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Review Article

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Impact of Fly Ash on the Aluminium Metal Matrix Composites: A Review

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Abstract

Composite materials are gaining popularity in the advanced 21st century because of their excellent characteristics in a wide range of fields, including transportation, architecture, engineering, the construction industry, sports, medicine, and the biomedical field. Enhancements in performance in the sectors of aviation and automobiles drew a lot of attention to aluminum metal matrix composites (AMMCs). Nowadays, factories are releasing a wide variety of trash into the environment. All garbage has an effect on the natural world. Fly Ash (FA), a by-product of thermal power plants, contributes to pollution. Despite this, there are numerous modern applications of FA. Because they are inexpensive, low in density, and widely accessible as waste byproducts in a thermal power generating plant, FA particles may find application in metal matrix composites (MMCs). This research explored using FA as a reinforcement in various composites, beginning with those made of pure aluminum and progressing to hybrid composites that combine the two materials. This article aims to observe the morphology characteristics of AMMCs, including their wear resistance, in addition to their mechanical characteristics, including hardness, tensile strength, flexural strength, and impact strength. According to the available literature, stir casting is the most extensive utilized method for processing materials in the liquid state because of its ease of use and low production cost.

Keywords

Aluminum based composites, Fly ash, Mechanical properties, Dry sliding wear

Introduction

Background on the development of modern composites can be traced back to the 1930s. The performance of polymer-based composites sparked a wide variety of fields of study in the 1960s. Intelligent materials, including alloys, ceramics, and composites, are the result of materials science research [1]. After rupturing of matrix, structural damage, spalling, and crack propagation plagued automotive and aviation applications [2-4] in the 1970s, AMMCs made with particles of silicon carbide (SiC) whisker were introduced as an alternative material [5]. MMCs are composites made from two or more different materials (a metal matrix with metal or non-metal reinforcement). The base metal attains improvement in characteristics in the mechanical and tribological aspects [6-10] when ceramic reinforcement is added to the matrix. It has been determined that, both technically and economically, casting with stirrer is the superior way. For AMMCs production, stir casting has many benefits, including simplicity, adaptability, scale, and the ability to create complex parts [11].

Materials and Methods

Matrix material

The matrix material constitutes the bulk of a MMC, as it is responsible for providing the composite's overall structure and binding the reinforcement particles together. Matrix materials for the production of MMCs include aluminum, magnesium, copper, iron, and titanium [12-15].

Reinforcement material

A crucial step in making MMCs is the use of reinforcement materials. Matrix materials can have their properties altered by incorporating these in varying percentages [16].

Fly ash

FA, a byproduct of burning coal, is widely available in the developed countries of the world. This includes the United States, the United Kingdom, Canada, and China. FA production in Canada averages about 5 million tons per year [17]. Bituminous coal combustion results in FA of class F, while lower grade coal combustion results FA (class C). Since there is less calcium oxide in class F, it is more suitable for the synthesis of Aluminum Matrix Composites (AMCs) than class C. Al_2O_3, SiO_2, and Fe_2O_3 are the most abundant oxides in the FA, with K_2O, NaO, and MgO also present. FA's high oxide content makes it a useful material for AMC synthesis. Additional defining features of FA include its low density and low cost [17].

Fabrication method for AMMCs

According to the research compiled here, MMCs can be prepared using a number of distinct fabrication methods. In this study, we focus on one specific method for manufacturing MMC: the stir casting method. In the manufacturing of MMC, stir casting is used to create a wide variety of intricate and asymmetrical shapes [18, 19]. A barometrically controlled heater melts metal in the form of powder, plates, or ingots. The molten base matrix metal can be supplemented with reinforcements like ceramic metal or supplementary metals at any time, with or without preheating. In order to incorporate the reinforcements into the molten metal, a stirrer is used. After MMCs have solidified in a mold, they can be removed for further processing [20]. Figure 1 depicts the stir casting process.

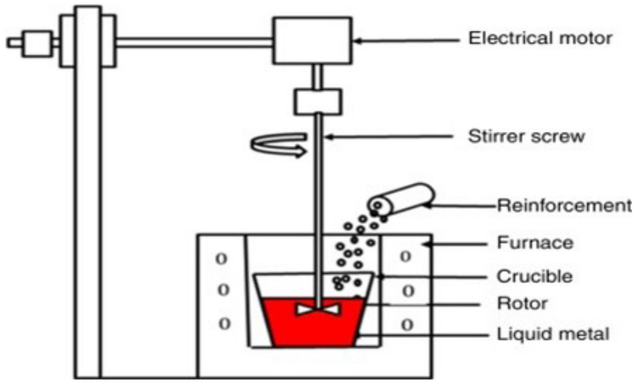

Figure 1: The stir casting procedure is depicted here in a simplified schematic form.

Discussion

Effect on mechanical properties of the AMMCs

For estimating the applicability of the produced composites, mechanical properties play the vital role. So, there is a need to test the sample mechanically. A number of studies provide a comparison of fabricated MMCs to their native material. Mechanical tests consist of hardness and tensile tests mainly. Some works describe the impact strength and flexural strength.

In the race of material advancement, Rao et al. fabricated the Al6061-(5/10/15 wt.%) FA MMC using the stir casting technique. The microstructure and hardness of composites were investigated. The manufactured composite has a hardness value of 80.79 BHN, which is remarkably greater than the hardness value of 53.45 BHN of Al 6061 alloy (shown in figure 2) [21]. Furthermore, Kumar et al. investigated the tensile strength of AMMC, in which Al-3 Cu-8.5 Si doped with FA (3, 6, 9, and 12 wt.%) having different sizes of 50 - 75, 75 - 103 and 103 - 150 µm. As the FA wt.% was raised, the tensile strength of the composites improved. 3 wt.% FA composites reinforced with 53 - 75 µm particles had the lowest tensile strength (245 MPa), while 12 wt.% FA composites reinforced with 103 - 105 µm particles had the highest tensile strength (320 MPa) [22]. In further study, Raja et al. incorporated FA (0, 4, 8, and 12 wt.%) in the AA6061 matrix by using compocasting technique. AA6061/12 wt.% FA AMC exhibits 132.21% higher microhardness. Figure 3 shows that when compared to unreinforced AA6061 alloy, the Ultimate Tensile Strength (UTS) of the reinforced version is 59% higher [23]. Adding FA and SiC to the AA6061, Raja et al. fashioned similar composites using the stir casting technique. The tensile strength of the composite is improved dramatically by

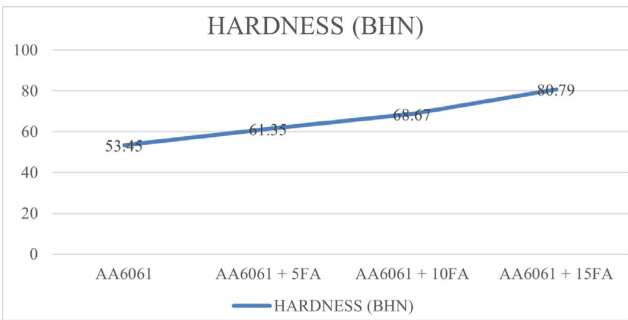

Figure 2: Variation in hardness with the change in FA fractions.

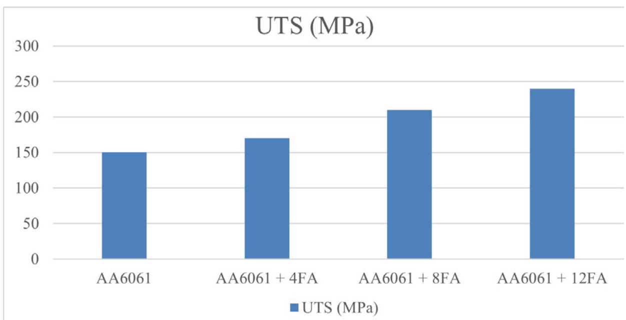

Figure 3: UTS variation with respect to the FA.

the incorporation of SiC and FA particles, going from 173 MPa to 213 MPa. The mechanism of load transfer through the reinforcement may be to blame. The micro and macro hardness of the composites rose from 69.53 HV and 49.4 BHN, respectively, to 78.8 HV and 57.21 BHN after the addition of SiC and a constant weight percentage of FA particles. It has been observed that the formation of the needle-like aluminum carbide (Al_4C_3) phase can be suppressed by adding FA to the SiC_p preforms [24].

Stir casting was also used by Sathishkumar et al. to produce Al359 and FA + SiC (0, 2.5, 5, 7.5, and 10 wt.%). All of the test parameters showed that the samples' tensile property was relatively stable up to 2.5%, and then gradually decreased after that. The values of hardness have followed a similar pattern. When more FA than necessary is added, as much as 10%, the resulting dilution behavior causes the binding behavior of the SiC particles over the Al359 matrix to oscillate [25]. Sathishkumar et al. took a similar approach by reinforcing A356 composites with boron carbide and fly ash (2.5%, 5%, and 7.5% wt.%). Aluminum alloy A356 can have its maximum hardness raised to 152 Vickers by adding 7.5 wt.% each of B_4C and FA [26]. Also, Kumar et al. embedded Al-Mg-Si-T6 aluminum alloy with FA concentrations of 0%, 5%, 10%, and 15% and B_4C concentrations of 2.5%, 5%, and 7.5%. Tensile strength is increased to 184.72 N/mm^2 by using a hybrid composite made up of 5% FA and 5% boron carbide. The hardness of Al-Mg-Si-T_6 alloy was raised from 56 to 61 Rockwell, an increase of 11.3% when compared to the unreinforced alloy, by adding 7.5% boron carbide and 5.0% FA. Reinforcement particles increase hardness, but 20% FA decreases it, because particles clumped [27]. While maintaining a constant wt.% of FA, i.e., 4%, and varying the Red Mud (RM) fractions from 2% to 8% in the Al6061 alloy, Parashurama et al. prepare the samples using a stir casting technique. Comparing the UTS of the base alloy, which is 48.3 MPa, to that of the sample, which is Al6061/4 wt.% FA/8 wt.% RM, it was found that the latter has a UTS of 112.1 MPa, indicated in figure 4a [28]. Using the stir casting route, some of the samples prepared by Kumaravel et al. include: 90% Al + 2.5% Basalt fiber ash (BFA) + 7.5% FA; 90% Al + 5% BFA + 5% FA; 90% Al + 7.5% BFA + 2.5% FA. The addition of FA to the first composition (90% Al-6061 + 2.5% BFA + 7.5% FA), as displayed in figure 4b, has increased the impact strength of the aluminum matrix [29].

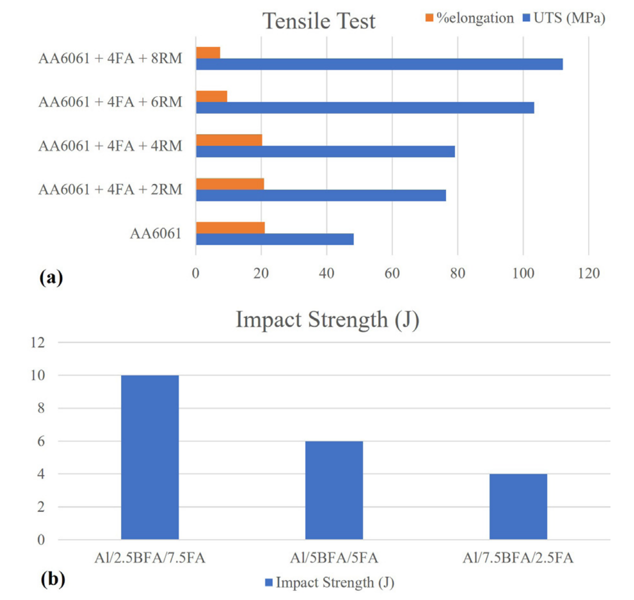

Figure 4: (a) Effect of FA and RM on the tensile properties of AA6061 and **(b)** Effect of BFA and FA on the impact strength of Al.

Effect on wear rate of the AMMCs

The primary advancement in materials research right now is aimed at enhancing tribological properties, specifically wear resistance in already existing metals. Insight into metal deformation and performance degradation can be gained from observing this phenomenon. Stir casting was used to create a composite with Al-4.5Cu as the matrix metal and FA and SiC at 5, 10, and 15 wt.%. This work was done by Mahendra et al. Wear rates were found to be inversely proportional to the number of particles present. The abrasive properties of FA and SiC could be to blame for this. Castings with narrower diameters show less wear than those with wider ones [10]. Using stir casting, Uthayakumar et al. have prepared AMMCs containing AA6351 and FA at 5, 10, and 15 wt.%. Experiments showed that after adding more FA to the mixture, the wear resistance properties of the composites were still present despite being subjected to lighter loads. The composites also showed some less wear with increasing sliding speed [30]. Furthermore, because of its lubricating properties, graphite (3 wt.%) was chosen by Prasat et al. in a combination with FA (3, 6, and 9 wt.%) and embedded in Al-Si-10Mg to boost performance against dry sliding wear. The Pin-on-Disc machine underwent a wear test. Hybrid composites exhibited an abrasive wear mechanism that worsened with increased load [31]. By combining FA and epoxy resin at varying concentrations (5%, 10%, 15%, 20%, and 25% wt.%), Prathipa et al. have developed a novel composite material. The wear rate of the sample (Al6061/25% FA/15% Epoxy Resin) is lower than the average (0.00282 mm^3/Nm).

Using finer reinforced particles and regulating the particle size present in the AMMC's can improve their mechanical properties [22], as noted in a review of the relevant literature. Literature review reveals that wear rate is influenced by a number of factors including average load, sliding velocity, sliding distance, and fraction of reinforcement. Wear during MMC testing is typically dependent on the average load applied.

Conclusion

- The aerospace, automotive, and defence sectors find extensive use for AMMCs.
- Because of its technical and cost advantages, stir casting is the preferable method for producing AMMCs.
- It has been discovered that the input framework of stir casting—including rpm of stirrer, stirring time, stirring temperature, and impeller shape—has a major effect on the performance of the composite.
- Grain refinement, uniform dispersion, and interspacing of reinforcement particles in the fabricated composite material all contribute to improved mechanical properties.

- The average load, slid distance, slid velocity, and reinforcement weight percentage of a wear test are all important factors in determining the wear behaviour of a manufactured composite.

Acknowledgements

None.

Conflict of Interest

None.

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