TO STUDY THE MECHANICAL BEHAVIOUR OF AL-6061/FLY-ASH/ZrO_2 METAL MATRIX COMPOSITES (MMCs) PROCESSED BY STIR CASTING METHOD

A
Dissertation
Submitted in partial fulfillment of the requirements for the degree of

Master of Engineering
in
Production Engineering

by

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to the

MECHANICAL ENGINEERING DEPARTMENT
THAPAR UNIVERSITY, PATIALA
July, 2014

CERTIFICATE

I hereby declare that the thesis entitled "**TO STUDY THE MECHANICAL BEHAVIOUR OF AL-6061/FLY-ASH/ZrO_2 METAL MATRIX COMPOSITES (MMCs) PROCESSED BY STIR CASTING METHOD**" is an authentic record of my study carried out as requirements for the award of the degree of **Master of Engineering** in **Production Engineering** at **Thapar University, Patiala** under the supervision of **Mr. Kishore Khanna,** Assistant Professor, Mechanical Engineering Department, Thapar University, Patiala during July, 2012 to July, 2014. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.

Date: 18 /07/2014

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It is certified that the above statement made by the student is correct to the best of my/our knowledge and belief.

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Dedicated to

My Parents

ACKNOWLEDGEMENT

I would like to express a deep sense of gratitude and sincere thanks to my thesis guide **Mr. Kishore Khanna** (Assistant Professor) for his sincere and invaluable guidance and suggestions which inspired me to submit thesis report in present form.

I am also thankful to **Dr. Ajay Batish**, Professor & Head, Department of Mechanical Engineering and workshop staff of Mechanical Engineering Department, Thapar University for their intellectual support.

My special thanks to my family members and friends who constantly encouraged me to complete this work.

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ABSTRACT

The present work has been carried out to investigate the effect of adding Zirconium oxide and Fly ash in Al-6061 to form a metal matrix composite. The composite has been produced by stir casting process. The volume fractions of both the reinforcing constituents have been varied. Tests like Tensile, Hardness, Impact and Dry wear friction tests have been performed on the prepared samples. SEM has also been done to see the distribution of fly ash and zirconium oxide in the matrix of Aluminium-6061. The results are showing the improvement in mechanical properties of the composite by the addition of these constituents.

Keywords: *Aluminium 6061, Fly-ash, Zirconium oxide, Metal Matrix Composite (MMCs), Stir casting.*

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ABBREVIATIONS

HRB = Rockwell Hardness Number

HV = Vickers Hardness

MMCs = Metal Matrix Composites

RPM = Revolutions per Minute

CHAPTER 1
INTRODUCTION

1.1. COMPOSITE MATERIALS

Composite materials (or composites) are materials made from two or more constituent materials having significantly different physical or chemical properties, which when combined together, produces a material having different characteristics from the individual components. The individual components will remain separate and distinct within the finished structure. [28]

Typical examples of engineered composite materials include:

- Composite building materials like cements, concrete
- Reinforced plastics like fiber-reinforced polymer
- Metal Composites
- Ceramic Composites

Composite materials are generally used in boat hulls, race car bodies, shower stalls, bathtubs, and storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on spacecraft in demanding environments.

1.2. CONSTITUENTS OF COMPOSITE MATERIALS

Composite materials are made up of individual materials generally called as constituent materials.

The two main categories of constituent materials are:-

a) Matrix and
b) Reinforcement.

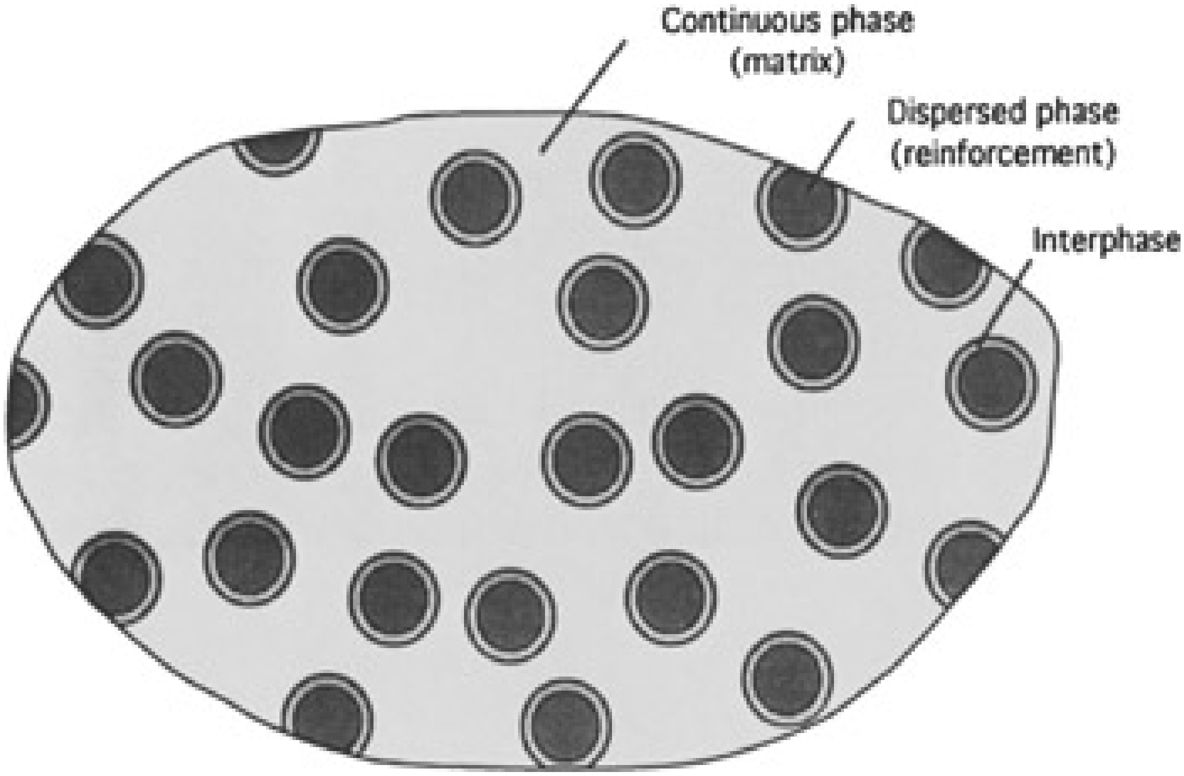


Figure 1.1: Phases of a Composite Material. [46]

a) **MATRIX:** The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. For example: - Resins, cement (concrete), polymers (fiber reinforced plastics), metals and ceramics. Road surfaces are often made from asphalt concrete which uses bitumen as a matrix.

b) **REINFORCEMENT:** The reinforcement materials are embedded in the matrix. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. For example: - Fiber, fibers used for reinforcement include glass fibers, carbon fibers, cellulose (wood/paper fiber and straw) and high strength polymers for example aramid. Other Reinforcement like Concrete uses aggregate, and reinforced concrete additionally uses steel bars (rebar) to tension the concrete. Steel mesh or wires are also used in some glass and plastic products.

1.3. CLASSIFICATION OF COMPOSITE MATERIALS [37]

The composites can be classified on the basis of material of the matrix and reinforcement.

1.3.1. CLASSIFICATION BASED ON MATRICES

On the basis of matrices materials the composites are classified as:

1. **POLYMER MATRIX COMPOSITES (PMCs):** It consists of a polymer (resin) as a matrix, with mostly fibers as the reinforcement material. These are widely used in the composite applications because of their room-temperature properties, ease of fabrication, and low cost.

   The Polymers used in composite materials are of two types, thermosets and thermoplastics. Thermosets generally used in commercial composites are polyester, epoxy, phenolic resins etc. whereas the generally used Thermoplastics are polyamide (nylon), poly-ether ether ketone etc.

2. **METAL-MATRIX COMPOSITES (MMCs):** It consists of a metal as a matrix material. Aluminium is the most popular matrix material for metal matrix composites. It mostly uses silicon carbide or alumina fibers embedded in a matrix made from an alloy of aluminum and magnesium, but other metals such as titanium, copper, and iron are also used as matrix material. Typical applications of MMCs include bicycles, golf clubs, and missile guidance systems. A Metal Matrix Composite made from silicon-carbide fibers in a titanium matrix is currently developed to use as the skin (fuselage material) of the US National Aerospace Plane.

3. **CERAMIC-MATRIX COMPOSITES (CMCs):** Ceramic Matrix Composites are the third major type of composite material. It composed of a ceramic matrix and embedded fibres of other ceramic material. Its example includes silicon carbide fibers fixed in a matrix material made from borosilicate glass. The ceramic matrix makes them particularly suitable for use in lightweight, high-temperature components, such as parts of airplane jet engines. Brittleness is the main disadvantage of CMCs.

1.3.2. CLASSIFICATION BASED ON REINFORCEMENT

The reinforcements in a composite material come in the following various forms:

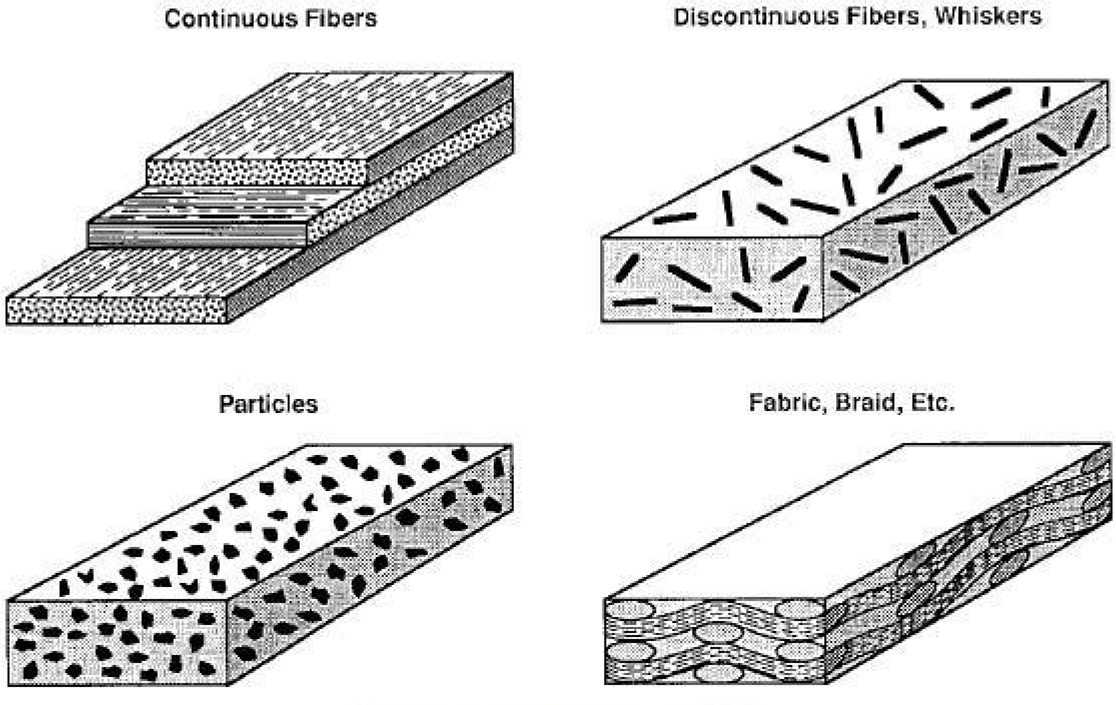


Figure 1.2: Types of Reinforcement in a Composite**.** [44]

1. **FIBRE:** Fibre is an individual filament of the material. A filament with length to diameter ratio above 1000 is called a fibre. The fibrous form of the reinforcement is the most widely used form. In the fibre reinforced composites, the fibre is the major load carrying constituent of the composite.
2. **PARTICULATE:** These types of reinforcements are in the form of particles which are of the order of a few microns in diameter. These particulates are generally added to increase the modulus and to decrease the ductility of the matrix materials. In this type of composites, the load is shared by both particulates and matrix materials. However, the load shared by the particulates is much larger than the matrix material. For example in an automobile Tyre carbon black (particulate reinforcement) is added in rubber (matrix material). The composite having reinforcement in particle form are called particulate composite.

3. **FLAKE:** Flake is a small, flat, thin piece or layer that is broken from a larger piece. These are two dimensional in geometry and impart nearly equal strength in all directions of their planes. So, these are very effective reinforcement components. The flakes can be packed more densely than unidirectional fibres and spheres, when they are laid parallel. For example, aluminum flakes used in paints imparts good properties by aligning themselves parallel to the surface of the coating.

4. **WHISKERS:** These are nearly perfect single crystal fibres. These are short, discontinuous and polygonal in cross-section.

1.4. PRODUCTION AND PROCESSING OF METAL MATRIX COMPOSITES [36]

MMC manufacturing can be classified into two types:

1) Solid state methods
2) Liquid state methods

1.4.1. SOLID STATE METHODS

The different solid state methods for the processing composites are:

1) DIFFUSION BONDING

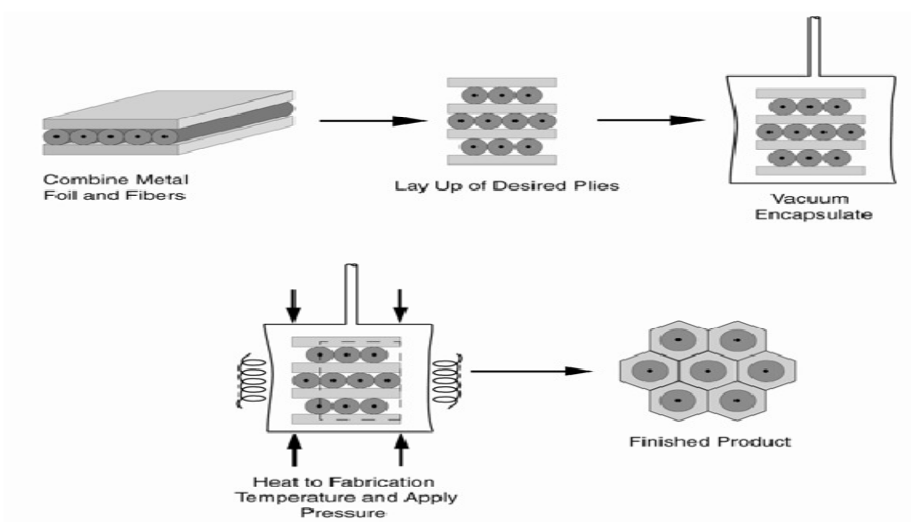


Figure 1.3: Diffusion Bonding Process [36]

It is a common solid-state processing technique for joining similar or dissimilar metals. In this method the matrix material in the form of foils and reinforcement materials in the form of long fibres are stacked in an order and pressed at an elevated temperature. This method is used for the fabrications of simple shape parts like plates, tubes etc.

The principal advantages of this technique are the ability to process a wide variety of metal matrices and control of fiber orientation and volume fraction.

The disadvantages of this process are long processing times, high processing temperatures and pressures (which makes the process expensive), and a limitation on the complexity of shapes that can be produced. There are many variants of the basic diffusion bonding process, although all of them involve simultaneous application of pressure and high temperature.

Vacuum hot pressing is an important step in the diffusion bonding processes for metal matrix composites.

2) DEFORMATION PROCESSING

This process can also be used to deform and/or densify the composite material. In metal–metal composites mechanical processing (swaging, extrusion, drawing, or rolling) of a ductile two-phase material causes the two phases to co-deform, causing one of the phases to elongate and become fibrous in nature within the other phase. These materials are sometimes referred to as in situ composites. The properties of a deformation processed composite depend largely on the characteristics of the starting material, which is usually a billet of a two-phase alloy that has been prepared by casting or powder metallurgy methods. Roll bonding is a common technique used to produce a laminated composite consisting of different metals in layered form. Such composites are called sheet laminated metal-matrix composites. Roll bonding and hot pressing have also been used to make laminates of Al sheets and discontinuously reinforced MMCs. Figure shows the roll bonding process for making a laminated MMC.

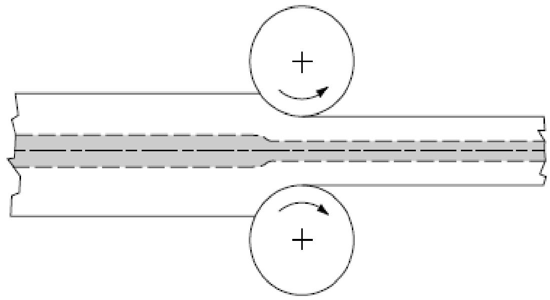


Figure 1.4: Roll Bonding Process of Making a Laminated MMC. [36]

3) **POWDER PROCESSING**

This method in conjunction with deformation processing is used to manufacture particulate or short fiber reinforced composites. This process typically involves cold pressing and sintering or hot pressing to manufacture primarily particle- or whisker-reinforced MMCs. The matrix and reinforcement powders are mixed to produce a homogeneous distribution. It is followed by cold pressing to produce a green body, which is about 80% dense. The cold pressed green body is canned in a sealed container and degassed to remove absorbed moisture from the particle surfaces if any. The material is hot pressed, uniaxially or isostatically, to produce a fully dense composite and extruded.

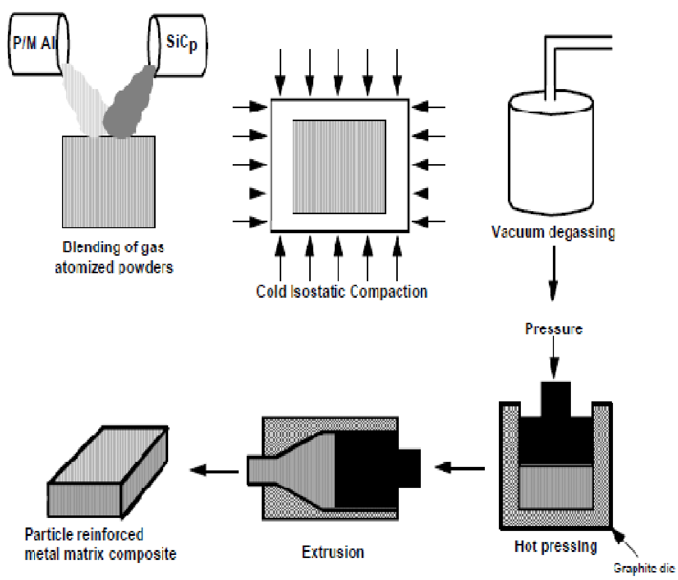


Figure 1.5: Powder Processing, Hot Pressing and Extrusion Process for Fabricating Particulate or Short Fiber Reinforced MMCs. [36]

4) **SINTER-FORGING**

It is a novel and low cost deformation process. In sinter-forging method a powder mixture of matrix and reinforcement materials are cold compacted, sintered, and forged to nearly full density. The main advantage of this process is that it is conducted to produce a close net shape material, and machining operations and material waste are minimized. The low cost, sinter-forged composites have tensile and fatigue properties that are similar to those of materials produced by extrusion.

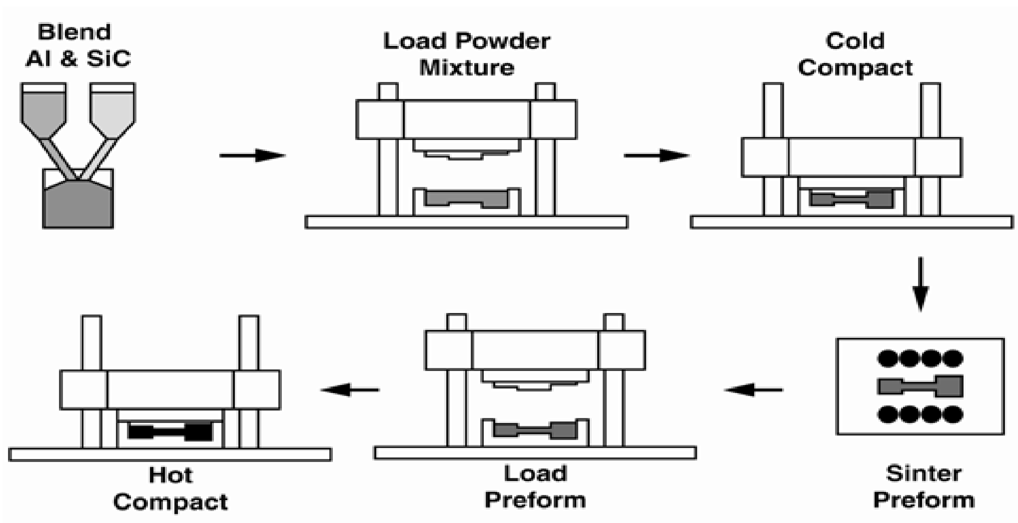


Figure 1.6: Sinter-Forging Technique for Producing Near-Net Shape, Low Cost MMCs. [36]

5) **DEPOSITION TECHNIQUES**

The various deposition techniques available are:

a) **DIPPING OR IMMERSION PLATING:** This method is similar to infiltration casting except that fiber tows are continuously passed through baths of molten metal, slurry, sol, or organometallic precursors.

b) **ELECTROPLATING:** This process produces a coating from a solution containing the ion of the desired material in the presence of an electric current. Fibers are wound on a mandrel, which serves as a cathode, and placed into the plating bath with an anode of the desired matrix material. The advantage of this method is that the temperatures involved are moderate and no damage is done to the fibers. Problems with electroplating involve void formation between fibers and between fiber layers, possible poor adhesion of the deposit to the fibers, and limited numbers of alloy matrices available for this type of processing.

c) **SPRAY DEPOSITION:** This process typically consists of winding fibers on a foil-coated drum and spraying molten metal on them to form a monotape. The source of molten metal may be powder or wire feedstock which is melted in a flame, arc, or plasma torch. The advantages of spray deposition are the easier control of fiber alignment and rapid solidification of the molten matrix.

d) **CHEMICAL VAPOR DEPOSITION (CVD):** In this process, a vaporized component decomposes or reacts with another vaporized chemical on the substrate to form a coating on that substrate. The process is generally carried out at an elevated temperature.

e) **PHYSICAL VAPOR DEPOSITION (PVD):** This method describes a variety of vacuum deposition methods used to deposit thin films by the condensation of a vaporized form of the desired film material into various work piece surfaces. This method is used in the manufacture of items, including semi-conductor devices and snack bags, and coated cutting tools for metal working. [31]

   The main disadvantage of using deposition techniques is that they are time consuming.

1.4.2. LIQUID STATE METHODS

The two Liquid state casting methods are:

1) **STIR CASTING METHOD** [14]

   Stir casting method is a liquid state method for making the Metal Matrix Composites. Stir Casting is a liquid state method of composite materials fabrication, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring. The liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

Figure 1.7: Stir Casting Apparatus.

Stir Casting is characterized by the following features:

- Content of dispersed phase is limited (usually not more than 30 vol. %).
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous.
  a) There are clusters of dispersed particles.
  b) There may be gravity segregation of reinforcement particles due to the difference in the densities of reinforcement and matrix phase.
- The technology is relatively simple and low cost.

2) **SQUEEZE CASTING OR PRESSURE INFILTRATION**

This method involves forcing a liquid metal into a fibrous or particulate preform. Pressure is applied until solidification is complete. By forcing the molten metal through small pores of the fibrous preform, this method does not the required good wettability of the reinforcement by the molten metal. Composites manufactured by this method have the advantage of minimal reaction between the reinforcement and molten metal because of the short processing time involved. Such composites are also typically free from common casting defects such as porosity and shrinkage cavities.

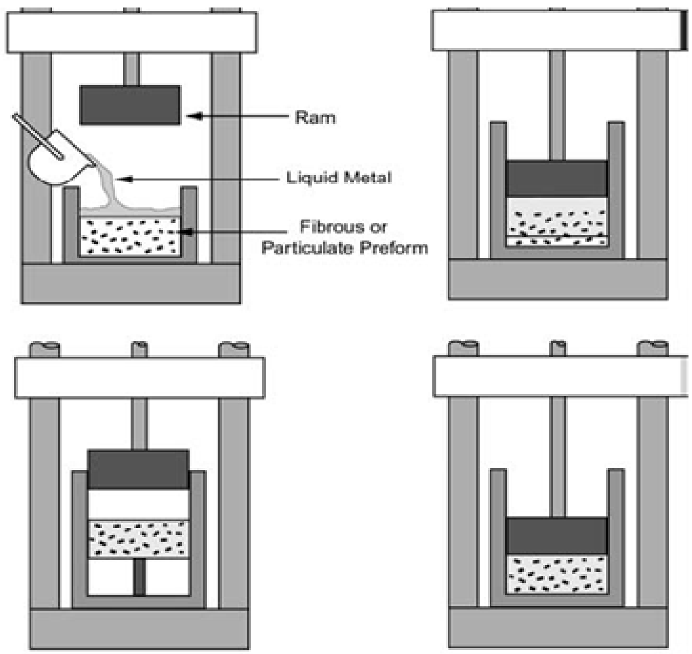


Figure 1.8: Squeeze Casting or Pressure Infiltration Process. [36]

Infiltration of a fibrous preform by means of a pressurized inert gas is another variant of the liquid metal infiltration method. The process is conducted in the controlled environment of a pressure vessel and rather high fiber volume fractions; complex shaped structures are obtainable. Alumina fiber reinforced intermetallic matrix composites, e.g., TiAl, Ni_3Al, and Fe_3Al matrix materials, have also been prepared by pressure casting. The technique involves melting of the matrix alloy in a crucible in vacuum, while the fibrous preform is heated separately. The molten matrix material (at ∼100°C above melting temperature) is poured onto the fibers and argon gas is introduced simultaneously. Argon gas pressure forces the melt, which contains additives to aid wetting of the fibers, to infiltrate the preform.

1.5. ALUMINIUM 6061:

It is a precipitation of hardening aluminium alloy having a density of 2.70 g/cm^3. Its major alloying elements are magnesium and silicon.

It is the most commonly used alloy of aluminium. It exhibits good weldability and has good mechanical properties. [26]

1.5.1. PROPERTIES OF ALUMINIUM-6061: [39]

The typical properties of Al-6061 are as follows:

1) Medium to high strength
2) Good toughness
3) Good surface finish
4) Excellent corrosion to atmospheric conditions
5) Good corrosion resistance to sea water
6) Good Weldability and brazability
7) Good workability
8) Widely available.

1.5.2. AVAILABLE FORMS OF ALUMINIUM-6061: [39]

Al-6061 is generally available in the following forms:

1) Rod
2) Pipe
3) Strips
4) Plates
5) Sheets
6) Blocks.

1.5.3. APPLICATIONS OF ALUMINIUM-6061: [39]

Various applications of Al-6061 are as follows:

1) Aircraft and aerospace components
2) Ship building
3) Bridges

4) Truck frames
5) Rivets
6) Brake components
7) Valves
8) Bicycle frames
9) Electrical fittings and connectors
10) Couplings
11) Making aluminium cans for packaging of foodstuffs and beverages.

1.6. ZIRCONIUM OXIDE (ZrO_2)

It is also called as zirconium dioxide or zirconia. It is a white colored crystalline oxide of zirconium. [25]

1.6.1. PROPERTIES OF ZIRCONIUM OXIDE

The properties of Zirconium oxide are:

1) High density
2) Wear resistance
3) High hardness
4) Chemical inertness
5) High fracture toughness [25]
6) High thermal expansion (α=11 x 10^{-6}/K)
7) Low thermal conductivity (2.5 to 3 W/mK)
8) Very high resistance to crack propagation, high fracture toughness (6.5 to 8 $MPam^{1/2}$)
9) Ability to conduct oxygen ions (used for the measurement of oxygen partial pressures in lambda probes. [40]

1.6.2. APPLICATIONS OF ZIRCONIUM OXIDE

Zirconium oxide is typically used for:

1) Hot metal extrusion dies
2) Oxygen sensors
3) High temperature induction furnace susceptors

4) Marine pump seals and shaft guides
5) Fuel cell membranes
6) Powder compacting dies. [25]

1.7. FLY-ASH

The term Fly-ash is generally referred to coal Fly-ash captured from coal fired power plants. It is one of the residues generated during the combustion of coal in coal fired plants. Fly-ash is a waste by-product material which must be disposed off or recycled. [29]

1.7.1. CLASSIFICATION OF FLY-ASH

As per ASTM C618 Fly-ash is classified into two classes:

1) Class F
2) Class C

The main difference between the two is the amount of chemical content in the Fly-ash (i.e. calcium, Silica, alumina and iron). Class F Fly-ash produces due to the burning of <u>older anthracite and bituminous coal</u> whereas Class C Fly-ash produces due to the burning of <u>young lignite or sub-bituminous coal.</u> [29]

1.7.2. USES OF FLY-ASH

Fly-ash can be used for:

1) Concrete production
2) Embankments and other structural fills (for road construction)
3) Cement clinkers production
4) Floor and ceiling tiles
5) Paints
6) Metal castings [29]

1.8. TENSILE TEST [42]

Tensile test is one of the most kindly used tests for quantitatively assessing the mechanical behaviour of materials. This test provides the mechanical properties like

1) Ultimate Tensile strength: The maximum stress a material can withstand before necking. Necking is the reduction in cross section due to stretching.
2) Yield Strength: It is the Stress at which the material begins to deform plastically.
3) Elastic Modulus (E): It is the tendency of a material to be deformed elastically. It is calculated by calculating the slope of the normal stress-strain curve within the elastic region.
4) Ductility: It is the ability of a material to deform under tensile stress. It can be calculated as percent elongation or percent reduction of area.

$$\text{Percent Elongation} = \frac{\text{Final Gauge Length} - \text{Initial Gauge Length}}{\text{Initial Gauge Length}}$$

$$\text{Percent Reduction of Area} = \frac{\text{Initial Cross Sectional Area} - \text{Final Cross Sectional Area}}{\text{Final Cross Sectional Area}}$$

1.9. ROCKWELL HARDNESS TEST

It is an empirical indentation hardness test. It is a fast, inexpensive and relatively non-destructive method leaving only a small indentation in the work piece material. [12]

It determines the hardness by measuring the depth of penetration of an indenter under a large load as compared to penetration made by a preload. It is measured in terms of a dimensionless number called Rockwell Hardness Number. There are different scales which are denoted by a single letter, which uses different loads or indenters. [32]

Table 1.1: Various Rockwell Scales [32]

Scale	Abbreviation	Load	Indenter	Use
A	HRA	60	120 diamond cone	Tungsten carbide
B	HRB	100	1/16 inch diameter (1.588 mm) steel sphere	Aluminium, Brass and soft steel
C	HRC	150	120 diamond cone	Harder steels > B100

1.10. VICKERS HARDNESS TEST

Vickers hardness test is used to measure the micro-hardness of materials. It consists of a pyramidal diamond indenter. In this test the load is applied smoothly, without impact, forcing the indenter into the work piece. The indenter is held in place for few seconds and then the load is removed. After the load is removed, the two diagonal impressions are measured and their average is taken as the final value. [41] The load used in the test ranges from 1 to 100 gmf. [35]

The Vickers hardness is calculated by using the formula: [35]

$$HV = \frac{2\ L\ \mathrm{Sin}\ (\square/2)}{d^2} \text{ or } HV = \frac{1.8544L}{d^2}$$

Where, L = Applied Load (in Kg)

d = Average Length of diagonals (in mm)

$\square$ = Angle between opposite faces of diamond = 136^{o}.

1.11. CHARPY IMPACT TEST

It is also called as Charpy V-notch test. It is a standard high strain –rate test which determines the amount of energy absorbed by a material before fracture. It is widely used because it is easy to perform and quick results are obtained and is cost effective. It consists of a pendulum of known mass and length which is dropped from a known height to strike the notched specimen. [27] The specimen is rectangular in shape with a notch cut in one side. The notch allows the predetermined location for a crack initiation. A standard Charpy impact test specimen is shown in the figure.

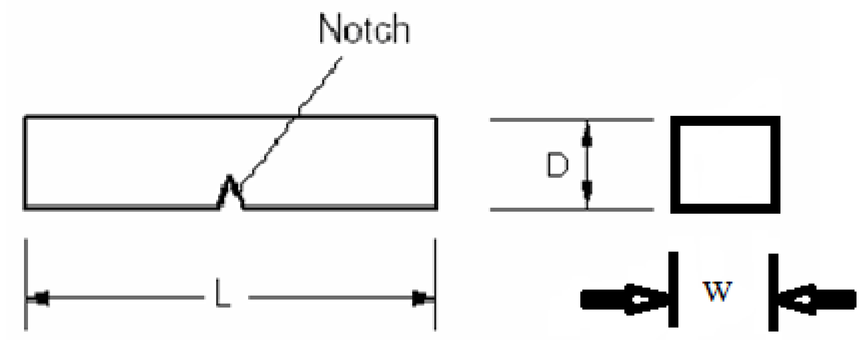


Figure 1.9: Specimen for Charpy Impact Test [11]

As per ASTM E23-02a standard the dimensions of the specimen should be

L = 55 mm

D = 10 mm

W = 10 mm

Notch dimension = 45^o with a depth of 2 mm.

As the pendulum strikes and breaks the specimen, it rises to some height. The difference in the initial and final heights is directly proportional to the amount of energy absorbed by the specimen. The total energy absorbed is determined by [11]

$$\Gamma_{Total} = mg\,(h_o - h_f)$$

Where, Γ_{Total} = Total energy absorbed

m = mass of the pendulum

g = gravitational acceleration

h_o = Initial height of the pendulum

h_f = Final height of the pendulum

1.12. PIN-ON-DISK APPARATUS

A Pin-on-disk apparatus consists of a fixed pin under an applied load in contact with a rotating disk. The pin can have any shape but spherical tip pins are mostly used for simplifying the contact geometry. [34] Figure 1.10 shows a schematic view of Pin-on-disk apparatus.

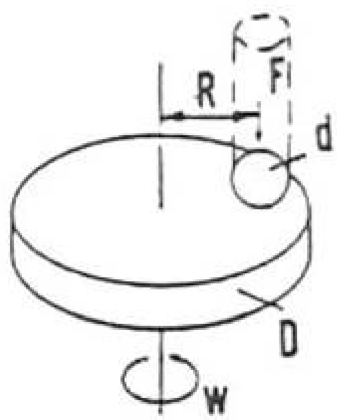


Figure 1.10: Schematic View of Pin-on-Disk Apparatus [45]

Where, F = Applied normal load

R = Radius of the wear track that is produced

d = Diameter of the spherical top of the pin

D = Diameter of the disk

ω = Rotational speed

In this apparatus, the user can control and measure the applied normal load, rotational speed and environmental factors such as temperature, pressure, type of gas (air, vacuum, nitrogen etc) and presence of a lubricant. [38] As per ASTM G99-95a standard the wear measurements are measured in terms of volume loss in cubic millimeters for the pin, assuming that there is no significant disk wear.

$$\text{Volume Loss, mm}^3 = \frac{\text{Mass loss (in gms)}}{\text{Density (in gms/cm}^3\text{)}} \times 1000$$

1.13. SCANNING ELECTRON MICROSCOPE

Scanning Electron Microscope is a type of electron microscope which uses electrons beam instead of light to produce images of a sample. The Scanning Electron Microscope has many advantages over traditional microscopes. It has a large depth of field and much higher resolution. Its magnification ranges from 10 times to more than 500,000 times which is near about 250 times the magnification of light microscope. [33] It is one of the most versatile instruments available for the examination and analysis of microstructure, morphology and chemical composition characterizations. [24]

CHAPTER 2
LITERATURE REVIEW

This chapter presents a review of literature specifically for data available on the effect of various types of reinforcement types, their volume fraction and size with Aluminium based MMCs.

Bienias *et al.* (2003) studied the microstructure and corrosion behaviour of aluminum Fly-ash composites. The composite was made of AK12 (AlSi12CuNiMg) aluminium-silicon base alloy and Fly-ash by gravity and squeeze casting method. The microstructure was studied using an optical microscope and a scanning electron microscope. Gravity castings result in non-uniform distribution of Fly-ash particles in the alloy structure. However, further re-melting of the composite material combined with squeeze casting improves the distribution of aluminium-Fly-ash castings. In the Al-Fly-ash composites, after squeeze casting the external pressure influences the microstructure of materials and there was a high probability of occurrence of wettability of Fly-ash particles by molten alloy whereas it does not occur in traditional gravity casting. The corrosion resistance experiment was done by potentiodynamic method on AK12/9% Fly-ash composite after gravity casting and its unreinforced matrix. In case of Al-Fly-ash composite the weight loss regularly increases in the entire range of time up to 50 days whereas in case of AK12 alloy the weight loss attains a constant value after 25 days. Due to higher value of threshold period AK12 alloy was more resistive to corrosion in the initial stages than Al-Fly-ash composite. But after the threshold period the corrosion of AK12 alloy occurs more rapidly than that of Al-Fly-ash composite. The corrosion of AK12 alloy up to the limiting thickness implies that the oxide film formed on the surface was compact, adherent and pore-free and the main component of the oxide surface film contains silicon oxides whereas in case of Al-Fly-ash composite the oxide film was composed of a high amount of silicon oxides and was porous and thick.

Fogagnolo *et al.* (2004) studied the effect of Al- 6061 reinforced with zirconium diboride (ZrB_2) particles processed by conventional powder metallurgy and mechanical alloying.

The powders were mixed in a horizontal ball mill for 90 min at 150 rpm, and after that in a high-energy centrifugal ball mill. The composite powders were uniaxially cold pressed by slowly increasing pressure up to 300 MPa, hot extruded at 500 ^{o}C, without canning and degassing, and cooled in stirred air at room temperature. Powder milled samples were withdrawn after 1.5, 3, 4.5, 6, 8, 10 and 12.5 hr of high-energy milling. The study carried out with 15% ZrB_2 showed that only 10 hr milling was required to produce a composite powder with a homogeneous reinforcement distribution. The presence of the reinforcement ZrB_2 particles in the mechanical alloyed powder and the difference between the microstructures of the as-received and the mechanically alloyed powders produce a great difference in their hardness. It was confirmed that mechanical alloying produces a composite material with better distribution of the reinforcement particles, but only a small decrease in the size of reinforcement particles is observed.

The Ultimate Tensile Strength of the A6061/15% ZrB_2 composite extruded from the low-energy mixed powders was lower than that of the A6061/5% ZrB_2 composite obtained by the same processing route. In the case of the composites obtained by low-energy mixing, the simple addition of ZrB_2 particles produces a small increase in the material hardness and a small decrease in the Ultimate Tensile Strength.

Das *et al.* (2006) investigated the synthesis and characterization of zircon sand/Al-4.5 wt% Cu composite produced by stir casting route. For the Al-4.5 wt% Cu alloy composites reinforced with zircon particles of various sizes (65, 90 and 135 µm) at a load of 15 N. It was observed that wear volume loss decreases marginally when the zircon particle amount are increased from 10 to 15 wt% for the composite reinforced with 65 or 90 µm size particle and 10–20 wt% for the composite reinforced with 135 µm size particle. However, the wear volume decreases significantly after further increase in the amount of zircon particle for all the composites. Material removal in a ductile material such as aluminum alloy matrix was due to the indentation and ploughing action of the sliding indenters (SiC abrasive particles). Incorporation of hard zircon particles in the Al-4.5 wt% Cu alloy restricts such ploughing action of sliding indenters and improves the wear resistance. An increase in zircon particle amount increases the hardness of the composite. Hence, the increase in hardness due to increase in particle amount decreases the wear rate of the composite. Abrasive wear resistance found improved with zircon particle reinforcement in Al-4.5 wt% Cu alloy. The abrasion resistance of the composites increases with increasing amount of particle and decreasing particle size.

Mahendra and Radhakrishna (2007) studied the fabrication of Al–4.5% Cu alloy with Fly-ash metal matrix composites and its characterization. The composite was made by stir casting method in an electric furnace at 850 °C stirred at 600 rpm. The percentage of Fly-ash added was 5, 10, or 15 wt. %. Composites produced were subjected to solutionisation and age hardening (T6). With an increasing percentage of Fly-ash particulates the fluidity length decreases and hardness increases. The microstructure of MMCs showed a uniform distribution of Fly-ash in the matrix. The tensile strength increases with an increasing percentage of Fly-ash particulates. Castings with smaller cross sections exhibit higher tensile strengths than those with larger cross sections due to a faster heat transfer from the mould, resulting in a finer grain structure of the castings. Compression strength increases with increasing percentage of Fly-ash particulates due to the hardening of the base alloy by Fly-ash particulates. The impact strength also increases with increasing Fly-ash content due to the presence of hard Fly-ash particulates and shows higher values for 10% and 15% Fly-ash composites than the base alloy. Wear decreases with increasing Fly-ash content due to the abrasive nature of Fly-ash. Castings with smaller diameters exhibit less wear than castings with the larger ones. Also with increasing Fly-ash content there was a decrease in frictional force and the coefficient of friction. It was observed that with an increasing percentage of Fly-ash particulates the slurry erosive wear decreases. Erosive wear in the case of a basic medium was larger than in an acidic one. Corrosion increases with an increasing percentage of Fly-ash particulates.

Rajan *et al.* (2007) investigated the fabrication and characterisation of Al–7Si–0.35Mg/Fly-ash metal matrix composites processed by different stir casting routes. In liquid metal stir casting, the incorporation of Fly-ash particle into melt and pouring of composite melt into the mould are carried out in a fully liquid state (i.e., above liquidus temperature of the matrix alloy). In case of compocasting process, both the incorporation and pouring steps are carried out in a semisolid state (a temperature in between the solidus (840 K) and liquidus (888 K) temperatures). On the other hand, in case of modified compocasting process, the particle addition and the casting are carried out in between the liquidus and solidus temperatures and above the liquidus temperature respectively. The composite synthesized by modified compocasting process shows better distribution of particles as compared to those made by liquid metal stir casting or semisolid processing technique. The densities of modified compocast composite are highest among the other two techniques. The advantages of modified compocasting are better dispersion of particles, lower interfacial reaction due to mixing at semisolid state as compared to liquid metal stir casting, fine primary aluminum grain size and improved fluidity due to casting at temperature above liquidus as compared to compocasting. The tensile strength of Fly-ash composites was reduced due to particle fracture and interfacial debonding. The compressive strength of Al (356)–15% Fly-ash composite processed by modified compocasting process are more than matrix alloy cast by squeeze casting and permanent mould respectively.

Ramachandra and Radhakrishna (2007) investigated the effect of Fly-ash on the sliding wear, slurry erosive wear and corrosive behavior of aluminium matrix composite. The specimens are made of Al (12 wt% Si) with 5, 10, and 15 % wt. of Fly-ash (with an average particle size of 10 μm) particulate by using the stir casting method. The optical micrograph of 5 and 10% Fly-ash reinforced MMCs showed near uniform distribution of particulates. The wear resistance of the MMCs has increased with increase in Fly-ash content. With increase in normal load and sliding velocity the wear of MMCs has doubled. Frictional force also increased with increasing sliding velocity. The coefficient of friction was decreased with increased Fly-ash content and increase in normal load. Slurry wear resistance increases with increase in Fly-ash content. The presence of Fly-ash particles essentially improved wear resistance in the beginning 8–10 hr but after that the testing weight loss are almost nil in all cases. Decreases in weight loss are because of formation of passive layer on the surface of the specimen which retards wear by acting as a protective layer. Corrosion resistance of reinforced samples was decreased with increasing Fly-ash content.

Sudarshan and Surappa (2008) studied the effect of addition of Fly-ash particles on wear resistance of A356 Al alloy during dry sliding wear. Sliding wear tests was conducted using a Pin-on-Disc Machine. The sliding speed and sliding distance in the experiments was kept constant at 1 m/s and 3000m respectively and the loads are varied from 10 to 80 N. The wear rate was calculated using weight loss method and graphical method was used to verify the results obtained by weight loss method. With increasing % of Fly-ash there was an increase in both the bulk hardness and micro hardness. In the graphical method wear rates are higher as compared to weight loss method. At low loads (10 and 20 N) effect of addition of Fly-ash on the wear resistance was negligible, but at higher loads (50–80 N) and higher volume fraction it shows marginal decrease in the wear rate. These results confirm that with increase in the reinforcement content, the magnitude of the difference in wear rates between these two methods decreases.

Robinson *et al.* (2009) investigated the influence of processing (hot deformation) and alloy composition on the tensile properties, tear toughness and exfoliation corrosion susceptibility of aluminium alloy 2025 aluminium with the addition of Zirconium. Two 2025 aluminium variants of different specification had been used one having Zr < 0.01 % (2025 LZ) and other having 0.12 % (2025 HZ). Both composite's compositions extruded successfully at 360 ^{o}C and 440 ^{o}C. At 300 ^{o}C some of the extrusions containing the Zr grain-refining element did not press to size, but at 360 ^{o}C, 400 ^{o}C and 440 ^{o}C all were forged to the required thickness. At the higher forging temperatures no exfoliation corrosion was observed and only pitting corrosion was detected. The influence of extrusion temperature was also detectable with specimens extruded at 440 ^{o}C exhibiting greater resistance to exfoliation corrosion. The HZ variant displayed a similar pattern of increasing resistance to exfoliation corrosion as the forging temperature increased. However, extruding the HZ variant at the lower temperature increased the susceptibility of material forged at 440 ^{o}C. The forging temperature was found to have a very strong effect on the resulting fully heat treated microstructure. At lower temperatures the retention of strain energy after forging was sufficient to allow almost complete recrystallisation during heat treatment. Hydraulic pressing of propellers at low temperatures (250–300 ^{o}C) offer the best opportunity of producing optimized exfoliation and tensile properties. However this imposes technological difficulties as the material has a high flow stress and can result in loss of dimensional control.

Agaogullari *et al.* (2010) studied the characterization of mechanically alloyed and sintered ZrC particulate reinforced Al matrix composites. ZrC particulate reinforced Al matrix composites were produced via mechanical alloying and sintering at 650°C for varied time duration (i.e. 2 hr, 4hr & 8 hr). There was no reaction between Al and ZrC particles after milling for 8 hr since Al and ZrC phases are still present in the powder mixtures. Continuous deformation of powder during milling, results in the crystallite refinement and increase in the lattice strain. With increase in mechanical alloying duration, there was an increase in relative density values. Micro hardness of the Al matrix is increased with increasing mechanically alloyed duration and increasing ZrC content. Increasing mechanically alloyed duration increased the volume fraction of Al_3Zr phase and homogeneity of ZrC particle distribution in the microstructures which naturally increase the mechanical properties of the composites.

Ebrahimi *et al.* (2010) analyzed the microstructure, hardness and tensile properties of a new super high strength aluminum alloy with Zr addition. Round bar shaped specimens are made by using extrusion method. Before machining and tensile test, T6 treatment was applied to all extruded specimens. In macro structural examination, all cast specimens performed equiaxed grains; the addition of Zr decreases the average grain size, causing the uniform dispersion of constituent as well as limiting the area fraction of recrystillized regions owing to the formation of the Al_3Zr particles. Microstructure of unrefined cast specimen revealed a dendritic structure surrounded by intermetallic compounds and eutectic structure meanwhile; in Zr-refined specimen a rosette- like structure was observed. After T6 heat treatment, the extruded refined specimens showed significant improvement of Ultimate Tensile Strength, Yield Strength and elongation values when compared with the solely heat treated unrefined ones.

Okafor and Aigbodion (2010) studied the effect of zirconium silicate reinforcement on the microstructure and properties of as cast Al-4.5% Cu matrix particulate composites synthesized via squeeze cast method by varying the percentage of ZrSiO4 in the range of 5-25 wt%.
The addition of ZrSiO4 reinforcements increases the hardness and apparent porosity by 107.65 and 34.23% respectively and decrease the impact energy by 43.16 %. The yield strength and ultimate strength increased with increasing % ZrSiO4 addition up to maximum values of 168.10 and 231.48N/mm2 at 15% ZrSiO4 addition respectively and then decreases to 123.281 and 189.394 N/mm2 at 25% ZrSiO4 addition. The addition of ZrSiO4 particles using Al-4.5% Cu alloy increases both the strength and hardness and an overall reduction in toughness and density. The impact energy and percentage elongation decreases as the percentage of ZrSiO4 addition increases in the alloy.

Ramirez *et al.* (2010) studied improved wear resistance of aluminum – Zirconia composite. The composite was created by compacting aluminum powder at room temperature in an automatic hydraulic press. The cellulose fibres used during the compacting process increased the porosity and allowed a homogeneous distribution of Zirconia. Specimens are sintered at a temperature of 600°C for 3 hr. The composites and pure aluminum were subjected to wear resistance test and compared. The best wear resistance was observed in the composite of Al – Zirconia. The decrease in wear was due to the fact that the ceramic material introduced into the pores acts as reinforcement. The best tribological behavior of the composite was achieved when there was a bigger presence and distribution of Zirconia in performs. The wear coefficient of composite and pure aluminum shows that using this new methodology, a composite with improved wear resistance (twice as much) can be obtained. By measuring the weight loss, it was shown that the composite had significant improvement in wear resistance compared to pure aluminum.

Abdizadeh *et al.* (2011) analyzed the improvement in physical and mechanical properties of aluminum/zircon composites fabricated by powder metallurgy method. In order to process the specimens, powders of aluminum and zircon have been weighed with the different volume percentages of zircon contents were prepared followed by sintering at two different temperatures, 600 and 650 ^{o}C for 65 min. The results showed that increasing the volume percent of zircon causes an increase in the density of specimens. Also with elevating the sintering temperature, the density of the specimens was increased. With the comparison of relative density of specimens, it was observed that higher sintering temperature causes the higher relative density up to 3.5% of zircon after that there is a decreasing trend. Yield stress and compressive strength changes with increasing zircon content. At first they increased up to 5% of zircon content but then they started to decrease.

Kumar and Swamy (2011) studied the mechanical properties of Flyash-eglass-Al6061 alloy composites having 2, 4, 6 and 8 wt% of Fly-ash and 2 and 6 wt % of e-glass fiber. The composite was fabricated by stir casting method and the properties are compared with Al-6061 alloy. The tensile strength of the composite material increased by 60-70% and a marginal improvement in compressive strength was observed. The hardness of the composite material also increased with increasing wt% of Fly-ash content in the composite. The microstructures of the composites were studied to know the dispersion of the Fly-ash and e-glass fiber in matrix. From the microstructure analysis it was evident that the reinforcements are evenly distributed in the composite material.

Ravesh and Garg (2012) studied the fabrication of aluminium based metal matrix composite and then characterized their mechanical properties such as hardness, toughness and tensile strength. Stir casting technique was used to achieve this objective. Aluminium 6061 was used as matrix material and SiC and Fly-ash are taken as reinforcement material. Experiments were conducted by varying the weight fraction of SiC as 2.5, 5, 7.5 and 10% wt. while keeping all other parameters constant. The hardness of Metal Matrix Composite increased with increase in SiC content. Tensile Strength increases with increase in weight percentage of SiC and was best obtained at 10% weight percentage of SiC & 5% of Fly-ash. The impact strength increases with increase in weight percentage of SiC and it is maximum at 10% wt. of SiC & 5% wt. of Fly-ash.

Arun L. R *et al.* (2013) studied the characteristics of aluminium based silicon carbide and Fly-ash particulate metal matrix composite. In this work, Al-Fa-SiC composites were produced by varying % of Fly-ash (9, 12 and 15 %)and keeping SiC 9% as constant by stir casting method. Fly-ash up-to 15% by weight can be successfully added aluminium 6061 alloy by stir casting route to produce composites. Hardness of aluminium (Al6061) was increased from 50 BHN to 88 BHN with addition of Fly-ash and magnesium. The Ultimate tensile strength was improved with increase in Fly-ash content. Whereas ductility decreased with increase in Fly-ash content. Compressive strength increases with increase in reinforcement wt%.

Boopathi *et al.* (2013) studied the evaluation of mechanical properties of aluminium alloy 2024 reinforced with silicon carbide and Fly-ash hybrid metal matrix composites. Stir casting method was used for the fabrication of hybrid composite material. The composites produced are examined by optical microscope to analyze the microstructure. The particles were not uniformly distributed in case of Al (5% SiC), Al (10% SiC), Al (5% Fly-ash) and Al (10% Fly-ash). But uniform distributions of particles were observed in the presence of SiC-Fly-ash mixture at various concentrations. Density of the composite specimens obtained experimentally showed that density of the composites decreased by increasing the content of reinforcement. It was found that, instead of Al-SiC and Al-Fly-ash composites, Al-SiC-Fly-ash composites showed better performance. The tensile testing was done using a computerized Universal testing machine. The tensile strength and yield strength of composites is higher than the unreinforced Al. The elongation of composites is gradually decreased than the unreinforced aluminium. Hardness of the composites increases by increasing SiC, Fly-ash and their mixtures.

Gode (2013) investigated the effect of Zr addition on the microstructure and wear behavior of aluminum alloy composites (AMCs) reinforced with B_4Cp and SiCp particles fabricated via hot pressing. AMCs are produced by the method of hot pressing with 0.2% Zr addition to Alumix 123 10% B_4C and Alumix 123 10% SiC composites. After production of composites, SiC and B_4C particles had a uniform distribution within the matrix alloy. The addition of B_4C /SiC particles into the matrix alloy slightly decreased the density, zirconium addition increased the density significantly, especially for the composite materials containing B_4C and thus the highest density value of 99.4% was obtained for the Alumix 123 + 10% B_4C + 0.2% Zr sample. Micro hardness measurements were conducted on the hot pressed samples to evaluate the effects of particle reinforcement type (SiC and B_4C) and zirconium addition on the hardness. The micro hardness results showed that, hard ceramic particle reinforcements and zirconium addition increased the hardness values. It was observed that the reinforcement materials improved both tensile strength and bending strength of the hot pressed samples. Wear tests were carried out on the hot pressed samples at a constant sliding speed of 5 mm/s and under 3 N loads. It was seen that with the addition of both reinforcement components (B_4C and SiC), the wear loss decreased.

Lokesh *et al.* (2013) investigated the effect of hardness, tensile, compression and impact properties as well as density of Al-Cu alloy reinforced Fly-ash metal matrix composites casted by both gravity and squeeze casting. The Al-4.5wt%Cu reinforced 3, 6, 9 and 12wt%Fly-ash composite was squeeze casted with an applied pressure of 120 MPa.

The hardness of metal matrix composite casted by squeeze cast increased from 84 to 92 BHN with the applied pressure of 120 MPa. The hardness increased with increasing percentage of Fly-ash and is 119 BHN for 12 wt% Fly-ash. The ultimate tensile strength of metal matrix composite casted by squeeze cast increases with increase in percentage of Fly-ash. The composite casted by gravity casting has lower UTS as compared to composites casted by squeeze casting. Density decreases from 2.7714 to 2.7112 g/cm^3 with increasing percentage of Fly-ash. Porosity on the other hand is higher for composites casted by gravity casting and lower for composites casted by squeeze casting. Impact strength is increases with increasing percentage of Fly-ash. Optical micro photographs show the uniform dispersion of the reinforcements in MMCs with good bonding between the matrix and reinforcements. The composite produced by squeeze casting shows lower porosity and higher compression strength.

Malhotra *et al.* (2013) investigated the effect of reinforcement (Zirconia+ Fly-ash) on the mechanical properties of Al-6061 composites samples, processed by stir casting techniques. The composites were prepared with fixed percentage of Fly-ash (10%) & with varying percentages of Zirconia (5% & 10%) by weight fraction. The Hardness and ultimate tensile strength were improved, when compared with the unreinforced alloy whereas elongation decreased as compared to unreinforced aluminium. Composite containing10 wt. % ZrO_2 fabricated at 950 ^oC showed the maximum value of the hardness and ultimate tensile strength as compared with the other specimens. Tensile strength of Aluminum alloy 6061 increases from 233 MPa to 278 MPa with the addition of Zirconia & Fly-ash. Hardness value increases from 78 to maximum of 94.

Prasad and Ramachandra (2013) studied the influence of Fly-ash, squeeze pressure and squeeze time on wear resistance in squeeze casting of LM6 Al-Fly-ash composite using Taguchi method. In this investigation, the composites are produced by incorporating Fly-ash as a reinforcement material and eutectic Al–Si alloy as a matrix. Stir casting method was used to disperse Fly-ash in the ratio of 5, 7.5, 10 and 12.5% wt. in the Al–Si alloy matrix which was followed by applying the squeeze pressure of 30, 60, 90 and 120 bars with varying squeeze time as 5, 10, 15 and 20 minutes. It was observed that the hardness increases with increase in weight percentage of Fly-ash particles and the squeeze pressure on the matrix alloy of the squeeze cast composites. Therefore it can be construed that % wt. Fly-ash was the most influential and significant parameter followed by squeeze pressure and squeeze time respectively in controlling the wear rate of the composite material.

Prasat and Subramanian (2013) studied the use of Fly-ash and graphite particles as low cost reinforcing materials for improved wear resistance, enhanced mechanical properties and reduction in the density of hybrid composites. The aluminium alloy (AlSi10Mg) was reinforced with Fly-ash in varying amounts of 3, 6 and 9 wt. % along with 3 wt. % graphite. Aluminium alloy reinforced with 3 wt. % graphite was also produced for comparison with the hybrid composite. The hybrid composite was synthesised by stir casting method. The dry sliding wear and friction behaviour of hybrid composites were studied by varying parameters like load and weight fraction of Fly-ash at a constant sliding speed of 2 m/s and sliding distance of 2,400 m. The incorporation of Fly-ash and graphite particles as reinforcements caused a reduction in the wear rate and coefficient of friction (COF) of the hybrid composites. Composite having 9 wt. % Fly-ash and 3 wt. % graphite exhibited the highest wear resistance and lowest COF at all applied loads. There was a decrease in the hardness and tensile strength due to the addition of graphite particles to the aluminium alloy. Al/FA/Gr hybrid composites exhibit higher hardness, higher tensile strength and lower density when compared to unreinforced alloy and Al/3Gr composite.

Singla and Mediratta (2013) investigated the mechanical properties of Al-7075/Fly-ash composite material. The specimens are made by stir casting method. Mg was added to increase wettability. Toughness of the composites was determined by using Izod and Charpy tests. As we increased the amount of Fly-ash the toughness value gradually increased up to 30 gms of Fly-ash but after that it diminishes. Similarly, with the increased amount of Fly-ash up to 30 gms hardness and tensile strength increases and after that they go down. The density of the composites decreased with increasing Fly-ash content. From the above results we found that composite sample having Fly-ash upto 30 gms had a good toughness, hardness, tensile strength and also having the low density comparative to alloys without reinforcement.

Sucitharan *et al.* (2013) investigated the Wear behaviour of Al-6063/Zircon Sand Metal Matrix Composite. Al-6063 alloy matrix composites reinforced with Zircon Sand particles can be successfully synthesized by the stir casting method. The specimens made are having 2, 4, 6, and 8 weight percent zircon sand. The pin on disk apparatus was used to analyze the wear rate of the composite. It was found that increase in the percentage of Zircon Sand particles reduces the wear rate and the composite with 8 wt% ZrSiO4 has the higher wear resistance rate.

Vivekananthan and Senthamarai (2013) studied the experimental evaluation of Aluminium-Fly-ash Composite Material to Increase the Mechanical & Wear Behaviour by Stir Casting

Method. The composites were made with different amounts of fly-ash (i.e.5, 10, 20, wt %). Magnesium and silicon were added to increase the wet ability of Fly-ash particles. Bulk hardness measurements were carried out on the base metal and composite samples by using standard Brinnel hardness test. Incorporation of Fly-ash particles in Aluminum matrix causes reasonable increase in hardness. The Fly-ash addition leads to improvement in the ultimate tensile strength. Also the addition of Mg improves the tensile properties of the composite. Ductility of the MMC decreased with increase in Fly-ash content. Wear behavior of different composite was studied with different parameter like sliding velocity and applied loads. The wear resistance of composite was much greater than the commercially pure aluminum. Bulk wear decreased with addition of magnesium. Incorporation of Fly-ash content significantly increased the wear resistance and reduces the coefficient of friction. The amount of wear has been increased with increase in normal load. The wear of the composite was significantly increased with increase in sliding velocity.

Akinci *et al.* (2014) analyzed the friction and wear performance of pure poly (methyl methacrylate) (PMMA) and zirconium oxide (ZrO_2) filled PMMA composites under dry sliding conditions. The friction and wear tests were realized using a pin-on-disk arrangement. Results for testing materials showed that the friction coefficient and the wear rate are sensitive to the applied loads and sliding speeds. The wear rates of the PMMA composite are changing between 3.01×10^{-7} mm^3/min and 5.50×10^{-6} mm^3/min, depending on ZrO_2 additive percentage, applied load and sliding speeds. Increase in load value caused the increase in friction coefficient and wear rate. It has been seen that the wear rates of PMMA polymer decreases with an increase in ZrO_2 content of ZrO_2 filled PMMA composites up to 30%wt addition. The hardness was changed linearly according to the increase of ZrO_2 content. The coefficient of friction increases with the increase in applied load, sliding speeds and increase in ZrO_2 filler content.

GAP IN LITERATURE:

After going through the available literature it is summarized that many studies are done to observe the effect of Silicon Carbide (SiC), Magnesium (Mg) and Fly-ash reinforced with aluminium matrix but no significant studies are found on the effect of Fly-ash and zirconium oxide reinforced with aluminium metal matrix. So, it is proposed

To study the mechanical behaviour of Al/Fly-ash/ZrO_2 metal matrix composite processed by stir casting method.

CHAPTER 3
PROBLEM FORMULATION

3.1. OBJECTIVES OF PRESENT WORK

The present work is to study the mechanical behaviour of Al-Fly-ash/ZrO_2 metal matrix composite (MMCs) processed by stir casting method. The specimens are made of aluminium 6061 with addition of varying percentage composition of Fly-ash and Zirconium oxide powder by stir casting method. The specimens are prepared and machined as per ASTM standards to perform different tests.

The objectives of present proposal are:

- To prepare the cost effective Metal matrix composite by taking Al-6061 as a matrix material and Fly-ash and zirconium oxide as reinforced material by stir casting method.
- To achieve uniform distribution of reinforcement particles in the metal matrix composite.
- To analyze the effect on mechanical properties by performing different tests. The tests performed on the samples are:
  1) Tensile Test
  2) Hardness Test
     a) Rockwell Hardness Test
     b) Vickers Microhardness Test
  3) Charpy Impact Test
  4) Sliding Wear Test
- To analyze the micro-structural characteristics of the metal matrix composites by SEM.

3.2. WORK PLAN FOR EXPERIMENTS

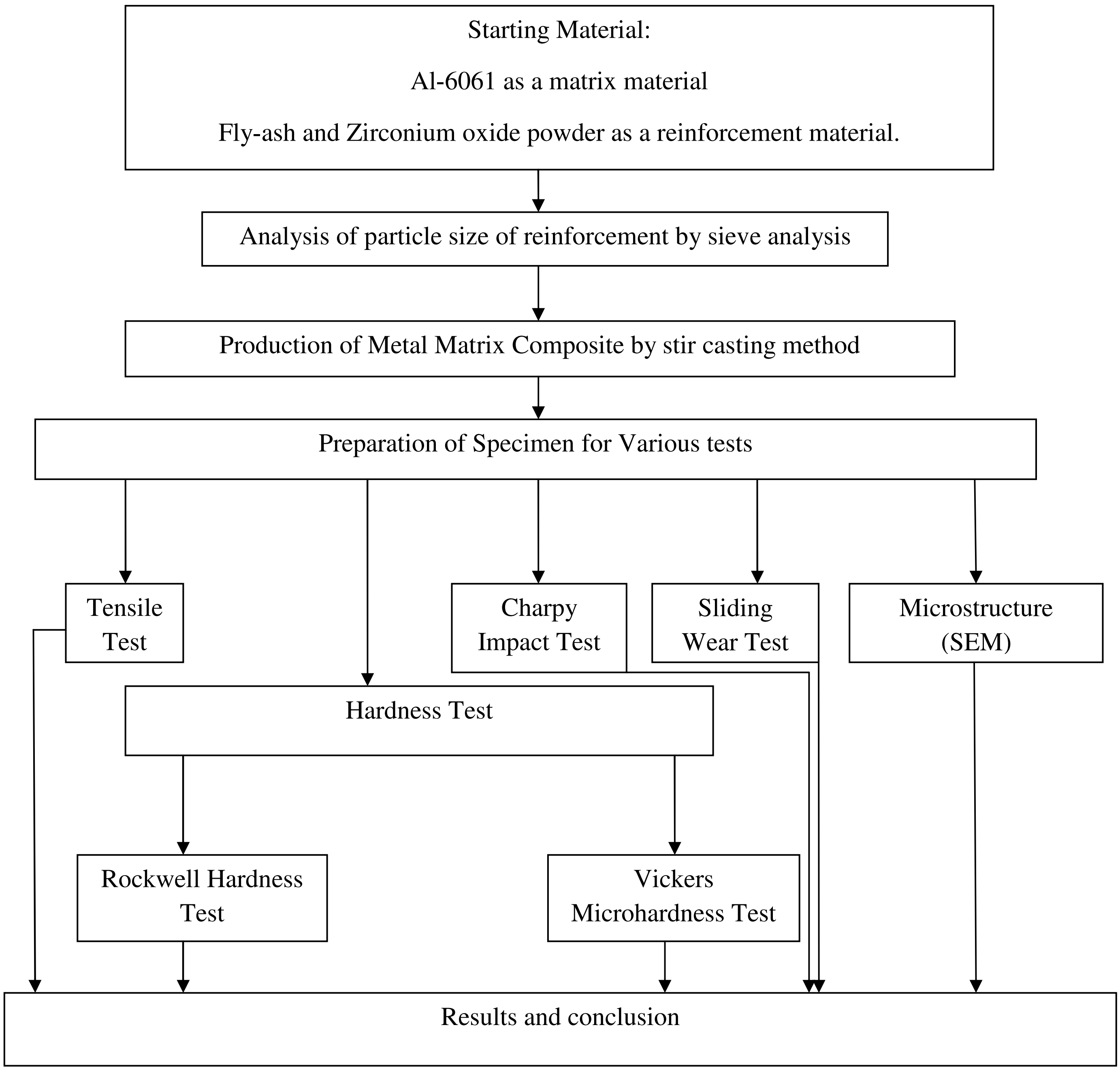


Figure 3.1: Experimental Technique Followed

CHAPTER 4
EXPERIMENTAL SETUP AND WORK

4.1. RAW MATERIALS

- **MATRIX MATERIAL:** Aluminium-6061

Table 4.1: Chemical Composition of Al-6061[26]

Components	Amount (% wt.)
Silicon	0.4 – 0.8
Iron	0 – 0.7
Copper	0.15 – 0.40
Manganese	0 – 0.15
Magnesium	0.8 – 1.2
Chromium	0.04 – 0.35
Zinc	0 – 0.25
Titanium	0 – 0.15
Others	0.15 (No more than 0.05 % each)
Aluminium	95.85 – 98.56

- **REINFORCEMENT MATERIALS:**
  1) Fly-ash and
  2) Zirconium oxide.

Figure 4.1: Fly-ash

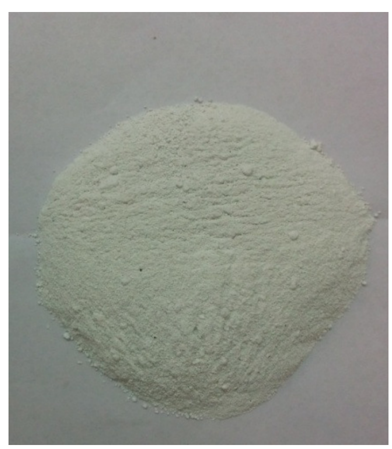


Figure 4.2: Zirconium oxide

Table 4.2: Chemical Composition of Fly-ash [29]

Components	**Amount (% wt.)**
SiO_2	67.2
Al_2O_3	29.6
Fe_2O_3	0.1
CaO	1.4
MgO	1.7

Table 4.3: Chemical Composition of Zirconium oxide [43]

Components	**Amount (% wt.)**
ZrO_2	99.6
SiO_2	≤ 0.3
CaO	0.2
MgO	< 0.1
Fe_2O_3	< 0.1
Al_2O_3	< 0.1
TiO_2	< 0.1

4.2. EXPERIMENTAL SETUP

For performing the Stir casting operation and testing of MMC the following Machine/Equipments are used:

1) Casting furnace
2) Graphite crucible
3) Graphite stirrer
4) Oven
5) Sieve shaker
6) Universal testing machine
7) Rockwell hardness tester
8) Vickers Hardness machine
9) Charpy Impact test machine
10) Pin-on-disk Apparatus
11) Scanning electron microscope

4.2.1. CASTING FURNACE

Figure 4.3: Casting Furnace

Casting furnace **(Make: Swastika Electric & Scientific Works)** available at ***Foundry Section, Central Workshop, MED, Thapar University*** is used to heat the material to desired temperature by electrical resistance heating elements. In casting furnace the material to be melted is placed apart from the fuel and other products of combustion like gases, Fly-ash etc. It is fitted with a RPM indicator to show the rpm and controller to adjust the stirrer speed and temperature controller to display and adjust the temperature inside the furnace.

4.2.2. GRAPHITE STIRRER

Stirrer is used for homogeneous mixing of reinforcement in the metal matrix. The stirrer is made of graphite with a stainless steel rod of diameter 12 mm and length 500 mm.

Figure 4.4: Graphite Stirrer

4.2.3. Graphite Crucible

Graphite crucible (**Make: Haryana Ceramic &Allied Products Ind., Size: 8 no.**) is used for melting the matrix material. A crucible is a refractory container which can withstand high temperature and is used for melting material. It may be made of clay, graphite or cast iron etc. The main point to be considered during its selection is that its temperature resistance should be higher than the material it is designed to hold.

Figure 4.5: Graphite Crucible

4.2.4. OVEN

Oven (**Make: SENTWIN India**) available at ***Sand Testing Lab, MED, Thapar University, Patiala*** is used for preheating of reinforcement particulate to remove moisture from the particulate. It is fitted with a temperature indicator to display the temperature inside the oven. The reinforcement Fly-ash and Zirconium oxide are preheated to a temperature of 200 ^{o}C for 2 hrs.

Figure 4.6: Oven for Preheating of Reinforcement Particles

4.2.5. SIEVE SHAKER

Sieve shaker (**Make: Mody Testing Instruments Co.**) available at ***Sand Testing Lab, MED, Thapar University, Patiala*** is used to determine the particle size distribution of Fly-ash and Zirconium oxide. It consists of different sizes of sieves arranged in decreasing order of size from up to down and is associated with an electric motor to provide vibrations. A measured sample of 100 gms of the powder is put on the upper sieve and the motor is started and leave it to vibrate for 15 min then stops the motor and weight the amount of powder particles retained in the sieve of different sizes.

Figure 4.7: Sieve Shaker

4.2.6. COMPUTERIZED UNIVERSAL TESTING MACHINE

Universal testing machine **(Make: Hung Ta Instrument Co. Ltd., Model: H-1000KN)** available at ***Structural Lab, Civil Engg. Deptt., Thapar University, Patiala*** is used to determine the Yielding strength, Ultimate tensile strength and % elongation of the MMC specimens. It has a capacity of 1000 KN. The UTM is programmed to a loading rate of 15 KN/min. Hold the specimen in the grips of the UTM and load is applied. After the specimen has fractured stop the machine loosen the grips and remove the fractured specimen and save the data and graphs generated in the computer.

Figure 4.8: Fully Computerized Universal Testing Machine

4.2.7. ROCKWELL HARDNESS TESTING MACHINE

Rockwell hardness tester **(Make: AVERY 6402)** available at ***Strength of Material Lab, MED, Thapar University, Patiala*** is used to determine the macro-hardness of the MMC specimens as per ASTM E18–11 standards. The load applied is 100 Kgf for a period of 10 secs. For each specimen 6 readings are taken and then their mean is taken as a final result.

Figure 4.9: Rockwell Hardness Testing Machine

4.2.8. VICKERS MICRO HARDNESS TESTING MACHINE

Vickers micro hardness testing machine **(Make: Mitutoyo MVK - H0)** available at ***SPMS, Thapar University, Patiala*** is used to determine the micro-hardness of the MMC specimens as per ASTM E 384 standard. The Load applied is 100 gms for a period of 10 secs. For each specimen 3 readings have been taken to calculate the Vickers hardness number and then their average is considered.

$$HV = \frac{2\ L\ Sin\ (\square/2)}{d^2}$$

L = Force (Load) in kilograms

d = diagonal length of the impression in mm

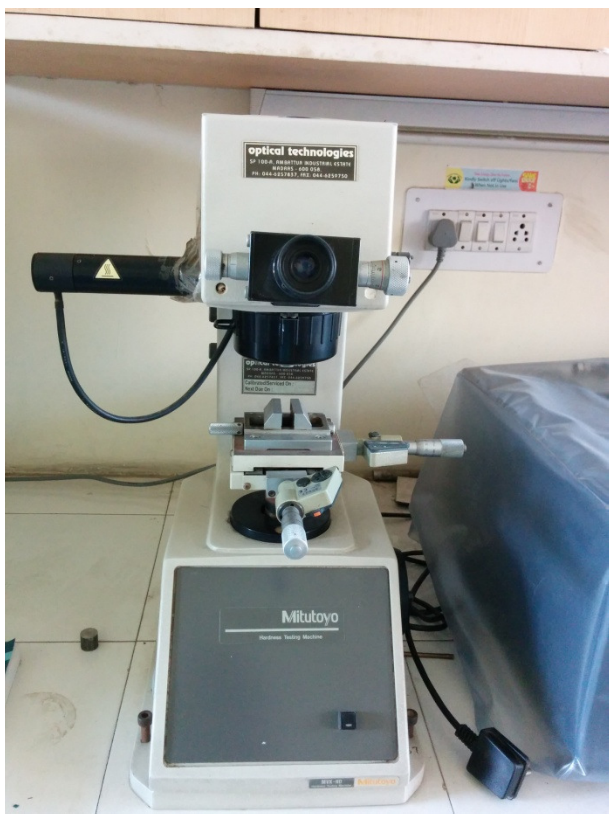


Figure 4.10: Vickers Hardness Testing Machine

4.2.9. CHARPY IMPACT TEST MACHINE

Charpy Impact Test Machine **(Make: ALFRED J.AMSLER & Co.)** is available at ***Strength of Material Lab, MED, Thapar University, Patiala*** have been used to determine the impact toughness of the MMC specimens as per ASTM E23-02a standard. This test determines the energy absorbed by the MMC during the fracture. The pendulum of the impact machine is raised to a known height and then allowed to fall under gravity. The pendulum impacts and breaks the specimen and rises to some height. The difference in the initial and final height is directly proportional to the energy absorbed.

Figure 4.11: Charpy Impact Test Machine

4.2.10. PIN-ON-DISK APPARATUS

Pin-on-disk apparatus **(Make: Ducom Instruments Pvt. Ltd.)** available at ***Machine Tool Lab, MED, Thapar University, Patiala*** is used to determine the wear of the MMC specimens as per ASTM G 99-95a standard. The specimens are machined to a size of 10mm X 10mm X 50 mm.

The conditions under which the wear tests are performed are as follows:

Table 4.4: Operating Conditions for Wear Test

Experiment	Time (min)	Load (Kgs)	RPM
1	5	2	400
2	5	3	400
3	5	4	400
4	10	2	400
5	10	3	400
6	10	4	400
7	15	2	400
8	15	3	400
9	15	4	400

During the test the specimen is held against a rotating (EN-32) steel disc by applying a counter weight which acts as applied load. The weight of the sample is measured before and after each set of experiment and the weight loss is calculated by the difference between the initial weight (i.e. the weight before the test) and the final weight (i.e. the weight after the test). Electronic weighing machine with an accuracy of 0.001 gm is used for weight measurement.

Figure 4.12: Pin-on-Disk Apparatus

4.2.11. SCANNING ELECTRON MICROSCOPE (SEM)

SEM **(Make: JEOL, JSM – 6510LV)** available at ***SAI Labs, Thapar University, Patiala*** is used to analyze the micro-structure of the metal matrix composite. The specimens are viewed at an accelerating voltage of 20 KV. The SEM micrographs are clicked at 100X, 500X and 1000X.

Figure 4.13: Scanning Electron Microscope (SEM)

4.3. SAMPLE PREPARATION:

The Metal matrix composite samples are prepared by stir casting method. A measured quantity of Al-6061 is taken in the graphite crucible and put in the casting furnace for melting. When the temperature of the furnace reaches 830 ^{o}C, measured quantity of preheated reinforcement in the melt is added. The reinforcement is preheated at a temperature of 200 ^{o}C for 2 hrs. The melt is then stirred at a stirrer speed of 400 rpm at 750

^{o}C for 4 minutes. The molten mixture is further heated upto a temperature of 830 ^{o}C and then poured into the prepared green sand mould of required shape. The melt is then allowed to solidify.

Table 4.5: Composition of Metal Matrix Composites (% wt.)

Sample Name	Al-6061 (% wt.)	Zirconium Oxide (% wt.)	Fly-ash (% wt.)
S1	100	0	0
SF1	95	0	5
SF2	90	0	10
SZ1	95	5	0
SFZ5	90	5	5
SZF	85	5	10
SZ2	90	10	0
SFZ	85	10	5
SFZ10	80	10	10

Figure 4.14: Mould Preparation and Casting of Samples

After the solidification the casting is machined to prepare specimens as per the ASTM standards for different tests.

4.3.1. SPECIMEN FOR TENSILE TEST

The specimen for tensile test is prepared as per ASTM E8-04 standard.

Figure 4.15: Tensile Test Specimen before and after the Test.

4.3.2. SPECIMEN FOR HARDNESS TEST

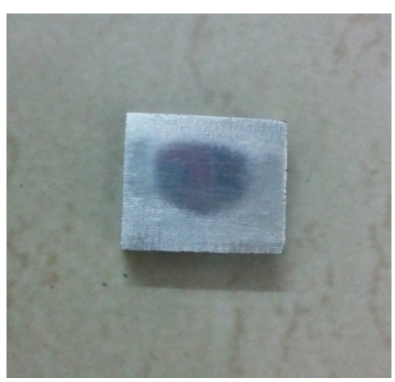


Figure 4.16: Specimen for Hardness Test

The specimens for both Rockwell hardness and Vickers micro-hardness test are machined to dimensions 20 mm X 20 mm X 10 mm. The surfaces of the specimens are finished by using emery paper of grades 180, 320, 800 and 1000.

4.3.3. SPECIMEN FOR IMPACT TEST

The specimens for Charpy impact test are machined as per ASTM E23-02a standard. The dimensions of the specimens are 55 mm X 10 mm X 10 mm with a notch of 45 ^{o} with 2 mm depth at the centre of one side.

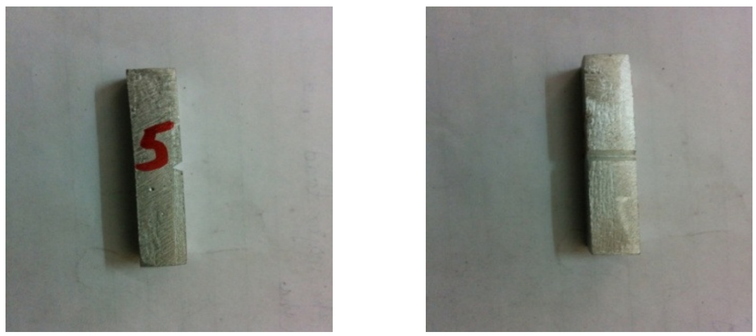


Figure 4.17: Charpy Impact Test specimen before the Test

Figure 4.18: Charpy Impact Test specimens after the Test

4.3.4. SPECIMEN FOR SLIDING WEAR TEST

The specimens for wear testing are machined to a dimension of 10 mm X 10 mm X 50 mm. The specimen surfaces are then finished with an emery paper of grade 320.

Figure 4.19: Specimen for Wear Test

4.3.5. SPECIMEN FOR SCANNING ELECTRON MICROSCOPE (SEM)

The specimens for SEM are machined to a dimension of 10 mm X 15 mm X 15 mm. The surface of the specimens is finished by using emery papers of grades 250, 320, 600, 800, 1000 and 2000.

Figure 4.20: Specimen for SEM

CHAPTER 5
RESULTS AND DISCUSSION

5.1. SIEVE ANALYSIS

Before putting the reinforcement material into the oven for preheating sieve analysis for both Fly-ash and Zirconium oxide has been carried out to determine the particle size of both.

5.1.1. SIEVE ANALYSIS OF FLY-ASH

Table 5.1: Particle Size Distribution of Fly-ash

Mesh Size (in microns)	% of Fly-ash retained
150	6.36
106	8.93
75	25.19
53	49.08
Less than 53	10.44

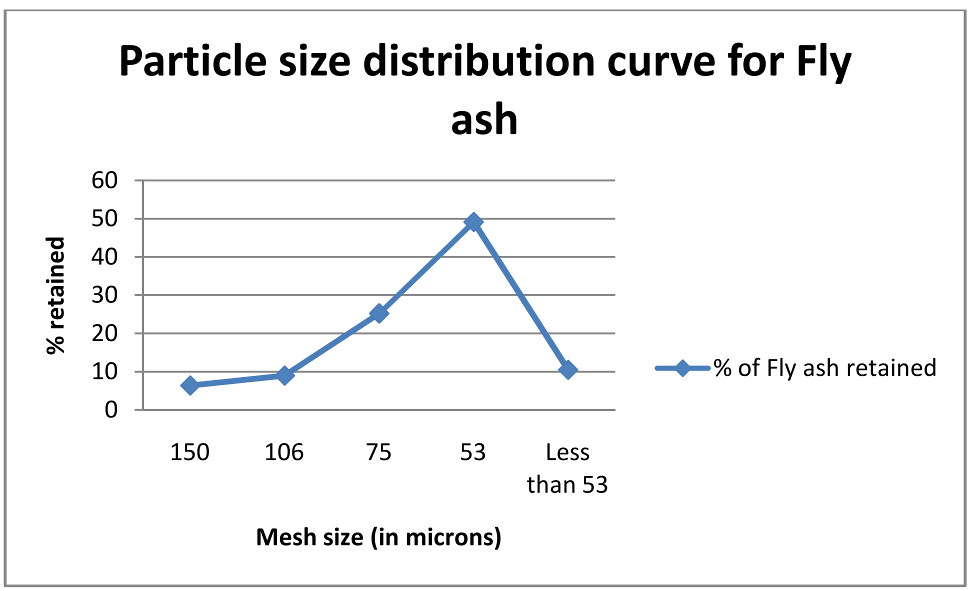


Figure 5.1: Particle Size Distribution of Fly-ash

The average particle size is 53 microns.

5.1.2. SIEVE ANALYSIS OF ZIRCONIUM OXIDE

Table 5.2: Particle Size Distribution of Zirconium oxide

Mesh Size (in microns)	% of Zirconium oxide retained
500	3.45
355	6.03
250	28.77
150	14.49
106	11.66
75	17.77
53	15.07
Less than 53	2.76

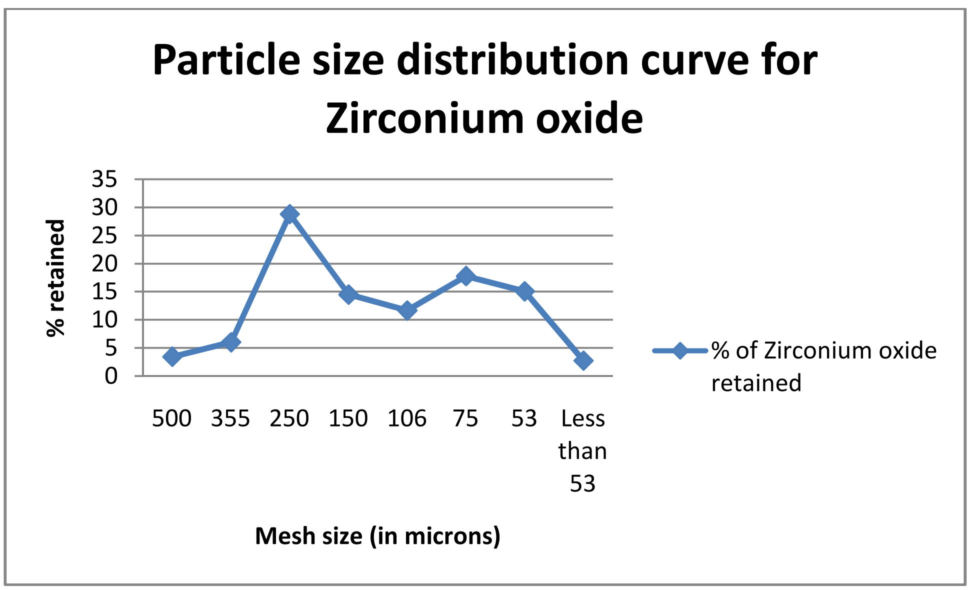


Figure 5.2: Particle Size Distribution of Zirconium oxide

The average particle size is 250 microns.

5.2. TENSILE TEST

The results of tensile test are shown in the table.

Table 5.3: Results of Tensile Test

Samples	Yield Strength (MPa)	UTS (MPa)	% Elongation
S1	32	42	7.19
SF1	44	64	3.69
SF2	40	45	4.97
SZ1	32	40	8.93
SFZ5	45	56	3.63
SZF	59	68	3.92
SZ2	47	58	8.42
SFZ	51	64	4.35
SFZ10	83	92	3.12

5.2.1. COMPARISON OF YIELD STRENGTH (YS)

1) Effect of Fly-ash on Yield Strength

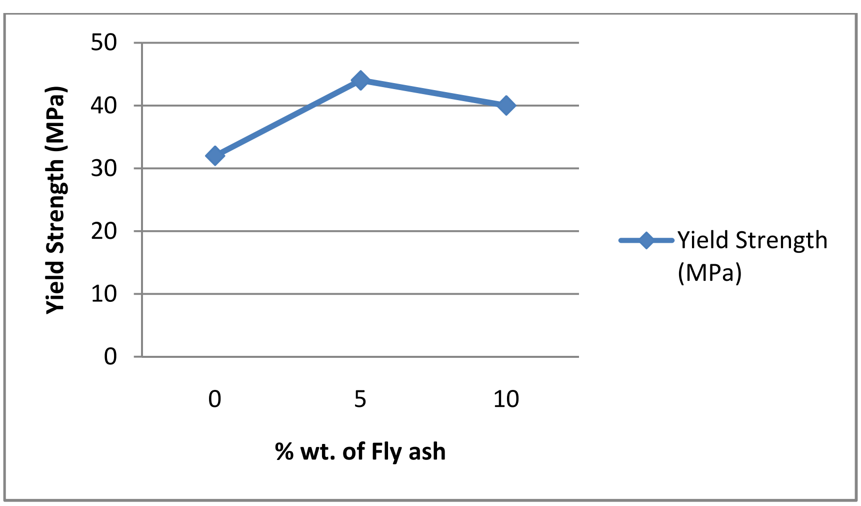


Figure 5.3: Variation of Yield Strength with variation in the vol. fraction of Fly-ash

With the addition of Fly-ash content in Al-6061 from 0 to 5 % vol., the yield strength increases significantly but it decreases slightly with further increase in the Fly-ash from 5 to 10 % vol. The increase noticed in the yield strength is 12 MPa with increase in Fly-ash from 0 to 5 % vol. and decrease noticed is 4 MPa with further increase in Fly-ash from 5 to 10 % vol.

2) Effect of Zirconium oxide on Yield Strength

Zirconium oxide has also been added to the Al-6061 and its effect on yield strength is discussed in this section.

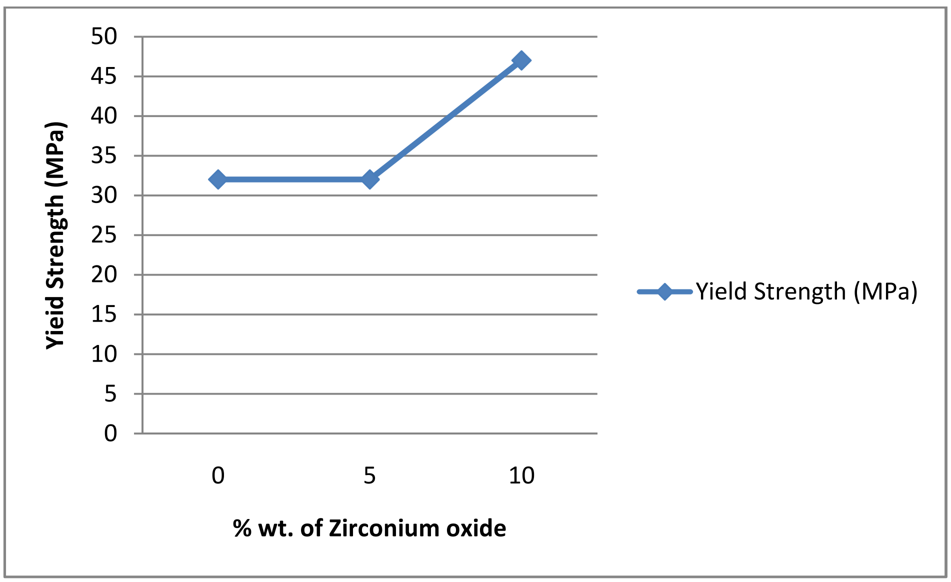


Figure 5.4: Variation of Yield Strength with variation in the vol. fraction of Zirconium oxide

With the addition of Zirconium oxide content in Al-6061 from 0 to 5 % vol. fraction, the yield strength remains constant but it increases with further increase in the Zirconium oxide from 5 to 10 % vol. The increase noticed in the Yield strength is 15 MPa with increase in Zirconium oxide from 5 to 10 % vol.

3) Effect of Fly-ash & Zirconium oxide on Yield Strength

Now the combined effect of both the constituents have also been studied and discussed as under:

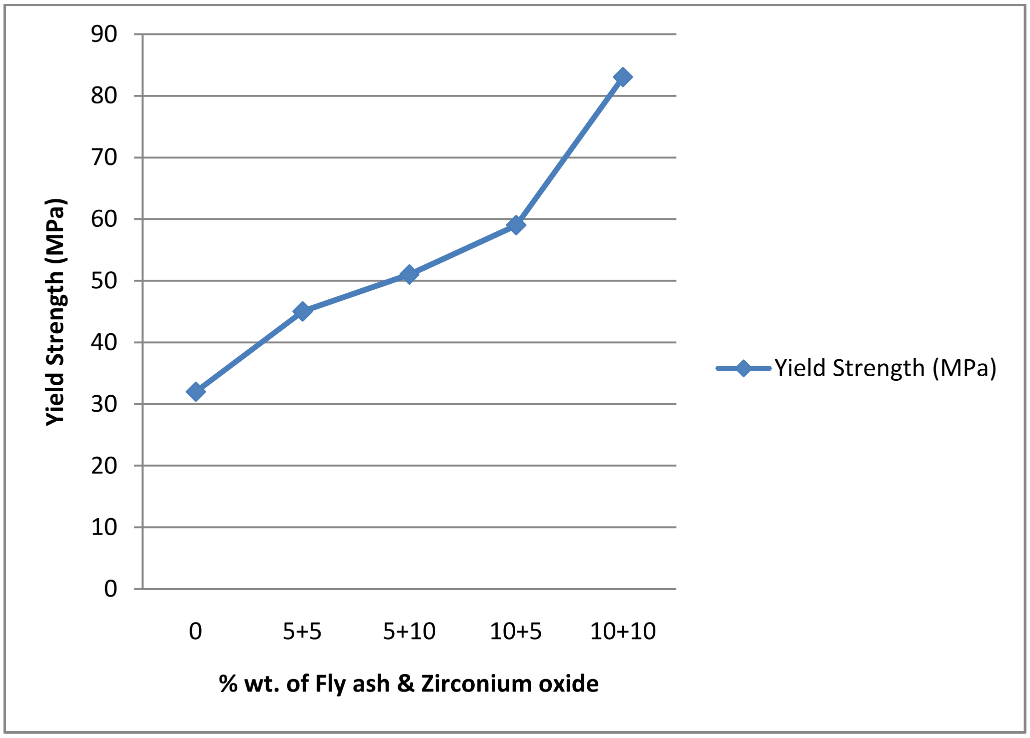


Figure 5.5: Variation of Yield Strength with variation in the vol. fraction of Fly-ash & Zirconium oxide

There has been a largely increase in the yield strength of the material with proportion to the increase in both constituents by 5 % each. With every increase in these constituents, yield strength increases. The total increase noticed in yield strength is 51 MPa when both the constituents are 10 % each in Al-6061.

5.2.2. COMPARISON OF ULTIMATE TENSILE STRENGTH (UTS)

1) **Effect of Fly-ash on Ultimate Tensile Strength**

   With the addition of Fly-ash in small amount in Al-6061, the tensile strength increases but at higher amount of fly-ash it decreases.

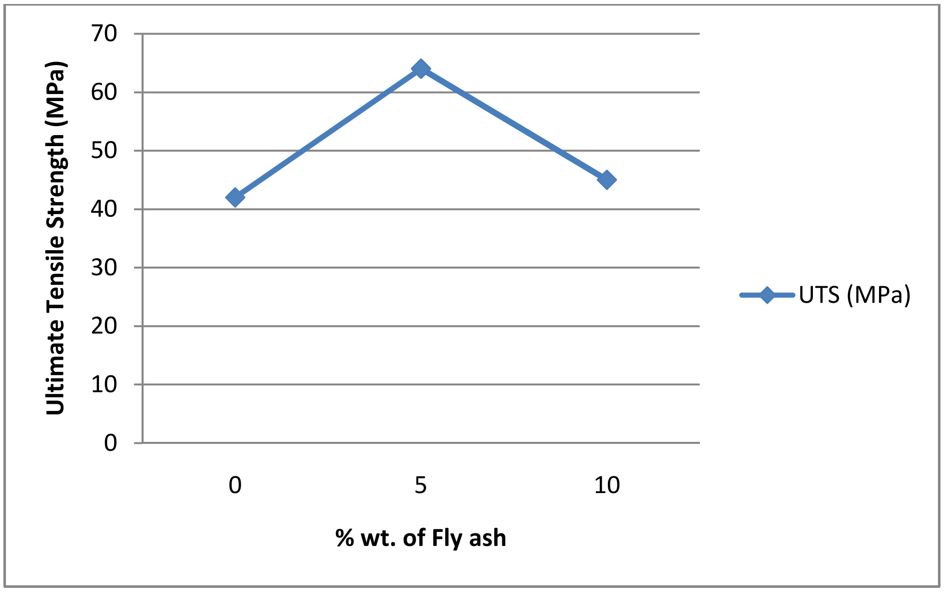


Figure 5.6: Variation of Ultimate Tensile Strength with variation in the vol. fraction of Fly-ash

The increase noticed in the Ultimate Tensile strength is 22 MPa with increase in Fly-ash from 0 to 5 % vol. fraction and decrease noticed is 19 MPa with further increase in Fly-ash from 5 to 10 % vol. fraction.

2) **Effect of Zirconium oxide on Ultimate Tensile Strength**

With the addition of Zirconium oxide in Al-6061, the tensile strength decreases slightly but at higher amount of zirconium oxide it increases significantly.

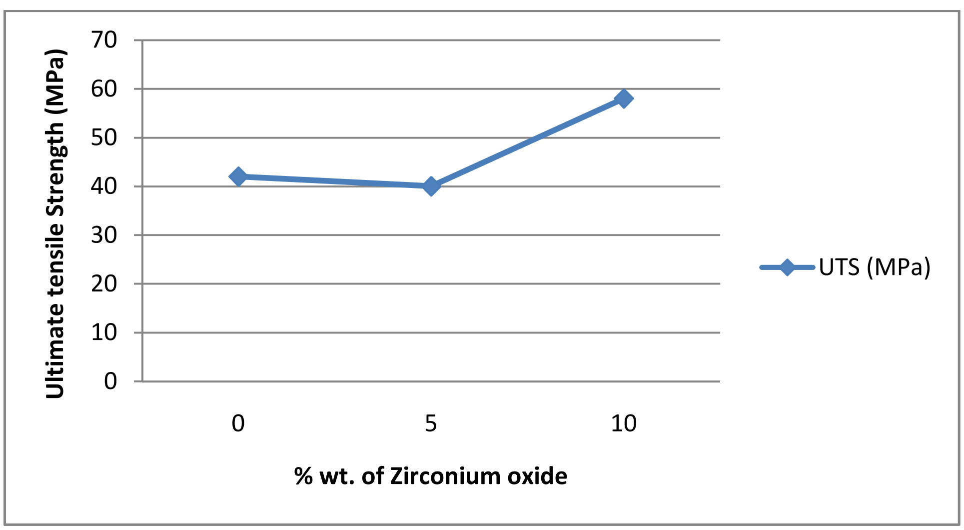


Figure 5.7: Variation of Ultimate Tensile Strength with variation in the vol. fraction of Zirconium oxide

The decrease noticed in the Ultimate Tensile strength is 2 MPa with increase in Zirconium oxide from 0 to 5 % vol. and increase noticed is 16 MPa with increase in Zirconium oxide from 0 to 10 % vol.

3) Effect of Fly-ash & Zirconium oxide on Ultimate Tensile Strength

The combined effect of both the constituents have also been studied and discussed as under:

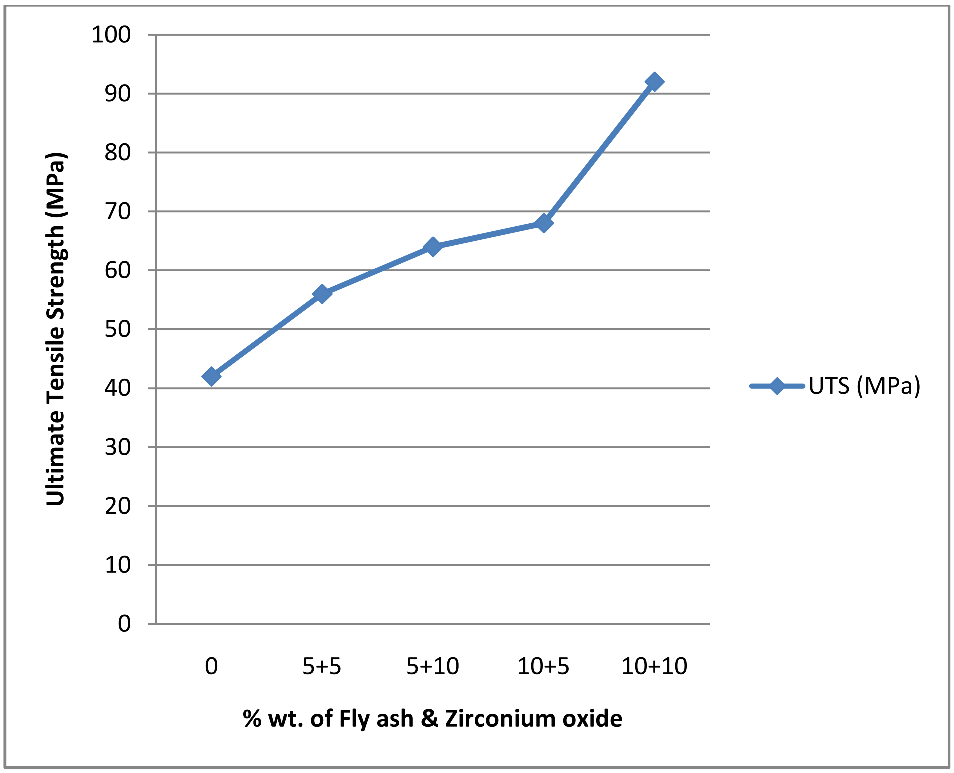


Figure 5.8: Variation of Ultimate Tensile Strength with variation in the vol. fraction of Fly-ash & Zirconium oxide

A large amount of increase in the Ultimate tensile strength of the material is observed with increase in the proportion of both the constituents in steps of 5 % each. With every increase in these constituents, ultimate tensile strength increases. The total increase in the ultimate tensile strength is 50 MPa when the amounts of both the constituents are 10 % each.

5.2.3. COMPARISON OF % ELONGATION

1) Effect of Fly-ash on % Elongation

With increase in the amount of Fly-ash content in Al-6061 from 0 to 5 % vol. fraction the % Elongation decreases significantly but it increases slightly with further increase in the Fly-ash from 5 to 10 % vol.

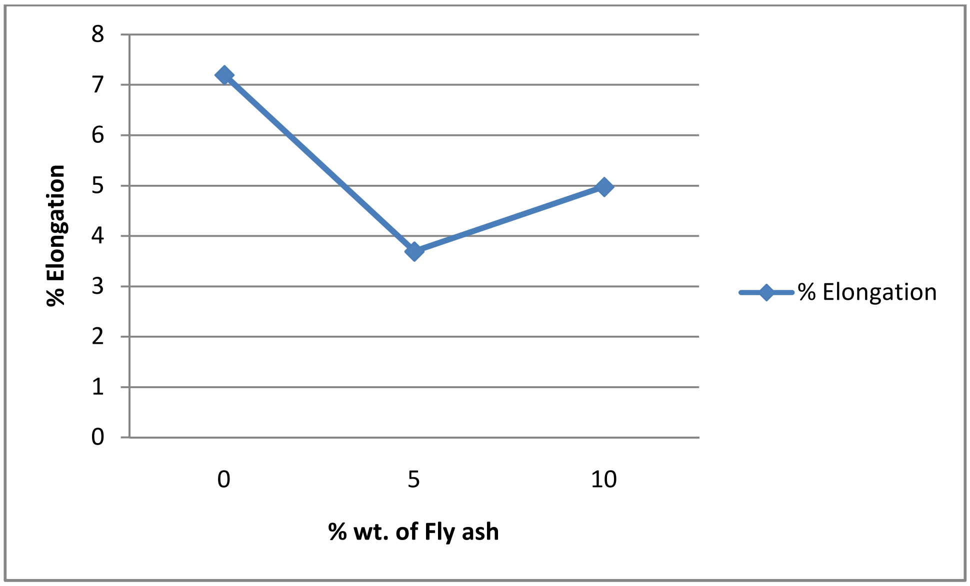


Figure 5.9: Variation of % Elongation with variation in the vol. fraction of Fly-ash

The decrease noticed in the % Elongation is 3.5 with increase in the amount of Fly-ash from 0 to 5 % vol. and increase noticed is 1.28 with further increase in the amount of Fly-ash from 5 to 10 % vol.

2) Effect of Zirconium oxide on % Elongation

With the increase in the amount of Zirconium oxide in Al-6061, the % elongation increases but at higher amount of zirconium oxide it decreases slightly.

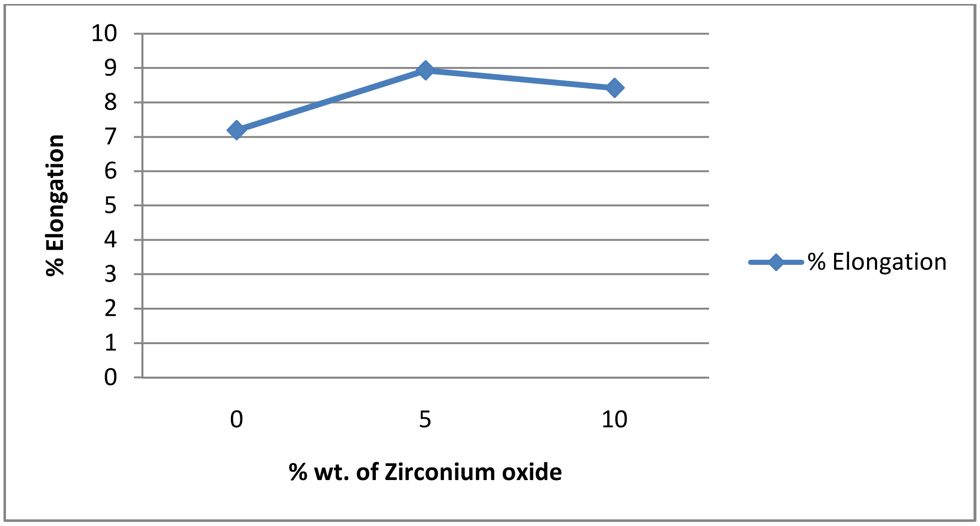


Figure 5.10: Variation of % Elongation with variation in the vol. fraction of Zirconium oxide

The increase noticed in the % Elongation is 1.74 with increase in the amount of Zirconium oxide from 0 to 5 % vol. and decrease noticed is 0.51 with further increase in the amount of Zirconium oxide from 5 to 10 % vol.

3) Effect of Fly-ash & Zirconium oxide on % Elongation

With the increase in the amount of both Fly-ash and Zirconium oxide the % Elongation decreases.

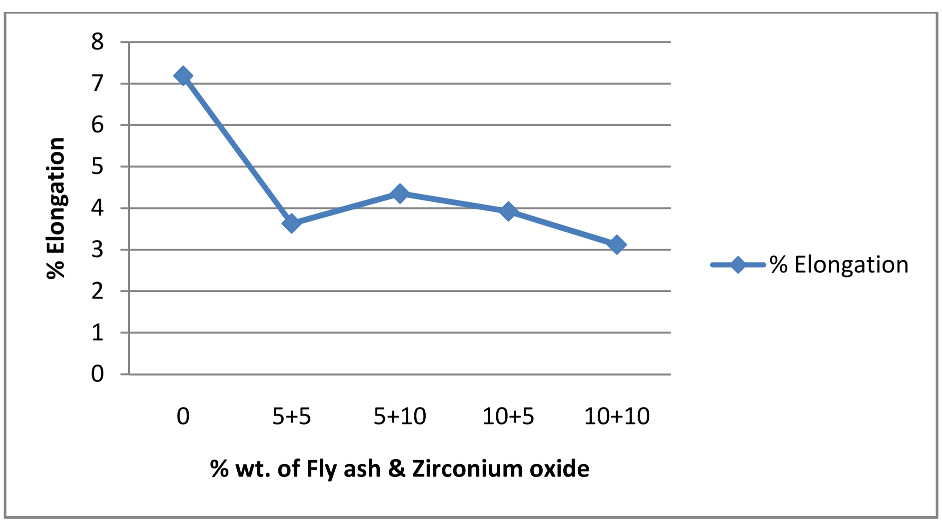


Figure 5.11: Variation of % Elongation with variation in the vol. fraction of Fly-ash & Zirconium oxide

The % Elongation firstly decreases with increase in the amount of both Fly-ash and Zirconium oxide from 0 to 5 %. Then it slightly increases with further increase in Zirconium oxide from 5 to 10 % vol. and also with further increase in Fly-ash from 5 to 10 % vol. but it again slightly decreases with the increase in the amount of both Fly-ash and Zirconium oxide from 5 to 10 %. The decrease noticed is 4.07 with increase in the amount of both Fly-ash and Zirconium oxide from 0 to 10 %.

5.3. ROCKWELL HARDNESS TEST

The results of Rockwell hardness test are shown in the Table.

Table 5.4: Results of Rockwell Hardness Test

Samples	Rockwell Hardness Number (HRB)						Mean Hardness
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	
S1	65	65	65.5	64	66	65	65.08
SF1	67	68	66	67	69	67.5	67.42
SF2	71.5	70	71	70	71	71.5	70.83
SZ1	70	69	71.5	70	68	70	69.75
SFZ5	73	74	72	73	73	72	72.83
SZF	76	75	74	75	74	75	74.83
SZ2	71	70.5	72	71	72	72.5	71.5
SFZ	76	75	76	74	75	77.5	75.58
SFZ10	80	78.5	79	78	80	79	79.08

5.3.1. COMPARISON OF ROCKWELL HARDNESS

1) Effect of Fly-ash on Rockwell Hardness

With increase in the amount of Fly-ash content in Al-6061 the Rockwell hardness increases. The increase noticed in the Rockwell hardness is 2.34 HRB with increase in Fly-ash from 0 to 5 % vol. and increase noticed is 5.75 HRB with increase in Fly-ash from 0 to 10 % vol.

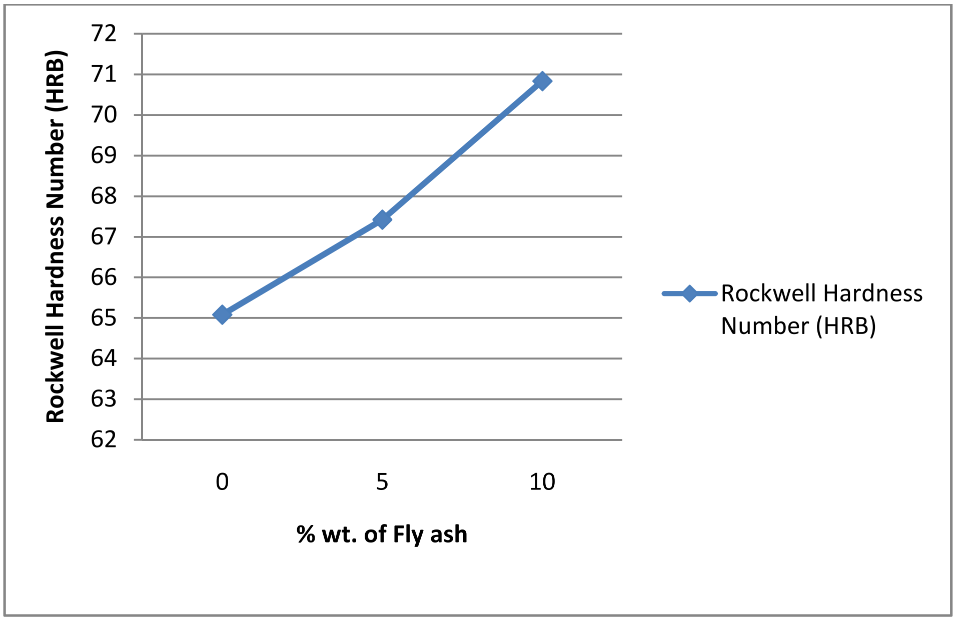


Figure 5.12: Variation of Rockwell Hardness Number with variation in the vol. fraction of Fly-ash

2) Effect of Zirconium oxide on Rockwell Hardness

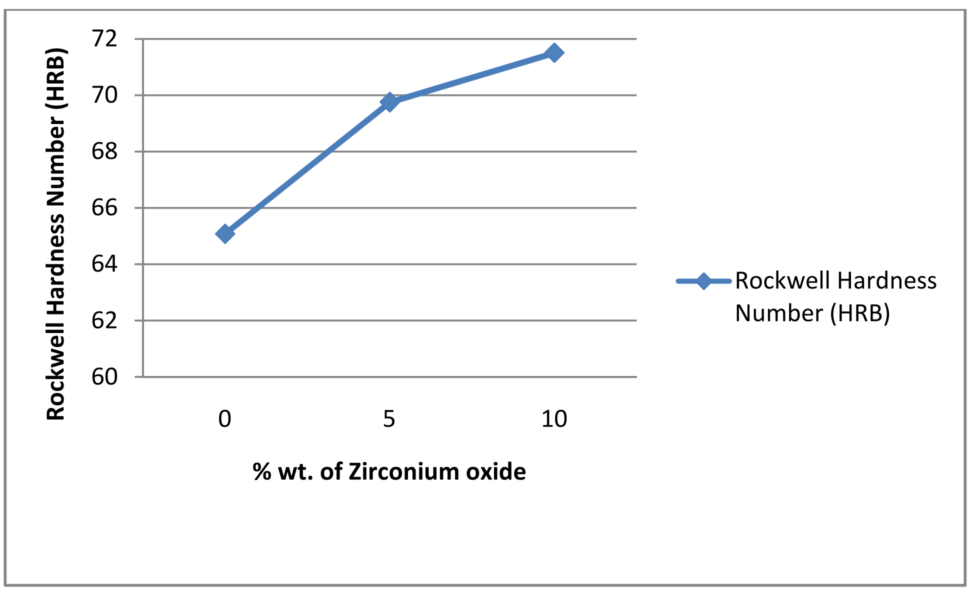


Figure 5.13: Variation of Rockwell Hardness Number with Variation in the Vol. Fraction of Zirconium Oxide

With increase in the amount of Zirconium oxide content in Al-6061 from 0 to 5 % vol. fraction the Rockwell hardness increases and it increases slightly with further increase in the amount of Zirconium oxide from 5 to 10 % vol. The increase noticed in the Yield strength is 4.67 HRB with increase in Zirconium oxide from 0 to 5 % vol. and increase noticed is 1.75 HRB with further increase in Zirconium oxide from 5 to 10 % vol.

3) Effect of Fly-ash & Zirconium oxide on Rockwell Hardness

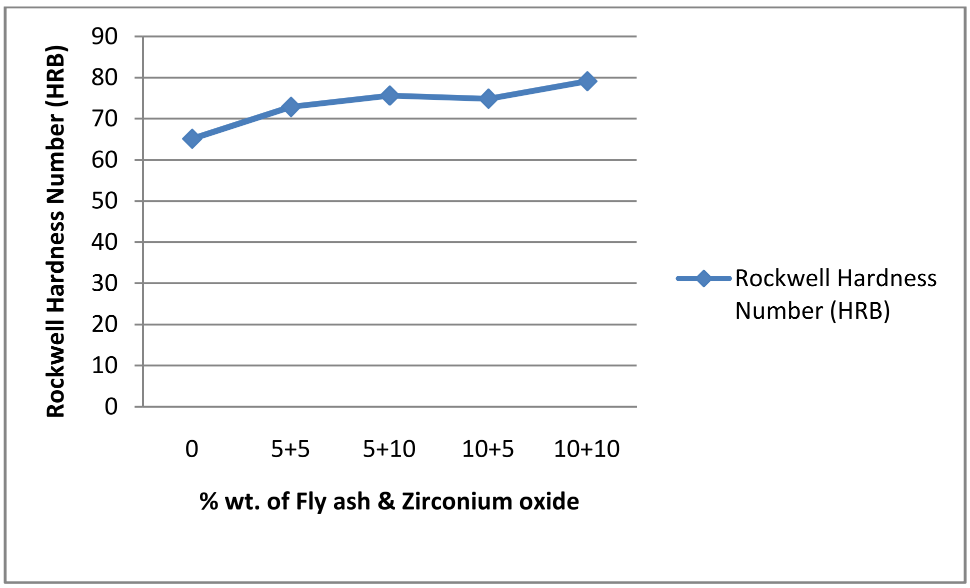


Figure 5.14: Variation of Rockwell Hardness Number with variation in the vol. fraction of Fly-ash & Zirconium oxide

With the increase in the amount of both of Fly-ash and Zirconium oxide the Rockwell Hardness increases. The increase noticed is 7.75 HRB with increase in the amount of both Fly-ash and Zirconium oxide from 0 to 5 % vol. and the increase noticed is 14 HRB with the increase in the amount of both Fly-ash and Zirconium oxide from 0 to 10 %.

5.4. VICKERS HARDNESS TEST

The results of Vickers Hardness are shown it the table below:

Table 5.5: Results of Vickers Hardness

Samples	Average Length of Diagonals (µm)			Mean	Vickers Hardness (HV)
	Reading 1	Reading 2	Reading 3		
S1	2.75	2.77	2.73	2.75	24.52
SF1	2.66	2.62	2.67	2.65	26.4
SF2	2.49	2.51	2.50	2.50	29.67
SZ1	2.66	2.64	2.65	2.65	26.40
SFZ5	2.475	2.48	2.485	2.48	30.15
SZF	2.265	2.275	2.28	2.27	35.98
SZ2	2.605	2.595	2.52	2.57	28.07
SFZ	2.33	2.32	2.31	2.32	34.45
SFZ10	2.22	2.21	2.20	2.21	37.96

5.4.1. COMPARISON OF VICKERS HARDNESS

1) Effect of Fly-ash on Vickers Hardness

Figure 5.15: Variation in Vickers Hardness with variation in the vol. fraction of Fly-ash

With increase in the Fly-ash content in Al-6061 the Vickers Hardness increases. The increase noticed in the Vickers hardness is 1.88 HV with increase in Fly-ash from 0 to 5 % vol. and the increase noticed is 5.15 HV with increase in the amount of Fly-ash from 0 to 10 % vol.

2) Effect of Zirconium oxide on Vickers Hardness

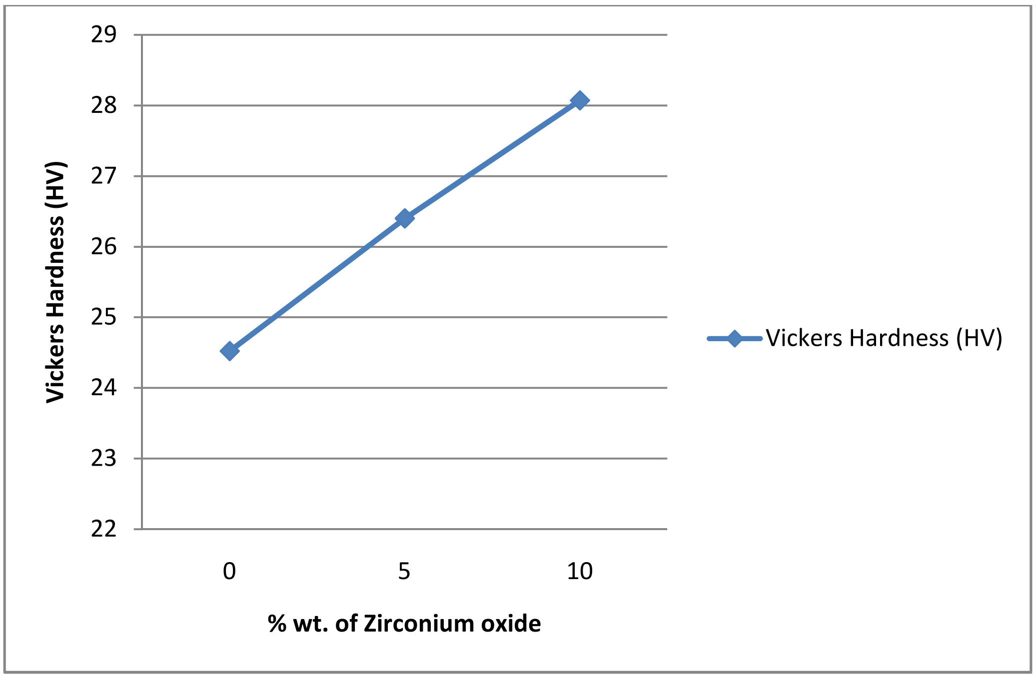


Figure 5.16: Variation in Vickers Hardness with variation in the vol. fraction of Zirconium oxide

With increase in the amount of Zirconium oxide content in Al-6061 the Vickers hardness increases. The increase noticed in the Vickers hardness is 1.88 HV with increase in Zirconium oxide from 0 to 5 % vol. fraction and increase noticed is 3.55 HV with increase in Zirconium oxide from 0 to 10 % vol. fraction.

3) Effect of Fly-ash & Zirconium oxide on Vickers Hardness

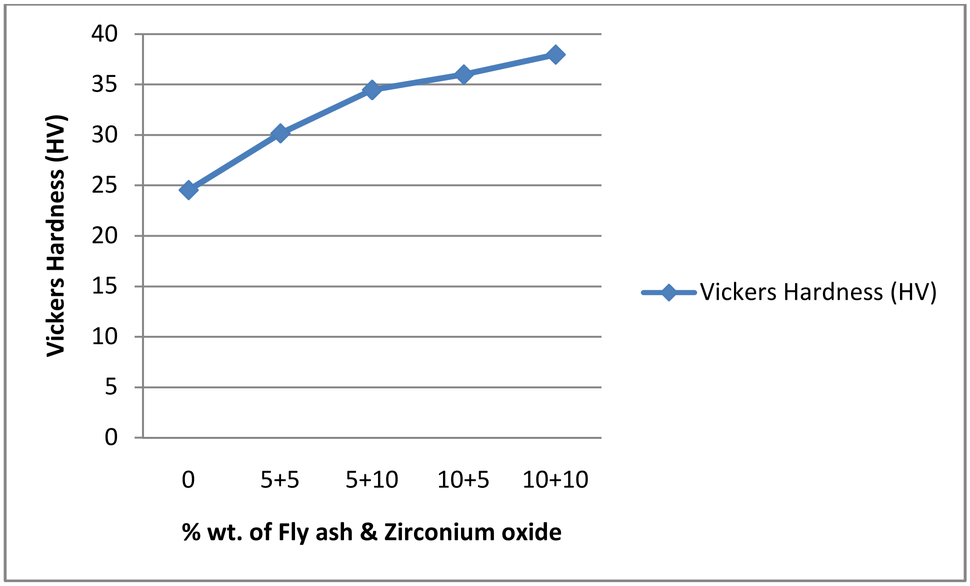


Figure 5.17: Variation in Vickers Hardness with variation in the vol. fraction of Fly-ash & Zirconium oxide

With the increase in the amount of both of Fly-ash and Zirconium oxide the Vickers hardness increases. The increase noticed is 5.63 HV with increase in the vol. fraction of both Fly-ash and Zirconium oxide from 0 to 5 % and the increase noticed is 13.44 HV with increase in the amount of both Fly ash and Zirconium oxide from 0 to 10 % vol.

5.5. CHARPY IMPACT TEST

Impact toughness of a metal is determined by measuring the energy absorbed by the specimen before fracture. The total energy absorbed is determined by

$$\Gamma_{Total} = mg\ (h_o - h_f)$$

Where, Γ_{Total} = Total energy absorbed

m = mass of the pendulum

g = gravitational acceleration

h_o = Initial height of the pendulum

h_f = Final height of the pendulum

Table 5.6: Results of Charpy Impact Test

Samples	Difference in height ($h_o - h_f$)			Mean of ($h_o - h_f$)	Energy Absorbed (Joules)
	Trial 1	Trial 2	Trial 3		
S1	11	11.1	10.9	11	107.91
SF1	13.8	13.7	13.9	13.8	135.38
SF2	10.8	10.7	10.9	10.8	105.95
SZ1	12.1	12.1	12.1	12.1	118.7
SFZ5	13.9	14.1	14.1	14.03	137.63
SZF	14.6	14.7	14.6	14.63	143.52
SZ2	13.7	13.6	13.5	13.6	133.42
SFZ	14.1	14.3	14.1	14.17	139.01
SFZ10	15	14.9	14.8	14.9	146.17

5.5.1. COMPARISON OF ENERGY ABSORBED

1) **Effect of Fly-ash on Energy Absorbed**

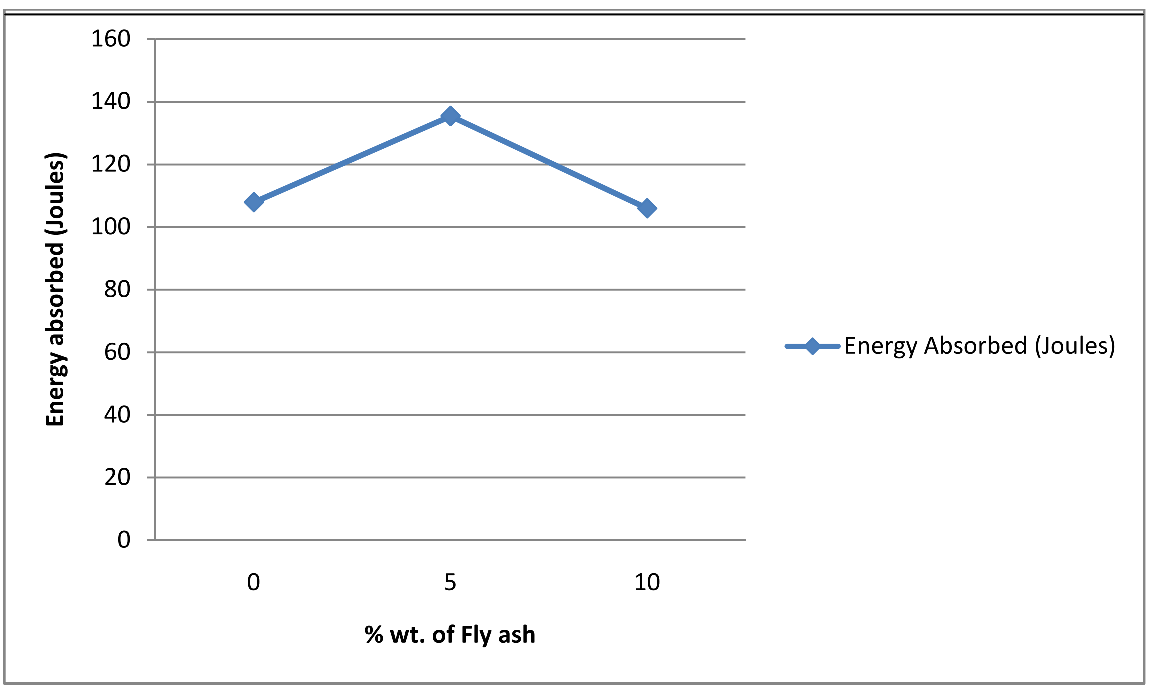


Figure 5.18: Variation in Energy Absorbed with variation in the vol. fraction of Fly-ash

With increase in the amount of Fly-ash content in Al-6061 from 0 to 5 % vol. the Energy absorbed increases but it decreases with further increase in the amount of Fly-ash from 5 to 10 % vol. The increase noticed in the Energy absorbed is 27.47 Joules with increase in Fly-ash from 0 to 5 % vol. and decrease noticed is 29.43 Joules with further increase in Fly-ash from 5 to 10 % vol.

2) Effect of Zirconium oxide on Energy Absorbed

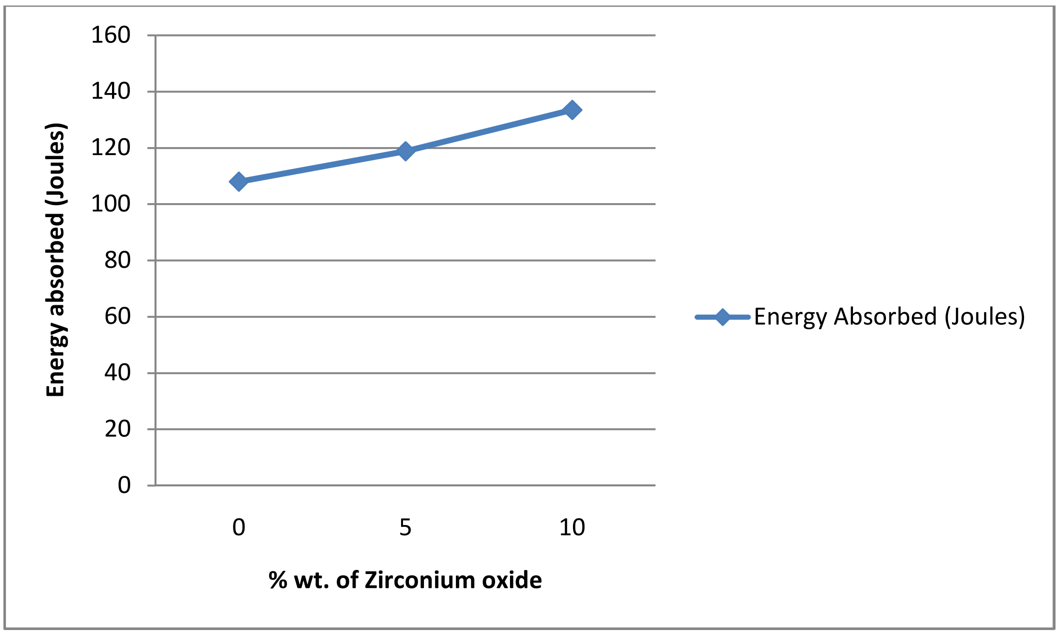


Figure 5.19: Variation in Energy Absorbed with variation in the vol. fraction of Zirconium oxide

With increase in the amount of Zirconium oxide content in Al-6061 the Energy absorbed increases. The increase noticed in the Energy absorbed is 10.79 Joules with increase in Zirconium oxide from 0 to 5 % vol. and increase noticed is 25.51 Joules with increase in Zirconium oxide from 0 to 10 % vol.

3) Effect of Fly-ash & Zirconium oxide on Energy Absorbed

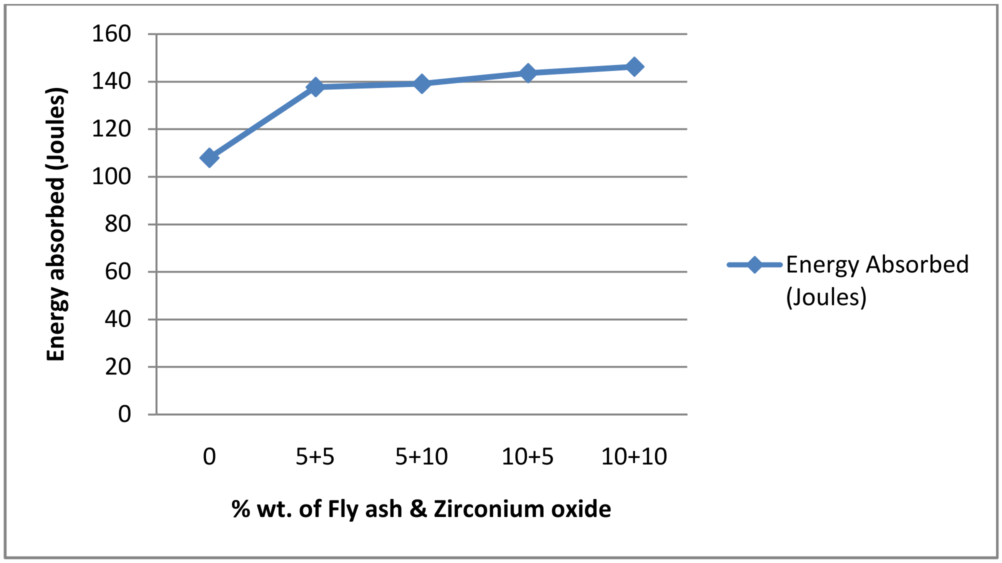


Figure 5.20: Variation in Energy Absorbed with variation in the vol. fraction of Fly-ash & Zirconium oxide

With the increase in the amount of both Fly-ash and Zirconium oxide from 0 to 5 % vol. the Energy absorbed increases significantly after that it increases slightly with further increase in the amount of both Fly ash and Zirconium oxide. The increase noticed is 29.72 Joules with increase in the amount of both Fly-ash and Zirconium oxide from 0 to 5 % vol. And the increase noticed is 8.54 Joules with the increase in the amount of both Fly-ash and Zirconium oxide from 5 to 10 %.

5.6. SLIDING WEAR TEST

The wear test results are as follows:

A) Weight Loss when the machine is running for 5 min. at 400 rpm with varying applied loads (i.e. 2, 3 and 4 Kgs).

Table 5.7: Weight Loss (gms) For Time = 5 min and RPM = 400

Samples	Applied Load = 2 Kg	Applied Load = 3 Kg	Applied Load = 4 Kg
S1	0.03	0.04	0.05
SF1	0.015	0.02	0.03
SF2	0.01	0.015	0.02
SZ1	0.01	0.018	0.027
SFZ5	0.008	0.01	0.015
SZF	0.003	0.015	0.02
SZ2	0.005	0.01	0.018
SFZ	0.002	0.01	0.02
SFZ10	0	0.005	0.01

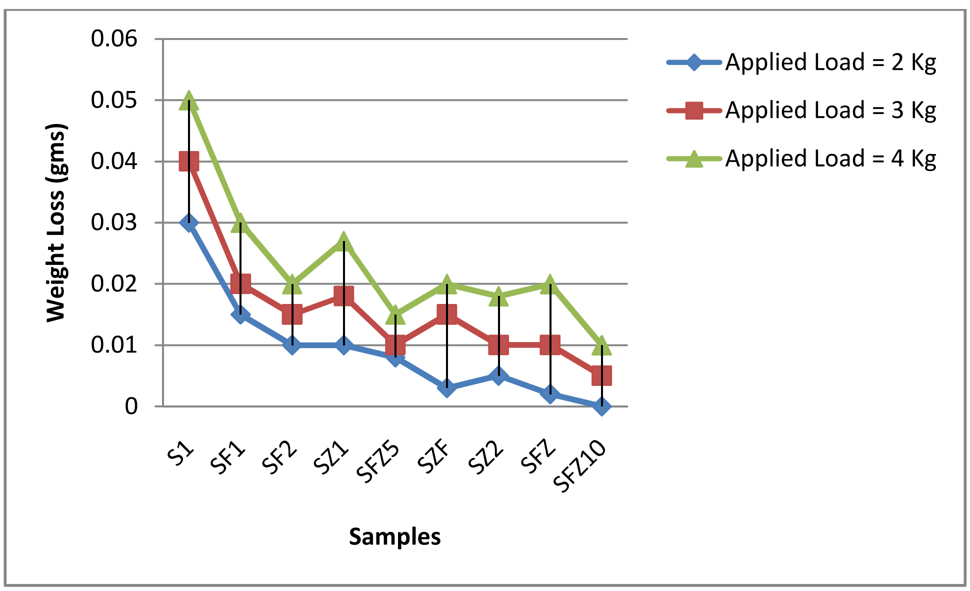


Figure 5.21: Weight Loss (gms) For Time = 5 min and RPM = 400

With the increase in % vol. of reinforcement the weight loss due to wear and friction of the MMCs decreases. The weight loss noticed in Al-6061 is 0.03, 0.04 and 0.05 gms at an applied load of 2, 3 and 4 Kgs respectively. Whereas the weight loss is 0, 0.005 and 0.01

gms respectively for 2, 3 and 4 Kgs of applied load with the increase in 10 % vol. of both Fly-ash and Zirconium oxide.

B) **Weight Loss when the machine is running for 10 min. at 400 rpm with varying applied loads (i.e. 2, 3 and 4 Kgs)**

Table 5.8: Weight Loss (gms) For Time = 10 min and RPM = 400

Samples	Applied Load = 2 Kg	Applied Load = 3 Kg	Applied Load = 4 Kg
S1	0.05	0.15	0.2
SF1	0.035	0.045	0.05
SF2	0.03	0.04	0.024
SZ1	0.03	0.04	0.06
SFZ5	0.03	0.035	0.04
SZF	0.02	0.03	0.037
SZ2	0.027	0.035	0.04
SFZ	0.018	0.02	0.03
SFZ10	0.01	0.015	0.02

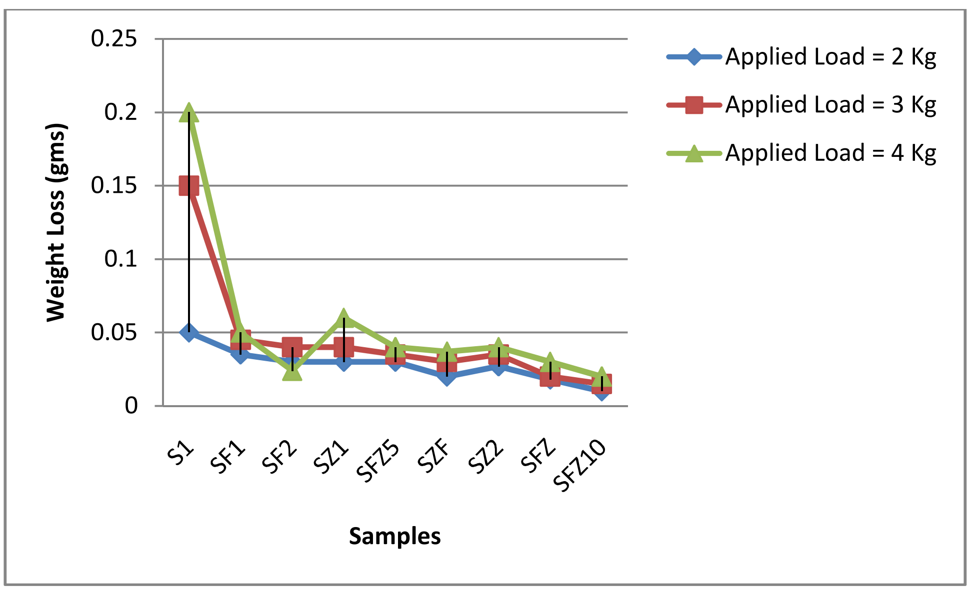


Figure 5.22: Weight Loss (gms) For Time = 10 min and RPM = 400

With the increase in the % vol. of reinforcement the weight loss due to wear and friction of the MMCs decreases. The weight loss noticed for Al-6061 is 0.05, 0.15 and 0.2 gms for an applied load of 2, 3 and 4 Kgs. With the increase in 10 % vol. of both the reinforcement the weight loss decreases and the weight loss is 0.01, 0.015 and 0.02 gms at an applied load of 2, 3 and 4 Kgs respectively.

C) **Weight Loss when the machine is running for 15 min. at 400 rpm with varying applied loads (i.e. 2, 3 and 4 Kgs)**

Table 5.9: Weight Loss (gms) For Time = 15 min and RPM = 400

Samples Name	Applied Load = 2 Kg	Applied Load = 3 Kg	Applied Load = 4 Kg
S1	0.1	0.2	0.27
SF1	0.07	0.1	0.15
SF2	0.05	0.08	0.12
SZ1	0.04	0.08	0.1
SFZ5	0.02	0.065	0.095
SZF	0.04	0.06	0.09
SZ2	0.035	0.06	0.085
SFZ	0.03	0.05	0.083
SFZ10	0.02	0.04	0.07

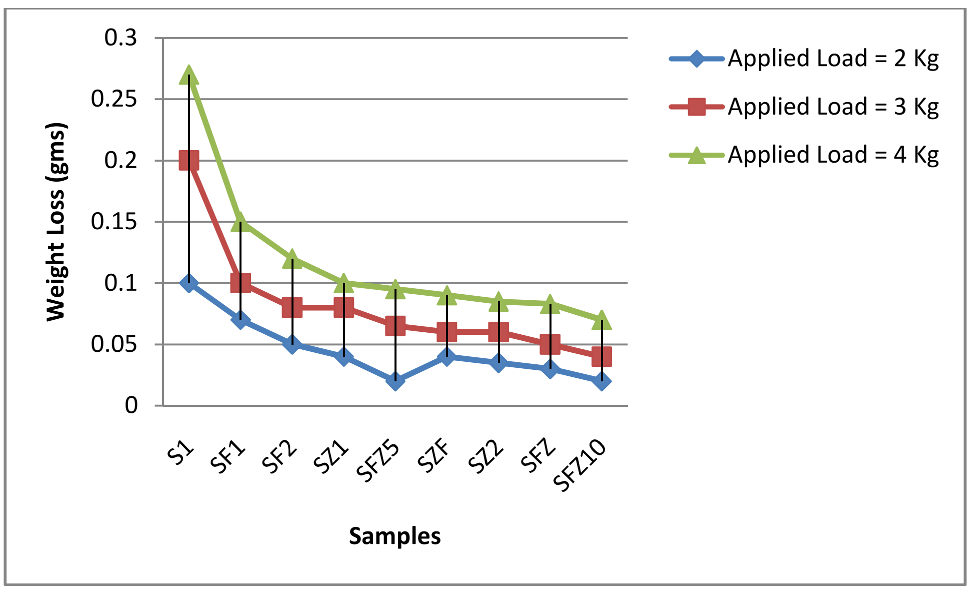


Figure 5.23: Weight Loss (gms) For Time = 15 min and RPM = 400

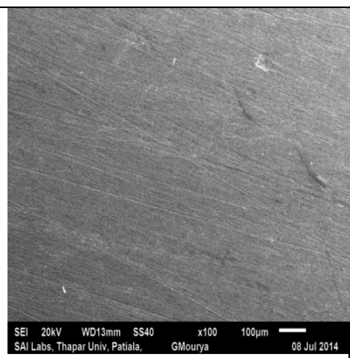
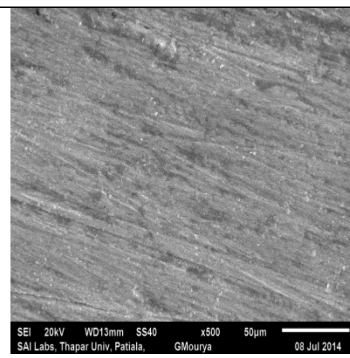
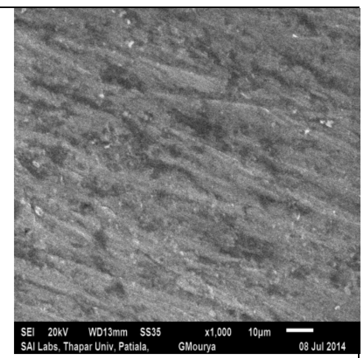
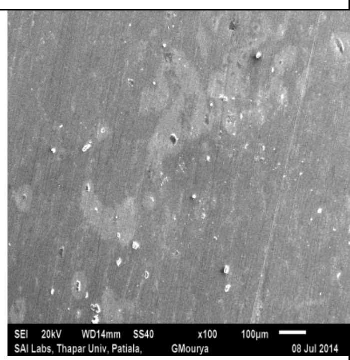
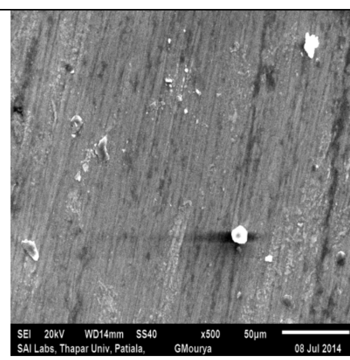
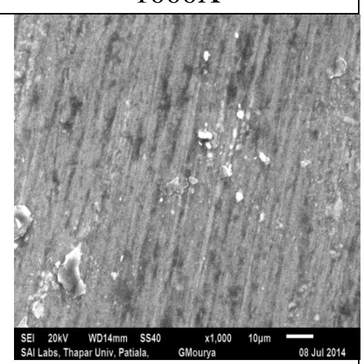
With the increase in the % vol. of reinforcement the weight loss due to wear and friction of the MMCs decreases. The weight loss noticed for Al-6061 is 0.1, 0.2 and 0.27 gms for an applied load of 2, 3 and 4 Kgs. With the increase in 10 % vol. of both Fly-ash and

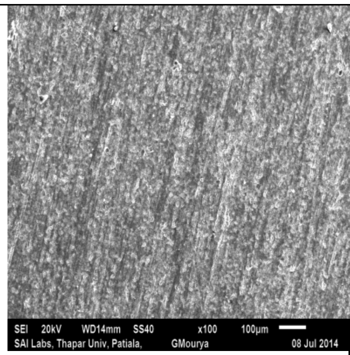
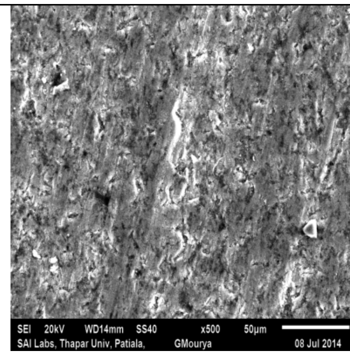
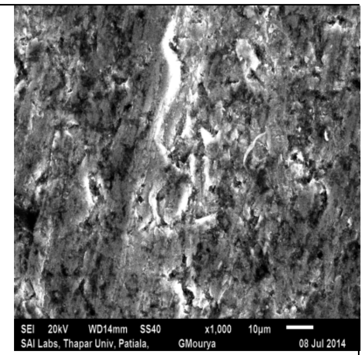
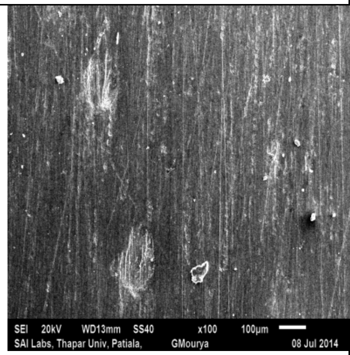
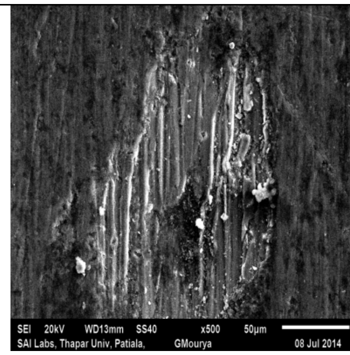
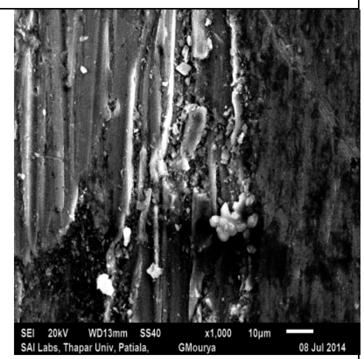
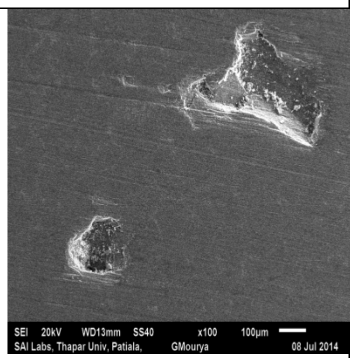
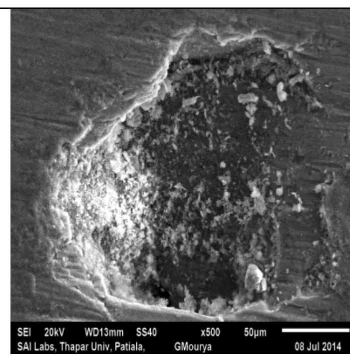
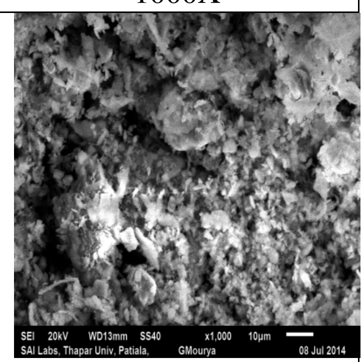
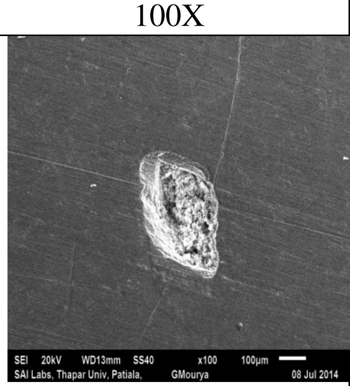
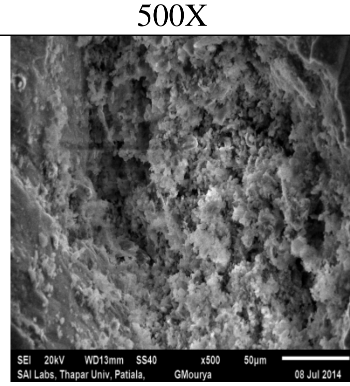
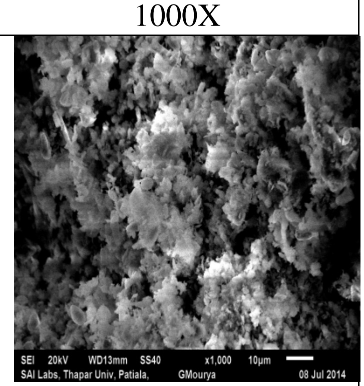
Zirconium oxide the weight loss decreases and the weight loss is 0.02, 0.04 and 0.07 gms at an applied load of 2, 3 and 4 Kgs respectively.

The increase in wear resistance is due to the incorporation of hard Fly-ash and zirconium oxide particles in the Al-6061 alloy because it restricts the indentation and ploughing action which are the main reason for material loss in Aluminium MMC. [7]

5.7. SCANNING ELECTRON MICROSCOPE

The results of SEM are shown below:

S1 Composition: Al-6061.	 100X	 500X	 1000X
SF1 Composition: Al-6061 with 5 % wt. of Fly-ash.	 100X	 500X	 1000X

SF2 Composition: Al-6061 with 10 % wt. of Fly-ash.	 100X	 500X	 1000X
SZ1 Composition: Al-6061 with 5 % wt. of Zirconium oxide.	 100X	 500X	 1000X
SFZ5 Composition: Al-6061 with 5 % wt. of Fly-ash & 5 % wt. of Zirconium oxide.	 100X	 500X	 1000X
SZF Composition: Al-6061 with 5 % wt. of Fly-ash & 10 % wt. of Zirconium oxide.	 100X	 500X	 1000X

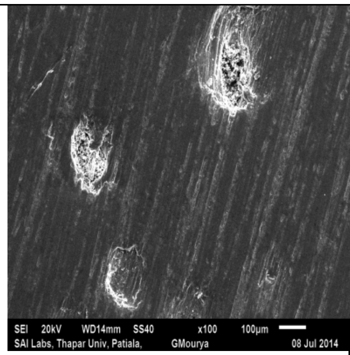
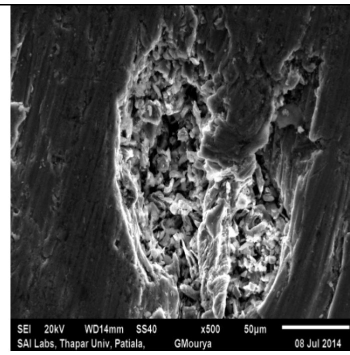
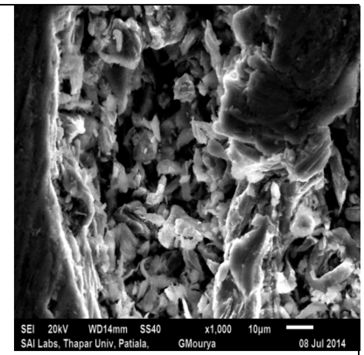
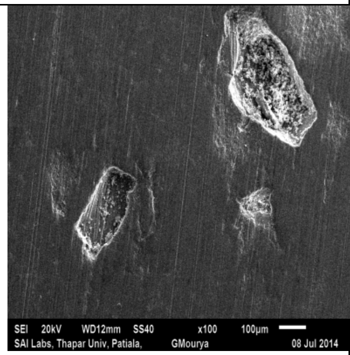
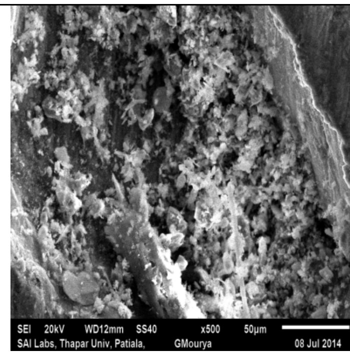
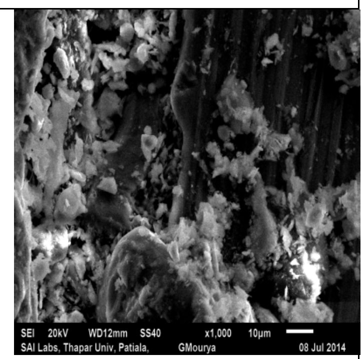
SZ2 Composition: Al-6061 with 10 % wt. of Zirconium oxide.	 100X	 500X	 1000X
SFZ Composition: Al-6061 with 5 % wt. of Fly-ash & 10 % wt. of Zirconium oxide.	 100X	 500X	 1000X

Figure 5.24: SEM micrographs of the MMCs

Figure 5.24 represents the SEM micrographs of cast Al-6061 and Al-6061/Fly-ash/Zirconium oxide composites. From the figures it is observed that, the distribution of reinforcement particles Fly-ash and Zirconium oxide in the Al-6061 matrix is nearly uniform. The micrographs also reveal the increased in the % wt. of reinforcement particles. Cracks and Blow holes are also seen in the microstructure of some MMCs.

CHAPTER 6
CONCLUSIONS

6.1. CONCLUSIONS

The conclusions drawn from the present investigation are as follows:

1) The Al-6061/Fly-ash/Zirconium oxide MMCs have been successfully fabricated by stir casting method.
2) The Yield strength and ultimate tensile strength increases with the addition of reinforcement particles whereas, ductility of the MMCs decreases with the increase in reinforcement particles.
3) Both macro-hardness and micro-hardness of the MMCs increases with the increase in the % wt. of reinforcement particles.
4) The impact toughness of the MMCs increases with the increase in the amount of reinforcement.
5) The weight loss of the MMCs during wear test also decreases with the increase in the volume fraction of reinforcement particles.
6) The SEM micrograph shows that the reinforcement particles are uniformly distributed in the Al-6061matrix.

The results confirmed that the Al-6061/Fly-ash/ZrO_2 reinforced composite is superior to the base alloy Al-6061 in comparison of tensile strength, Hardness, impact strength and wear resistance.

6.2. SCOPE OF FUTURE WORK

1) This work can be further extended by varying the volume fraction of the reinforcement added and stirring speed.
2) By using different method of production of MMCs like powder processing, squeeze casting etc.
3) Heat treatment process can be done to improve the properties of the MMCs.

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