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Optimization of Aluminium 6061 and 5083 Metal Matrix Composites with Fly-Ash Based on Physical Characteristics

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Abstract

Most engineering applications today, such as aviation, defence, marine, and automotive, require components with favourable mechanical qualities as well as low weight; this demand is provided by metal matrix composites (MMCs) of aluminium due to its unique accomplishment. The MMC suffer from insufficient process stability, economic efficiency, and dependability. This experimental investigation pointed to the production of low-cost, insignificant aluminium metal matrix composites. In the current study, an experiment is carried out to recreate metal matrix material boosted with Fly-ashand Epoxy-resin utilising two-stage in situ stir casting procedures. Aluminium 5083, aluminium 6061, and Fly-ash Epoxy-resin were combined in ten various ratios. The elements of both aluminium compounds have bonded reversibly and formed its coordination structure. Thermal TGA and FTIR spectroscopic tests were done to analyse physical features such as SEM analysis, EDS analysis, and wear characteristics. Finally, the results of each experiment were discussed, with particles indicating a percentage of total Fly-ash, Epoxy-resin, and enriched al alloy composites qualities.

Keywords: Al MMC, SEM Analysis, EDS Analysis, FTIR Analysis, Wear Resistance Test, Al 5083, Al 6061.

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1. Introduction

The strength of metal matrix composite materials was the primary factor in their selection. The favoured experimental setup was a mix of aluminium (A1 6061), Fly-ash & Epoxy-resin. It has been correctly recognized and steadily advances technical properties such as wear rate, low density, specific strength, and stiffness. It is possible to overcome the tough reinforcement levels as well as specifics of reinforcing materials such as Zirconium, Alumina (Al_2O_3), and Silicon Carbide in aluminium alloys (SiC).

Innovative composite materials are introduced, such as aluminium (Al 6061) mixed with Fly-ash and Epoxy-resin composites and will improve mechanical qualities. In general, aluminium alloy is mostly employed in lightweight applications. As a result, novel composite materials made of aluminium (Al 6061) mixed with Fly-ash & epoxy glue are generated. The specimen has been experimentally manufactured in the ratios of 10.00%, 15.00%, 20.00%, and 25.00% in an ASTM standard size plate. The coordination structure of formed metals is represented in figure 1. Alloys and Al-related MMCs have found use in the construction of various vehicle engine components. Many composite materials are employed in residential and industrial manufacturing, and compound working modules are designed to include desired properties of diverse materials. Reduces weight in fast-moving automotive engine parts such as the crankshaft, tying the bucket to weight reduction, and reducing wear [1]. As the volume content of reinforcement rises, the wear rate reduce. As the volume content of reinforcement rises, the coefficient of friction decreases somewhat. The hybrid composites have a reduced friction coefficient and wear rate when compared to matrix alloys and individual composites. With increasing reinforcement volume concentration, the micro-hardness of the composite specimens evaluated after the wear test increases [2].

An experiment is carried out to investigate the results of Al 6061 by inserting different percentage weights of SiC and Fly-ash and SiC and Red Mud, Al 6061-SiC-Fly-ash aluminium-based MMC and Al 6061-SiC-Redmud with stir casting method, with reasonably clear Silicone carbide delivery, Fly-ash and red mud were also successfully manufactured. The impact power of Al 6061 + SiC + Fly-ash has increased as the Fly-ash percentage has increased. The impact power of Al 6061 + SiC + Red Mud has been increased by maintaining a constant SiC and Red Mud weight %. The impact intensity was greater in Al 6061+SiC+Fly-ash [3].

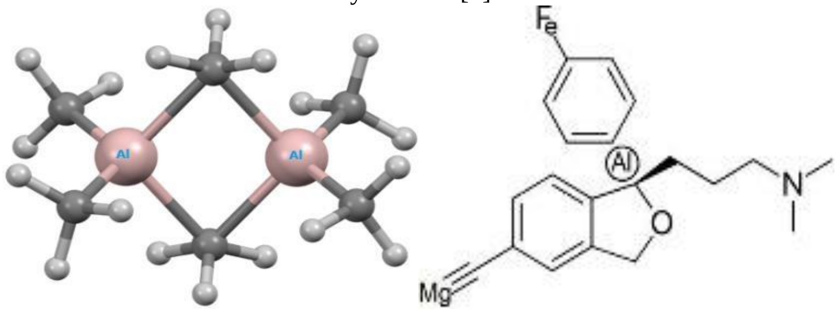

Figure 1. Coordination structure of Al metals

The theoretical densities of the composites utilized in the development of the composite materials' overall rule of thumb and the experimental densities are in agreement. The Al6061 alloy and the Al7075 alloy include SiC and Al_2O_3 in varying amounts, which helps to increase the composite's tensile strength. To demonstrate the composite material's higher wear resistance, a composite needle was employed as a specimen. The wear member obtained the top disc wear tester using a computerized pin, and the floor was built of an EN31 steel disc (HRC60) [4]. A lightweight construction with an aluminium core and a low total weight is elegant, according to aluminium-based composites (AMCS) [5]. In asset management firms, the reinforcement may take the form of quantitative fractions such as whiskers, granules, or continuous or discontinuous fibers. This project focused on producing aluminium (AL6061) alloys with agitation casting orientations of 75 m, 88 m, and 105 m of 3 to 12% by weight of glass particles and 250 m of guiding AMC's. The newly established asset management business's framework and operations were investigated.

However, fly-ash can be used to generate industrial capital for the development of composites. The problem of preserving and reusing Fly-ash might also be solved [6]. In rotational bending fatigue testing, the presence of one artificial pitting hole affects the fatigue endurance of the aluminium alloy 6061-T6, and the presence of two near artificial pitting holes has a considerable influence. It is very likely that two or more pitting holes may form in metallic alloys used in industrial applications that are vulnerable to corrosion attack and fatigue. The proximity of two adjacent pitting holes increases the stress concentration factor exponentially; this work contains an exponential equation over a range of proximity [7]. The highest value of a broad range of materials obtained using the approach is determined using finite element analysis. In this example, the inner steel is used to represent the base composite's reinforcing debris, which is shaped to match desired everyday geometry such as spherical, square, cylindrical, and pyramidal forms [8].

The work that was seen involved improving the mechanical characteristics of an aluminium matrix by adding strengthening components such as TiC, silicon carbide, alumina, titania, titanium nitride, etc. [9]. The in-situ strategy supports the titanium carbide (TiC) or ceramic-grade aluminium matrix over the in-situ EX technology. A TiC-enhanced Al-Cu-based composite was used as the matrix in this investigation. Combinations of Al-5% Cu, 10% TiC, and Al-4.5% Cu in MMC material show excellent yield quality, high strength, and hardness. The range of individual Vickers hardness starts at around 35%, whereas the yield and extreme stiffness percentage increments are specified as 5% and 24%, respectively. The proof's enhanced hardness serves as proof that the TiC particles' inclusion boosted the matrix's hardness [10].

When both reinforcements are present, the production of dendrites and voids with uniform dispersion is reduced, according to the SEM study. Because of the lower production of dendrites and voids, the combination of 88 percent AA 6063 + 3 percent B_4C + 9 percent $ZrSiO_4$ has the highest tensile, flexural, and hardness strength. Because of the lower production of dendrites and cavities, the compressive strength for the mixture of 88 percent AA 6063 + 3 percent B_4C + 9 percent $ZrSiO_4$ is the lowest. The mechanical characteristics of 88 percent AA 6063 + 3 percent B_4C + 9 percent $ZrSiO_4$ are superior to those of the others, consequently, it is suitable for a wide range of applications [11]. The dispersion of the SiC and B_4C particles is uniform throughout the specimens, as illustrated in the photos. The data show that an increase in processing temperatures causes an increase in particle clustering [12]. It is discovered that stir casting may be used to efficiently synthesise aluminium alloy matrix composites boosted with a hybrid. The stirrer configurations and position, the mixing velocity and melting time and pouring temperature, the particulate preheating temperature, the mouth and scale, and the reinforcement particle size and amount are all critical process characteristics [13]. Flight ash particles were homogeneously disseminated in the metallic matrix in the majority of metal matrix Fly-ash reinforced composites, with no formation of clusters or pore residues. The microstructural investigation revealed that the Fly-ash particles may react with the molten metallic matrix, resulting in the production of rigid, dendritic Mg2Si and MgAl2O4 phases [14].

A mixture of readily available Al-3% bromine and Al-10% Ti was cast in order to better understand the Al7075-TiB 2 in-situ composite. Microhardness tests, particle size analyses, and toughness tests were used to microscopically assess both matrix chemicals and composites. The matrix compound's TiB2 element is transported in a very consistent manner because of the microstructure. The combination's average particle size is less than that of the unreinforced mixture. When compared to the unreinforced composition, the Al7075-TiB 2 composite has extremely high microhardness, yield quality, and extreme stiffness [15]. It has been discovered that a composite metal consisting of up to 8% rice husk ash and silicon carbide particles may be manufactured easily utilising a double metal casting technique. In the matrix, SiC and rice husk ash are transported uniformly. As porosity and hardness grow across the thickness of the hybrid composite, the amount of porosity decreases [16]. RHA and SiC concentrations increase with yield quality and high rigidity. It is vulnerable to variations in the basic aluminium combination, and adding support speeds up the precipitated active [17]. This effect is attained by a curing heat treatment in which the hardest part is also made softer.

Researchers finished the examination of the production of Al MMC using a fluid powder metallurgy method [18, 19], and the aluminium mixture composite, including TiO2 reinforce molecules, was given to consider the mechanical characteristics, such as rigidity and hardness. The results explain the evolution of the reinforcement with the mechanical characteristics, and the description is further done to clarify the stage presence in the composite. Results show that the mechanical characteristics of full aluminium are improved by adding five weight levels of TiO2.

Finally, composite materials made from aluminium matrix are frequently employed in engineering applications. The outstanding performance provided by aluminium matrix composites cannot be matched by any monolithic material. The nature of the matrix, which can take the shape of continuous or irregular fibres, greatly improves the qualities of the aluminium matrix composite. Furthermore, it depends on the manufacturing process for the aluminium matrix composite, which in turn depends on a variety of elements, such as the patient's choice of matrix and reinforcement material, the level of necessary microstructural integrity, and their mechanical, chemical, electrical and thermal properties [20].

Research Motivation:

In order to build novel materials with a long enough lifespan for a variety of applicationsIn Fly-ash MMC subjected to wear testing, it is crucial to comprehend the complex patterns of almost all frictional strengths that may develop.

- Recognize and quantify the mechanical characteristics of Fly-ash MMC.
- Maximum performance and strength, and minimal weight.
- Composite sheet fabrications under regulated circumstances.
- SEM analysis and wear resistance of composite samples were carried out using ASTM standards.
- To investigate the layer's alignment influence in the SEM, FTIR and the wear of the MMC.
- To comprehend the impact of thickness on the mechanical characteristics of a substratum.
- The composition was compared to the performance of other samples.

2. Material Selection

According to the literature survey research, it is determined that the best material for metal matrix composites (MMC) was chosen based on the required product attributes. Aluminium might be utilised as a base metal for matrix composites, while Fly-ash could be used as a matrix material for composites. Furthermore, the Epoxy-resin substance is used as the adhesive binder for the composites. The selected materials for the composite are:

- Aluminium 6061
- Aluminium 5083
- Fly-ash
- Epoxy-resin

2.1 *Aluminium 6061 (Al 6061)*

The 6000 series aluminium alloy 6061 is the one that is most frequently used in this Material. It is a medium to high strength sintered alloy that is heat treatable.

a. Physical Properties

- Density - 2700 kg/mm^3
- Melting Point - 620ºC
- Young's Modulus - 70 GPa
- Poisson Ratio - 0.333

b. Key properties

- Better toughness, workability and surface finish

c. Applications

- Aerospace, Automobile and Marine industries

Table 1 Composition of Al6061 Alloy

S. No.	Components	Amount (Wt. in %)
1	Chromium	0.04 – 0.35
2	Magnesium	0.80 – 1.20
3	Silicon	0.40 – 0.80
4	Iron	0.70
5	Copper	0.15 – 0.40
6	Zinc	0.25
7	Titanium	0.15
8	Manganese	0.15
9	Others	0.05
10	Aluminium	Balance

2.2 Aluminium 5083 (Al 5083)

Aluminium 5083 is a magnesium, manganese, and chromium alloy. It is very resistant to bothsaltwater and industrial compounds. It possesses the best strength of any non-treatable alloy but should not be used at a temperatures beyond 650 °C.

a. Physical Properties

- Density – 2650 kg/ mm^3
- Melting Point - 570 ºC
- Young's Modulus - 72 GPa
- Poisson Ratio - 0.333

b. Applications

- construction of ships
- Rail vehicles
- automobile bodies
- Tipping truck bodies
- Mine cages and skips
- pressure vessels

Table 2 Compositions of Al 5083 Alloy

S. No.	Components	Amount (Wt. in %)
1	Chromium	0.05 – 0.25
2	Magnesium	4.0 – 4.9
3	Silicon	0.4
4	Iron	0.4
5	Copper	0.1
6	Zinc	0.25
7	Titanium	0.15
8	Manganese	0.4 – 1.0
9	Aluminium	Balance

2.3 Fly-ash

The combustion of power plants to pulverized coal determines the formation of Fly-ash. The mineral impurities of the coal burn are carried out of the chamber with the exhaust gas. The moltensubstance cools and freezes into round glass shards known as Fly-ash as it climbs.

a. Key properties

- Seasonal limitations

b. Applications

- Blocks and bricks

2.4 Epoxy-resin

Epoxy-resins are among the highest performing resins on the market today. A chemical molecule known as an epoxy-resin is one in which two oxygen atoms are linked in the same way that two carbon atoms are.

Key properties

- Outstanding mechanical & adhesive strength and heat resistance
- Low-curing contraction

a. Applications

- Industrial tooling and Wind turbine

3. Experimentation Procedure

In this experiment, several samples of aluminium alloys al 6061 and al 5083 are combined with Fly-ash and Epoxy-resin in various ratios, as shown in Table 3. The matrix composition was chosen because it offers a nice balance of stability.

Table 3 Compositions of the matrix and reinforcement, expressed as % wt.

Aluminium Content	Sample	Al 6061 or Al 5083 (Weight in %)	Fly-ash (Weight in %)	Epoxy-resin (Weight in %)
Aluminium 6061	1	90	10	0
	2	80	15	5
Aluminium 5083	1	90	10	0
	2	80	15	5

Table 2 contains information on Al6061 and Al5083, as well as Fly-ash and Epoxy-resin, which are employed as matrix and reinforcements. Metal matrix composite materials are created using the stir casting process in this experimental setup. This is a simple and low-cost approach for producing reinforced metal matrix composite materials. To attain the best features, the MMC is employed.

Stir casting was used to create Al 6061 with Fly-ash and Epoxy-resin and Al 5083 with Fly-ashand Epoxy-resin. After machining the specimen with various ratios of metal of MMC material mixing and TGA, FTIR, SEM analysis, EDS analysis, and wear resistance testing.

Figure 2. Stir Casting Method

Table 4 Properties of Matrix and Reinforcements

Material	Density, kg/m^3	Melting temperature, °C
Al 6061	2700	620
Al 5083	2650	570
Fly-ash	994	1400
Epoxy-resin	1.1 - 1.4	177

3.1 Wear Test

Wear tests were performed on a pin-on-disc machine. Samples were machined by normal test sizes. Acetone is used to clean the working contact surface. The wear test experimentation is carried out at room temperature. The wear experiments were carried out on four distinct material samples with varying ratios. Table 3 depicts the various composite material ratios.

- Wear rate = Wear Volume / (Sliding Distance x Normal Load)
- Wear rate = V_i/F x Smm^3/Nm
- V_i = wear volume in mm^3
- F = Load, N
- S = Slide distance, mm

Table 5 Sample 1 - Wear Rate of Al MMC 6061

Al 6061 (90 %) + Fly-ash (10 %)			
Sliding Velocity (m/s)	**Normal Load (N)**	**Sliding Distance (mm)**	**Wear Rate (mm^3/Nm)**
1.50	10.0	100	0.0034
3.00	20.0	150	0.00328
4.50	30.0	200	0.00335

Table 6 Sample 2 - Wear Rate of Al MMC 6061

Al 6061 (80%) + Fly-ash (15%) + Epoxy-resin (5%)			
Sliding Velocity (mm/s)	**Normal Load (N)**	**Sliding Distance (mm)**	**Wear Rate (mm^3/Nm)**
1.5	10.0	100	0.00325
3	20.0	150	0.00328
4.5	30.0	200	0.00323

Figure 3. Wear Characteristics of Al 6061 MMC

Table 7 Sample 1 - Wear Rate of Al MMC 5083

Al 5083 (90%) + Fly-ash (10%)			
Sliding Velocity (mm/s)	**Normal Load (N)**	**Sliding Distance (mm)**	**Wear Rate (mm^3/Nm)**
1.5	10.00	100	0.00351
3	20.00	150	0.00349
4.5	30.00	200	0.00346

Table 8 Sample 2 - Wear Rate of Al MMC 5083

Al 5083 (80%) + Fly-ash (15%) + Epoxy-resin (5%)			
Sliding Velocity (mm/s)	**Normal Load (N)**	**Sliding Distance (mm)**	**Wear Rate (mm^3/Nm)**
1.5	10.00	100	0.00337

3	20.00	150	0.00334
4.5	30.00	200	0.00331

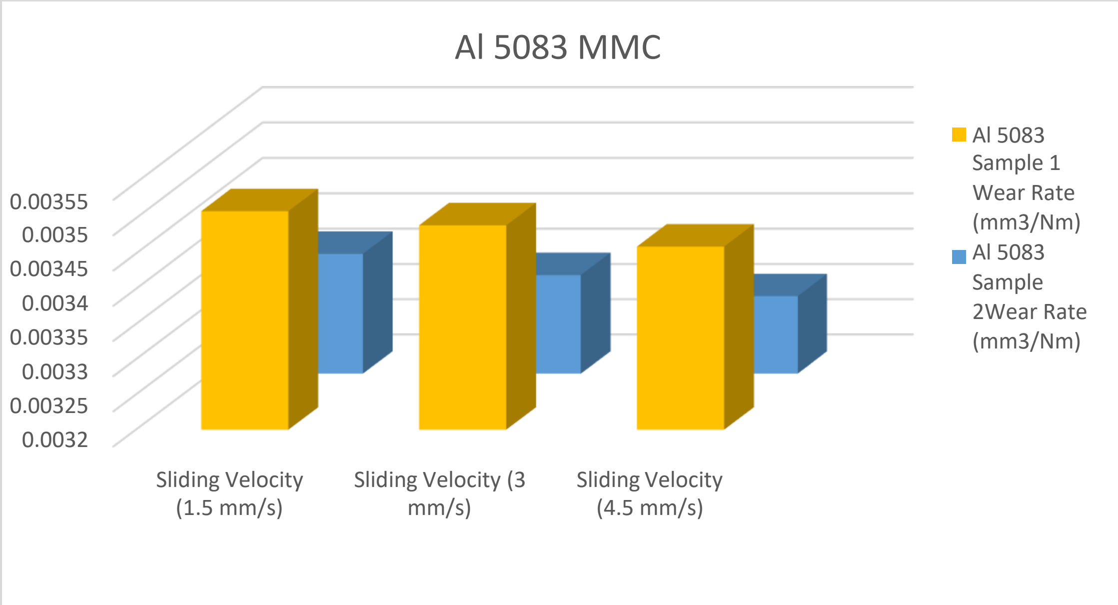

Figure 4. Wear Characteristics of Al 5083 MMC

3.2 SEM Analysis

The element appropriation of Metal Matrix Composites was investigated using a Scanning Electron Microscopy (SEM) interface (MMC). Under 100 µm, Al 6061 MMC and Al 5083 MMC samples were subjected to SEM examination.

3.3 FTIR Analysis

Fourier transform infrared spectroscopy which means FTIR uses the mathematical technique (Fourier transform) to convert raw data (interferograms) into real spectra. For surface characterization of nanoparticles, FTIR is a very flexible technique. The obtained spectra of FTIR analysis for Aluminium 6061 Metal Matrix Composite (Al 6061 MMC) were shown in Figures 9 and 10. The spectrum of all compositions has been documented in the range of 500 – 4000 cm^{-1} wavenumbers.

Similarly, the FTIR analysis has conducted for the Al 5083 MMC and obtained results of different compositions represented from Figures 11 & 12.

3.4 MMC Thermogravimetric Analysis (TGA)

The Thermogravimetric Analysis (TGA) has been conducted for the both Al 6061 MMC andAl 5083 MMC compositions. The obtained TGA results for Al 6061 were shown through Figure 12 & 13. Figure 14 & 15 represents the TGA results of Al 5083 MMC compositions.

3.5 EDS Analysis

The EDS x-ray detector records how many x-rays are released relative to their energy. The most common way to display an EDS spectrum is as an x-ray count versus energy (in keV) graph. Energy peaks in the sample's various elements match up with those peaks. They are often narrow and straightforward to resolve, even though several components create numerous peaks. The obtained EDS results for Al 6061 were showed in Figure 17 & 18. Figure 19 & 20 represents the EDS results of Al 5083 MMC compositions.

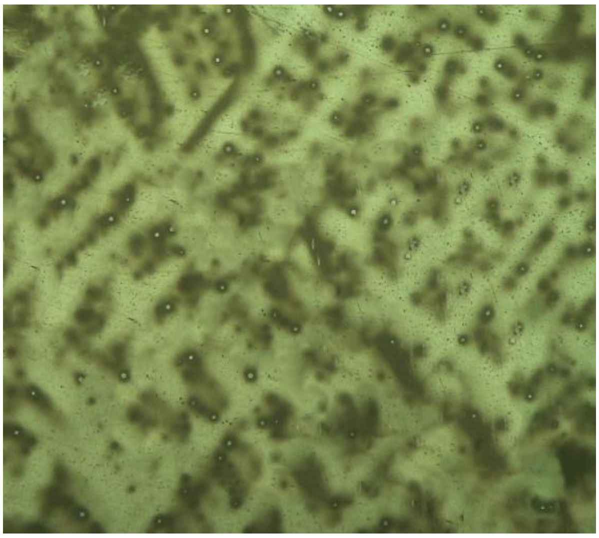

Figure 5. SEM Micrograph of Sample 1 (Al 6061)

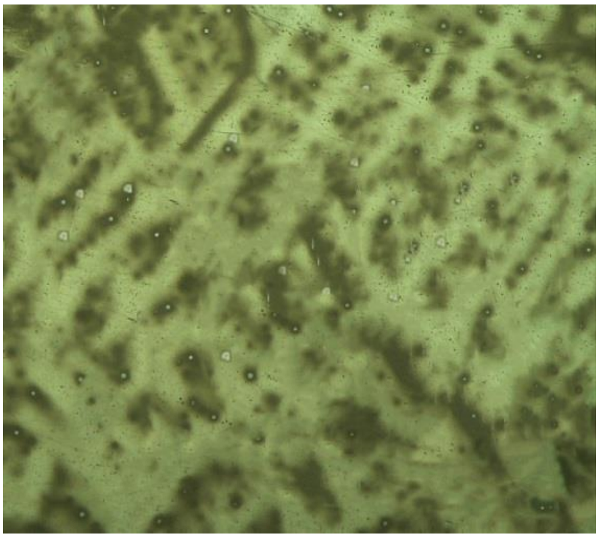

Figure 6. SEM Micrograph of Sample 2 (Al 6061)

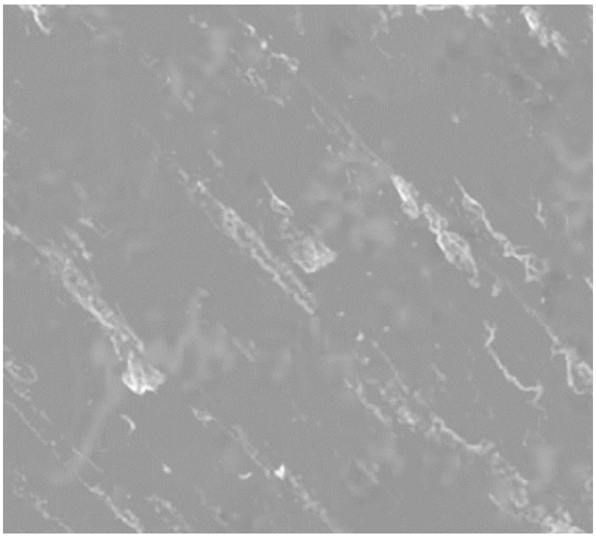

Figure 7. SEM Micrograph of Sample 1 (Al 5083)

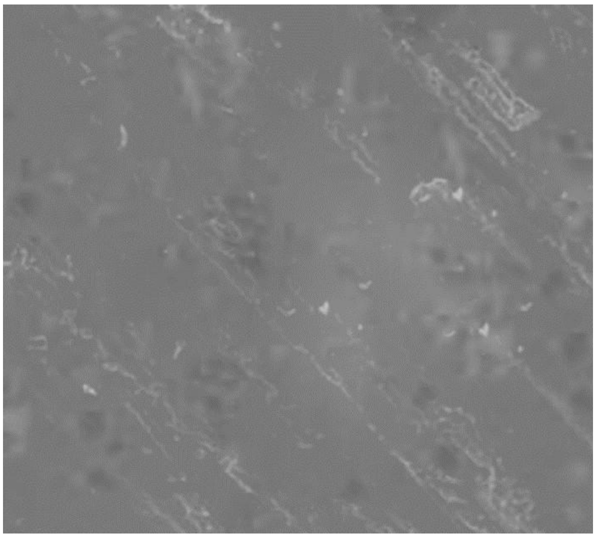

Figure 8. SEM Micrograph of Sample 2 (Al 5083)

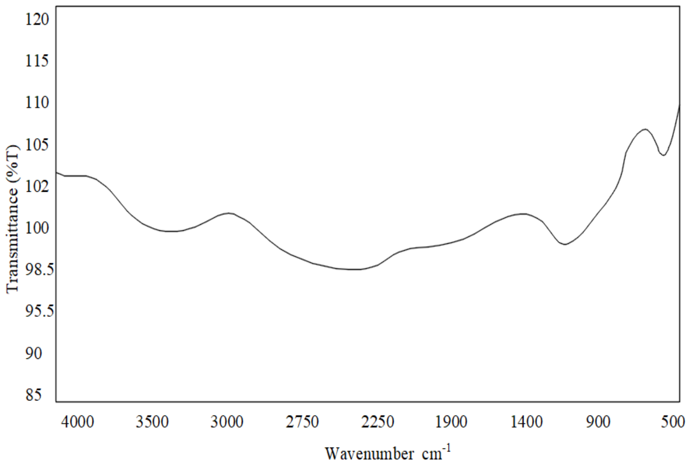

Figure 9. FTIR Spectra of Sample 1 (Al 6061 MMC)

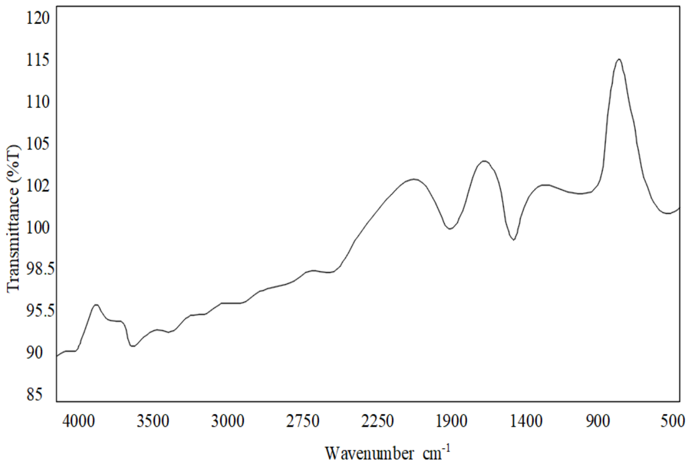

Figure 10. FTIR Spectra of Sample 2 (Al 6061 MMC)

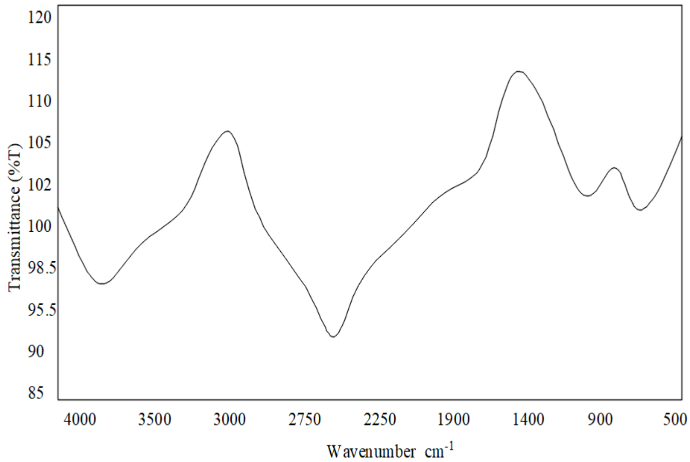

Figure 11. FTIR Spectra of Sample 1 (Al 5083 MMC)

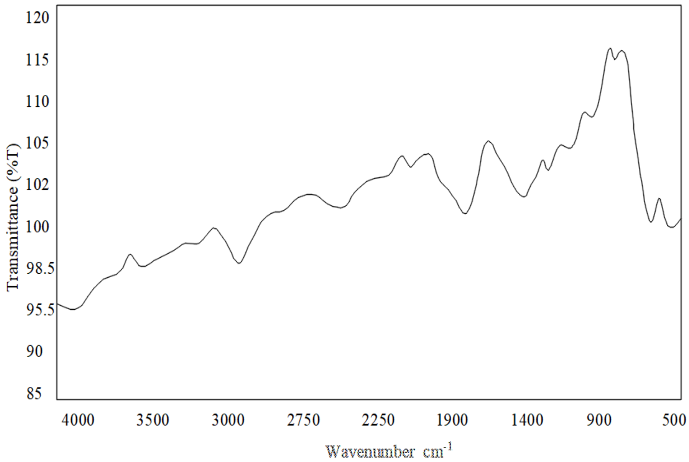

Figure 12. FTIR Spectra of Sample 2 (Al 5083

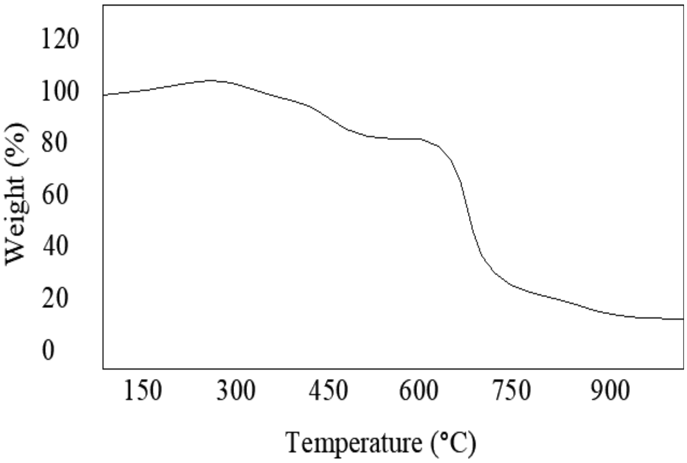

Figure 13. TGA Variation of Sample 1 (Al 6061 MMC)

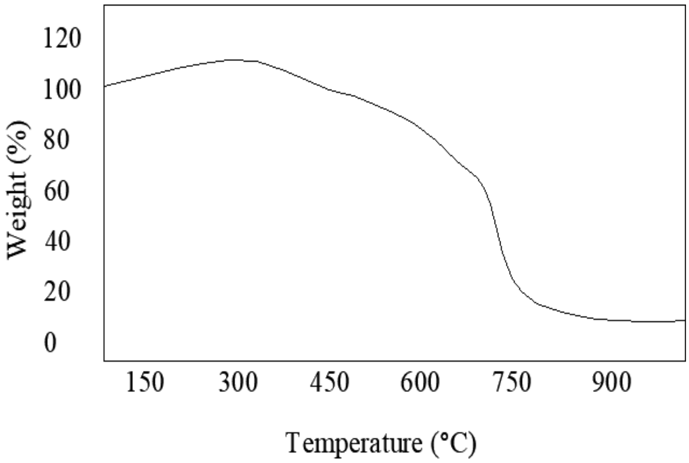

Figure 14. TGA Variation of Sample 2 (Al 6061 MMC)

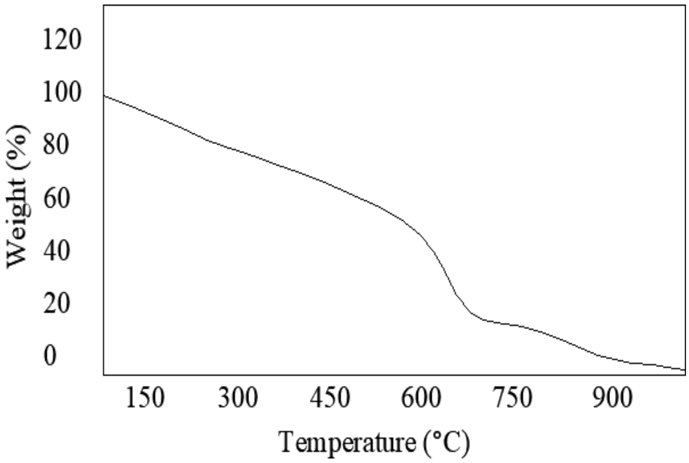

Figure 15. TGA Variation of Sample 1 (Al 5083 MMC)

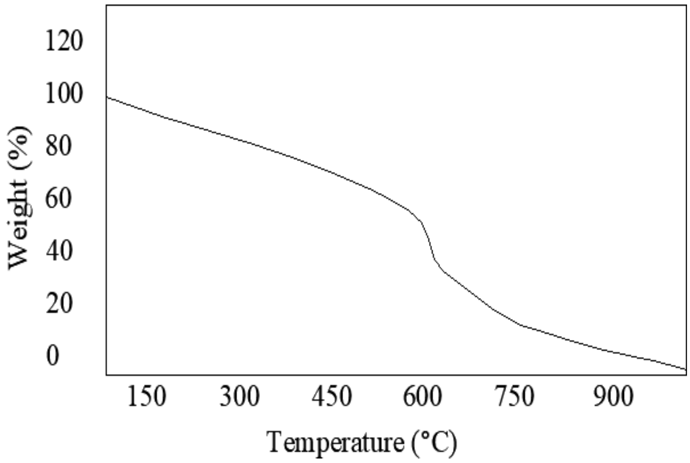

Figure 16. TGA Variation of Sample 2 (Al 5083 MMC)

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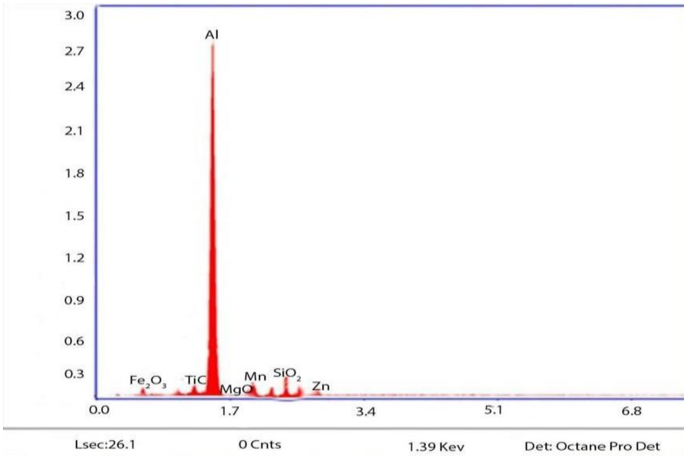

Figure 17. EDS of Al 6061 (Sample 1)

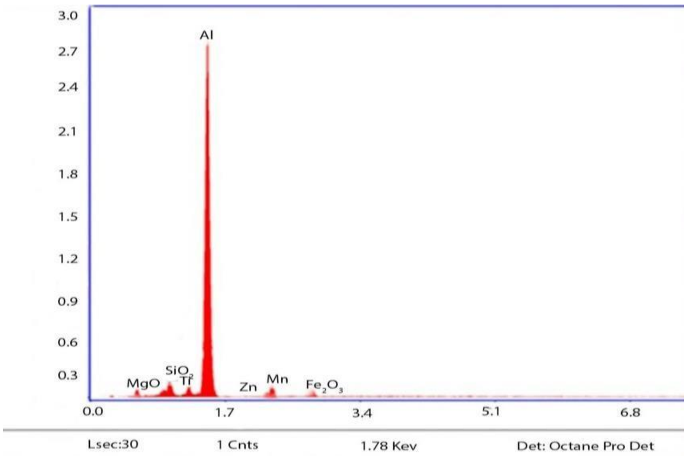

Figure 18. EDS of Al 6061 (Sample 2)

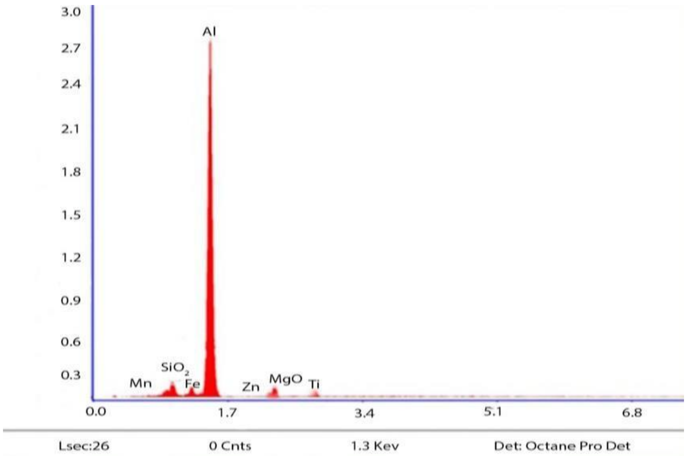

Figure 19. EDS of Al 5083 (Sample 1)

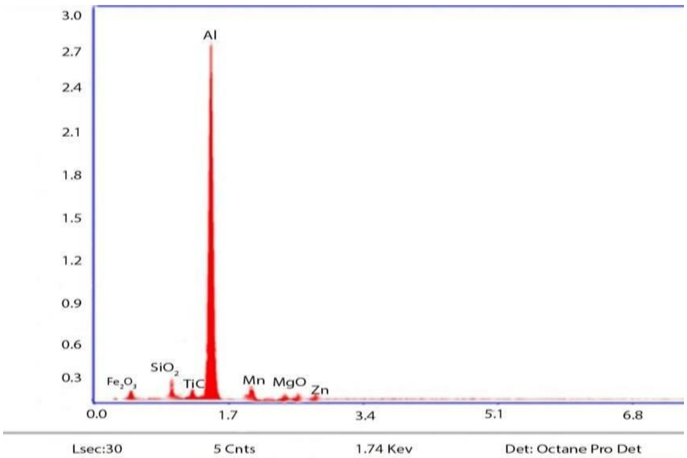

Figure 20. EDS of Al 5083 (Sample 2)

4. Conclusion

The current study sought to investigate the strengthening of Epoxy-resin with Fly-ash. The stir casting technology has been chosen for the production of the new AMMC. The structural strength study of wear test, SEM analysis, FTIR test, and TGA analysis were carried out experimentally for varied mix ratios of both alloys. This study's main findings are summarized below:

- The wear behaviour of the Al 6061 alloy of sample 2 performed better, with a lower wear rate of 0.00332 mm3/Nm when compared to the other samples.
- The findings of SEM research demonstrate that the material bonding nature of Al 6061 alloys is stronger.
- According to the FTIR study, the band absorption spectra develop better for Al 6061 compositions sample 2.
- In comparison, in Thermogravimetric Analysis, sample 2 of Al 6061 had the highest melting point of 790°C.

Different compositions of aluminium 6061 and aluminium 5083 are tested. Aluminium 6061 alloy outperformed aluminium 5083 alloys in comparison.

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