Production and Characterisation of Aluminium-Fly ash composite using Stir Casting Method

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Abstract:

Stir casting is one of the simplest ways of producing aluminum matrix composites (AMCs). This work focuses on the fabrication of AMCs reinforced with various weight percentages of respective particulates and a constant weight percentage of Fly Ash by modified stir casting route.Metal matrix composites (MMCs) have greatly improved properties including high specific strength; Specific modulus, damping capacity and good wear resistance compared to unmodified alloys. There is increasing interest in composites with low density and low-cost consolidated validation. Among the various simulators used, fly ash is the cheapest and low-density aggregator available in large quantities as a solid energy byproduct during coal horns in thermal power plants. Therefore, composites with fly ash in the form of consolidation are likely to pose a cost constraint for a wide-spread range in building and small engine production. It is therefore expected that the incorporation of fly ash particles into the active alloy will promote another use of this low-cost waste byproduct and, at the same time, has the potential to conserve energy intensive energy and thus From, Reduces costs online products. Now-a-days particulate reinforced alumina matrix composites are gaining importance due to low cost with benefits such as isotropic properties and the possibility of secondary processing to facilitate fabrication of secondary components. The present investigation has focused on the use of plentifully available industrial energy fly-ash to produce composites by the stir casting method in order to disperse it by accident.

Key words: - composites, industrial waste, applied load and sliding velocity

1.Introduction

The production of composite materials has gained significant attention in recent years due to their unique properties, such as improved mechanical, thermal, and electrical properties, compared to their constituent materials. One such composite material is the aluminium-fly ash composite, which is produced by combining aluminium and fly ash using stir casting method.

Stir casting method is a widely used technique for producing composite materials, which involves mixing the reinforcement material (in this case, fly ash) with the molten metal (aluminium) using a mechanical stirrer. The mixture is then cast into the desired shape and allowed to cool and solidify.

The aluminium-fly ash composite has gained attention due to its lightweight, high strength, and low cost. Fly ash, which is a waste material produced during the combustion of coal, is used as the reinforcement material due to its high silica content, which improves the mechanical properties of the composite. Aluminium, on the other hand, is used as the matrix material due to its low density and excellent mechanical properties.

The production and characterisation of aluminium-fly ash composite using stir casting method involves several steps, including sample preparation, mixing of the materials, casting, and characterisation of the composite material. The characterisation of the composite material involves various techniques, such as microstructure analysis, mechanical testing, and thermal analysis, to determine the properties of the composite material.

Overall, the production and characterisation of aluminium-fly ash composite using stir casting method offers a promising approach for the development of lightweight and high-strength composite materials with low cost and environmental impact.

2.Composite

Composite materials are materials made from two or more different materials that are combined to create a new material with improved properties. The individual materials, known as the matrix and the reinforcement, retain their own physical and chemical properties but work together to enhance the overall performance of the composite material.

The matrix material is typically a polymer, metal, or ceramic material, while the reinforcement material is usually in the form of fibers, particles, or flakes, made of materials such as carbon, glass, or aramid.

Composite materials can offer a range of benefits over traditional materials such as improved strength, stiffness, durability, and corrosion resistance, while being lightweight and easy to shape. These properties make them attractive for use in a range of applications, including aerospace, automotive, construction, and sports equipment.

Composite materials can be manufactured using various methods, including layup, injection molding, pultrusion, filament winding, and compression molding. The selection of the manufacturing method is based on the properties required, the complexity of the final product, and the cost-effectiveness of the method.

Composite materials are an exciting and rapidly growing field of materials science, and ongoing research and development are expected to lead to new and innovative applications for these materials in the future..

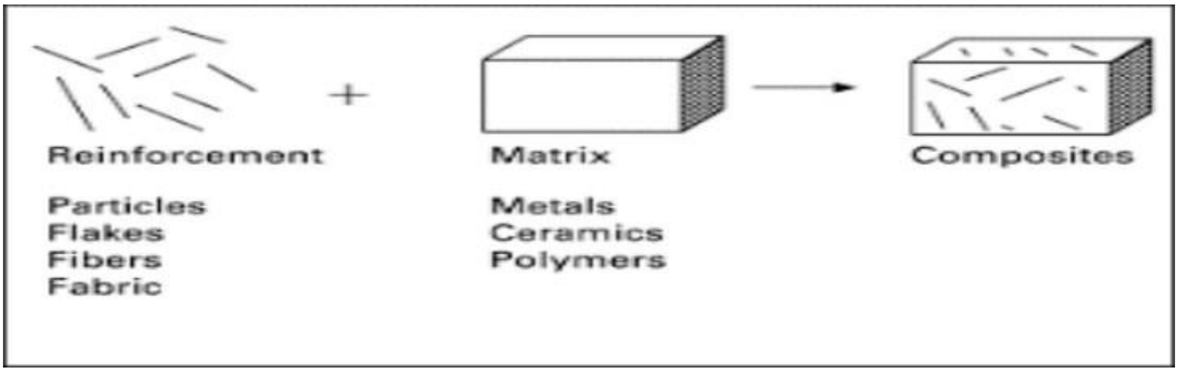

Fig 1: Schematic Diagram of Composite material

Performance of Composite depends on:

The performance of a composite material depends on several factors, including:

1. **Matrix material:** The properties of the matrix material, such as stiffness, strength, and ductility, can greatly affect the overall performance of the composite material.
2. **Reinforcing material:** The type, size, and orientation of the reinforcing material can greatly affect the mechanical and physical properties of the composite material.
3. **Interfacial bonding:** The strength and durability of the bonding between the matrix and reinforcing materials can greatly affect the performance of the composite material.
4. **Manufacturing process:** The manufacturing process can affect the properties of the composite material, such as its porosity, void content, and fiber alignment.
5. **Environmental conditions:** The performance of the composite material can be affected by exposure to various environmental factors, such as temperature, humidity, and chemicals.
6. **Loading conditions:** The performance of the composite material can also be affected by the type

and magnitude of the load applied, such as tensile, compressive, or shear loading.

7. **Design factors:** The design of the composite structure, such as its geometry, thickness, and shape, can also affect its performance.

Composite mainly divided into two parts:

a. Reinforcement
b. Matrix

2.1.1 Reinforcement

Reinforcement in the context of composite materials refers to the substance that gives the composite its strength and rigidity. Fibres, particles, or sheets embedded in a matrix material can serve as reinforcement. A composite's reinforcing material performs a variety of crucial tasks, including as improving certain characteristics, increasing toughness, and providing strength and stiffness.

The unique application of composite material determines the choice of reinforcing material. In composites utilised in aircraft applications, carbon fibres, for instance, may be used as a reinforcing material. When it comes to automated automobile applications, glass fibres can be utilised. To optimise the qualities of the composite for intended uses, the orientation, size, and form of the reinforcing material can also be changed.

2.1.2 Matrix

The matrix is the substance that surrounds and supports the reinforcing fibres or particles in composite materials. The matrix material, which often consists of a polymer, ceramic, or metal, is in charge of distributing loads among the reinforcing fibres or particles. In a composite, the matrix material performs a number of crucial tasks, such as fusing the reinforcing fibres or particles together, transmitting stresses and loads, and offering potential and environmental resistance.

The unique application of composite material determines the choice of matrix material. For applications requiring great strength and low weight, a polymer matrix material may be employed, but a ceramic matrix material may be used if the composite material will be used in high temperature conditions.

Based on matrix used composite can be classified as three types.

1. Metal matrix composite (MMC)
2. Ceramic matrix composite (CMC)
3. Polymer matrix composite (PMC)

2.2 Metal matrix composite (MMC):

A form of composite material known as a metal matrix composite (MMC) is made of a metal matrix that has been reinforced with one or more reinforcing elements. The reinforcing components, which might take the shape of fibres, particles, or whiskers, are frequently constructed of materials like ceramic, carbon, or glass.

A number of metals, such as aluminium, titanium, magnesium, and copper, can be used to create the metal matrix in an MMC. The particular use of the composite material and the required qualities of the finished product determine the metal matrix to be used.

To increase the mechanical characteristics of the composite, such as strength, stiffness, and wear resistance, the reinforcing components in an MMC are often added to the metal matrix. As a result of the reinforcing materials' often greater strength and stiffness compared to the metal matrix, stresses are dispersed more uniformly throughout the composite.

2.2.1 Advantages of MMCs:

MMCs have a variety of benefits over conventional metals, such as:

• Higher strength-to-weight ratio: By adding reinforcing elements to the metal matrix, the composite material's strength-to-weight ratio may be greatly increased.

• Increased wear resistance: An MMC's reinforcing components can increase the composite material's wear resistance, making it the perfect choice for applications requiring great durability.

• High temperature resistance: Some MMCs are able to endure high temperatures, making them suitable in situations where high temperature resistance is required.

MMCs are employed in a variety of applications, including those in the automotive, electrical, and aerospace sectors, where they can offer special combinations of features that are not available with conventional materials.

2.3 Ceramic matrix composite (CMC):

A ceramic matrix reinforced with one or more reinforcing elements is the foundation of a ceramic matrix composite (CMC), a form of composite material. The reinforcing materials are often formed from substances like silicon carbide, alumina, or carbon and can take the shape of fibres, particles, or whiskers.

Oxides, carbides, and nitrides are just a few of the ceramics that may be used to create the ceramic matrix in a CMC. The specific use of the composite material and the desired qualities of the finished product determine the ceramic matrix to be used.

In a CMC, the ceramic matrix is generally supplemented with reinforcing elements to enhance the composite's mechanical characteristics, such as strength, stiffness, and fracture toughness. The ceramic matrix is often weaker and less durable than the reinforcing components, which aids in more uniformly distributing stresses throughout the composite.

2.3.1 Advantages of CMCs:

CMCs have a number of benefits over conventional ceramics, such as:

• Greater fracture toughness: By adding reinforcing materials to the ceramic matrix, the composite material's fracture toughness can be greatly increased, making it more resilient to cracking and fracture.
• Improved strength-to-weight ratio: By incorporating reinforcing materials into the ceramic matrix, the strength-to-weight ratio of the composite material may be increased, making it the perfect choice for applications where both strength and weight are crucial.
• High temperature resistance: Because CMCs are capable of withstanding high temperatures, they are beneficial in applications that call for high temperature resistance.

CMCs are employed in a variety of industries, such as the automotive, aerospace, and industrial ones, where they can offer special combinations of qualities that are not available with conventional materials.

2.4 Polymer matrix composite (PMC):

A polymer matrix reinforced with one or more reinforcing components makes up a polymer matrix composite (PMC), a form of composite material. Reinforcing materials are often formed of substances like carbon, glass, or aramid and can take the form of fibres, particles, or sheets.

Thermoplastics, thermosets, and elastomers are just a few of the polymers that can be used to create the polymer matrix in a PMC. The specific use of the composite material and the desired qualities of the finished product influence the choice of polymer matrix.

In a PMC, the reinforcing components are often included into the polymer matrix to enhance the composite's mechanical characteristics, such as strength, stiffness, and impact resistance. The stress is typically distributed more uniformly throughout the composite because the reinforcing components are typically stronger and stiffer than the polymer matrix.

2.4.1 Advantages of PMCs

Compared to conventional polymers, PMCs have a number of benefits, including:

• Greater strength-to-weight ratio: The composite material's strength-to-weight ratio can be greatly increased by adding reinforcing elements to the polymer matrix.

• Greater stiffness: The polymer matrix can become stiffer with the inclusion of reinforcing components, which makes the composite material excellent for applications requiring a high degree of rigidity.

• Increased toughness: The PMC's reinforcing components can increase the composite material's toughness and impact resistance, making it more durable.

In a variety of applications, such as the aerospace, automotive, and sporting goods industries, PMCs are used because they can offer special combinations of qualities that are not available with conventional materials.

3.1 Materials Details:

- Aluminum (Al)
- Fly Ash

3.2 Methodology:

We used stir casting method for the preparation of Al and Fly ash metal matrix composite. The following figure 3. 1 shows the actual process.

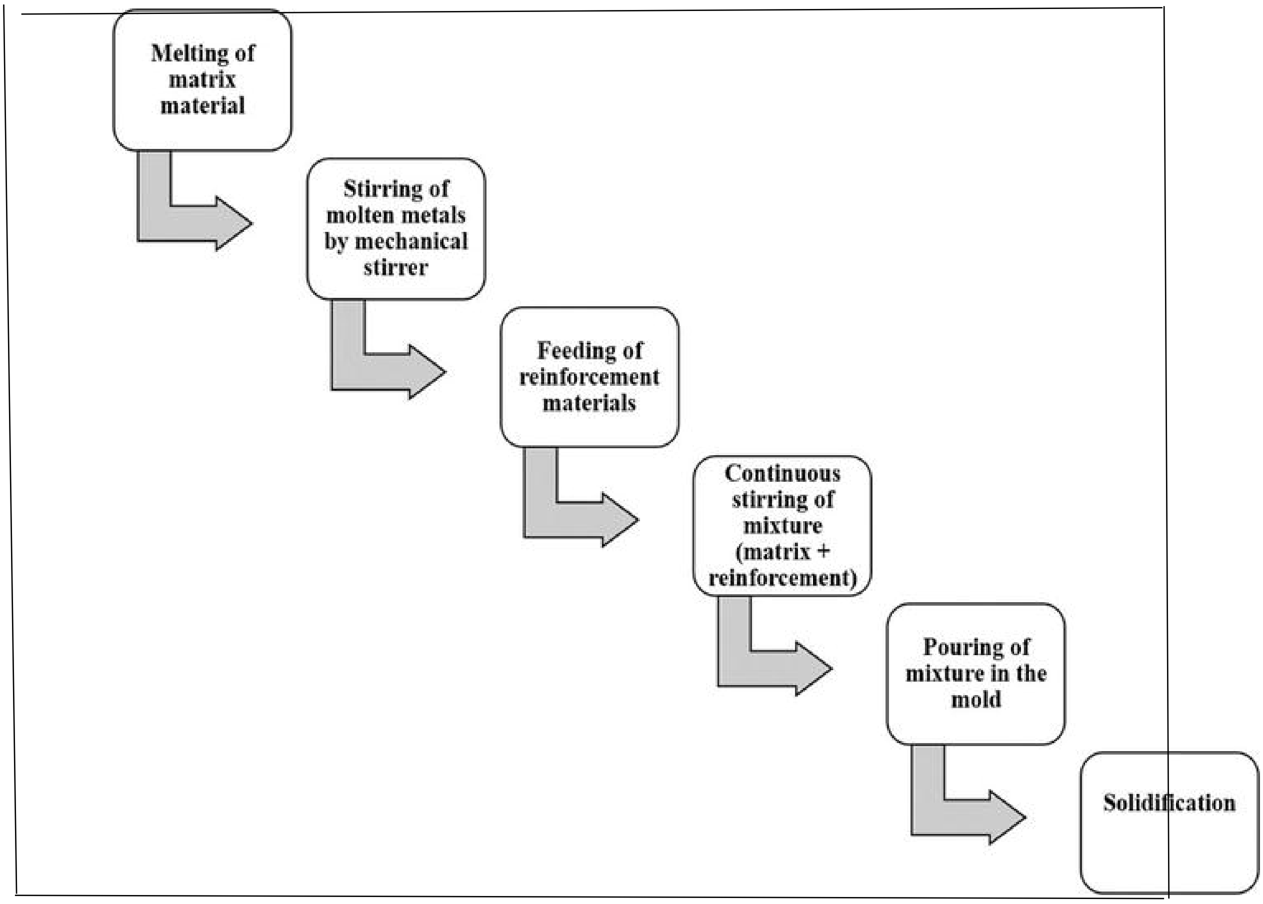

Fig: stir casting process

3.2.1 STIR CASTING METHOD OF FABRICATION OF MMCs

The stir casting method is a commonly used technique for the fabrication of metal matrix composites (MMCs). It involves the incorporation of a reinforcing material, such as ceramic or metallic particles, into a molten metal matrix under high shear. The resulting composite material exhibits improved mechanical, thermal, and electrical properties compared to the base metal.

The stir casting process typically involves the following steps:

1. **Preparation of the matrix material:** The matrix metal is melted in a crucible and brought to the desired pouring temperature.

2. Preparation of the reinforcing material: The reinforcing material, such as ceramic or metallic particles, is preheated to prevent any thermal shock during the stirring process.

3. Mixing of the matrix and reinforcing materials: The preheated reinforcing material is added to the molten matrix material, and the mixture is stirred using a rotating impeller or a rotating rod. The stirring is carried out at a high shear rate to ensure proper distribution of the reinforcing particles throughout the matrix.

4. Casting of the composite material: The stirred mixture is poured into a preheated mold and allowed to solidify. The solidified composite material is then removed from the mold and machined to the desired shape and size.

5. Heat treatment: The composite material may be subjected to a heat treatment process to improve its mechanical properties and reduce residual stresses.

The stir casting method is a versatile technique that can be used to fabricate a wide range of MMCs with different combinations of matrix and reinforcing materials. The process can be easily scaled up for industrial production and is relatively cost-effective compared to other methods of MMC fabrication.

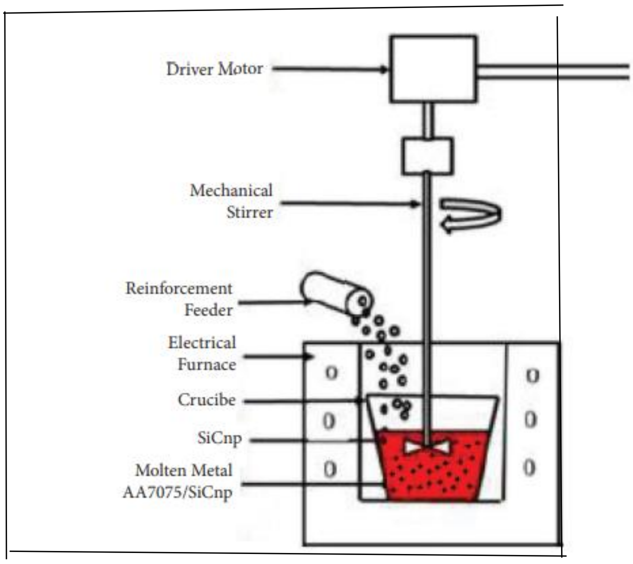

FIG 3.1.1 STIR CASTING

3.3 Characterization of Al and Fly Ash MMCs

To determine the characteristics, we are performing the following tests on the Al and Fly Ash MMCs.

- Chemical analysis of fly ash
- Density and hardness measurement
- Scanning electron microscope (SEM) analysis
- Wear behaviour
- EDS micro analysis

4.Experimental work

4.1 Experimental procedure

First, a resistance-heated muffle furnace was used to melt 400 g of commercially pure aluminium before it was cast in a clay graphite crucible. For this, hexachloro ethane tablets were used to purge the gas and boost the melt temperature to 993K. Then, using the stir casting method, the aluminum-fly ash (10%) composite was created. For this, we used 40 g of fly ash and 400 g of commercially pure aluminium. To eliminate the moisture, the fly ash particles were warmed for two hours at 373K. By increasing the temperature of commercially pure aluminium to 993 K, it was melted, and hexachloro ethane tablets were used to expel the gas. A mild steel stirrer was then used to stir the melt. Fly-ash particles were incorporated into the melt when a vortex started to form as a result of churning. The melt temperature was held constant between 953K and 993K while the particles were added. The melt was then cast in a crucible made of clay and graphite. For fly ash, analyses of the chemical content and particle size were performed. Both commercially pure aluminium and an aluminum-fly ash composite with an alpha content of 10% underwent hardness testing and density measurements. Using a 500 kg load and a 10 mm steel ball indenter, a Brinell hardness testing machine was used to gauge the samples' hardness. The hardness measurement's detention period lasted 30 seconds.

Utilising a wear testing machine, the wear properties of commercially pure Al and Al-10% fly ash composite were assessed. For this, cylindrical specimens made of a combination of cast aluminium and Al-10% fly ash measuring 1 cm in diameter and 2.1 cm in length were created. A test with a 68.68 N load and 500 rpm was run for ten minutes. For both samples, SEM and EDS analysis was performed.

4.1.1 Works Done

1. Casting was done using melted, commercially pure aluminium.

2. A stir casting technique was used to create an Al-10% fly ash composite.

3. The chemical makeup of the fly ash used was analysed.

4. For the fly ash used, a particle size analysis was performed.

5. Both the Al-10% fly ash composite sample and the commercially pure Al sample had their density and hardness measured.

6. Both commercially pure Al and Al-10% fly ash composites had their wear parameters assessed and compared.

7. SEM analyses were performed on both samples.
8. For both samples, EDS microanalysis was performed..

5.Results

5.1 CHEMICAL ANALYSIS OF FLY ASH

A byproduct of burning coal in power plants is fly ash. A pollution control device collects the fine, powdery particles that is carried up the smokestack. With traces of other compounds, fly ash is primarily made of silica, alumina, iron oxide, and calcium oxide.
Identification and measurement of the various components contained in fly ash are done chemically. Some of the common methods for analysing fly ash include the following:

COMPOUNDS	PERCENTAGE (%)
SiO2	67.2
Al2O3	29.6
Fe_2O_3	0.1
CaO	1.4
MgO	1.7

TABLE 5.1 CHEMICAL ANALYSIS OF FLY ASH

5.2 DENSITY AND HARDNESS MEASUREMENT

SPECIMEN	DENSITY (gm/cm^3)	HARDNESS (BHN)
As Cast Al	3.398	16
Al-10% fly ash Composite	2.807	18

Incorporating fly ash particles into an aluminium matrix results in a reasonable increase in hardness as well as a reasonable decrease in density, as shown in the above table. Both particle reinforcing and dispersion strengthening may contribute to the composite's increased strength.

Therefore, using fly ash as a filler in an aluminium casting lowers the cost, lowers the density, and increases the hardness, all of which are required in various industries like the automotive industry.

5.3 Wear Behaviour

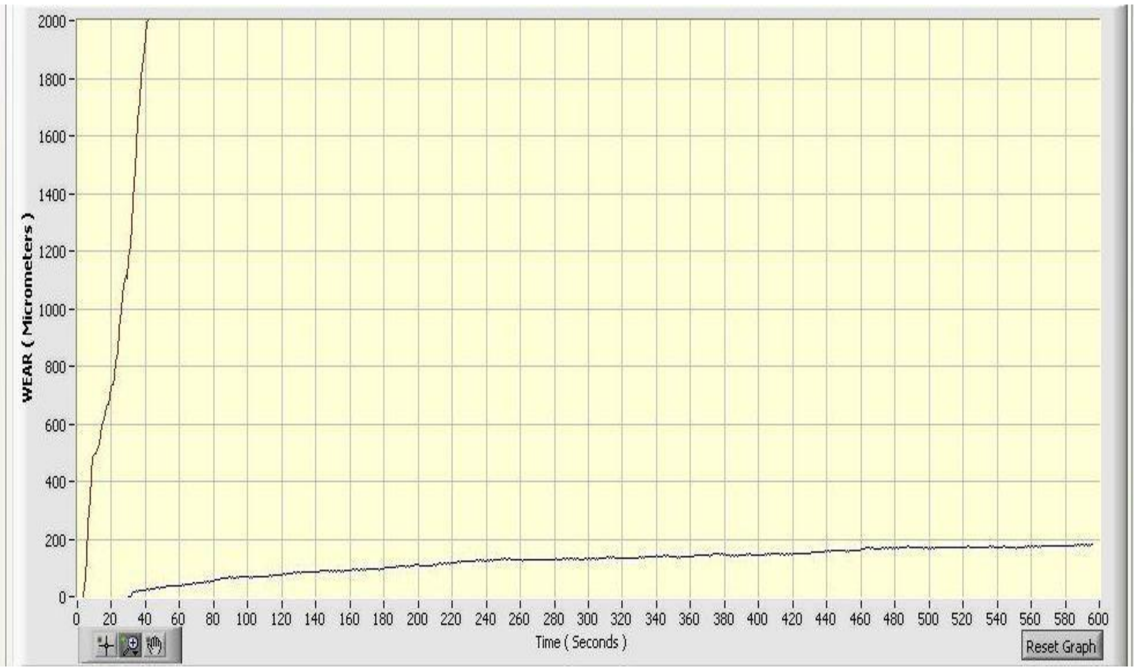

FIG 5.3 (a) – Wear Vs Time

(RED-FOR Al, BLUE-FOR Al-10% FLY ASH)

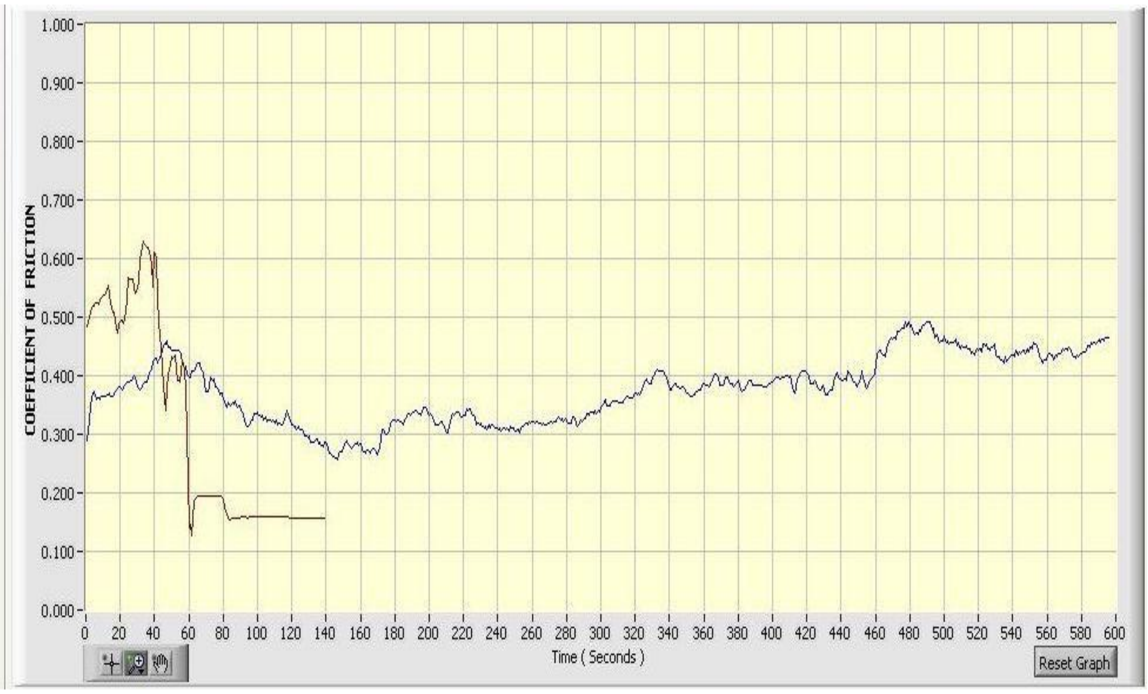

FIG 5.3 (b) COF Vs Time
(RED-FOR Al, BLUE-FOR Al-10% FLY ASH)

FOR FIG 4.4 (a)

This figure clearly indicates that wear rate has improved significantly with the addition of fly-ash.

Fly ash increases the composite's hardness by acting as a barrier to the migration of dislocations. Thus, the addition of fly ash particles to the aluminium melt greatly improves its resistance to abrasive wear. The hard aluminosilicate component found in fly ash particles is what improves wear resistance.

FOR FIG 4.4 (b)

This graph contrasts the usual friction coefficients of cast aluminium versus an aluminium composite with 10% fly ash. The friction coefficient of the Al-10% fly ash composite is lower than that of the as-cast aluminium. As a result, the friction coefficient is dramatically reduced when fly ash is added to Al melt.

In this graph, the friction coefficients of cast aluminium and an aluminium composite containing 10% fly ash are compared. The Al-10% fly ash composite has a lower friction coefficient than as-cast aluminium. When fly ash is added to Al melt, the friction coefficient is thus significantly decreased.

5.4 SEM Analysis

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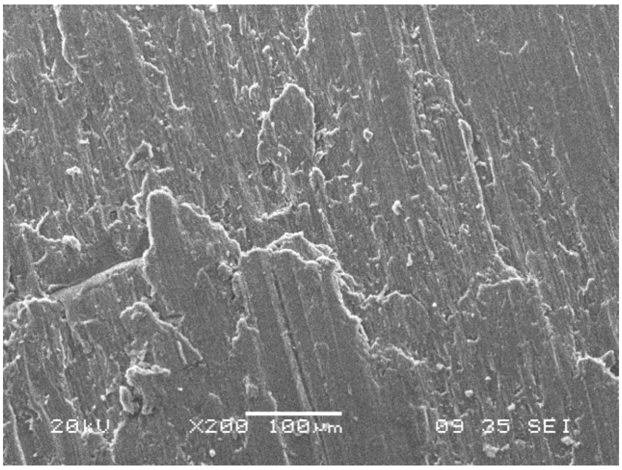

FIG 5.4 (a) SEM microstructure of as cast Al

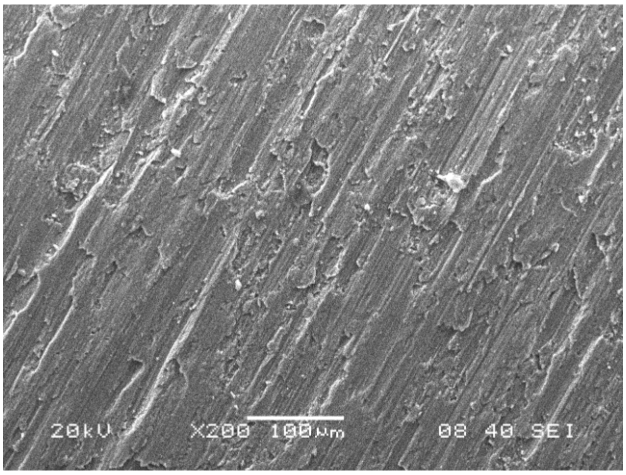

FIG 5.4 (b) SEM microstructure of Al-10% fly ash composite

In comparison to the Al- 10% fly ash composite, SEM research reveals that higher wear has taken place in the case of as cast aluminium. This is because wear in the case of as-cast aluminium is primarily metallic wear, whereas wear in the case of Al-10% fly ash composite is primarily oxidative wear.

Thermodynamic investigation suggests that there may be a chemical reaction between fly ash particles and aluminium melt. These fly ash particles, which are made of alumina, silica, and iron oxide, are likely to go through the following chemical reduction when they come into contact with the melt:

2Al(l) + 3/ 2SiO2(s) = 3/2 Si(s) + Al2O3(s)…… (1)

2Al(l) +Fe2O3(s) = 2Fe(s) +Al2O3(s)…… (2)

Si and Fe, two elements created by the reduction reaction, would alloy with the matrix. Gibbs free energy and reaction temperatures have a strong exothermic character. A larger quantity of eutectic silicon is present in the composites as a result of this reaction

5.5 EDS (ENERGY DISPERSIVE SPECTROSCOPY) MICROANALYSIS

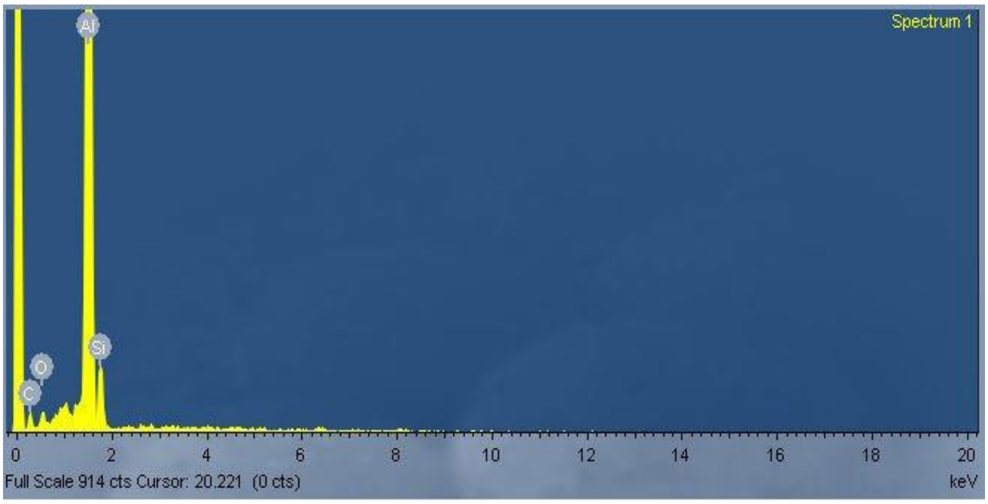

FIG 5.5(a) EDS microanalysis for as cast Al

Element	App Conc.	Intensity Corrn.	Weight%	Weight% Sigma	Atomic%
C K	3.39	0.1817	20.14	2.64	35.46
O K	1.98	0.5478	3.89	1.00	5.14
Al K	80.78	1.2315	70.77	2.47	55.48
Si K	2.41	0.5007	5.20	0.46	3.91x
Totals			100.00		

TABLE 5.5 (a) EDS MICROANALYSIS FOR AS CAST Al

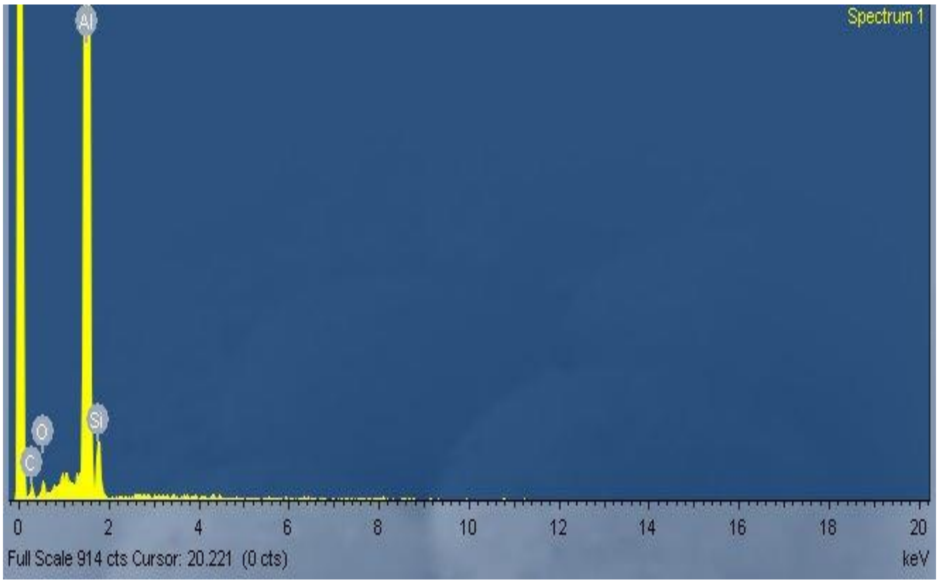

FIG 5.5(b) EDS microanalysis for Al-10% fly ash composite

Element	App	Intensity	Weight%	Weight%	Atomic%
	Conc.	Corrn.		Sigma	
C K	2.79	0.1771	17.65	3.38	31.81
O K	2.10	0.5624	4.19	1.20	5.67
Al K	80.39	1.2386	72.73	3.14	58.34
Si K	2.39	0.4935	5.43	0.57	4.18
Totals			100.00		

\TABLE 5.5 (b) EDS MICROANALYSIS FOR Al-10% FLY ASH COMPOSITE

The increase in the amount of eutectic Si indicates the incorporation of fly ash in Al melt.

6.Conclusion

1. The study's findings suggest that fly ash can be used to make composites, converting industrial waste into financial gain. Additionally, this can address the issue of fly ash storage and disposal.

2. By using the stir casting method, fly ash up to 10% by weight can be successfully added to aluminium to create composites.

3. The addition of 10% fly ash raised the hardness of pure aluminium from 16 BHN to 18 BHN.Additionally, the density of the Al melt decreased noticeably when fly ash was added, going from 3.398 gm/cm3 to 2.807 gm/cm3.

4. The addition of fly ash to Al melt greatly reduced the wear rates and friction coefficients.

5. Particle reinforcing and dispersion strengthening are responsible for the composite's increased strength..

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