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# Impact of Fly-Ash on the Flexural and Microstructural Properties of Aluminum Composite

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**Abstract:** Fly ash has gained the widespread attention of researchers in aluminum matrix composite (AMC) production as reinforcement to enhance the properties of AMCs and reduce the production cost. This work was carried out in order to explore the impact of the flexural and microstructural properties of fly ash on the Aluminum composite. In this research, aluminum alloy was reinforced with different amounts (10, 20, 30 and 40 wt. %) of fly ash. The alloy, reinforced with fly ash were fabricated by stir casting method. The AMCs were then characterized based on their flexural strength, flexural modulus and microstructural analysis (phase analysis). The results showed that the flexural strength gave an optimum strength of 314.3040 N/mm² at 30wt% and flexural modulus of 25807.1107 N/mm² at 10wt%. These results showed that the addition of fly-ash improved the properties of the composites. This were further confirmed through the microstructural analysis which showed a good interfacial bonding between the reinforcement and the matrix. This composite can be applied in automobile industry for the production of machine parts like the motorcycle hub, etc.

**Keywords:** *Aliminium alloy; Fly-ash; Aluminium Matrix Composites (AMCs); Flexural Properties; Microstructural Properties.*

## 1. Introduction

Composite materials are novel substances derived by the macroscopic combination of two or more constituent materials. Two or more materials are combined to create composite materials, which offer novel thermal and mechanical behavior with reference to intricate loading systems and operating circumstances. Because of their superior stiffness to density ratios, increased corrosion resistance, and high strength, composite materials are utilized to create multi-objective structures including fluid reservoirs, transmission pipes, heat exchangers, and pressure vessels (Mohsen, 2023).

Aluminum and its alloys have garnered significant interest as the base metal in metal matrix composites (MMCs), which are metals reinforced with other metals. These alloys offer superior malleability, low weight, high strength, superior corrosion resistance, easy machining, and good thermal and electrical conductivity (Khalid *et al.*, 2023; Kar *et al.*, 2023). Advanced metal-matrix composites with exact balances of mechanical, physical, and tribological properties are produced when ceramic particles are used to reinforce aluminum and its alloys. The resulting aluminum matrix composites provide an unparalleled combination of qualities that are currently unmatched by any monolithic material on the market (Ahmed *et al.*, 2016).

In recent years, researchers have become very interested in the creation of aluminum matrix composites (AMCs) reinforced with industrial and agro-waste materials. Numerous advantages are provided by AMCs, including low cost, great strength, excellent mechanical and physical qualities, low density, and favorable thermal characteristics (Osunmakinde *et al.*, 2023). AMCs have been reinforced using a variety of industrial (fly ash, red mud) and agro-waste (rice husk ash, bamboo leaf ash, ground nut shell ash, bagasse) materials (Seikh *et al.*, 2022; Ervina Efzan *et al.*, 2021). Among them, fly ash is the least expensive waste material with low density that may be easily obtained and found in big amounts. It is a waste product that is visible as the residues that exit furnaces and is produced when coal is burned in thermal power plants. It is created by the mineral compounds found in coal. The majority of these mineral compounds are found in ceramic spheres made of aluminosilicate, with trace numbers of spheres rich in iron. Ash particles can be divided into two categories: precipitator (solid particles) and cenosphere (hollow particles). Due to its notably low density (0.6 kg/cm3), tenosphere fly ash can be utilized in the synthesis of ultralight composites, whilst precipitator fly ash can be employed to enhance the stiffness, strength, and wear resistance of matrix materials. (Ervina *et al.*, 2017).

The use of fly ash can optimize the mechanical properties of the base metal, according to prior research on aluminum-reinforced materials (Emekwisia *et al.*, 2024). However, these studies are only applicable to certain base metals, such as aluminum alloys Al-8FA and AA6061, as well as aluminum 7075 alloys. (Juang and Li, 2022). Kumar *et al.*, 2018 investigated the flexural properties of aluminum matrix composites reinforced with varying percentages of fly-ash content (5%, 10%, and 15%). They discovered that the composite with 10% fly-ash had the highest modulus and flexural strength. They attributed the improvement to the fly-ash particles' strong interfacial interaction with the aluminum matrix. The modulus showed a declining return beyond this percentage, perhaps because to increased porosity and particle agglomeration.

Singh *et al.*, 2020 studied the effect of fly-ash particle size on the flexural properties of aluminum composites, with 5% to 20% fly-ash by weight. Their findings showed that, as a result of a more uniform distribution and improved bonding within the matrix, smaller fly-ash particles (10% weight) contributed to increased flexural strength and modulus. Subsequently, a decrease was noted at elevated concentrations as a result of inadequate particle dispersion and elevated void content. Aluminum composites containing fly-ash particles of different sizes (10 µm, 20 µm, and 30 µm) were studied by (Patel *et al.*, 2017). The flexural modulus of the composites was found to be higher in those with smaller fly-ash particles because of improved interfacial bonding and load transmission efficiency.

Sharma and Mehta, 2019 used microstructural analysis to study the interfacial bonding in aluminum-fly-ash composites. They came to the conclusion that because the stress transfer between the reinforcement and matrix was more effective at well-bonded interfaces, there was a noticeable increase in flexural modulus.

This study therefore aimed at the use of stir casting method to study the impact of fly ash addition ratio on the flexural and microstructural properties of ALFA composites.

## 2. Materials and Methods

### *2.1 Materials*

The materials and equipment used includes; Calcium carbonate powder, Water, Gloves, Aluminum scrap, Sand Crucible, Furnace, Shovel, Brush, Trowel, Rammer, Riddle, Draw spikes, Clamps, Stirring rod, Crucible, Laddle, Engine oil, Fly ash, Aluminum foil and Ingots, Silica Sand, Binder, Airtight container, Vernier-caliper, Ruler, Weighing balance. Microstructural observations were conducted with these materials: 2.5ml Nitric acid ($HNO_3$), 1.5ml Hydrochloric acid (HCl), 1ml Hydrogen fluoride (HF), 95ml distilled water, the beaker, the Applicator or brush, the gloves, and eye google.

### *3.0 Methods*

### *3.1 Preparation of the mold*

In order to make the aggregate acceptable for molding, silica sand and calcium carbonate ($CaCO_3$), which is used as a binding agent, were combined with water. This strengthened the sand and allowed for plasticity. Sand molding provides accuracy and is reasonably priced.

### *3.2 Steps in mold making*

The method of mold making consists of six steps:

- To make a mold, draw a pattern on the sand.
- Use sand and the pattern in a gating system; otherwise, remove the pattern.
- Pour molten material into the mold cavity.
- Permit the substance to cool.
- Take out the casting and break off the sand mold.

### *3.3 Preparation of the furnace for melting.*

- Collecting the Aluminum: The leftover aluminum was collected, and the contaminants were extracted from the body by peeling them off.

- Furnace setup: After heating the furnace to the proper temperature, charcoal was placed underneath it and it was ignited.

- Preheating: The crucible was placed inside the furnace along with additional melting equipment.

- Assembling the Blower: The blower was positioned next to the furnace to force heated air and oil into the furnace through the ducts.

- Setting up the Blower: A blower was placed next to the furnace to force hot air and condemn oil through the ducts into the furnace.

- Melting and Pouring the Aluminum Mold: After the aluminum sheets were heated to 700 degrees Celsius, they were taken out of the furnace using a ladle and poured into the mold through the runner, which allowed the oil to emerge from the riser.

### *3.4 Heat treatment process*

In order to optimize the properties for the fabrication of composites, the aluminum sheets were heat-treated before being cast. The fly-ash reinforcement was thermally treated to lower its carbon content and increase its pozzolanic reactivity. The particle size distribution was uniformly achieved through mechanical milling, which helped to promote dispersion in the aluminum matrix.

### *3.5 Stir casting process*

Using mechanical stirring, the fly ash was combined with the molten metal matrix in this process. This is a process where large sized composites can be manufactured in a highly economical way. The key process parameters during this process include a number of variables such the distribution of the reinforcement material, wettability, porosity of the cast composites, and the chemical reaction between the matrix and the reinforcement material. Fabrication of MMC using this process involved the use of aluminum as a matrix along with the combination of 10%, 20%, 30%, and 40% weight fraction of fly ash, which was done with a stirring rod in crucible still soaking at approximately 700$^{o}$C.

### *3.6 Flexural strength*

A three-point flexural setup was used for the Flexural Strength test. The specimen size was cut according to the specifications of the equipment. The same Universal Testing Machine (UTM) is used to conduct the test. After inserting the test specimen into the apparatus, force was applied to it until it broke and fractured. Stress vs. strain graphs are produced, and the bending strength at peak was recorded. (Emekwisia *et al.*, 2020).

### *3.7 Flexural Modulus.*

The flexural modulus test specimen was cut to the proper dimensions for the testing apparatus. It was inserted into the flexural machine with three points. When force is applied, the specimen flexes and breaks. The same Universal Testing Machine (UTM) was used for this test. Stress vs. strain graphs were created and the bending modulus (MPa) was recorded. (Emekwisia *et al.*, 2020).

### *3.8 Mass Fraction Expression*

The mass fraction is the amount of mass of one substance, divided by the mass of the total mixture. It can also be expressed, with a denominator of 100, as percentage by mass. (In commercial contexts often called percentage by weight, abbreviated wt %). Mass fraction (wt %) was determined with this expression;

Wt% = $\frac{m}{m\ total} \times 100$ **Eqn. 1**

For 3g($W_1$); Wt% = $\frac{W_1}{W_1 + W_2 + W_3 + W_4} \times 100$ **Eqn. 2**

For 6g($W_1$); Wt% = $\frac{W_2}{W_1 + W_2 + W_3 + W_4} \times 100$ **Eqn. 3**

For 9g($W_1$); Wt% = $\frac{W_3}{W_1 + W_2 + W_3 + W_4} \times 100$ **Eqn. 4**

For 12g($W_1$); Wt% = $\frac{W_4}{W_1 + W_2 + W_3 + W_4} \times 100$ **Eqn. 5**

### 3.9 Microstructural/Optical Analysis.

Following the casting process, the microstructural observations was conducted to study the internal structure of the cast specimens. Metallographic analysis techniques were employed, involving sample preparation, grinding, polishing, etching, and microscopic examination using a metallurgical microscope. The prepared specimens were mounted and ground to achieve a smooth surface. Polishing was performed meticulously to remove any surface imperfections that could interfere with the microstructural observations. Etching was carried out using suitable chemical reagents to reveal the microstructure clearly. The specimens were then examined under a metallurgical microscope to study the grain structure, grain boundaries, and other microstructural features. This analysis was employed to gain a comprehensive understanding of the cast specimens. It was utilized to determine the percentage purity of aluminum and Fly Ash, as well as trace elements. This information is crucial for accurately calculating the charge composition and alloying process.

## 4 Results and Discussions.

### *4.1 Determination of mass fraction (%) of fly-ash composites.*

From the Equations 1 to 4 above, the mass fraction values were determined as follows;

For 3g($W_1$); $\text{Wt\%} = \frac{3}{3+6+9+12} \times 100 = 10\%$

For 6g($W_1$); $\text{Wt\%} = \frac{6}{3+6+9+12} \times 100 = 20\%$

For 9g($W_1$); $\text{Wt\%} = \frac{9}{3+6+9+12} \times 100 = 30\%$

For 12g($W_1$); $\text{Wt\%} = \frac{12}{3+6+9+12} \times 100 = 40\%$

**Table 1.** Mass Fraction of Each Al-FA Composite

| Aluminum- Fly Ash Composites (g) | Mass Fraction of AL-FA Composites (%) |
|---|---|
| 3g | 10% |
| 6g | 20% |
| 9g | 30% |
| 12g | 40% |

### *4.2 Flexural strength*

The flexural strength test of the composite specimens was conducted with variations in wt% of fly-ash, and tested in the universal testing machine (UTM). The Flexural strength versus fly-ash wt% graph was generated as presented in Table 2 and Figure 1 below,

**Table 2.** Flexural Strength of AL-FA Composites.

| Samples of AL-FA Composite (wt%) | Flexural Strenght (N/mm$^2$) |
|---|---|
| 0% | 89.188 |
| 10% | 311.819 |
| 20% | 220.2083 |
| 30% | 314.3040 |
| 40% | 190.170 |

The results for the flexural strength (MPa) of the Al-FA composite as in Figure 1 were analyzed. The flexural strength for the composite showed that at 30wt%, the optimum strength was obtained, while at 0%, the minimum strength was obtained. This increase in 30wt% might be due to the excess reinforcement particles in the aluminium metal composite. The excess particles caused the development of pores in the composite leading to the development of a crack propagation thereby making the material more brittle than ductile. At the optimum strength of 314.3040MPa, the aluminium matrix and the fly ash reinforcement achieved an optimum bond with low porosity level on the addition of 30%wt. of fly ash.

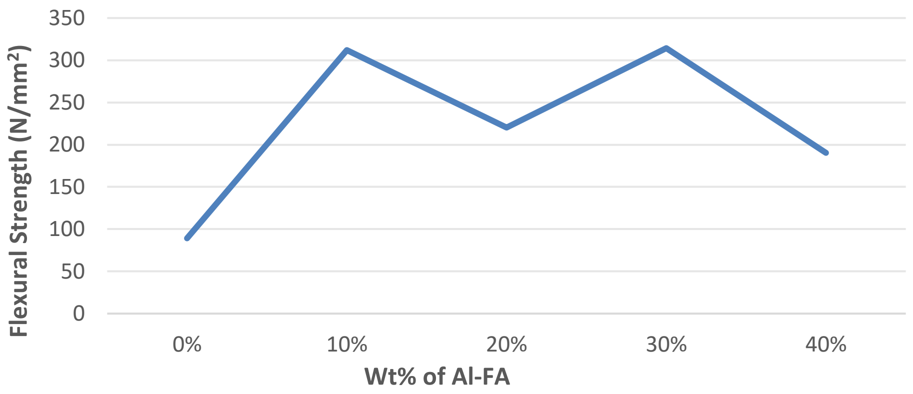

**Figure 1.** Graph of flexural strength of Al-FA Composite

### *4.3 Flexural modulus*

The experiment for the flexural modulus of the composite specimens was conducted with variations in wt% of fly-ash, and tested in the universal testing machine (UTM). The result generated were presented in Table 3 and Figure 2 below,

**Table 3.** Flexural Modulus of AL-FA Composites.

| Samples of AL-FA Composite (wt%) | Flexural Modulus (N/mm$^2$) |
|---|---|
| 0% | 10707.6690 |
| 10% | 25807.1107 |
| 20% | 22816.8137 |
| 30% | 16447.8350 |
| 40% | 12101.995 |

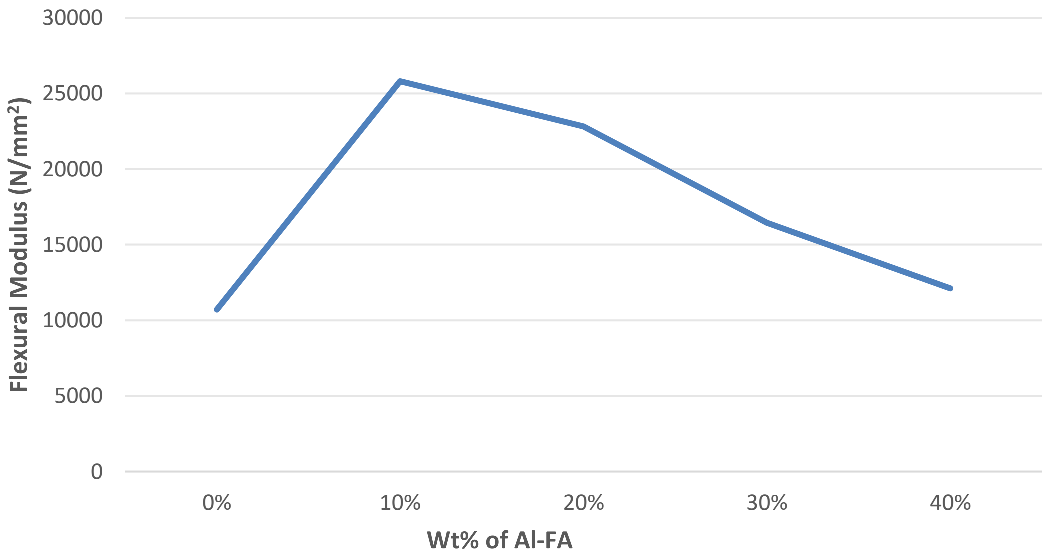

**Figure 2.** Graph of Flexural Modulus of Al-FA Composite

The results for the flexural modulus (MPa) of the Al-FA composite as in Figure 2 were analyzed. The result showed that at constant increase in wt% of fly-ash, the flexural modulus experienced a continuous decrease till it got to the maximum weight (40wt%). It reached its optimum point at 10wt% of fly-ash. This suggests that the fly-ash particles caused pores creation in the composite leading to brought about propagation of crack, thereby making the material more brittle at this point. The composite therefore was observed to reach the optimum flexural modulus at 25807.1107MPa, as the matrix and the reinforcement at 10%wt. of fly ash obtained stronger bonding.

### *3.4 Microstructural Analysis*

As seen in Figures 3–7, the microstructural examination of the composite was examined and interpreted. The composite samples' photo-micrographic components underwent analysis and interpretation. The fly ash particles' distribution and morphology, as well as the composite's structural features, particle size distribution, and interfacial bonding, were all disclosed by the microstructure of the materials.The primary reinforcement (FA) partially formed intermetallic phases with aluminum and partially dissolved in the aluminum solution, strengthening it.

**Figure 3.** Al - 0%wt of fly ash

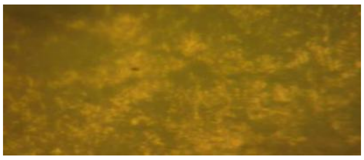

**Figure 4.** Al – 10%wt of fly ash

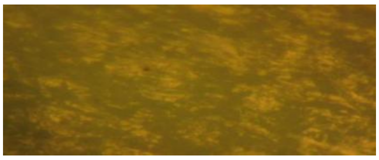

**Figure 5.** Al – 20%wt of fly ash

**Figure 6.** Al - 30%wt of fly ash

**Figure 7.** Al – 40%wt of fly ash

## Conclusion

This research was done to find out the impact of fly ash composite on the flexural properties of Aluminium fly-ash composite. From the observations, the following conclusions were drawn; the aluminium composite showed optimum flexural strength and modulus on the addition of 30%wt. and 10%wt. of fly ash respectively. This showed that at these points, the fly ash aluminium composite possesses ultimate strength, and experienced a strong decline at the 0%wt (unreinforced composite). These observations were further revealed through the microstructural analysis.

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*Compliance with Ethical Standards:* This article does not contain any studies involving human or animal subjects.

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