An Investigation of Mechanical Properties Of AL6061 Hybrid Metal Matrix Composites

Esakki Muthu M[1], Manokar S[2], Mari Durai V[3], Venkatesh R[4], Suthan A[5]
[1, 2, 3, 5] Dept of mechanical engineering
[4]Assistant professor, Dept of mechanical engineering
[1, 2, 3, 4] PSR Engineering College, Sivakasi–626 140
[5]Sethu Institute of Technology,kariapatti-626 115

Abstract- *Among automobile manufacturers, in recent times, a paramount importance has been given to less fuel consumption of the vehicles by utilizing lightweight and high strength materials. Metal matrix composites (MMCs) have been used commercially in the automotive market for nearly twenty years. Metal Matrix Composites (MMCs) have very light weight, high strength, stiffness and exhibit greater resistance to corrosion, oxidation, and wear. Tensile and compressive strength is an especially important property of Aluminium matrix composites which is essential for automotive application. In this study hybrid Aluminium matrix composite was fabricated through crucible casting route. Zirconium dioxide (ZrO2) and Egg shell particles were used as reinforcement phases for the present study. The hybrid MMC was prepared with varying the ZrO2 particles weight ratio ranging from 2% to 4% and Es were varied 3% to 5% fixed quantity 1% of magnesium. The various mechanical properties were investigated and compared with non-metal matrix alloy of Al6061. Finally, medium level of reinforcement enhanced the tensile and compressive strength moderately*

Keywords- Aluminium matrix composites, Automobile applications, Crucible casting route, Tensile and compressive strength.

I. INTRODUCTION

Composite Material

Composite material is a material composed of two or more distinct phases (matrix phase and reinforcing phase) and having bulk properties significantly different from those of any of the constituents. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their constituents (physical property of steel are similar to those of pure iron) . Favorable 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.

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.

Reinforcing Phase

1. Second phase (or phases) is imbedded in the matrix in a discontinuous form,
2. Usually stronger than the matrix, therefore it is sometimes called reinforcing phase. Composites as engineering materials normally refer to the material with the following characteristics:

Performance of Composite depends on:

1. Properties of matrix and reinforcement,
2. Size and distribution of constituents,
3. Shape of constituents,
4. Nature of interface between constituents.

Classification of Composites

Composite materials are classified
a. On the basis of matrix material,
b. On the basis of filler material.

On the basis of Matrix:

A. Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (Aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.

B. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and imbedded fibers of other ceramic material (dispersed phase).

C. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated polyester (UP), Epoxy) or thermoplastic (PVC, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

Metal Matrix Composites (MMCS)

Automobile manufacturers are responding to demands for greater fuel efficiency through use of alternate materials such as metal matrix composites (MMCs). Parts made of MMCs offer significant weight savings while maintaining if not improving performance as compared with conventional materials. Over the last decade, MMCs have made slow but steady progress toward mainstream utilization in the automobile industry. Advanced materials, such as metal matrix composites (MMC) appears a promising way to achieve significant improvements in performance.

MMC Attributes and Applications

MMCs are composed of a metal or metal alloy base (called the matrix) and a reinforcing (usually ceramic) material that is dispersed in the matrix. MMCs typically are stronger, stiffer, operate at higher temperatures, have better abrasion resistance, and have other advantages. MMC technology was first developed in the early 1960s.Aluminum companies specifically targeted aluminum MMCs as a method of expanding aluminum demand.MMC properties and production costs are dependent on the type of reinforcement and the manufacturing process. The least expensive type of MMC part is the discontinuous type reinforced with particulates, which is relatively inexpensive. This type can be produced using conventional metal casting techniques. However, particulate MMCs can also produce using powder metallurgy processes that are more expensive but that produce MMCs with better physical properties.

The most promising MMCs for automobile applications are the aluminum-based types. Reinforced with particulates of silicon carbide or alumina, aluminum MMCs have been shown to be able to take the place of certain steel and cast iron parts in automobiles with weight savings in excess of 50 percent. Small amounts of aluminum MMCs are currently being used as cylinder liners and in pistons of certain Japanese automobiles.

Aluminum Metal Matrix Composites

Aluminum alloys are used in advanced applications because of their combination of high strength, low density, durability, machinability, availabilityandcostisveryattractivecomparedtocompetingmaterials.However,thescopeof these properties can be extended by using aluminum matrix composite materials. Aluminum matrix composites can be defined as follows: It must be man-made. It must be a combination of at least two chemically distinct materials (one being aluminum) with a distinct interface separating the constituents. The separate materials must be combined three dimensionally.Itshouldcreatepropertieswhichcouldnotbeobtainedbyanyoftheindividualconstituents. The major advantages of AMCs compared to unreinforced materials are as follows:

►Greater strength
►Improved stiffness
►Reduced density(weight)
►Improved high temperature properties
►Controlled thermal expansion coefficient
►Thermal/heat management
►Enhanced electrical performance
►Improved abrasion and wear resistance
► Control of mass (especially in reciprocating Applications)
►Improved damping capabilities.

AMC material systems offer superior combination of properties in such a manner that today no existing monolithic material can rival. Driving force for the utilization of AMCs in automobile sector include performance, economic and environmentalbenefits.

Typesof AMCs

AMCs can be classified into four types depending on the type of reinforcement.

1. Particle-reinforced AMCs(PAMCs)
2. Whisker-or Short Fiber-reinforced AMCs(SFAMCs)
3. Continuous Fiber-reinforced AMCs(CFAMCs)
4. Mono Filament-reinforced AMCs(MFAMCs)

Some of the salient features of these four types of AMCs are detailed below.

Particle Reinforced Aluminum Matrix Composites (PAMCs)

These composites generally contain equiaxed ceramic reinforcements with an aspect ratio less than about 5. Ceramic reinforcements are generally oxides or carbides or borides (Al_2O_3 or SiC or TiB_2) and present in volume fraction less than 30% when used for structural and wear resistance applications. PAMCs are less expensive compared to CFAMCs. PAMCs are used as rotating blade sleeves in helicopters.

II. MATERIALS AND EQUIPMENTS

Chemical Composition of 6061A Aluminium

Table: 1 Typical chemical composition for aluminium alloy 6061

ELEMENT	PRECENTAGE(%)	
	MIN	MAX
Si	0.4	0.8
Fe	0.0	0.7
Cu	0.15	0.4
Mn	0.0	0.15
Mg	0.8	1.2
Zn	0.0	0.25
Ti	0.0	0.15
Cr	0.04	0.35
Al	-	Bal

Table: 2 Mechanical Properties of Aluminium Alloy 6061

Density	2.70g/cm^3
Melting Point	652°c
Modulus of Elasticity	68.9 gpa
Thermal conductivity	167 W/m.K
Thermal Expansion	24 x10-6 /K
Electrical resistivity	3.99 x10-6 Ω .m

Fabrication of 6061 Aluminium

- Process Rating
- Workability - Cold Average
- Machinability Average
- Weldability – Gas Excellent
- Weldability – Arc Excellent
- Weldability – Resistance Excellent
- Brazability Excellent
- Solderability Good

Applications of 6061A Aluminium

Shipbuilding, Motorboats, Aircraft structures, Truck bodies, Pylons & towers, Rail coaches

Machinability

The heat-treated alloy has fairly good machining properties, but tools should preferably be of high speed steel and must be kept sharp. A moderately high rate of tool wear may be expected. Liberal cutting lubricant should be employed.

Casting Characteristics

1. FLUIDITY -Good, suitable for fairly thin castings.
2. PRESSURE TIGHTNESS -Excellent, suitable for castings required to be leak tight
3. HOT-TEARING -Excellent, problems due to hot tearing are rarely seen.
4. TYPICAL POURING TEMPERATURE -710°C

ZIRCONIUM DI OXIDE

Sometimes known as zirconium(not to be confused with zircon), is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure, is the mineral baddeleyite. A dopant stabilized cubic structured zirconia, cubic zirconia, is synthesized in various colours for use as a gemstone and a diamond stimulant. Zirconium dioxide is one of the most studied ceramic materials. ZrO_2 adopts a monoclinic crystal structure at room temperature and transitions to tetragonal and cubic at higher temperatures.

The change of volume caused by the structure transitions from tetragonal to monoclinic to cubic induces large stresses, causing it to crack upon cooling from high temperatures. When the zirconia is blended with some other oxides, the tetragonal and/or cubic phases are stabilized. Effective dopants include magnesium oxide (MgO), yttrium oxide (Y2O3, yttria), calcium oxide (CaO), and cerium (III) oxide (Ce2O3). Zirconia is often more useful in its phase 'stabilized' state. Upon heating, zirconia undergoes disruptive phase changes. By adding small percentages of yttria, these phase changes are eliminated, and the resulting material has superior thermal, mechanical, and electrical properties.

In some cases, the tetragonal phase can be metastable. If sufficient quantities of the metastable tetragonal phase is present, then an applied stress, magnified by the stress concentration at a crack tip, can cause the tetragonal phase to convert to monoclinic, with the associated volume expansion. This phase transformation can then put the crack into compression, retarding its growth, and enhancing the fracture toughness. This mechanism is known as transformation toughening, and significantly extends the reliability and lifetime of products made with stabilized zirconia

USES

The main use of zirconia is in the production of ceramics, with other uses including as a protective coating on particles of titanium dioxide pigments, as a refractory material, in insulation, abrasives and enamels. Stabilized zirconia is used in oxygen sensors and fuel cell membranes because it has the ability to allow oxygen ions to move freely through the crystal structure at high temperatures. Zirconium dioxide (ZrO_2) is used as one of the reinforcement’s owing to its higher hardness, melting point, and oxidizing properties it possess. ZrO_2 of 100 microns grain size was used for the composite preparations. Inclusion of ZrO_2 was varied in various percentages for the analysis. It is available in nature as mineral zircon. Because of the good oxidizing properties it possess, ZrO_2 enables good corrosion resistance. ZrO_2 was prepared in the form of powder at a grain size of 100 microns. Table represents the constituents of ZrO_2.

EGG SHELL

Eggshells were rinsed in water to remove the membrane and then packed in a circular stainless steel tray. The rinsed egg shells contained in the tray were dried in the sun for 6 hours.

The dried eggshells were crushed manually with the aids of hand compression and then finally pulverized in a planetary ball mill. This milling was done for 3hours after which the mill was offloaded. Reveals the eggshells in two different forms.

Fig No: 1 Egg shells

Fig No: 2 pulverized Egg shells

MAGNESIUM

Magnesium is a chemical element with the symbol Mg and atomic number 12. Its common oxidation number is +2. It is an alkaline earth metal and the eighth-most-abundant element in the Earth's crust and ninth in the known universe as a whole. Magnesium is the fourth-most-common element in the Earth as a whole (behind iron, oxygenandsilicon), making up 13% of the planet's mass and a large fraction of the planet's mantle.

The relative abundance of magnesium is related to the fact that it easily builds up in supernova stars from a sequential addition of three helium nuclei to carbon .Due to magnesium ion's high solubility in water, it is the third-most-abundant element dissolved in seawater. Magnesium is produced in stars larger than 3 solar masses by fusing helium and neon in the alpha process at temperatures above 600 mega kelvins. The free metal burns with a characteristic brilliant-white light, making it a useful ingredient in flares. The metal is now obtained mainly by electrolysis of magnesium salts obtained from brine. In commerce, the chief use for the metal is as an alloying agent to make aluminum-magnesium alloys, sometimes called magnesium or magnesium.

Since magnesium is less dense than aluminum, these alloys are prized for their relative lightness and strength. In human biology, magnesium is the eleventh-most-abundant element by mass in the human body. Magnesium ions are sour to the taste, and in low concentrations they help to impart a natural tartness to fresh mineral waters. In this composite ratio magnesium were mixed 1% for all ratios.

III.EXPERIMENTALSETUPFORMODAL ANALYSIS

ROCKWELL HARDNESS TEST

Fig No: 3 Rockwell Hardness Test

1. Rockwell Hardness systems as shown in fig 3.1. Use a direct readout machine determining the hardness number based upon the depth of penetration of either a diamond point or a steel ball. Deep penetration indicated a material having a low Rockwell Hardness number.
2. However, a low penetration indicates a material having a high Rockwell Hardness number. The Rockwell Hardness number is based upon the difference in the depth to which a penetrator is driven by a definite light or "minor" load and a definite heavy or "Major" load.
3. The ball penetrators are chucks that are made to hold 1/16" or 1/8" diameter hardened steel balls. Also available are ¼" and ½" ball penetrators for the testing of softer materials.
4. There are two types of anvils that are used on the Rockwell hardness testers. The flat faceplate models are used for flat specimens. The "V" type anvils hold round specimens firmly.
5. Test blocks or calibration blocks are flat steel or brass blocks, which have been tested and marked with the scale and Rockwell number. They should be used to check the accuracy and calibration of the tester frequently.

Using the "B" Scale:

a. Use a Diamond indenter.
b. Major load: 100 Kgf, Minor load: 10 Kg.
c. Use for alloy metal.
d. Do not use on hardened steel.

IMPACT TEST

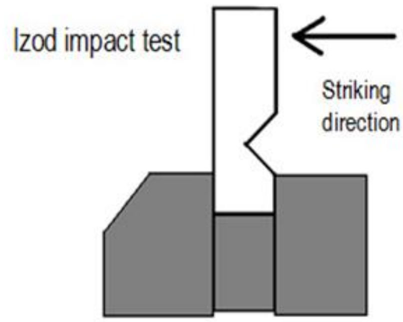

Fig No: 4 Impact Test

Izod impact strength testing is an ASTM standard method of determining impact strength as shown in fig 3.2. A notched sample is generally used to determine impact strength. Impact is a very important phenomenon in governing the life of a structure. The North American standard for Izod Impact testing is ASTM D256. The results are expressed in energy lost per unit of thickness (such as ft-lb/in or J/cm) at the notch. Alternatively, the results may be reported as energy lost per unit cross-sectional area at the notch (J/m² or ft-lb/in²). In Europe, ISO 180 methods are used and results are based only on the cross-sectional area at the notch (J/m²). The dimensions of a standard specimen for ASTM D256 are 4 x 12.7 x 3.2 mm (2.5" x 0.5" x 1/8").

The most common specimen thickness is 3.2 mm (0.125"), but the width can vary between 3.0 and 12.7 mm (0.118" and 0.500"). TheIzod impact test differs from the charpy impact test in that the sample is held in a cantilevered beam configuration as opposed to a threepoint bending configuration.

TENSILE TEST

Fig No: 5 Tensile Test

Friction processed joints are evaluated for their mechanical characteristics through tensile testing as shown in fig 3.3. A tensile test helps determining tensile properties such as tensile strength, yield strength, percentage of elongation, and percentage of reduction in area and modulus of elasticity. Then the joints were made and evaluate the mechanical and metallurgical characteristics.

The friction welded specimens were prepared as per the ASTM standards. The test was carried out in a universal testing machine (UTM) 40 tones FIE make.

Elongation

Deformation in continuum mechanics is the transformation of a body from a reference configuration to a current configuration. A configuration is a set containing the positions of all particles of the body.

Different equivalent choices may be made for the expression of a strain field depending on whether it is defined with respect to the initial or the final configuration of the body and on whether the metric tensor or its dual is considered. In a continuous body, a deformation field results from a stress field induced by applied forces or is due to changes in the temperature field inside the body. The relation between stresses and induced strains is expressed by constitutive equations, e.g., Hooke's law for linear elastic materials

On the other hand, irreversible deformations remain even after stresses have been removed. One type of irreversible deformation is plastic deformation, which occurs in material bodies after stresses have attained a certain threshold value known as the elastic limit or yield stress, and are the result of slip, or dislocation mechanisms at the atomic level. Another type of irreversible deformation is viscous deformation, which is the irreversible part of viscos elastic deformation.

COMPRESSION TEST

A compression test (as shown in fig 6.4) is any test in which a material experiences opposing forces that push inward upon the specimen from opposite sides or is otherwise compressed, **"squashed"**, crushed, or flattened on Purpose of Compression Tests: The goal of a compression test is to determine the behavior or response of a material while it experiences a compressive load by measuring fundamental variables, such as, strain, stress, and deformation.

Fig No: 6 Compression Test

IV. RESULT ANALYSIS

HARDNESS TEST

Table: 3 Hardness value

S.NO	COMPOSITION	HARDNESS HRB
R_1	AL 6061-100%	65
R_2	Al6061+ZrO_2-2%+ES-3%+Mg-1%	68
R_3	Al6061+ZrO_2-4%+ES-5%+Mg-1%	71

HARDNESS TEST GRAPH

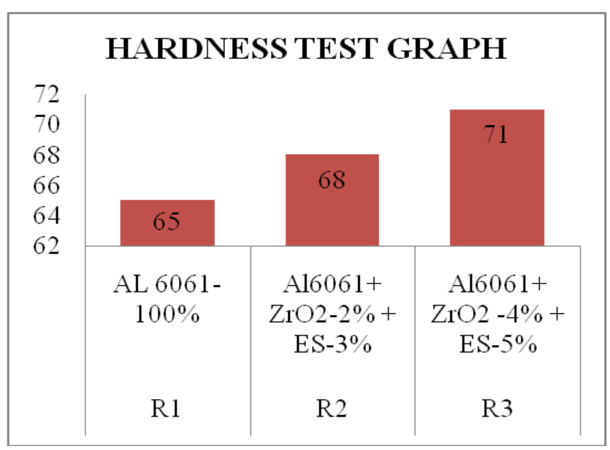

Fig: 7 Hardness Strength Graph

IMAGE OF HARDNESS STRENGTH

Fig: 8 After Hardness Strength Specimen Image

IMPACT STRENGTH

Table: 4 Impact value

S.NO	COMPOSITION	IMPACT STRENGTH (JOULES)
R_1	AL 6061-100%	4
R_2	Al6061+ZrO_2-2%+ES-3%+Mg-1%	3
R_3	Al6061+ZrO_2-4%+ES-5%+Mg-1%	2

IMPACT STRENGTH GRAPH

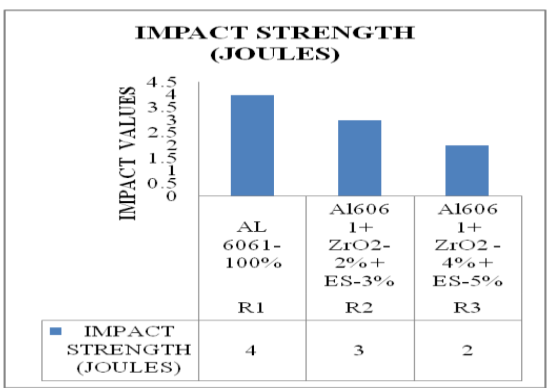

Fig: 9 Impact strengthGraph

IMPACT STRENGTH IMAGE

Fig: 10 After Impact Strength Specimen Image

TENSILE STRENGTH

Table: 5 Tensile Strength

SAMPLE	DIA (mm)	CSA (mm²)	TL (KN)	TS (N/mm²)	IGL (mm)	FGL (mm)	%E
A_1	16.00	201.06	19.98	99.37	122.50	126.00	2.86
A_2	16.00	201.06	24.41	121.41	121.50	123.00	1.23
A_3	16.00	201.06	22.53	112.06	118.00	120.00	2.54

TENSILE STRENGTH GRAPH

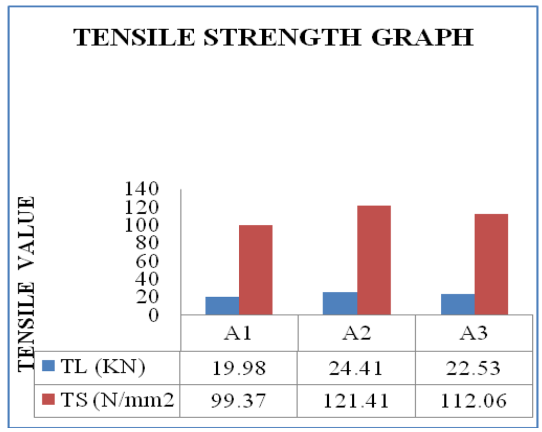

Fig: 11 Tensile strengthGraph

TENSILE STRENGTH IMAGE

Fig: 12 After Tensile Strength Specimen Image

COMPRESSIVE STRENGTH

Table: 6 Compression Strength

S.NO	COMPOSITION	COMPRESSION STRENGTH N/mm^2
R_1	AL 6061-100%	341.69
R_2	Al6061+ZrO_2-2%+ ES-3%+Mg-1%	457.57
R_3	Al6061+ZrO_2-4%+ ES-5%+Mg-1%	382.47

IMAGE OF COMPRESSIVE STRENGTH

Fig: 13 After Compression Strength Specimen Image

COMPRESSION STRENGTH GRAPH

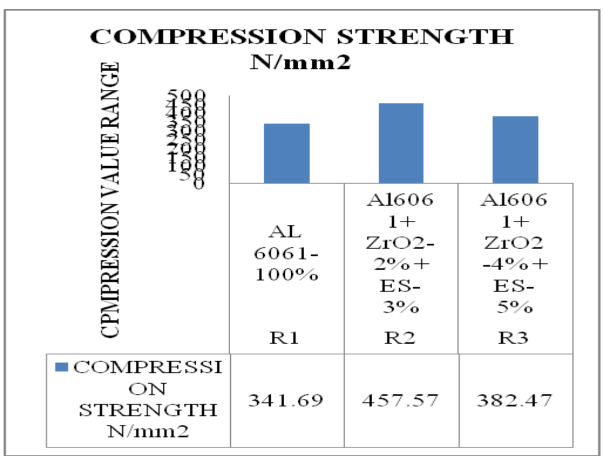

Fig: 14 Compression strengthGraph

V. CONCLUSION

It is found that the zirconium di oxide and chicken eggshell (ZrO2 and ES) particles have been successfully incorporated in Al 6061 matrix alloy through crucible casting technique. It has been observed that the Tensile and compressive strength of composites increases with the addition of ZrO_2 and ES particles and the maximum values were achieved at 2 and 3 wt% with constant 1% of Mg. And then observed that Hardness of composites increases with the addition of ZrO_2 and ES particles and the maximum values were achieved at 4 and 5 wt%. Further increase of ZrO_2 and ES particles in the matrix leads to increase in hardness and strength which may be due to the increased amount of trapped air thereby increasing the amount of pores. It has also been found that with the increase in amount of ZrO2 and ES reinforcement the density decreases. With the increase in ZrO2 and ES reinforcing particles in matrix, particle pulled out and particle-matrix debonding has been observed which lead to brittle fracture.

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