MECHANICAL CHARACTERIZATION OF Al_2O_3/ Mg REINFORCED ALUMINIUM-BASED METAL MATRIX COMPOSITES

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Abstract

Matrix of Crystalline Metal For its cost and resource savings, composites are rapidly being used in sectors including aerospace, automobiles, and structural components. Stiffness, elasticity, thermal coefficient, fatigue life, and dimensional stability are all improved in particle-reinforced aluminium metal matrices compared to unreinforced alloys. In this work, we use the stir casting technique to produce composites with Al 6061 serving as the metal matrix and being strengthened by Al_2O_3 particles.2 and 4 percent increments changed the percentage of reinforcement particles. By ASTM guidelines, the specimens were produced. The composites' tensile hardenability parameters were analysed to determine their characteristics. Particles of reinforcement were mixed into the aluminium matrix and dispersed uniformly at concentrations of 2% and 4% Al_2O_3Mg. Composites have better tensile and hardness characteristics than the unreinforced Al 6061 matrix. In addition, raising the addition level has led to additional increases in both the strength properties and hardness values, and the optimum value has been attained.

Keywords: Aluminum composites, reinforcements, Al_2O_3, Mg;

Introduction

Traditional monolithic materials are restricted in their ability to provide an optimal balance of these four characteristics: strength, stiffness, toughness, and density [1]. Composites are among the most exciting and promising new materials because of their potential to address these limitations and keep up with the ever-increasing demand for modern technologies [2]. Metallic matrix composites (MMCs) offer better properties than unreinforced alloys, including higher specific strength, specific stiffness, damping capacity, and wear resistance. The need for low-density, inexpensive reinforcements in composites has increased [3]. One of the cheapest and lowest-density reinforcements used today is fly ash, a sewage sludge by-product from coal combustion in power plants. It is expected that composites reinforced with fly ash will be inexpensive enough to be widely used in vehicle and lightweight engine applications [4]. The incorporation of foundry sand particles into all alloys is thus expected to promote yet another use for this cheap waste by-product even while having the capacity to preserve energy-intensive aluminium and, therefore, cut the cost of aluminium items [5]. Ceramic particles aluminium matrix composites are gaining popularity because of their low cost, advantages including isotropic characteristics, and the potential of secondary processing, which makes it easier to fabricate secondary components [6]. Cast aluminium matrix particles reinforced composites are superior than unreinforced alloys in terms of specific hardness, modulus, and fatigue strength. While investigating fly-high ash's possible usage as a reinforcing material in the aluminium melt, scientists found that it exhibited electrical resistance, poor thermal conductance, and low density. These properties might be useful in the creation of lightweight insulating composites

[7]. A cast particulate composite may be made by introducing the reinforcing particles into the liquid matrix using the liquid metallurgy approach. The casting method is favoured due to its low manufacturing cost and high output capacity. Stir casting is the easiest and most cost-effective manufacturing method for materials in a liquid condition. The sole drawback of this procedure is that the particles are not distributed evenly due to poor moist ability and gravity-controlled segregation. The reinforcement's volume percentage, matrix material, and interface response all affect how a composite material's mechanical characteristics turn out.Numerous academics have weighed in on these issues [8]. It is reported that the hardness value of Al (precipitator type) composite increases as the proportion of fly ash in the mixture increases. The tensile young's modulus of the volcanic alloy, he says, rises as the percentage of fly ash in the mixture rises. The young's modulus, tensile, compressive strength, and fracture characteristics of the Al2O3 particles reinforced Al MMCs are reported to rise with an improvement in the reinforcement particles. The properties of MMCs are heavily influenced by the interaction between both the matrix and reinforcement [9].Load transmission over an interface is essential for stiffening and strengthening. Fracture deflection at the junction affects toughness, whereas peak stress relaxation close to the contact affects ductility. Al MMCs with reinforcements like SiC and Al2O3 have had a great deal of research done on their tribological properties. However, there is a dearth of literature on the friction and wear behaviour of slag reinforced AMCs. According to Rohatgi, the wear resistance of an aluminium alloy is greatly improved by mixing in tiny particles of fly ash. The hard aluminosilicate component he found in fly ash particles was the reason for the increased durability he observed [10]. The present study makes use of fly-ash, which is rich in refractory oxides such as silica, aluminium, and iron oxides, as a reinforcing phase.Composites are materials made from at least two different materials, and there are many other names for this type of material. Because of the striking differences in chemistry or physical properties between the constituent materials, the resulting material exhibits characteristics that are unique from those of the constituent elements [11]. Composites are unique from mixes and solid solutions in that the constituent parts retain their respective identities inside the final structure [12].One component of a composite of metals (MMC) must be a metal, whereas the other component can be another type of material like ceramics or organic compound [13]. As can be seen in Figure 1, MMCs are created by incorporating a reinforcing element into a metal matrix.

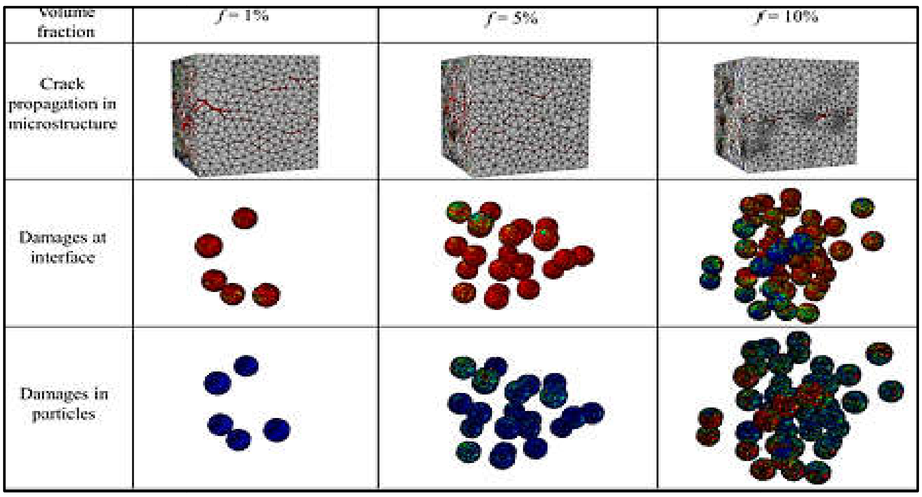

Figure 1: Matrix composition*(Source:Yan Li, Vol 34Issue13, Cambridge University Press)*

1.4 Reinforcement

Matrixes are used to include the reinforcing material. In addition to its structural function (i.e., reinforcing the compound), reinforcement is sometimes employed to alter the compound's physical qualities, such as its resistance to wear, impact resistance, or thermal conductivity. Both continuous and discontinuous reinforcing are possible. It is possible for discontinuous MMCs to have isotropic properties, making them amenable to processing by conventional metalworking methods including extrusion, forging, and rolling. As an added bonus, they may be polished using standard methods. Monofilament wires or fibres, such those found in carbon fibre and silicon carbide, are used in continuous reinforcing. The direction in which the fibres are placed in the matrix determines the material's anisotropy, or whether it is strong or weak. MMCs with boron filament reinforcement were among the earliest types. The "whiskers," short strands, or particles used in discontinuous reinforcement. Both aluminium and silicon carbide are frequently used as reinforcements in this material type.

1.6 Aluminium 6061 alloy:

The aluminium alloy 6061, also known as UNS A96061, is precipitation-hardened thanks to the addition of magnesium and silicon. It was first created in 1935 and given the name "Alloy 61S." It's typically extruded, has high mechanical strength, and can be easily welded. Among aluminium alloys, it is considered to be the most widely used. It's readily accessible in a variety of tempered and pre-tempered forms, including 6061-O (annealed), 6061-T6, as well as 6061-T651. All of the chemical constituents are listed inTable 1.1.

Table 1: Chemical Composition

Element	**Amount (wt %)**
Aluminium	97.85
Magnesium	0.8
Silicon	0.6
Iron	0.7
Copper	0.29
Chromium	0.8
Zinc	0.8
Titanium	0.9
Manganese	0.04
Others	0.04

3. MATERIAL AND METHODOLGY

3.1 Composite

Composites are multi-phase materials with distinct bulk properties from their constituent parts. These materials typically include a basic phase and a reinforcing phase. Even though steel's physicochemical characteristics were quite comparable to those of ductile iron, many common types (materials, alloys and materials combined with admixtures) also had a limited proportion of dispersed phase in their structures and are thus not termed composites. Composites offer several desirable properties, including low weight and high rigidity and strength, as well as stability at high temperatures, high conductivity, a thermal expansion coefficient that may be adjusted, corrosion resistance, and wear resistance.

3.2Stir Casting Method of Fabrication

The following characteristics define Stir Casting:

- Dispersed phase content is low (often less than 30 vol.
- There is a lack of uniformity in the scattered phase distribution throughout the matrix.

First, the scattered particles (Mg) form local clouds (clusters); second, the density differential between the scattered and matrix phases may lead to gravity separation of the dispersed phase.Easy to implement and inexpensive, the technology has many potential applications. If the matrices is in a semi-solid state, the scattered phase may be more evenly distributed. Rheocasting is a process that involves churning metal composite materials while they are in a semi-solid condition. The semi-solid matrix material's high viscosity aids in the dispersed phase's mixing.

3.3Strengthening Mechanism of Metal Reinforced Composite

The reinforcing phase bears the majority of the load in this composite, with the matrix transferring it through the seam mechanism. The matrix is unable to freely extend close to the reinforcing phase because of the latter's high strength, but it can do so at further distances. When a matrix undergoes a non-uniform deformation, shear stress develops at the matrix reinforcing contact, causing tensile stress in the reinforcing phase. This causes the tension to be transmitted to the strengthening stage. In a matrix, the metals may either be discontinuous or continuous. In the former, the tension throughout the length of the reinforcing phase is the same since the load is delivered directly to it. The average tensile strength generated is always lower in the case of a discontinuous matrix than a continuous matrix because the stresses in the alloy increases from zero at the end to a highest benefit in the centre. As with continuous particle reinforced composites, the strength of discontinuous particle reinforced composites grows with increasing particle length when the reinforcing phase fractures, whereas artefacts develop in continuous particle reinforced composites. Furthermore, under the iso strain situation, when the particle are oriented in the direction in which the applied stress, the hardness of the particle-reinforced composite is maximised. The basic rule of mixes may be used to calculate the volume percent of the basic concept contained in the composite and hence the composite's strength.

4. MATERIAL AND MANUFACTURE

4.1 Materials Manufacturing: To conduct these experiments, the materials are prepared with Al-6061 base alloy. Tables 2 and 3 detail the material composition analysis and other test findings, including hardness, tensile, and flexure strength.

Table 2 : Compositional analysis of aluminium

S. No	Si	Fe	Ti	V	Cu	Mn	Al
1	0.08	0.1 5	0.001	0.007	0.001	0.003	99.76

Table – 3 Density, Hardness & Tensile Strength of Aluminium

S. No	Density	2.7 gm/cc
1	Hardness	40.8 VHN
2	Tensile strength	67 MPa

4.2 Methodology:

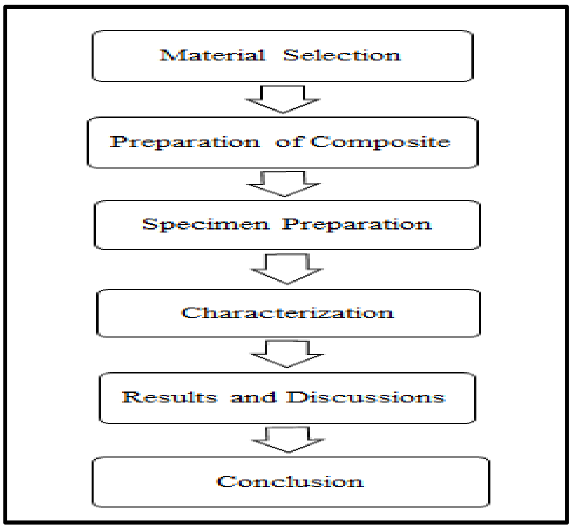

Figure2: Methodology

4.3 Experimental Procedure

Wasteful friction accounts for one-third of our worldwide energy use. Beyond the obvious energy savings, there is also a huge opportunity cost savings from not having to produce as many replacements for broken parts so soon. Wasted energy has a significant negative impact on the economy and the quality of life for the majority of the population. Therefore, it is always preferable to minimise metal wear and keep it under control.

4.4 Melting and casting of the test specimen

In a graphite crucible 3-phase electrically heated furnaces equipped with a temperature regulating system, the measured amount of pickled aluminium was melted at a superheating temperature of 8000C. A mechanical stirrer was used to continually mix the molten metal after the requisite number of particles had been introduced and warmed to roughly 4000C. At an impeller rpm of 550 rpm, the mixing time was kept constant between 60 and 80 seconds. Tiny amounts of mg are added to the melted mixture while it was being stirred in order to improve its wettability. After preparing a cylindrical mould, the melt containing the reinforcement particles was poured into it from the bottom. It was poured into a mould and let to cool and harden there. In order to provide a point of reference, the composite material was likewise cast using the same methods. The casting was removed from the mould after it had hardened and then sized and shaped as needed for the wear test. Samples were cut into smaller pieces and examined under a microscope to determine where the reinforcement particles were located. Particles of red dirt are dispersed in the matrix at varying volume percentages.

As can be seen in Figure 3, the reinforcement particles were evenly dispersed throughout the aluminium matrix.

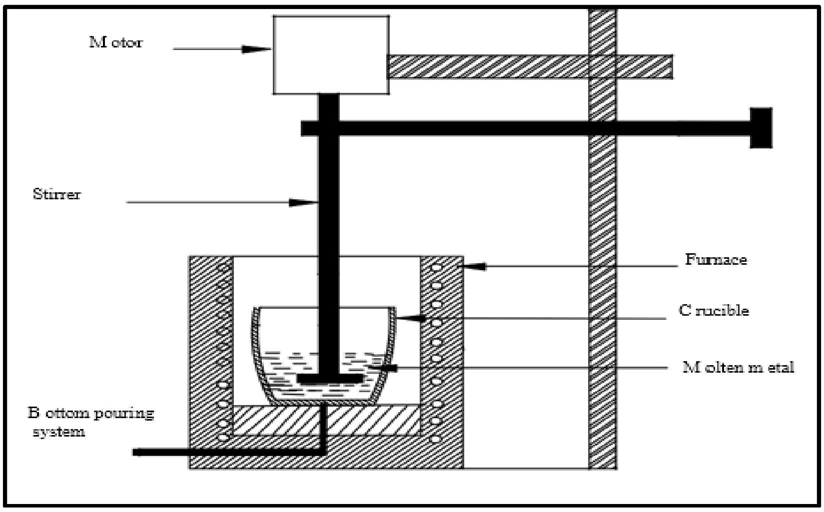

Figure 3: MMC by casting route through the Stir Casting method

Table 4: Mechanical properties of specimens

Specimen	Yield Stress (MPa)	Ultimate Stress (MPa)	Modulus of Elasticity (GPA)	Percentage Elongation	Impact Strength ($Kg.m/cm^2$)	Hardness (VHN)
Pure Al	24.95	68	74	26	6.3	40.78

4.5 Work done:

1. Melting and casting commercially pure aluminium.
2. The Al_2O_3Mg that was put to use was analysed for particle size.
3. stir casting to create an Al_2O_3Mg composite.
4. Density and hardness measurements were carried out for both commercially pure Al samples and Al-4% Al_2O_3 along the Mgcomposite sample.

4.6 Preparation of Specimen

A stir casting procedure is used to warm aluminium 6061 and composites with metal matrix before their processing. Figure 4 depicts the results of combining Al2O3 alloy matrix composites with temperatures ranging from 0C to 6100C. With the aid of a stirrer spinning at a consistent speed, a vortex is generated in the molten metal, and the reinforcement is injected.

Figure4: Heating of Al- Al_2O_3/MgMMCs using Stir Casting

Figure 5: Pouring of molten metal in the mould

Figure 6: Specimen

The fly ash mouldshave been preparing the dimensions 150mm×100mm×5mm, and thenmoulds will be changedfrom wet to dry have to apply gas flame for dry moulds. The Al-Ti alloy of NMMC's has to stir continuously up to preheated is 610^0C and time taken is 2 hours. Then pour the liquid form of Al- Al_2O_3 alloy of matric composite in the moulds as shown in Figure 4. While pouring the liquid, have to be careful there will be two holes in the mould from that final it will solidify metal matrix composite within the 10-15 minutes as shown in Figure5,6 and 7.

Figure 7: Al- Al_2O_3 manufactured specimen samples.

4.7 Testing of Mechanical Properties:

The testing was performed as per ASTM standards on a universal testing machine which is as shown in the Figure 8.

Figure 8: INSTRON-1195

4.8 Tensile test

All of the produced samples had their tensile behaviouranalysed to look for links among wear and tensile qualities. Tensile tests were performed on specimens having a circular cross section, the gauge length of which was 60 mm, the grasp distance of which was 100 mm, and the gauge diameter of which was 8 mm. An INSTRON-1195 testing equipment with a 100 kN capacity was used to conduct the tests at a constant uniaxial speeds of 5 mm/min and a maximum loading range of 20 kN, which translated to an initially sample rate of 9.103 pts/sec. Tensile test results for a variety of composites are provided in the text that follows.

4.9 Impact test

The impact test used a specimen that was 10 millimetres by 10 millimetres by 50 millimetres and had a 2 millimeter-square notch. The Charpy impact testing machine was used to conduct the tests at room temperature. Tests were conducted using a hammer with a remaining energy of 30 Kg.m and an impacting range of 5.6 m/s. Previous chapter presents the results of impact tests conducted on various specimens.

4.10 Fracture

One of the keys to expanding MMCs' usefulness is understanding their fracture behaviour, which may then be used to enhance the materials' mechanical characteristics, most notably their strength and ductility. The qualities of the composite cannot be enhanced without a deeper comprehension of the underlying processes controlling those properties. Particle-reinforced composites' rudimentary mechanisms of crack initiation and progression have been examined at length. The microscopic void coalescence concept is used to the tensile fracture of common alloys (MVC). When particles in an unreinforced alloy fail or their interfaces decohere, the resulting voids form at the particle level. While decohesion is the norm, particle fracture may happen with elongated particles. Particle cracking and composite void formation are the three processes for void nucleation in composites. This is the same mechanism that happens in unreinforced alloys.

4.11 Mechanical Properties

- Metal matrix composites have been studied extensively because of the desirable physical and mechanical features they may achieve, such as large specific modulus, strength, and thermal stability. Several researchers have analysed the impact of the production method on the characteristics of MMCs and the numerous parameters regulating the characteristics of particulate MMCs. Modulus, strength, fatigue, creep, and wear resistance have all been shown to improve with various reinforcements. Tensile strength is often used as an indicator of quality since it is one of the most easily quantified characteristics and because it is crucial in a broad variety of contexts. The literature reveals that there is still a lack of understanding about the factors regulating the mechanical characteristics of particle reinforced composites. But now we're starting to see some of the key components.

- It has been shown that the volume percentage and grain size of reinforcement have the greatest effect on the strength of particulate composites.

- Enhanced dislocation density means that dislocation strengthening will have a larger impact on MMC than on the unreinforced alloy.

- It has been shown that there is a wide range of mechanical characteristics due to the presence of flaws and inhomogeneities introduced at different phases of processing.

4.12 Effect of reinforcement distribution

The MMC's ductility, fracture toughness, and hence its strength, are all affected not only by the total amount of reinforcement but also by how that reinforcement is distributed throughout the material. In order to make full use of the reinforcement's load-carrying capability, it must be distributed evenly throughout the structure. This material's ductility, strength, and toughness were all diminished due to its non-uniform reinforcement distribution, which was shown to persist from the early phases of processing as streaks or cluster of un integrated reinforcement with its associated porosity.

4.13 Effect of Reinforcement Volume Fraction

It has been hypothesised that due to inefficient load distribution from matrix to reinforcement in MMCs, there exists a crucial reinforcement volume portion above which the composite potency can be enhanced relative to that of the un - reinforced material and well below whereby the composite strength decreases. The composite capacity was increased to be controlled by the leftover matrix strength for low volume fractions of reinforcement, and to decrease with increasing volume fractions of reinforcing material. Figures 9 and 10 represent the Al2O3Mg's assumed composition.

Figure 9: Al_2O_3/Mg

The prepared specimen of 2% (Al_2O_3Mg) and 4% is shown in Figure 10 and Figure 11.

Figure 10: 2% Specimen sample	Figure 11: 4% Specimen sample

The prepared specimen is tested in a universal testing machine INSTRON-1195, which is shown in Figures12 and Figure 13. The tests are carried out as per ASTM standards.

Figure 12: Specimen testing of 2% sample

Figure 13: Specimen testing of 4% sample

The experimentation conducted showed a way for the improved mechanical properties, which are discussed in the results.

5. Results and Discussion:

5.1 Tensile test

The specimen's tensile properties have been tested in accordance with the latest ASTM standards. The elastic modulus, ultimate tensile strength elongation at 2% strain, etc., are often the primary metrics examined in these publications. While conducting our experiments, we zeroed on on determining the component's strength to weight ratio. In order to learn about the MMC's mechanical properties, tensile tests were performed utilising an ASTM E8-compliant Universal Testing Machine (UTM). Table 5 shows that as compared to the Al alloy, the composites had much higher tensile strengths.

Table 5: Tensile strength of the Al- Al_2O_3Mgsamples

S.No	Composition	Tensile Strength (MPa)
1	Al base alloy	89.92
2	2% (Al_2O_3Mg)	110.05
3	4% (Al_2O_3Mg)	431.25

When compared to the strength properties of the as-cast Al alloy, the composites significantly outperform. By acting as a barrier to deformations in the matrix, reinforcing particles boost tensile strength as their concentration in MMC rises. The data is used to generate the graphs in Figure 5.1.

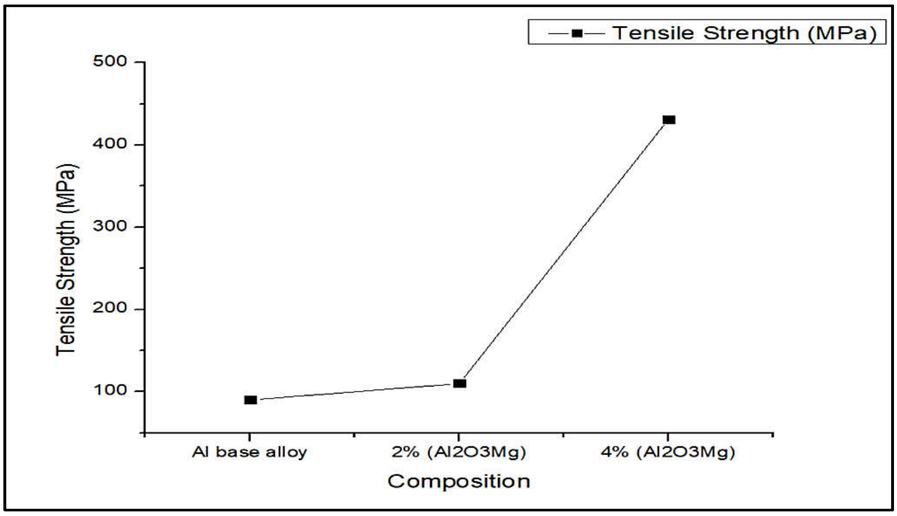

Figure 14: Tensile strength of specimen Al-Al_2O_3Mg samples

From Figure 14, it was observed that the 4% composition of the materials had higher tensile strength when compared to the 2% weight composition and base metal. From the results clearly shows that with an increase in the composition of the material, the tensile strength also increases respectively.

5.2 Impact test:

Standardized instrumented impact testing was conducted using the ASTM E23 technique. Table 6 displays the findings from the instrumented impact tests conducted on all materials and unreinforced Al alloys. The findings demonstrated that the presence of Al2O3 particles greatly dampened the impact behaviour of aluminium.

Table 6: Impact energy of the Al- Al_2O_3 samples

S.No	Composition	Impact energy (J)
1.	Al base alloy	26.32
2.	2% (Al_2O_3Mg)	29.50
3.	4% (Al_2O_3Mg)	31.02

The rise of impact strength with increased particles is an expected result as the ductility increases with concentrations of particulates. The lower impact strength of Al base alloy + Al_2O_3 MMCs can be attributed to Al_2O_3elements, which may act at stress attention areas, as shown in Figure 5.2.

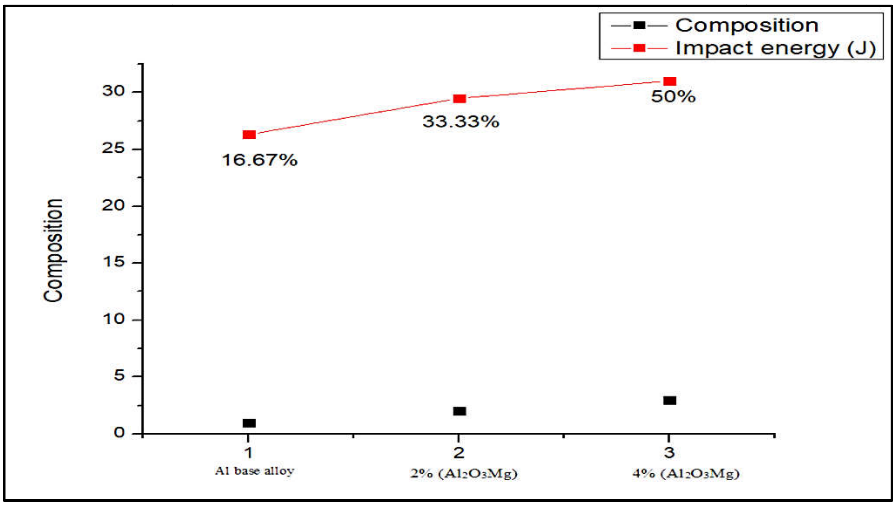

Figure 15: Impact energy of specimen Al-Al_2O_3Mg samples

From Figure 15, it was observed that the 4% composition of the materials had higher impact energy required when compared to 2% and base metal. From the results, it clearly shows that with an increase in composition, the material the energy consumed is also higher.

5.3 Flexure test:

The specimen was ready on an universal test machine for the flexure test. Both its corrosion resistance and its ductility are very high in aluminium. There are benefits, but its hardness and wear resistance aren't as high. Aluminum is reinforced with several types of reinforcement to enhance these qualities. UTM was subjected to a flexural test in accordance with E290 specifications. Table 6 displays the results of tests performed on specimens representing three distinct concentrations.

Table 6: Flexure strength of the Al- Al_2O_3Mg samples

S.No	Composition	Flexure Strength (GPa)
1	Al base alloy	446.021
2	2% (Al_2O_3Mg)	639.225
3	4% (Al_2O_3Mg)	688.808

The results shown that with increase in composition in the base material, the flexure strength said to be enormously increased. It was observed that the 4% composition of the materials had higher flexure strength when compared to 2% weight composition and base metal as shown in the Figure 16. From the results it clearly shows that the with increase in composition the material

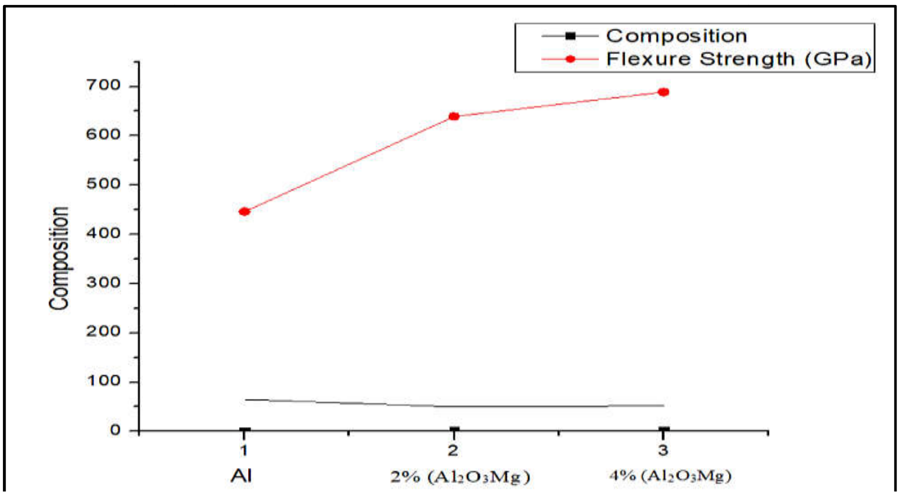

Figure 16: Flexure strength of specimen Al- Al_2O_3 samples

5.4 Three-point bend test

The ready specimens were bent in the centre, the midpoint, and the ends using an universal testing equipment to conduct the test. Table 6 displays the graphed findings.

Table 6: Flexure strength of the Al- Al_2O_3Mg samples

S.No	Composition	Load (kN)
1	Al base alloy	0.855082
2	2% (Al_2O_3Mg)	0.883417
3	4% (Al_2O_3Mg)	0.904502

Samples of metal matrix composites were bent in three directions according to ASTM-D79 standards. The tests were conducted using a hydraulic testing equipment, and the results are shown in Figure 17.

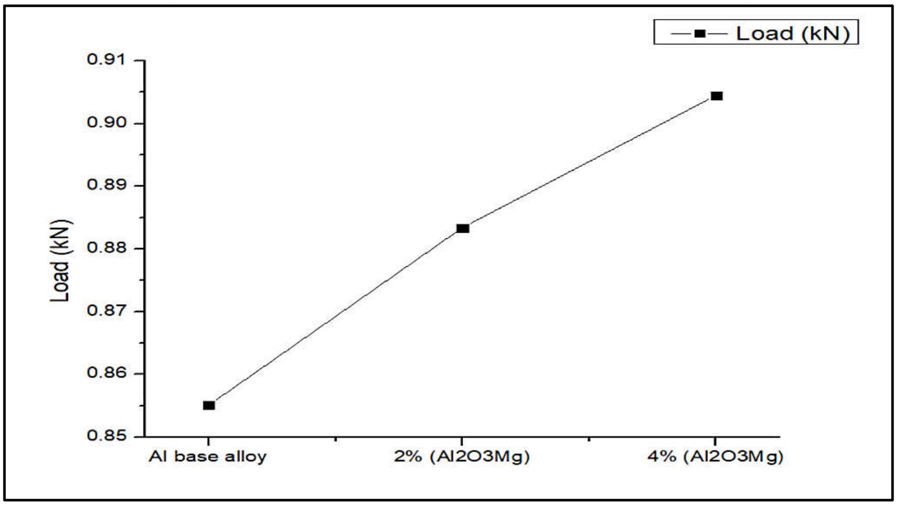

Figure 17: Load baring capability of specimen Al- Al_2O_3 samples.

Figure 17 depicts a weight comparison of the specimens. The 3 point bend strength of a material may be calculated from its final fatigue strength and flexural strain, and it was found that the 4 percent composition of the components had better strength than base metal. Figure 5.4 displays the results, which indicate that as the material's composition increases, so does its load-bearing capacity.

5.5 Analyzing Wear and Tear

To determine how factors such sliding speed, weight, sliding distance, and reinforcing % relate to dry slide wear of the composite, a battery of experiments was designed. The wear findings for varying configurations of parameters were gathered from experiments conducted according to orthogonal array L9 (34), and are displayed in Table 7.

Table 7: Flexure strength of the Al- Al_2O_3Mg samples

S.No	Composition	Wear rate 10^{-11} m^2/N
1	Al base alloy	8.929
2	2% (Al_2O_3Mg)	6.085
3	4% (Al_2O_3Mg)	4.980

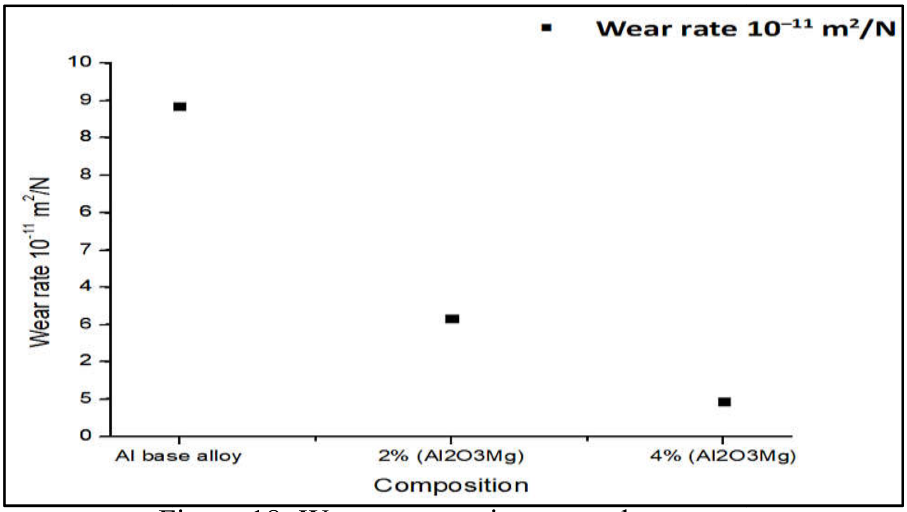

Figure 18: Wear rate specimensamples.

Conclusion

The essential requirements of the expanding Composite sector were investigated, and comprehensive research was conducted to compile the academic data on Aluminum based MMCs. This encompasses a wide range of processes, such as microstructural characterisation, manufacture, testing, analysis, and connection with the resulting attributes.

The conclusions drawn from this study are

1. The results demonstrate that the composite strength is maximised at a 4 percentAl_2O_3 composition, as opposed to 2 percent and base metal.
2. Results show a more significant flexure difference between Al_2O_3 at 4% and base metal at 2%, which is explored.

3. Third, pure aluminium is preferred over the other alloy matrices due to its high thermal stability. In the case of alloy matrices, lower operating temperatures are seen due to poorer longevity of the matrix alloy and agglomerates of the grains. Load transfer is also improved in the situation of a homogeneous aluminium matrix due to the soft contact.
4. In the literature, you may find a wealth of data on the many types of reinforcements utilised in metal matrix composites made of aluminium.
5. It was discovered that the purity of the reinforcement, the particle size of the reinforcement, the origin of the interface, the size distribution of reinforcement, the design and manufacturing route adopted, the significance of hot working, the presence of any intermetallic induces, and the degree in which the second phase was consistent with the matrix all affected the fracture method of particle-reinforced composites.
6. Metal matrix composites may be made using several different methods. There are benefits and drawbacks to each possibility. There are also significant price differences between various options. Typically, the manufacturer will go for the cheapest option. For this reason, a sizable fraction of the MMCs used in industrial settings today is cast using the stir-casting method.
7. Because of this, preparing MMC with Al_2O_3 as reinforcement and investigating its wear properties will be the focus of this effort. Variables such as sliding speed, average load, heat treatment temperature, and cooling media will all play a role in the outcome, thus, their effects need to be investigated.

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