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Experimental Mechanical Characterization of Aluminium Based Metal Matrix Composites Using Al-6061

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ABSTRACT

Metal Matrix Composite materials are widely used in a variety of applications such as aerospace, automotive and structural components resulting in savings of material and energy. Particulate reinforced Aluminium metal matrix composite materials which are having desirable properties such as high specific stiffness, high specific strength, high coefficient of thermal expansion, increased fatigue resistance and superior dimensional stability compared to unreinforced alloys. In the present work, an attempt has been made to develop composites using Al 6061 as a matrix material reinforced with Al_2O_3 particulates using the stir casting technique. The reinforcement particulates were varied in steps of 2%, and 4%. The Specimens were prepared as per the ASTM standards. The prepared composites were characterized by using tensile strength and hardness properties were evaluated. Reinforcements particles are added and were distributed homogeneously in the aluminium matrix at 2%and 4% Al_2O_3. The tensile and hardness properties were higher in the case of composites when compared to the unreinforced Al 6061 matrix. Also increasing the addition level has resulted in a further increase in both tensile strength and hardness values and optimum value was obtained.

KEYWORDS: Accuracy configurable, approximate multiplier, area-efficient, low energy, scalable, truncating

1. INTRODUCTION

Conventional monolithic materials have limitations in achieving a good combination of strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever-increasing demand of modern-day technology, composites are the most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low-cost reinforcements. Among various discontinuous dispersoids used, fly ash is one of the most inexpensive and low-density reinforcement available in large quantities as a solid waste by-product during the combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for widespread applications in automotive and small engine applications. It is therefore expected that the incorporation of fly ash particles in the aluminium alloy will promote yet another use of this low-cost waste by-product and, at the same time, has the potential for conserving energy-intensive aluminium and thereby, reducing the cost of aluminium products. Nowadays the particulate reinforced aluminium matrix composite is gaining importance because of its low cost with advantages like isotropic properties and the possibility of secondary processing facilitating the fabrication of secondary components. Cast aluminium matrix particle reinforced composites have a higher specific strength, specific modulus and good wear resistance as compared to unreinforced alloys.While investigating the opportunity of using fly-ash as a reinforcing element in the aluminium melt, observed that the high electrical resistivity, low thermal conductivity and low density of fly-ash may help makelightweight insulating composites. The particulate composite can be prepared by injecting the reinforcing particles into the liquid matrix through the liquid metallurgy route by casting. The casting route is preferred as it is less expensive and amenable to mass production. Among the entire liquid state production routes, stir casting is the simplest and cheapest one. The only problem associated with this process is the non-uniform distribution of the particulate due to poor wet ability and gravity regulated segregation. Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. These aspects have been discussed by many researchers. Reports that with the increase in volume percentages of fly ash, hardness value increases in Al–fly ash (precipitator type) composites. He also reports that the tensile elastic modulus of the ash alloy increases with an increase in volume per cent of fly ash. The Al_2O_3 particle reinforced Al MMCs, with varying particulate volume percentages and report improvement in elastic modulus, tensile strength, compressive strength and fracture properties with an increase in the reinforcement content. The interface between the matrix and reinforcement plays a critical role in determining the properties of MMCs. Stiffening and strengthening rely on load transfer across the interface. Toughness is influenced by the crack deflection at the interface and ductility is affected by the relaxation of peak stress near the interface. Extensive studies on the tribological characteristics of Al MMCs containing reinforcements such as SiC and $Al_2O_3$are available in the literature. However, reports on friction and wear characteristics of fly ash reinforced AMCs are very limited. Rohatgi has reported that the addition of fly ash particles to the aluminium alloy significantly increases its abrasive wear resistance. He attributed the improvement in wear resistance to the hard aluminosilicate constituent present in fly ash particles. In the present work, fly-ash which mainly consists of refractory oxides like silica, alumina, and iron oxides is used as a reinforcing phase.

2. MATERIALS AND METHODS

2.1 MATERIALS

2.1.1 Aluminium 6061 alloy:

Aluminium 6061 (Unified Numbering System (UNS) designation A96061) is a precipitation-hardened aluminium alloy, containing magnesium and silicon as its major alloying elements. Originally called "Alloy 61S", it was developed in 1935. It has good mechanical properties, exhibits good weldability, and is very commonly extruded (second in popularity only to 6063). It is one of the most common alloys of aluminium for general-purpose use.It is commonly available in pre-tempered grades such as 6061-O (annealed), tempered grades such as 6061-T6 (solutionized and artificially aged) and 6061-T651 (solutionized, stress-relieved stretched and artificially aged). The chemical composition is shown in Figure 1.2.

Element	Amount (wt %)
Aluminium	96.85
Magnesium	0.9
Silicon	0.7
Iron	0.6
Copper	0.30
Chromium	0.25
Zinc	0.20
Titanium	0.10
Manganese	0.05
Others	0.05

Figure 1: Aluminium 6061 alloy

2.1.2 Aluminium oxide (al2o3)

Aluminium oxide is a chemical compound of aluminium and oxygen with the chemical formula Al_2O_3. It is the most commonly occurring of several aluminium oxides and is specifically identified as aluminium (III) oxide. It is commonly called alumina and may also be called alkoxide, alkoxide, or alundum depending on particular forms or applications. It occurs naturally in its crystalline polymorphic phase α- Al_2O_3 as the mineral corundum as shown in Figure 1.3, varieties of which form the precious gemstones ruby and sapphire. Al_2O_3 is significant in its use to produce aluminium metal, as an abrasive owing to its hardness, and as a refractory material owing to its high melting point.

Figure 2.1: Aluminium oxide

3. EXPERIMENTAL PROCEDURE

3.1 COMPOSITE

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and has bulk properties significantly different from those of any of the constituents. Many common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small number of dispersed phases in their structures, however, they are not considered composite materials since their properties are similar to those of their base constituents (the physical property of steel are similar to those of pure iron). Favourable properties of composites materials are high stiffness and high strength, low density, high-temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

3.2 MATRIX PHASE

1. The primary phase, having a continuous character,
2. Usually more ductile and less hard phase,
3. Holds the reinforcing phase and shares a load with it.

3.3 REINFORCING PHASE

1. Second phase (or phases) is embedded in the matrix in a discontinuous form,
2. Usually stronger than the matrix, therefore it is sometimes called the reinforcing phase.

Composites as engineering materials normally refer to the material with the following characteristics:

1. These are artificially made (thus, excluding natural materials such as wood).
2. These consist of at least two different species with a well-defined interface.
3. Their properties are influenced by the volume percentage of ingredients.
4. These have at least one property not possessed by the individual constituents.

3.4 TESTING OF MECHANICAL PROPERTIES:

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

Figure 4.8: INSTRON-1195

3.4.1 Tensile test

The tensile behaviour of all the prepared samples was determined to examine the possibility of correlations between wear and tensile properties. Circular cross-sectionspecimens with a specific gauge length of 60 mm, grip distance of 100 mm and a gauge diameter of 8 mm were used for the tensile tests. These tests were carried out at a constant crosshead speed of 5 mm/min and a full-scale load range of 20 kN corresponding to an initial sample rate of 9.103 pts/sec in an INSTRON-1195 tensile testing machine of 100 kN capacities. The results of the tensile tests for different composites are presented in preceding below.

3.4.2 Impact test

The size of the specimen for the impact test was 10 mm x 10 mm x 50 mm with a rectangle notch size of 2 mm. The tests were carried out at room temperature using an impact-testing machine of Charpy type. The tests were carried out with an initial energy of hammer 30 Kg.m and with a striking velocity of 5.6 m/s. Impact test results for different test specimensis presented in the preceding chapter.

3.4.3 Fracture

The fracture behaviour of MMCs has been identified not only for extending their applications but also for improving mechanical properties, especially strength and ductility.

A better understanding of the underlying mechanisms affecting composite properties is essential if the properties of the composite material are to be improved. The fundamentals of fracture initiation and propagation mechanism in particle-reinforced composites have been discussed in detail. Tensile fracture of conventional alloys is considered in terms of the micro void coalescence model (MVC). Void nucleation in unreinforced alloys occurs at constituent particles, either through particle failure, or through interface decohesion. Decohesion is most common, but particle cracking occurs with elongated particles. In composites, there are three possible mechanisms for void nucleation particle cracking, interface decohesion, and matrix void nucleation is the same mechanism as occurs in the unreinforced alloys.

4. RESULTS AND DISCUSSION

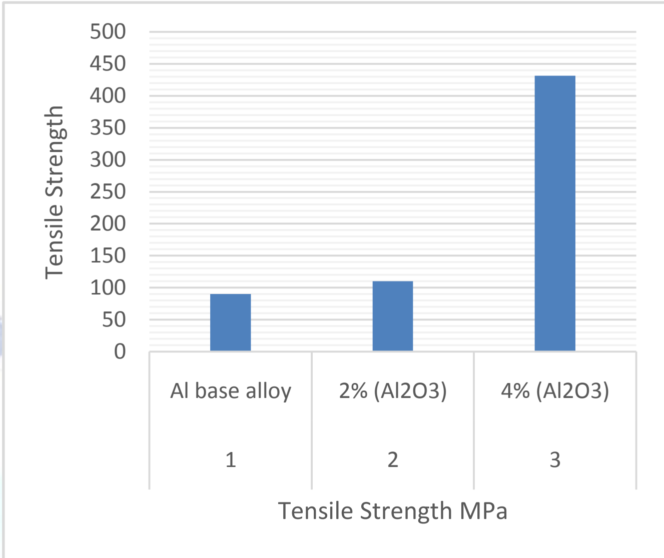
4.1 Tensile test

ASTM standards have been thoroughly followed while testing the specimen for its tensile properties. Most of the papers focus on the yield strength, ultimate tensile strength, elongation at 2% strain etc. However, we focused our experimentation on finding out the strength per weight ratio of the component. Tensile tests were done using a Universal Tensile testing Machine (UTM), for investigating the mechanical behaviour of the MMC as per the ASTM E8 standards. From Table 5.1, it is evident that the tensile strength of the composites is greater when they are compared with the as-cast Al alloy.

Table 4.1: Tensile strength of the Al- Al_2O_3 samples

S.No	Composition	Tensile Strength (MPa)
1	Al base alloy	89.92
2	2% (Al_2O_3)	110.05
3	4% (Al_2O_3)	431.25

The tensile strength of the composites is greater when they are compared with the as-cast Al alloy. When the content of the particles in MMC increases, the tensile strength increases because the addition of the reinforcement particles hinders the plastic deformation in the matrix. From the data, the graphs are plotted as shown in Figure 5.1.



samples

From Figure 4.1, 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 the material the tensile strength also increases respectively.

4.2 Impact test:

Impact tests were carried out according to ASTM E23method, in a standard instrumented impact testing unit. The results of the instrumented impact tests of all materials and unreinforced Al alloys are given in Table 4.2.The results showed that the impact behaviour of aluminium was significantly reduced by the presence of Al_2O_3 particles.

Table 4.2: 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_3)	29.50
3.	4% (Al2O3)	31.02

The increase 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 the presence of Al_2O_3 particles which may act at stress concentration areas as shown in Figure 4.3.

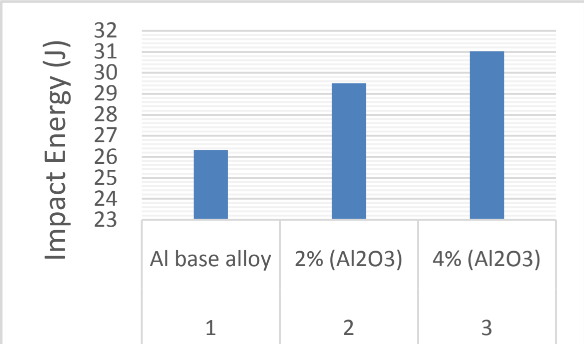


Figure 4.3: Impact energy of specimen Al- Al_2O_3 samples

From Figure 4.3, 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 increase in composition the material the energy consumed is also higher.

4.3 Flexure test:

The flexure test was performed on the specimen which are prepared on a universal testing machine.Aluminium has high resistance to corrosion and ductility. Despite many advantages, it has less hardness and wears resistivity. To improve these properties, different type of reinforcement is added with aluminium. The Flexural test was conducted on UTM according to E290. Specimen of 3 different percentages were tested as shown in Table 4.5.

Table 4.5: Flexure strength of the Al- Al_2O_3 samples

S.No	Composition	Flexure Strength (GPa)
1	Al base alloy	446.021
2	2% (Al2O3)	639.225
3	4% (Al2O3)	688.808

The results showed that with an increase in composition in the base material, the flexure strength is said to be enormously increased. It was observed that the 4% composition of the materials had higher flexure strength when compared to the 2% weight composition and base metal as shown in Figure 5.3. From the results, clearly shows that the with an increase in composition the material

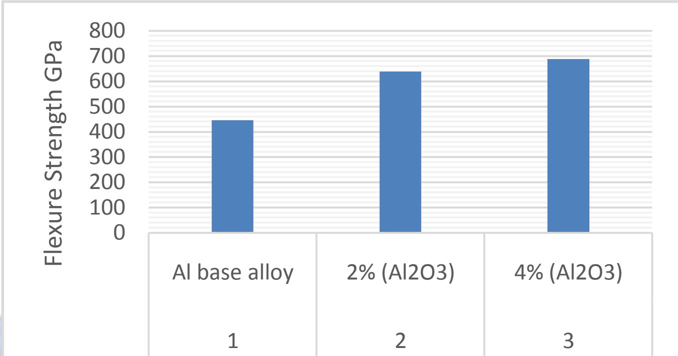


Figure 4.4: Flexure strength of specimen Al- Al_2O_3 samples

4.4 Three-point bend test

A 3-Point bending test was performed on the specimens prepared on a universal testing machine. The results plotted are shown in Table 4.6.

Table 4.6: Flexure strength of the Al- Al_2O_3 samples

S.No	Composition	Load (kN)
1	Al base alloy	0.855082
2	2% (Al2O3)	0.883417
3	4% (Al2O3)	0.904502

Three-point bending tests were conducted on metal matrix composite samples according to tothe standard procedures outlined in ASTM-D79. The tests were carried out with a hydraulic testing machine and the results are plotted as shown in Figure 4.7.

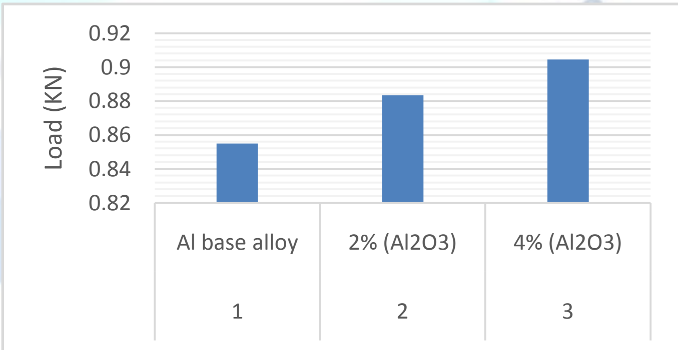


Figure 4.7: Load bearing capability of specimen Al- Al_2O_3 samples.

The specimen is compared for the weight percentage as shown in Figure 5.4, From the ultimate failure load and flexural strain obtained, we can determine the 3 points bending strength of the material, it was observed that the 4% composition of the materials had a higher in strength when compared to the base metal. From the results, clearly shows that with increase in composition the material load bearing capability is also increased which is as shown in Figure 4.7.

5. CONCLUSION

A detailed study was undertaken to pool up the existing literature on Aluminium-based MMCs and efforts were put to understand the basic needs of the growing Composite industry. This includes various aspects such as Characterization, fabrication, testing, analysis and correlation between microstructure and the properties obtained.

The conclusions drawn from this study are

1. The results show that higher in the composition the strength of the composite is increased for 4%$Al_2O_3$when compared to 2% and base metal.
2. The flexure is observed higher difference in 4%Al_2O_3 than 2% and base metal which is discussed in the results.
3. Pure aluminium matrix is preferred to various alloy matrices due to the high-temperature stability of the aluminium as compared with aluminium alloys. Lower working temperatures in the case of alloy matrices are attributed to the lower stability of the alloy matrix and coarsening of the grains. In addition, the load transfer in the case of the pure aluminium matrix is more effective due to the clean interface.
4. There exists a wide range of databases in the literature for different types of reinforcements in Aluminium Metal Matrix Composites.
5. In particle reinforced composites, the fracture mode was observed to depend on reinforcement purity, reinforcement particle size, nature of the interface, the volume fraction of reinforcement, fabrication route adopted, the extent of hot working, presence of any intermetallic precipitates and extent of coherency of the second phase with the matrix.
6. There are varieties of techniques available for the production of metal matrix composite. Each having its own merits and demerits. In particular, some are far more expensive than others. The manufacturer generally prefers the lowest cost route. Therefore, stir-casting technique represents a substantial proportion of the MMCs in commercial sectors today.
7. Thus, the priority of this work will be to prepare MMC using Al_2O_3as reinforcement material and to study its wear characteristics. The effect of different dependent factors primarily sliding velocity, normal load, effect of heat treatment temperature and cooling media are also to be studied.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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