparation of MMCs like Nanoscale dispersion, high energy ball milling, ultrasonic cavitation, and Stir casting have been adopted. Stir casting technique is the preferred and economical method when compared to powder metallurgy and is a widely used process.

Reinforced particles are dispersed in the molten metal and solidify the composite melt. This method has been used for large scale production of metal matrix particulate composites. Multi-walled Carbon nanotubes (MWCNTs) as fillers in Al6061 MMCs for structural applications has been reported in the literature [5-6]. MMCs were prepared with MWCNTs content of 0.25% and 0.50% by mass of metal matrix. Increased tensile strength of 60.58% for 0.25% and 107.94% for 0.5% nano-composites were reported when compared to pure parent aluminum alloy. Further hardness of the composites increased while their density compared to parent aluminum alloy. Sintering temperature affects the properties of graphene reinforced aluminum matrix composites.

The powder metallurgy process did graphene reinforced aluminum MMCs. SEM studies showed a dendrite microstructure indicating the formation of the Al4C3 phase due to the reaction between aluminum and graphene particles. The density and hardness of the samples depend on the sintering temperature, while compressive strength depends on the concentration of graphene reinforcement. The addition of graphene as reinforcement in the aluminum matrix increased the strength of aluminum [7]. Spark plasma sintering (SPS) method was used to prepare graphene-reinforced Al7055 composites with varied contents of graphene [8]. Structural and mechanical testing of the composites was carried out, and the results showed improved mechanical behavior with the addition of 1wt% graphene. A clean, strong interface was formed between the metal matrix and graphene via metallurgical bonding on the atomic-scale [8]. Potential challenges in the development of MMCs reinforced with both carbon nanofibers and carbon Nanotubes have been reported in the literature [9].

The present work focuses on reinforcing carbon fiber and Flyash into the Al7076 MMCs in different quantities. The filler concentrations were varied from 1% and 1.5% by mass) and analyzing the mechanical properties such as tensile strength, hardness, impact strength, wear property and density when compared to the parent metal alloy. FESEM, X-Ray diffraction (XRD) characterization was carried out to verify the homogeneous distribution of carbon fiber particles in AA7076 by Stir casting.

2. EXPERIMENTAL DETAILS

In the present investigation, AA7076 alloy was chosen as matrix material, and micro-fillers such as fly ash and carbon fibers are used as reinforcements. The Carbon fibers were coated with Ni before dispersion into the matrix. However, the fly ash was directly used to prepare the composite.

The Carbon fibers were subjected to electroless coating technique to deposit thin adherent nickel-phosphide coating. The detailed coating procedure is described as follows. A required weighed quantity of Carbon fibers were taken in a beaker, was soak cleaned by immersing into the propane, followed by acetone wash. A distilled water rinse followed this. This procedure was used to remove dust, oil, and other unwanted materials from the surface of the Carbon fibers. Thus, the cleaned Carbon fibers were immersed in nitric acid and vibrated. This is done to roughen the surface for further sensitivity and activation. A distilled water rinse followed this. The surfaces of Carbon fibers were sensitized for further activation in a solution of stannous chloride and hydrochloric acid (0.63 gms of Stannous chloride in 0.2 ml hydrochloric acid and 25 ml of water) followed by a distilled water rinse. The activated Carbon fibers were allowed to stay in the freshly prepared electroless Nickel bath. The chemical composition of the Nickel bath is shown in the table. The temperature of the bath was maintained at about 85°C. The duration for the coating was 30 minutes. The pH of the bath was maintained at 4.5. Ni-P coated Carbon fibers were then thoroughly cleaned in distilled water and dried by heating in an oven at a temperature of 50°C for 60 minutes.
Table 1. Bath composition for electroless nickel deposition

| Sl. No | Bath constituents | Quantity (g/liter) |
|-------|-------------------|-------------------|
| 1     | Nickel Chloride, hexahydrate (NiCl₂,6H₂O) | 30                |
| 2     | Sodium Succinate, hexahydrate (Na₂C₄H₆O₇.6H₂O) | 10                |
| 3     | Sodium Hypophosphite, monohydrate (NaH₂PO₂, H₂O) | 20                |
| 4     | Glycin (H₂NCH₂COOH) | 10                |
| 5     | Lead Nitrate (Pb(NO₃)₂) | 0.02              |

Table 1 reveals the chemical composition of AA7076 material. For the fabrication of AA7076/fly ash and AA7076/carbon fiber composites, the fillers were added at 800°C. A motorized stir casting technique was used for uniform distribution of filler reinforcements in the AA7076 matrix material. The AA7076 matrix material was heated to its melting point temperature. Fillers were added to molten melt at 800°C. The melt was stirred using a controlled motorized stirrer for 5 minutes. The molten composites were poured into a preheated metallic mold. The rectangular plate of AA7076/carbon fiber and fly ash composite fabricated for further mechanical testing as ASTM standards. This procedure is repeated for different wt.% of carbon fiber particles.

3. RESULTS AND DISCUSSION

The results and discussion section describe the work into two sections. The first and second sections explain the comparative work done on microstructural and mechanical properties of the AA7076/fly ash and AA7076/carbon fiber composites fabricated through the motorized stir casting technique.

3.1. The Microstructure of AA7076/fly ash and AA7076/carbon fiber composite.

The morphology, density, and reinforcing materials used in the fabrication of composite and its homogeneous distribution in the matrix material play a vital role in influencing the behavior of the composites for structural, automotive, and aerospace applications. It is a basic need in the casting process to distribute the particles or fibers uniformly across the matrix material. Also, segregation and agglomeration of reinforcements have to reduce, so that the required properties of the composite has achieved successfully.

The micron-sized fly ash particles, as received from the thermal power plant, were added to the AA7076 matrix and distributed uniformly using a motorized stir casting technique. Similarly, micron-sized carbon fibers were added to the AA7076 matrix and fabricated uniformly through the motorized stir casting technique. Figure 1 shows the micrographs of AA7076/1wt.% fly ash and AA7076/1wt.% carbon fiber composites. The micrographs (figure 1 (a) and (b)) revealed the size of the fly ash particles and carbon fiber reinforcements. Both the filler materials are in micron size. The figure 1 (c and d) revealed the homogeneous distribution of reinforcements (fly ash and carbon fiber) in the base AA7076 matrix material. The homogeneous distribution of the composite may be due to the proper application of the stirring process adopted during the casting process. The motorized stirring process helps to distribute the reinforcements uniformly along the grain boundaries of the matrix alloy and also reduces the agglomeration and segregation of the composite. Figure 1 (c and d) also depicts that the level of porosity has been reduced and indicating the prominence of the motorized stir casting technique. These reduced casting defects in the processing of the composite improved the properties of the composite.

The energy dispersive spectroscopy analyses (figure 1 (e) and (f)) explains the interfacing between the reinforcements and the AA7076 matrix material. The peaks show the availability of the materials in the fly ash, such as elements of Al₂O₃ and MgO. Similarly, for the carbon fibers, C and MgO. This confirms the presence of fly ash particles and carbon fibers in the composites. This analysis helps to understand the type of elements present in the tested composite sample.
Figure 1. SEM micrographs and elemental mapping of AA7076 composite reinforced with 1 wt.% fly ash and carbon fiber, respectively.

3.2. Mechanical properties of AA7076/fly ash and AA7076/carbon fiber composite

Figure 2 shows the comparative study of the hardness of the AA7076/fly ash and AA7076/carbon fiber-reinforced composites. The figure revealed that the addition of reinforcements increases the hardness of the composites. The improved hardness of the composites is due to the homogeneous distribution hard and high strengthened particle and fiber reinforcements. The reduced porosity, agglomeration, and segregation of the reinforcements in the composite also enhance the hardness of the composite. The carbon fiber-reinforced composite shows superior hardness as compared to fly ash composite. The composite having 1 wt.% reinforcements shows the superior hardness as compared to base AA7076 matrix material. The fiber reinforcements were coated with Ni-P, gives substantial hardness to the fibers, thereby increases the hardness of the fiber-reinforced composite. The fiber-reinforced composites show superior hardness as compared to fly ash reinforced composite.
The composite materials used for the engineering applications are usually chosen based on their properties, such as yield strength, ultimate tensile strength, and modulus of elasticity. The tensile test is the most common method for determining these mechanical properties.

Figure 2. Comparison between the hardness of the AA7076/fly ash and AA7076/carbon fiber-reinforced composites.

Figure 3. Comparison between the yield strength, UTS, and percentage elongation of the AA7076/fly ash and AA7076/carbon fiber composites.

Figure 3(a, b, and c) shows the comparative study between the yield strength, UTS, and percentage elongation of the AA7076/fly ash and AA7076/carbon fiber composites in comparison with the base AA7076 matrix alloy. The tensile strength of the composites increases with an increase in the reinforcements. The addition of fly ash particle and carbon fiber reinforcements increases the tensile strength of the composite (0.5, 0.75, and 1 wt.%). The increase in the tensile strength of the composite is due to the hard fly ash, and Ni-P coated carbon fibers distributed uniformly along the grain boundaries of the AA7076 matrix material. The homogeneous distribution of reinforcements in the matrix alloy, achieved through the motorized stir casting technique, enhanced the interfacial bond between reinforcements (fly ash and carbon fiber) and the AA7076 matrix. The strong interfacial bond between reinforcements and matrix reduces the dislocations, thereby reduces the crack growth.
As observed in the micrographs of the composite, the motorized stir casting technique reduced the casting defects such as porosity, agglomeration, and segregation. These parameters influence the development of the tensile strength of the composite.

The bar graphs revealed that a further increase in the reinforcements (1.5 wt.%) decrease in the tensile strength of the composite. The decrease in the tensile strength of the composite is due to the agglomeration of the reinforcements in the base matrix alloy.

4. CONCLUSION

The following conclusions are drawn from the present investigation:

- AA7076/fly ash and AA7076/carbon fiber composites have been fabricated successfully by using a motorized stir casting technique.
- SEM micrographs revealed the homogeneous distribution of reinforcements (1 wt.% of fly ash and 1 wt.% carbon fiber) along the grain boundaries of the AA7076 matrix material.
- The addition of fly ash and carbon fiber improved the hardness and tensile strength of the composite as compared to the base matrix. AA7076/1 wt.% carbon fiber composite showed higher hardness and tensile strength.

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