Experimental analysis of microstructure and mechanical characteristics of LM6 & fly ash composite through stir casting method

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Abstract. Fly ash has received a lot of attention as a possible support for aluminium alloy composites (AMCs) to improve characteristics while lowering production costs. Al alloy MMC was made with different amounts of fly ash (2, 5, and 8%). The semi-solid state mould was gradually filled with reinforced particles. The optical microscope investigation of the microstructure of AMCs reveals homogenous fly ash dispensation. With the increase in fly ash particulate, the microstructure with refined composition displays reducing Si-needle structure and extending space of eutectic-Al grid space. While hardness increases by 88 percent, tensile strength increases by 57 percent and yield strength by 17% of the AMCs with the increment of fly ash. The addition of fly ash particles improved the AMCs’ physical and mechanical qualities. As a result, it leads to upgrade the energy utilisation.

Keywords: LM6, Fly ash (FA), microstructure, mechanical properties, Stir Casting, Metal Matrix Composites (MMCs)

1. Introduction

Automobile industry is continually striving towards decrease of fuel utilization by limiting the vehicle weight without compromising its performance which leads towards choice of lightweight materials [1]. Aluminium, one of the lightest primary material, most abundantly accessible is broadly utilized because of simple accessibility, high strength and stiffness to weight proportion, simple casting process, simple machinability, sturdiness, pliability and flexibility [2]. Consequently auto businesses are progressively supplanting ferrous segments with aluminium and aluminium alloys, for example, Intake manifolds, extra sections, low-load sections, oil container, valve covers, alternator covers, and water pumps [3]. Aluminium matrix composites are used in various applications i.e automotive, aerospace, defence, because of its excellent strength-to-weight ratio, stiffness-to-weight ratio, temperature stability, and abrasion and wear resistance [4] [5] [6] [7]. As a result, in this research, an approach to fabricating and analysing Al-based composites has been developed. Furthermore, as compared to base metal, depending on the reinforcement mix and volume percent of the reinforcement, provide better estimations of specific strength, stiffness, wear resistance, fatigue, corrosion, and creep. In the aviation, space, and automotive industries, AMCs play a critical role. as a result of these improvements in characteristics, [8]. Metal matrix composites offer the automobile sector a chance to decrease vehicle weight, improve execution
Aluminium due to the attractive properties is utilized in automobiles [9] [10]. The LM6 alloy is a eutectic alloy with an aluminium content of 85.95 percent and a silicon content of 11 to 13 percent. It's a common alloy for automotive and aerospace applications because of its resistance to hot cracking, pressure tightness, die-filling capacity, and corrosion resistance. [11]. Because of their low cost and superior performance, particulate reinforced aluminium matrix composites (AMCs) are a great alternative for these applications. [12] [13] [14] [15]. However, traditional reinforcements such as SiC, B4C, Al2O3, BN, TiB2, and others are prohibitively expensive. To minimise the cost of production, traditional reinforcements must be replaced by low-cost reinforcements such as rice husk, FA, natural minerals, and so on. Fly ash is an affordable, easily accessible reinforcement with improved mechanical characteristics, such as strong electrical resistance, low thermal conductivity, and low density etc [10].

There are two kind of FA particles: cenosphere and precipitator. By and large, the strong spherical - particles of FA are called precipitator and the empty cylindrical particles of FA with density under 1.0 g/cm³ are called cenosphere. In the current work precipitator FA is chosen as reinforcing particles in AMMC. The current work makes an endeavour to combine the Al alloy – fly ash (strong) composites (2, 5, 8% weight of FA) was employed using a stir casting method to explain increased mechanical characteristics such as hardness, density, and tensile strength. Weight reduction, enhanced composites life, and greater recyclability are all potential benefits that should be considered. but cost is the most important issue for AMCs more widespread adoption in today's industry. [16] [17]. Simpler fabrication procedures, bigger production volumes and less expensive reinforcements are the only ways to save costs[18]. These composite materials provide vehicle makers a new product option to improve performance while lowering costs. Different traditional strategies have been utilized to manufacture AMCs with various types of reinforcements which incorporate yet not restricted to powder metallurgy [19], mechanical alloying [20], squeeze casting [21], compo casting [22] and spray deposition [23]. The processing method additionally impacts the properties of the AMCs. As of late, research on FA as a filler and support in MMCs has been developing. Just simple casting technique, huge amount or volume creation of mmc using less expensive reinforcement can minimize the expense of MMCs. Stir casting, also known as liquid metallurgy, is the most cost-effective method of producing MMCs out of all the numerous casting techniques available. [24] [25]. Arun L.R. et al. [26] revealed that a definitive elasticity has likewise improved with increment in Fly Ash weight rate and contrasted with base metal it has expanded by 23.26%. Dr. Selvi. S et.al [27] investigated the mechanical properties of AL-MMCs and found that the hardness of the Al-MMC composites improves as the FA content enhances. Vivekanadan et al. [28] revealed that the rigidity has improved with increment in FA content. This is because of wide size scope of particles. In this way, composite fortification is due to scattering fortification, just as of molecule support. However, pliability has diminished with increase in FA content. Mahendra Boopathi et.al [29] announced an expanding pattern of hardness was seen with increment in weight part of SiC and fly debris. Greatest hardness is seen at Al/(10% of SiC+10% of FA). P.K. Rohatgi [30] detailed that the pliability of the composite reductions with increment in the weight division of strengthened FA and diminishes with increment in molecule size of the FA. Be that as it may, for composites with over 15% weight division of FA particles, the rigidity is accounted for to be diminishing. Sudarshan et al. [31] examined portrayal of A356 AI - FA composites with particles of limited reach (53 -106 μm) and in wide range (0.5 - 400 μm) and announced that expansion of FA lead to increment in hardness, versatile modulus and 0.2% confirmation stress. Basavarajappa et al. [32] explored the mechanical properties of Al2024, an aluminium alloy with SiC and graphite particles. Their findings revealed that the composite's mechanical characteristics improves prevalently with the expansion in volume part of fortification. Present investigation aims to carry out further work on micron size (150 – 175) of fly ash which was mainly not mentioned in most of the research work which plays a vital role in performance enhancement of MMC.

Table 1: Chemical Composition of LM6
Table 2: Details of Class F Fly Ash powder

| Product name | Class F Precipitator Fly ash |
|--------------|-----------------------------|
| Particle size| 150 μm                      |
| Color        | Grey                        |
| Form         | Solid Spherical             |
| Density      | 2.2 gm/cc                   |

Table 3: Chemical Composition of Class F Fly Ash

| Composition | Al₂O₃ | Fe₂O₃ | SiO₂ | Na₂O | TiO₂ | CaO | MgO | K₂O | P₂O₅ | Mn₂O₃ | SO₃ | LOI |
|-------------|-------|-------|------|------|------|-----|-----|-----|------|-------|-----|-----|
| %           | 29.61 | 10.72 | 49.45| 0.31 | 1.76 | 3.47| 1.3 | 0.5 | 0.53 | 0.17  | 0.27| 1.45|

2. Experimental Details

2.1 Material fabrication

In this current work, Aluminium has been employed as matrix material and FA particle with micron size of (150 – 175 μm) were used as the particulate materials. In this work, Al - fly debris composites were manufactured with a differing weight % of fly debris (2, 5 & 8) and Magnesium (1.5 wt %) by two phase mix projecting strategy. The FA particles were preheated in a muffle furnace to 600ºC for 2 hours to eliminate the moisture availability and moreover make oxide layer on the particulates which overhauls the mixing limit of the particulates with the base metal. The graphite crucible was charged with aluminium, and the temperature was elevated above the liquidus temperature of 750ºC to melt the Al scraps absolutely and further the temperature was dropped to beneath the liquidus temperature to accomplish the semi-strong state. Magnesium and a short time later preheated FA particles were poured in the crucible of bottom poured furnace. Mg was blended into the mould to propel successful wetting between Al composite and FA particles. The liquid Al composite slurry was mixed at the stirrer speed of 400 rpm for 20 minutes. Since high power was needed in mixing of the composite slurry in semi-solid state, a variable power - speed controlled mechanical stirrer was used. The dispersing of fly ash and magnesium with aluminium were refined by the two phase mix projecting cycle. Finally the composite soften was warmed to 750ºC and filled the 50 mm cylindrical steel mould to solidify.

Figure 1: Bottom Poured Stir Casting Resistance Furnace
2.2 Microstructure
In this examination, microstructural concentrate through optical magnifying instrument was done on as-projected composites. Test was cleaned by emery paper of evaluation 120, 180, 400, 800, 1200, 1500, 2000, 2500, 3000. Followed by velvet fabric cleaning with non-ferrous cleaning fluid for scratch-free mirror completing shine. Further the examples are carved by Keller's etchant establishes Keller's-nitric corrosive 2.5 ml, hydrochloric corrosive 1.5 ml, hydrofluoric corrosive – 1 ml with 100 ml refined water. The compositional assessment of the as-cast alloy and composites is accomplished during elastic and hardness tests. Tests for these tests are set up from as-projected bars through processing, moulding, turning and cleaning.

2.3 Tensile Test
In the current investigation, Composites were put through a tensile test utilizing UTM. Examples were machined with standard measurements by following ASTM E-10. Three samples were tested for every composition and mean value was considered for UTS, elastic modulus, tensile strain and yield stress.

2.4 Hardness Test
The micro hardness of the manufactured composites was measured using a HUL micro hardness analyser (Model-VMHT MOT, Technische Mikroskopie) in accordance with ASTM standard E384-99 in the current investigation. For indentation on example surfaces, a diamond indenter is used, and a 50 gmf load is applied with a 15-second holding time. Every sample is indented five times in five different regions. The hardness analyzer is connected to a computerised system that captures space marks using a high-tech camera. The hardness value is determined by examining space impressions.

3. Results and discussions
3.1 Composite microstructure
The morphological structure, intensity, type of particulate strengthening, and distribution of the particulates all have an impact on the properties of particle composite materials. The solidifying velocity, fluidity, quite reinforcement, and therefore the inclusion technique are the variables that control particle dispersal. The particulates are spread equally throughout the casting using wettability during the manufacturing process, and subsequently segregation/agglomeration of particulates occurs during the pouring process. Magnesium was added to improve wettability. At various places, the particle distribution of microstructure was examined. Figure 2 depicts the optical microstructure of Al alloy-FA composites (a to c). The grain boundary was detected after the etching process, and the well-established modules were discovered before the etching procedure, based on these images. Because the segregation was controlled by gravity, a non-uniform distribution of Al alloy and fly ash particulate occurs. While the micrographs revealed consistent distributions of particle debris. The distribution of fly ash particulates is relatively homogeneous. It demonstrates that the matrix phase and reinforcements phase have strong interfacial connection. As the percentage of fly ash increases, some agglomeration occurs. Optical micrographs also reveal the presence of equiaxed grains in manufactured composites. The presence of equiaxed grains indicates that fly ash particulates caused recrystallization. In the micrographs of MMC, similar distributions of particulate matter of fly ash were identified. The Physical and mechanical properties of composite are heavily influenced by particle distribution.
Figure 2. Optical images (500X) of composites (a) Al-2% FA (b) Al-5% FA (c) Al-8% FA

3.2 Tensile Test

Figure 3 to 9 demonstrates the graphical representation of UTS, elastic modulus, yield strength & tensile strain of the composite materials with 2, 5 and 8 % of fly ash particulates. From the figure, it is found that the composite materials UTS with upto 8 % fly ash is enhanced by 57 % than its base alloy (112 MPa). There is substantial increase (100.3 %) of elastic modulus. It is also found that yield strength increases by 16.97 % on enhancement of fly ash particulate. However tensile strain of the composite enhanced by 44.11 %. Therefore, as the amount of FA particle in the composite increases, the mechanical characteristics of the composite improve.
Figure 3. Tensile test of Fabricated Composite specimen with 2% of FA

Figure 4. Tensile test of composite specimen with 5% of FA

Figure 5. Tensile test of composite specimen of 8% of FA
Table 4: Mechanical Properties

| Mechanical Properties/ Fly Ash % | 2   | 5   | 8   |
|----------------------------------|-----|-----|-----|
| Tensile stress at Maximum Load (MPa) | 136.14 | 152.95 | 175.82 |
| Young’s Modulus (MPa)             | 17400 | 19750 | 25046 |
| Yield stress (MPa)                | 98.79  | 100.91 | 115.56 |
| Tensile strain at Maximum Load    | 1.827  | 2.282  | 2.633 |

Figure 6: Elastic Modulus of MMCs with different wt % of fly ash

Figure 7: Yield stress of MMCs with different wt % of fly ash

Figure 8: Tensile Stress of MMCs with varying wt % of FA

Figure 9: Tensile strain of MMCs with varying wt % of FA
3.3 Micro Hardness Test

Figure 10 demonstrates that the hardness of composite materials with various weight percents of fly ash particulates, represented graphically. When the fly ash particle weight fraction is raised, the hardness improves by 88 percent, as seen in the graph. As a result, the maximum hardness of MMC is found at 8% fly ash particulate, resulting in deformation when subjected to strain.

Table 5: Micro hardness of MMCs for different wt % of fly ash

| Fly Ash | Base Metal | 2 | 5 | 8 |
|---------|------------|---|---|---|
| VHN     | 120.3      | 129.8 | 161.3 | 226.2 |

Figure 10. Hardness value of composite with different wt % of fly ash

4. Conclusion

Based on the data supplied, the following conclusions can be drawn:

- In this examination Al – fly debris miniature composites are created by utilizing Stir casting method.
- As the weight level of FA added increases, the mechanical properties of the composites, such as hardness, ultimate tensile strength, and Young's modulus, increase.
- Optical micrographs have shown that fly debris particles have been all around dispersed all through the aluminum composite. It unmistakably shows that the increment of consistency in molecule circulation leads better mechanical properties. So there is no uncertainty in that the utilization of this material in automobile and space sector will be degree for what's to come.
- Fly ash would be widely used in the manufacturing of composites in enterprises because its use in composites may transform mechanical waste into modern values.

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