

**TO STUDY THE EFFECT OF GRAPHITE  
AND ZIRCONIUM OXIDE ON AL-6061  
METAL MATRIX COMPOSITES (MMCs)  
PROCESSED BY STIR CASTING  
TECHNIQUE**

*A Dissertation Submitted*  
In Partial Fulfillment of the Requirements  
for the Degree of

**Master of Engineering**  
in  
**Production Engineering**

by  
**Manish Moonglia**  
**(Roll No. 801282011)**



*to the*

**MECHANICAL ENGINEERING DEPARTMENT  
THAPAR UNIVERSITY, PATIALA**

July, 2014


# CERTIFICATE

I hereby declare that the Dissertation entitled "**TO STUDY THE EFFECT OF GRAPHITE AND ZIRCONIUM OXIDE ON AL-6061 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.


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
  
Manish Moonglia

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

  
\_\_\_\_\_  
**Mr. Kishore Khanna**  
Mechanical Engineering Department  
Thapar University, Patiala - 147004

Countersigned by

  
\_\_\_\_\_  
**Dr. Ajay Batish**  
Professor & Head  
Mechanical Engineering Department  
Thapar University, Patiala - 147004

  
\_\_\_\_\_  
**Dr. S. K. Mohapatra**  
Dean of Academic Affairs  
Thapar University, Patiala - 147004

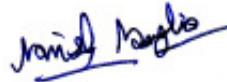
*Dedicated to*  
*My Parents*

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MANISH MOONGLIA

ROLL NO. 801282011

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# Abstract

This work investigates the properties of Aluminium Metal Matrix Composites (Al. MMC) reinforced with Zirconium Oxide and Graphite. The composite material has been prepared by Stir casting technique. Zirconium Oxide and Graphite both have been mixed in different proportions in the Aluminium Matrix. Various tests like: Tensile test, Rockwell hardness test, Impact test and Wear and friction test have been performed to check the properties of Al. Metal Matrix. Samples were prepared and tested as per ASTM standards. Both reinforcement constituents were added in different combinations, so as to investigate the effect of each of these two and their individual effects. SEM was later performed to check the distribution of the  $ZrO_2$  and Graphite in Al. Metal matrix composites.

Keywords: Zirconium oxide, Graphite, Aluminium, Metal matrix composites, Stir casting.

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# Abbreviations

**MMC:** Metal Matrix Composites

**Al:** Aluminium

**ZrO<sub>2</sub>:** Zirconium Oxide

**Gr:** Graphite

**SEM:** scanning electron microscope

**HRB :** Hardness Rockwell on B scale

**mm** micrometer

**min:** minute

**rpm:** rotation per minute

**mm:** millimeter

**kgf:** kilogram force

**UTM:** universal testing machine

**MPa:** Mega Pascal's

**m/s:** meter per second

**N:** Newton

**Avg. :** Average

# Chapter 1

## INTRODUCTION

---

### 1.1 Composite materials

Composite materials will be materials which are produced using two or more constituent materials with altogether different chemical or physical properties, that when joined together, produce a material with characteristics different from the individual parts. The individual components stay separate and different inside the completed structure. The composites generally used in structural applications are best classified as high performance. They are typically made from synthetic materials, have high strength-to-weight ratios, and require controlled manufacturing environments for optimum performance. [23]

Typical engineered composite materials include:

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

### 1.2 Characteristics of a Composite Material:

The constituents of a composite are generally arranged so that one or more discontinuous phases are embedded in a continuous phase. The discontinuous phase is termed the *reinforcement* and the continuous phase is the *matrix*. In general the reinforcement is much stiffer and stronger than the matrix. But both constituents are required and each must accomplish specific tasks. A material is generally stronger and stiffer in fiber form than in bulk form. The strength of the fiber is greater than that of the bulk material. Without a binder material to separate them, they can become hard, twisted, and knotted to separate. The binder (matrix) material must be surrounding and continuous each fiber so that they are kept distinctly separate from adjacent fibers and the entire material system is easier to work and handle. The mechanical and physical properties of composites are dependent on the concentration, geometry, and properties of the constituents. Increasing the volume content of reinforcements can

increase the stiffness and strength of a composite to a point. If the volume content of reinforcements is too high there will not be enough matrixes to keep them separate. Similarly, the geometry of individual reinforcements and their arrangement within the matrix can affect the performance of a composite. [23]

1.2.1 **Reinforcements:** -Reinforcements are used to make the composite structure or component stronger. The most commonly used reinforcements are Kevlar, boron, graphite (often referred to as simply carbon), and glass. There are some other types of reinforcements such as titanium, alumina, aluminum, silicon nitride, and silicon carbide

1.2.2 **Fibers:** -Fibers are a special case of reinforcements. They are generally continuous and have diameters ranging from 120 to 7400 pin (3-200  $\mu\text{m}$ ). Fibers are typically linear elastic or elastic-perfectly plastic and are generally stiffer and stronger than the same material in bulk form. The most commonly used fibers are carbon, glass, boron, and Kevlar.

1.2.3 **Matrix:** -The matrix is the binder material that protects, separates, and supports the fibers. It provides a path by which load are both transferred to the redistributed and fibers among the fibers in the event of fiber breakage. The matrix typically has a lower strength, stiffness, and density than the fibers. Matrix can be ductile, brittle, elastic, or plastic. They can have either nonlinear or linear stress-strain behavior. The most commonly used matrices are polymeric, ceramic, metal, glass and carbon.

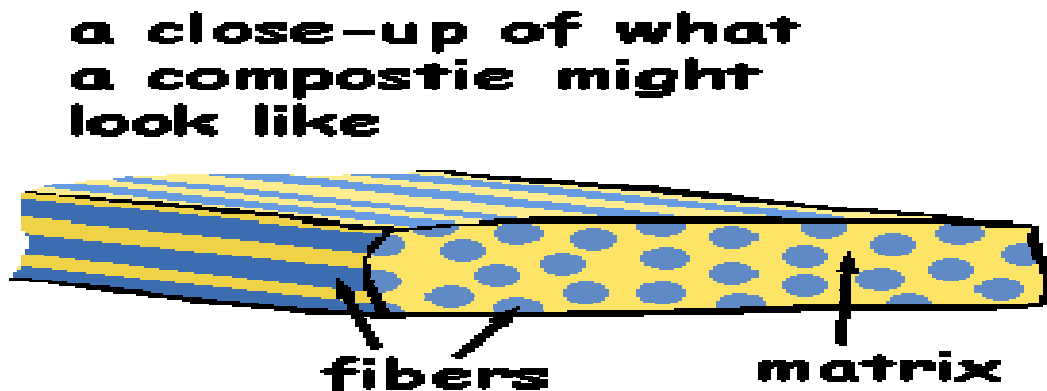


Figure 1.1: Composite material [32]

Each has special appeal and usefulness, as well as limitations.

1. **Carbon Matrix:** -

- a) Has a high heat capacity per unit weight.
- b) Used as rocket nozzles, ablative shields for reentry vehicles, and clutch and brake pads for aircraft.

2. **Ceramic Matrix:** -

- a) Usually brittle.
- b) Carbon, ceramic, metal, and glass fibers are typically used with ceramic matrix in areas where extreme environments (high temperatures, etc.) are anticipated.

3. **Glass Matrix:** -

- a) Usually have an elastic modulus much lower than that of the reinforcement.
- b) Carbon and metal oxide fibers are the most common reinforcements with glass matrix composites.
- c) The best characteristic of glass or ceramic matrix composites is their strength at high service temperatures.
- d) The primary applications of glass matrix composites are for heat-resistant parts in engines, exhaust systems, and electrical components.

4. **Metal Matrix:** -

- a) Especially good for high-temperature use in oxidizing environments.
- b) Most commonly used metals are iron, nickel, tungsten, titanium, magnesium, and aluminum.

5. **Polymer Matrix:** -

- a) Most common and least expensive.
- b) Polymers are easy to process.
- c) Offer good mechanical properties.
- d) Generally wet reinforcements well, and provide good adhesion.
- e) They are a low-density material because of low processing temperatures; many organic reinforcements can be used.

### **1.3 Metal matrix composite**

A **metal matrix composite (MMC)** is composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a **hybrid composite**. [24]

### **1.4 Composition**

MMCs are made by a reinforcing material dispersed into a metal matrix. To prevent from the chemical reaction the reinforcement surface can be coated with the matrix. For example, carbon fibers are commonly used in aluminum matrix to synthesize composites showing high strength and low density.

### **1.5 Types of Metal-Matrix Composites**

The Characteristics of the reinforcement are described below:

- Continuous fiber- or layered MMCs
- Particle reinforced MMCs
- Short fiber- or whisker-reinforced MMCs

### **1.6 Aluminium 6061**

Aluminium alloy 6061 is one of the most extensively used of the 6000 series aluminium alloys. Typical properties of aluminium alloy 6061 include: [26]

- Medium to high strength
- Good toughness
- Good surface finish
- Excellent corrosion resistance to atmospheric conditions
- Good weldability
- Widely available

The density of the Al-6061 is  $2.7 \text{ g/cm}^3$  and the melting point is  $727^\circ\text{C}$  [27]

Applications for aluminium alloy 6061 are as follows:

1. Aircraft and Aerospace components
2. Marine fittings
3. Transport
4. Bicycle frames
5. Drive shafts
6. Brake components
7. Valves

## 1.7 Zirconium Oxide

**Zirconium dioxide** ( $ZrO_2$ ), sometimes known as zirconia is a white crystalline oxide of zirconium. The fundamental properties of zirconium oxide are as follows [28]:

1. High strength
2. High fracture toughness
3. High hardness
4. Wear resistance
5. Good frictional behavior
6. Low thermal conductivity



Figure 1.2: Zirconium Oxide

## 1.8 Graphite

Graphite is used widely as an engineering material over a variety of applications. Applications include thrust bearings, piston rings, vanes and journal bearings. It is very unique in that it has both of properties of a non-metal and metal. It is flexible but not elastic, has a high electrical and thermal conductivity. [29]

Other Applications of graphite are as follows:

1. Pencil production
2. Batteries
3. Lubricants
4. Grinding wheels



Figure1.3: Graphite

## 1.9 Processing

Metal-matrix composites can be processed by various techniques. Some of these very important techniques are described as below.

### 1.9.1 Liquid-State Processes

#### Stir Casting process

The process of Stir casting was performed for making the MMC samples. Stir Casting is a fluid state system for composite materials creation in which ceramic particles or short filaments are blended with a molten matrix metal by means of mechanical stirring. The fluid composite material is then casted by conventional casting strategies.

Stir Casting is described by the following features:

- Content of dispersed stage is limited (usually not more than 30 vol. %).
- The technique is simple and cost-effective.



Figure 1.4: Stir casting apparatus

**Casting or liquid infiltration** it involves infiltration of a particulate reinforcement preformed by a liquid metal. Liquid infiltration of MMCs is not so easy due to difficulties in wetting the ceramic reinforcement by the molten metal. When infiltration of fibre perform takes place, a reaction between the molten metal and fibre occurs which degrades the properties of the fibre. Fibre coatings have been produces which improves wetting and controls interfacial reactions when applied prior to infiltration. But when fibre coating is exposed to air prior to infiltration, surface oxidation of fibre coating takes place which is a limitation for this case. To overcome this limitation, a process called 'Duralcan' process can be used. In this process, ingot-grade Al. and ceramic particles are mixed and melted. It is stirred above  $600-700^{\circ}$  (Liquidus Temperature). The solidified ingot undergoes secondary process: Rolling or Extrusion.

The process involves use of 8-12  $\mu\text{m}$  particles to make particulates for liquid metal casting. For small particles (2-3  $\mu\text{m}$ ), there is a large interface region which results in a viscous melt. In foundry grade MMCs, to prevent the formation of brittle compound like  $\text{Al}_4\text{C}_3$  (formed due to interfacial reaction between Al. and SiC), high Si Al. alloys (A356) are used.  $\text{Al}_4\text{C}_3$  is very detrimental to mechanical properties like: Toughness and Corrosion Resistance. [25]

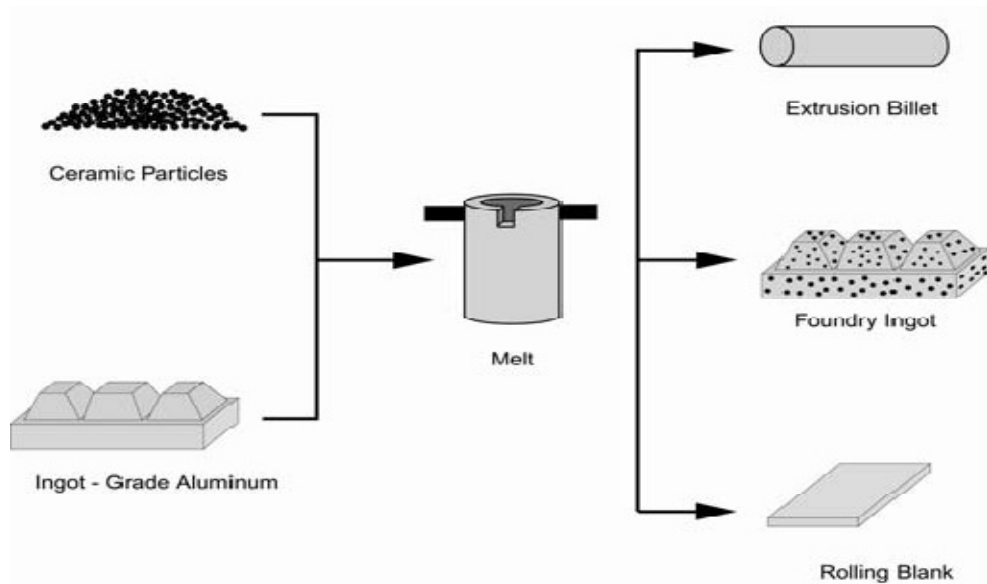


Figure 1.5: Casting process for particulate or short fiber MMCs [25]

**Pressure infiltration** It involves forcing of liquid metal into a fibrous or particulate pre-form. Pressure is applied until solidification is complete. This method obviates the need of good wettability of the reinforcement by forcing the molten metal through small pores of fibrous pre-form. There is a minimal reaction between the reinforcement and molten metal because of short processing time involved. Free-form common casting defects such as: Porosity and Shrinkage Cavities are absent. Another variant of liquid metal infiltration technique is by performing infiltration of a fibrous pre-form by using pressurized inert gas. Complex shaped structures can be achieved when the process is usually conducted in controlled environment (Pressure Vessel) and with high fibre volume fractions.

Pressure casting technique has been used to prepare Alumina fibre-reinforced inter-metallic matrix composites (TiAl, Ni<sub>3</sub>Al, and Fe<sub>3</sub>Al). This can be done by melting the matrix alloys in a crucible in vacuum, where the fibrous preform is heated separately. The molten matrix material (at  $\approx 100^\circ$  above  $T_m$ ) is poured onto the fibres with the introduction of argon gas at the same time. Argon gas pressure forces the melt to infiltrate the preform.

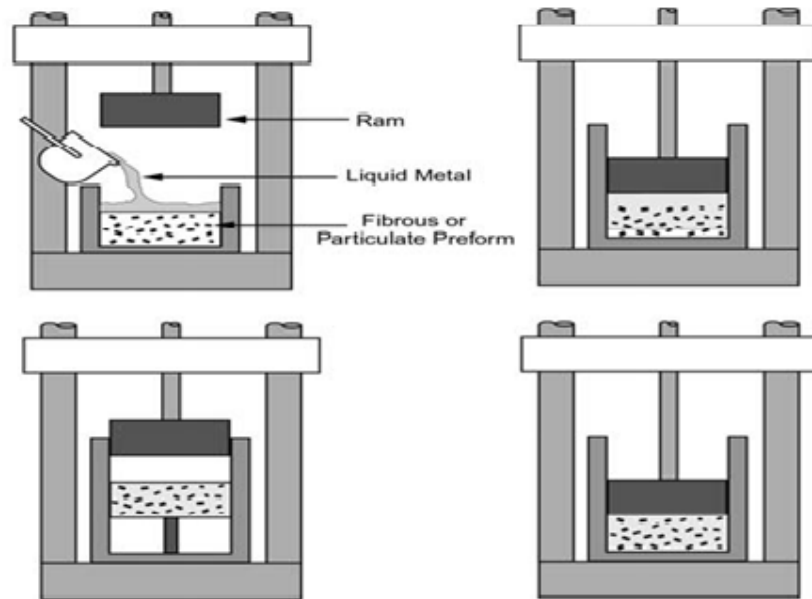


Figure 1.6: Pressure infiltration process [25]

### 1.9.2 Solid-State Processes

**Diffusion bonding** is a solid-state processing technique to join together similar or dissimilar metals. Inter diffusion of atoms between the clean metallic surfaces which are in contact (at an elevated temperature) leads to bonding. Advantage with this technique is that a wide variety of Metal Matrix can be processed and large fibre orientations and volume fractions can be controlled. Among the disadvantages are high processing temperature and pressure, long processing time, and limitation on complexity of shapes that can be produced.

There are various variants of the basic diffusion bonding process. All of these involve simultaneous application of pressure and high temperature. Matrix alloy foil and Composite wire fibre arrays or mono layer laminae are

stacked into a pre determined order. Vacuum hot pressing is very important step for the diffusion bonding processes in MMCs. Hot iso-static pressing (HIP) instead of uni-axial pressing can be used. In hot iso-static pressing (HIP), gas pressure against a can consolidates the composite present inside the can. With HIP, it is comparatively easy to apply high pressure at elevated temperatures with variable shapes. [25]

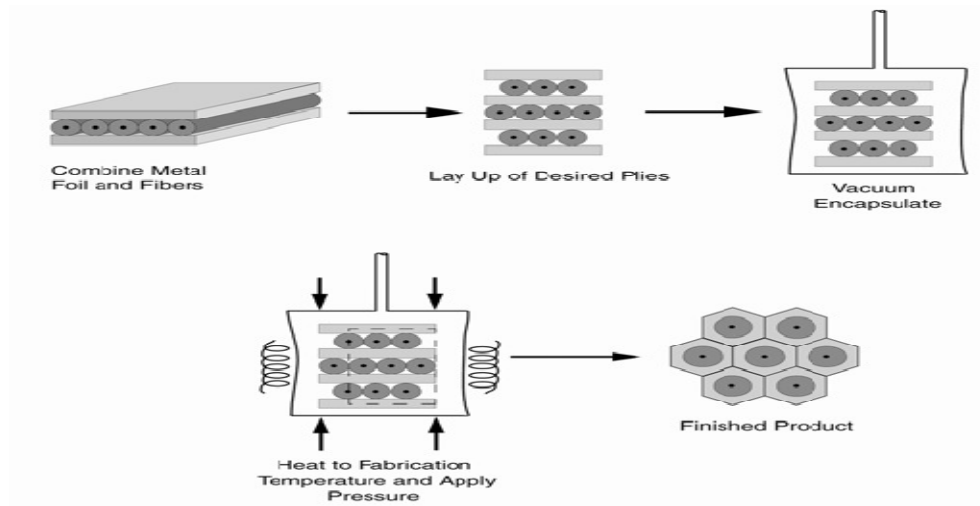


Figure 1.7: Diffusion bonding process: (a) apply metal foil and slice to shape, (b) layup desired utilizes, (c) vacuum epitomize and hotness to manufacture temperature, (d) apply weight and hold for combination cycle, and (e) cool, remove, and clean part. [25]

**Deformation process** is used to deform or densify the composites in MMCs mechanical processes like: swaging, extrusion, drawing or rolling, of a ductile 2-phase material causing the 2 phases to co-deform. One of the phases elongate and become fibrous in nature within the other phase. These materials are sometimes referred as ‘in-situ’ composites. The properties of these composites are dependent on the characteristics of the starting material. Usually a billet of a 2-phase alloy prepared by casting or powder metallurgy method is used. Roll bonding is a common technique used to produce laminated composites which consists of different metals is layer form. These composites are called sheet laminated MMCs. Roll bonding and hot pressing can also be used to make laminates of Al. sheets and discontinuously

reinforced MMCs. Below figure (Figure 1.8), shows roll bonding process for making laminated MMCs. [25]

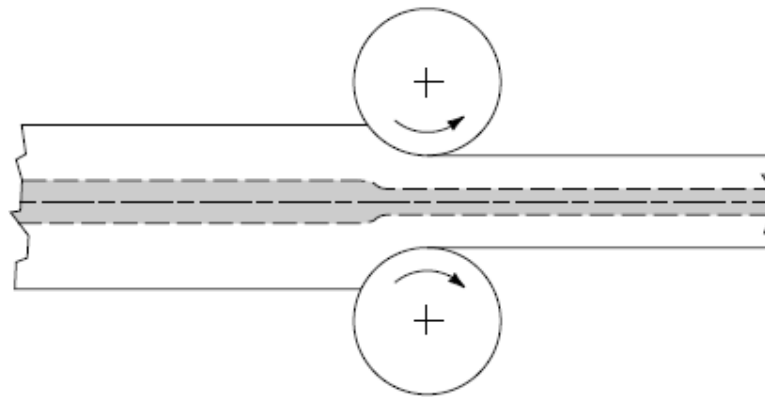


Figure 1.8: Roll bonding process of making a laminated MMC; a metallurgical bond is produced. [25]

**Powder processing** is used to manufacture particulates or short fibre reinforced composites in conjunction with distortion processing. This normally includes cold pressing, sintering, or hot pressing to manufacture whiskers or particles of reinforced MMCs. Reinforcement powders and matrix are mixed to produce a homogenous dispersion. The mixing stage is followed by cold pressing process to create a green body, which is 80% thick and easy to handle. The cold pressed green body is canned in a fixed container and then degassed to remove any moisture from the surface of molecules. The material is hot pressed uni-axially or iso-statically. A thick composite is then extruded. Dynamic crystallization occurs at the molecule matrix interface throughout the hot extrusion. This yields randomly situated grains close to the interface, and relatively textured grains a long way from the interface. [25]

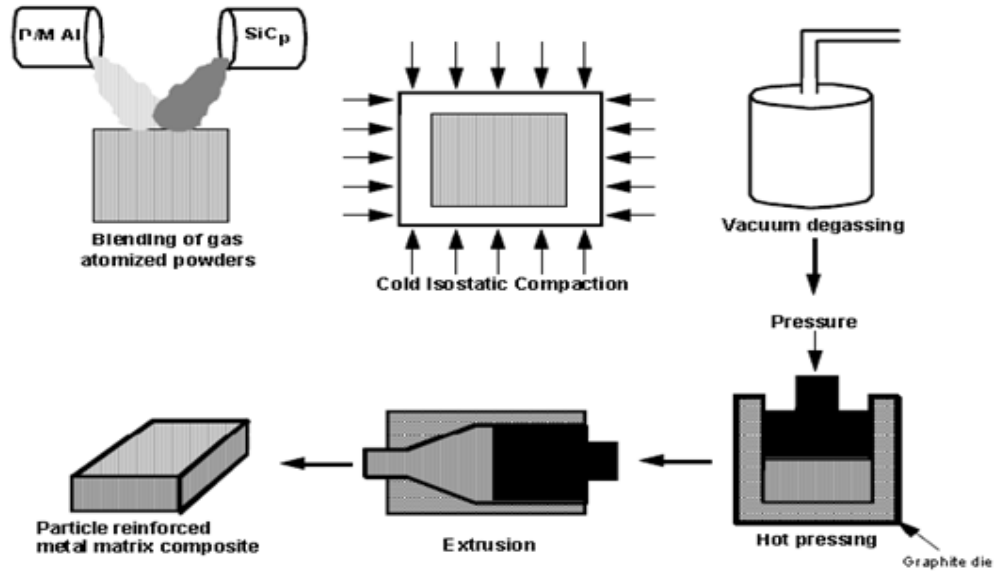


Figure 1.9: Powder processing, hot pressing, and extrusion process for fabricating particulate or short fiber reinforced MMCs. [25]

**Sinter-forging** is a novel and minimum cost deformity preparing technique. In sintering manufacturing process, a powder mixture of matrix and reinforced is cold compacted, sintered, and then manufactured to almost full density. The main advantage with this technique is that forging can be conducted to produce a nearly net shaped material. Material waste is also minimal. These sinter-forged composites have tensile and fatigue properties which are similar to those materials which are created by extrusion.

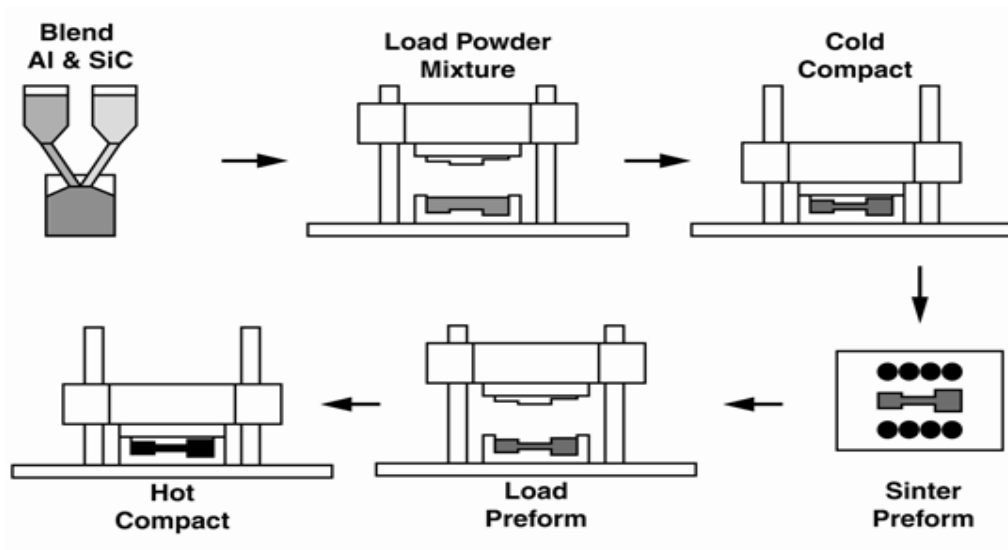


Figure 1.10: Sinter-forging technique for producing near-net shape, low cost MMCs [25]

# Chapter 2

## LITERATURE REVIEW

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**Das et al. (2006)** investigated the effect of zircon sand particles with different size and amount incorporated in Al-4.5 wt% Cu alloy by using stir casting process. Coarser particles of size between 90 -135  $\mu\text{m}$  were dispersed in substantial amounts (up to 30 wt %), where as finer particles of size 15-65  $\mu\text{m}$  had limited dispersion, 10 and 20 wt%, respectively. The matrix of the composites had cellular structure; whereas the size of the cell was dependent on zircon particle size and its amount in the composite. Wear test of cast alloy and composites were subjected to abrasive wear under dry conditions at a load of 15 N. The abrasive wear resistance of the composite improved with the increase in amount or decrease in size of zircon particles.

**Gao et al. (2007)** investigated the effect of Zr on the microstructure and properties of chopped carbon fiber/carbon composites. Zr improved the interface bonding and promotes the graphitization and perfect degree of crystallite size of the composites. Thermal conductivity at room temperature was measured by the thermal gradient method and bending strength was tested by three-point bending method. Zr improved the thermal and mechanical properties of the composites effectively. A high thermal conductivity of 464 W/ m K and excellent bending strength of 83.6 MPa for the composites with a Zr concentrating of 13.9 wt% was obtained when HTT was 2500 °C. Whereas at HTT 3000 °C, thermal and mechanical properties of the composites decreased dramatically.

**Shishkovsky et al. (2007)** investigated the Alumina–zirconium ceramics synthesized by specific laser sintering/melting. The porous refractory ceramics synthesized by specific laser sintering/melting from a mixture of zirconium dioxide, aluminum and/or alumina powders were subjected to optical metallography and X-ray investigation to study their microstructure and phase composition depending on the laser processing parameters. It was demonstrated that fast laser sintering in air yields ceramics with thick structure and a uniform distribution of the balancing out stages. They used ceramic–matrix composites which may be utilized as

thermal and electrical protectors and wear resistant covering in solid oxide energy units, pots, heating components, medical instruments. By applying finely scattered  $Y_2O_3$  powder inclusions, the type of the ceramic structure altogether changed. The surface macro- and microstructure examined by optical metallography was relatively dense, smooth and uniform, but contained pores and cracks. The optimal processing parameters were successfully determined for monolayer and layer-by-layer laser sintering within a narrow process parameter window (laser power, scan velocity, beam diameter and hatch distance) in order to minimize shrinkage and eliminate cracking and delaminating.

**Robinson *et al.* (2009)** investigated the influence of hot deformation and alloy composition on the exfoliation corrosion, tear toughness and tensile properties susceptibility of Al-2025 with the addition of zirconium. The addition of 0.12% Zr to Al-2025 in ingot, extrusion, forging and fully heat-treated microstructures that do not differ significantly to a standard 2025 alloy composition.

At the lower temperature, recovery resulted in a fine equiaxed substructure while at 440 °C partial recrystallisation occurred. However these micro-structural changes only had a small effect on subsequent processing and mechanical properties; the lower extrusion temperature did appear to promote higher tensile properties in samples forged at 400 and 440 °C.

The forging temperature had 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. Forging at 400 °C and 440 °C however resulted in partial recrystallisation after heat treatment and a mixture of fine sub grains mixed with very large elongated recrystallised grains. Partially recrystallised samples performed well due to the lack of exposed end grain and the relatively small volume fraction of sub grain containing material compared to similarly process full scale propellers.

Hydraulic pressing of propellers at low temperatures (250–300 °C) offered the best opportunity of producing optimized exfoliation and tensile properties. However this method imposed technological difficulties as the material had a high flow stress and this can result in loss of dimensional control.

**Ebrahimi *et al.* (2010)** studied the tensile properties, hardness and microstructure of a new super high strength aluminum alloy with Zr addition. The results showed that Zr addition decreases average grain size. The addition of Zr to Al–12.24, Zn–3.25, and Mg–2.46, Cu

alloy decreased the average grain size, causing uniform dispersion of constituent as well as limiting the area fraction of recrystallized regions owing to the formation of the  $\text{Al}_3\text{Zr}$  particles.

After heat treatment, the extruded refined specimens showed significant improvement of Ultimate Tensile Strength, Yielding Strength and particularly elongation values when compared with the solely heat treated unrefined ones.

**Ramirez *et al.* (2010)** found that the wear resistance of Al with the addition of zirconia increases. The composites were created by compacting aluminum powder (Almex) 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; also, the quantity of zirconia present was increased in the interior of the aluminum preforms.

Wear test was carried out on a pin-on-disc machine rotating at a speed of 360 rpm with a load of 9 N without lubrication for 2 hrs and the weight loss of the piece was measured after every 30 minutes. By measuring the weight loss, it was observed that the composite had significant improvement in wear resistance when compared to pure aluminum.

The best wear resistance was observed in the composites of Al-Zirconia. It was found that the decrease in wear was due to the fact that the ceramic material introduced into the pores acted as reinforcement. The best tribological behavior of this composite was achieved when there was a bigger presence and distribution of zirconia in per-forms. The wear coefficient of composite and pure aluminum showed that, by using this new methodology, a composite with improved wear resistance can be obtained.

**Abdizadeh *et al.* (2011)** investigated the improvement in physical and mechanical properties of Al/Zircon composites fabricated by powder metallurgy method. Micro-structures of these composites in powder metallurgy conditions showed different size distribution of zircon when present in different proportions in the composite. The green specimens prepared by isostatic pressing of prepared powders with different zircon percentages, were sintered at two temperatures 600° and 650 °C. These samples were then examined by distinctive physical and mechanical testing strategies to see, which conditions acquired the best properties. The most enhanced pressure quality was achieved with the example including 5% of zircon sintered at 650° C. With increase in zircon content of composites, the hardness of specimens increased to a maximum value of 75 BHN. While further increase in temperature follows the same trend. Also, higher temperatures increased sintering density and relative density up to 92%. Adding

more zircon content increased sintering density to 92% but relative density decreased to 86%. Moreover, sintering temperature improved mechanical properties like: Yield stress and Elongation and Compressive strength. In this experiment 650 °C as the sintering temperature showed better results than 600 °C.

**Ceren (2013)** investigated the improvement of mechanical properties of hot pressed SiCp and B<sub>4</sub>Cp/Alumix 123 composites alloyed with minor Zr. In this study, effect of Zr addition on the microstructure and wear behavior of aluminum alloy composites (AMCs) reinforced with B<sub>4</sub>Cp and SiCp particles fabricated with hot pressing were investigated. The samples for the study composed of unreinforced aluminum alloy (Alumix 123) and the composites reinforced with 10% of B<sub>4</sub>Cp and SiCp were prepared by hot isostatic pressing (HIP) method. Similarly, all the samples alloyed with 0.2% Zr were also produced in order to make a comparison. The produced samples were evaluated for micro-structural properties and mechanical tests like hardness, tensile and bending strength. Wear tests were carried out at 5 mm/s sliding speed under 3 N loads for all kinds of hot pressed samples. The hot pressed composite micro-structures had a more uniform distribution of the reinforcements. The addition of Zr increased the yield and tensile strength of the samples. The highest tensile strength was achieved for the hot pressed composite containing 10% B<sub>4</sub>C and 0.2% Zr.

**Akinci et al. (2014)** investigated the friction and wear behavior of zirconium oxide reinforced with PMMA Composites. Wear tests were performed at room temperature under loads 5N, 10N and 20N at Sliding speed of 0.5 m/s, 1.0 m/s and 1.5 m/s respectively. The coefficient of rubbing for the composites was fundamentally affected with the presence of ZrO<sub>2</sub> content. Results for testing materials showed that the rubbing coefficient and the wear rate were sensitive to the sliding speed and applied loads. The wear rates of the PMMA composite were changing, depending upon ZrO<sub>2</sub> added percentage, applied load and sliding speed. Increase in the sliding speeds, applied loads and ZrO<sub>2</sub> filler content in the sliding tests results in the increase in coefficient of friction of the pure PMMA and ZrO<sub>2</sub> filled PMMA composites. Wear rates of ZrO<sub>2</sub> filled PMMA composites decreases with increase in ZrO<sub>2</sub> substance up to 30% wt. and with increase in the sliding speeds and applied loads.

**Yang et al. (2004)** investigated the tribological qualities of A356.2Al alloy/Gr composites. The Graphite particulates were covered with an electro-less copper brought into an aluminum compound by compocasting method to make A356.2 Al/2 wt. %, 4 wt. %, 6 wt. % and 8 wt.

% graphite particulate composite. Wear debris, variations in friction coefficient, wear rate and electrical contact resistance were examined and identified with variations in graphite particulate under different sliding speed and normal loading. The largest friction coefficient occurred when particulate quantity was 2 wt. %. The wear rate of the composite with 8 wt. % graphite particulate was the largest and with 4 wt. % or 6 wt. % was the smallest, however the normal weight and the sliding speed had little impact on the wear rate.

**Basavarajappa *et al.* (2007)** investigated the impact of sliding speed on the dry sliding wear and sub-surface deformation on hybrid MMCs, Al 2219/15SiCp and Al 2219/15SiCp/3% graphite all produced by the liquid metallurgy method. Dry sliding wear tests were conducted by using pin-on-disk machine. The results showed that with increase in sliding speeds in the mild wear area, the level of subsurface deformation also increased. The addition of SiCp reinforcement to Al 2219 compound expanded the wear safety of the composites. The expansion of graphite support in Al–SiCp composites further expands the wear safety at all sliding rates.

**Basavarajappa and Chandramohan (2007)** investigated the application of Taguchi technique to study dry sliding wear conduct of MMCs. Aluminum metal matrix composites reinforced with graphite (Gr) and SiCp particles were made by fluid metallurgy course. Dry sliding wear conducted on the composites and results were compared. An arrangement of analyses based on Taguchi technique was utilized to obtain the information in a controlled manner to investigate the impact of wear parameters like: sliding speed, sliding distance and normal load on dry sliding wear of the composites. The goal was to study which design parameter significantly affects the dry sliding. The results showed that graphite particles were effective operators in increasing dry sliding wear resistance of Al/SiCp composite. SiCp composite present a contribution of sliding distance (57.57%), load (24.34%), and sliding speed (6.8%). SiCp–Gr reinforced composites present a contribution of sliding distance (57.24%), load (22.58%) and sliding speed (9.66%). The connections between the wear parameters had statistical significance however they did not have any physical significance.

**Das *et al.* (2007)** investigated the abrasive wear of zircon sand and alumina strengthened Al–4.5 wt% cu alloy matrix composites. In this examination a relative study on abrasive wear of aluminum MMC strengthened with alumina and zircon sand particles had been finished. Microstructures of the composites in as-cast condition showed uniform distribution of

particles and better holding in case of zircon particles reinforced composite compared with that in alumina particles reinforced composite. Abrasive wear resistance of both the composites enhanced with the reduction in molecule size. It was seen that the alumina reinforced composite showed moderately poor wear resistance property as compared with zircon-reinforced composite. Wear resistance properties of Al-4.5 wt% Cu alloy improved fundamentally after the increase in alumina and zircon particles. Decrease in molecule size enhanced wear resistance property for both alumina and zircon strengthened composites as little molecule reinforced composites had higher hardness and are found to be more effective in blunting SiC rubbing surface.

**Akhlaghi *et al.* (2009)** investigated the impact of graphite substance on the dry sliding and oil impregnated sliding wear conduct on Al 2024-graphite composites delivered by in situ powder metallurgy technique. The impact of graphite particles on the dry sliding and oil impregnated sliding wear aspects of sintered aluminum 2024 alloy-graphite (Al/Gr) composite materials had been evaluated utilizing a pin-on-disc wear test. The composites with 5–20 wt. % graphite particles were prepared by in-Situ powder metallurgy procedure. The hardness of the sintered materials was measured using Brinell hardness analyzer and their bending test was measured by three-point bending test. Scanning electron microscopy (SEM) was utilized to determine the wear surfaces and crack surfaces of samples. It was discovered that composite with graphite substance had low coefficient of rubbing for both dry and oil impregnated sliding, yet this impact was more pronounced in dry sliding. Hardness and break strength of composites decreased with increase in graphite content. The wear rates for both dry and oil impregnated sliding were dependent upon graphite content in the compound. In both cases, Al/Gr composites holding 5 % wt. graphite showed better wear properties over the base metal. The wear rate of the oil impregnated Al/Gr composites holding 10 wt. % or more graphite particles were higher than that of the base metal.

**Basavarajappa *et al.* (2009)** studied dry sliding wear of Graphite filled glass-epoxy composites. Polymers and their composites are rising as suitable option items to metal-based and composite based ones in number of basic and advanced designing applications. The feature that makes polymer composites so guaranteeing in mechanical applications is the likelihood of customizing their properties with extraordinary fillers. The performance of glass-epoxy composite with impact of Graphite filler were examined under applied load, sliding distance and sliding speed by utilizing a pin-on-disk assembly. Increase of Graphite in

glass–epoxy composite showed lower weight reduction, whose value dropped as the amount of Graphite increased in the composite. SEM investigation was made to recognize the phenomenon of wear as a capacity of applied load, sliding distance and sliding velocity.

**Suresha and Sridhara (2010)** investigated the impact of addition of graphite particulates on the wear resistance in aluminium–silicon carbide–graphite composites. Aluminium composites with varying reinforcements (hybrid AMCs) were discovered increased applications in light of enhanced mechanical and tribological properties and subsequently had better substitutes for single reinforced composites. Few examinations had been accounted for on the tribological conduct of these composites with % reinforcement over 10%. This study aimed to find out the impact of adding graphite (Gr) particulates as a second reinforcement on the tribological behaviour of aluminum grid composites strengthened with silicon carbide (SiC) particulates. Dry sliding wear tests were performed to study the impact of Gr particulates, sliding distance, load and sliding speed on the wear of hybrid composite examples with combined % reinforcement of 2.5%, 5%, 7.5% and 10% with equivalent weight % of SiC and Gr particulates. The wear of hybrid composites indicates that hybrid composites display better wear attributes as compared with composites strengthened with SiC alone.

**Suresha and Sridhara (2010)** investigated the wear qualities of aluminum matrix composites reinforced with graphite and silicon carbide particulates. This examination concentrated on the dry sliding wear conduct of Al matrix composites which were reinforced with Gr and SiC particulate up to 10%, and to study the impact of % reinforcement, load, sliding speed and sliding distance on stir cast Al–SiC–Gr mixture composites, Al–Gr and Al–SiC composites. The hybrid composites had better wear attributes. Increasing the speed reduced wear and increase in either load or sliding distance or both further increased wear.

**Babu et al. (2011)** investigated the dry sliding wear behavior of aluminum based hybrid composites with graphite nano fiber–alumina fiber. The composites reinforced with graphite nano fiber (GNF) and alumina short fiber ( $\text{Al}_2\text{O}_{3\text{sf}}$ ) in different volume % of fibres (10%, 15% and 20%) was taken for study. The Taguchi methodology was utilized to distinguish the testing parameters that have the largest impacts on wear loss and coefficient of friction of the composites. Sliding distance was used to be the noticeable parameter which influenced wear loss; applied load influenced coefficient of friction. The consequences of Taguchi

investigation showed that wear loss increases with increase in load and sliding distance, yet it decreased with increase in sliding speed. Coefficient of friction decreased with increase in applied load and sliding rate while it increases with increase in sliding distance. The composites with 10 vol. % and 15 vol. % of fiber had the most reduced wear loss and friction on account of the mixture impact of GNFs and  $\text{Al}_2\text{O}_{3\text{sf}}$ .

**Suresha and Sridhara (2012)** investigated the friction characteristics of aluminum silicon carbide graphite hybrid composites. Hybrid aluminum MMCs strengthened with silicon carbide (SiC) and graphite (Gr) were utilized because of their high quality and wear resistance. Friction coefficient of such mixture composites was very important in choosing the ideal combination of SiC and Gr. The sliding wear of stir cast hybrid aluminum composites reinforced with equivalent weight % of SiC and Gr particulates of 2.5%, 5%, 7.5% and 10% reinforcement was examined. The impact of % reinforcement, sliding distance, sliding speed and load on friction coefficient was examined by using pin-on-disk method with focus on DOE. Hardness of the composites decreased with increase in % reinforcement. Friction coefficient was affected by sliding speed and load.

**Baradeswaran and Perumal (2014)** investigated the Wear and mechanical qualities of Al 7075/graphite composites. This work investigates 7075 aluminum alloy-graphite composites for its tribological and mechanical behavior under dry sliding conditions. The conventional fluid casting system was used for the creation of composite material and subjected to T6 heat treatment. The reinforcement constant was picked as 5, 10, 15 and 20 wt. % of graphite to identify its potential for self-lubricating property under dry sliding conditions. Wear tests were performed by pin on disc apparatus. The wear rate decreased with increase in graphite substance and achieved its base at 5 wt. % graphite. The wear loss was decrease with increasing sliding distance. The normal coefficient of friction decreased with increase in graphite substance and was discovered to be least for 5 wt. % graphite. The mechanical properties decreased with increase in graphite content as compared with base alloy. The worn surfaces were examined through SEM.

**Baradeswaran and Perumal (2014)** studied the effect of graphite on the mechanical and wear properties of Al 7075/ $\text{Al}_2\text{O}_3$ /graphite hybrid composites fabricated by liquid metallurgy method. The MMC was prepared with 5% wt. of graphite particles and 2, 4, 6 and 8% wt. of  $\text{Al}_2\text{O}_3$ . The study discovers the importance of graphite particles in the MMC for obtaining

wear reduction. The hardness, tensile strength, flexural strength, compression strength and wear properties of the MMCs increases with the increased in percentage of the reinforcement particles.

### **Gap in Literature Review**

As per the literature available investigations are done on the individual effect of reinforcement like silicon carbide, magnesium, zirconium, graphite, zirconium oxide and fly ash on aluminium matrix but no significant work is found on the effect of Zirconium Oxide plus Graphite on the Aluminium metal matrix.

# Chapter 3

## PROBLEM DEFINITION

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As per the literature available investigations are done on the individual effect of reinforcement like silicon carbide, magnesium, zirconium, graphite, zirconium oxide and fly ash on aluminium matrix but no significant work is found on the effect of Zirconium Oxide plus Graphite on the Aluminium metal matrix. The present study will aim to improve the interfacial bonding between Graphite and Zirconium oxide (reinforcement) and aluminum (matrix) composites during manufacturing by stir casting method.

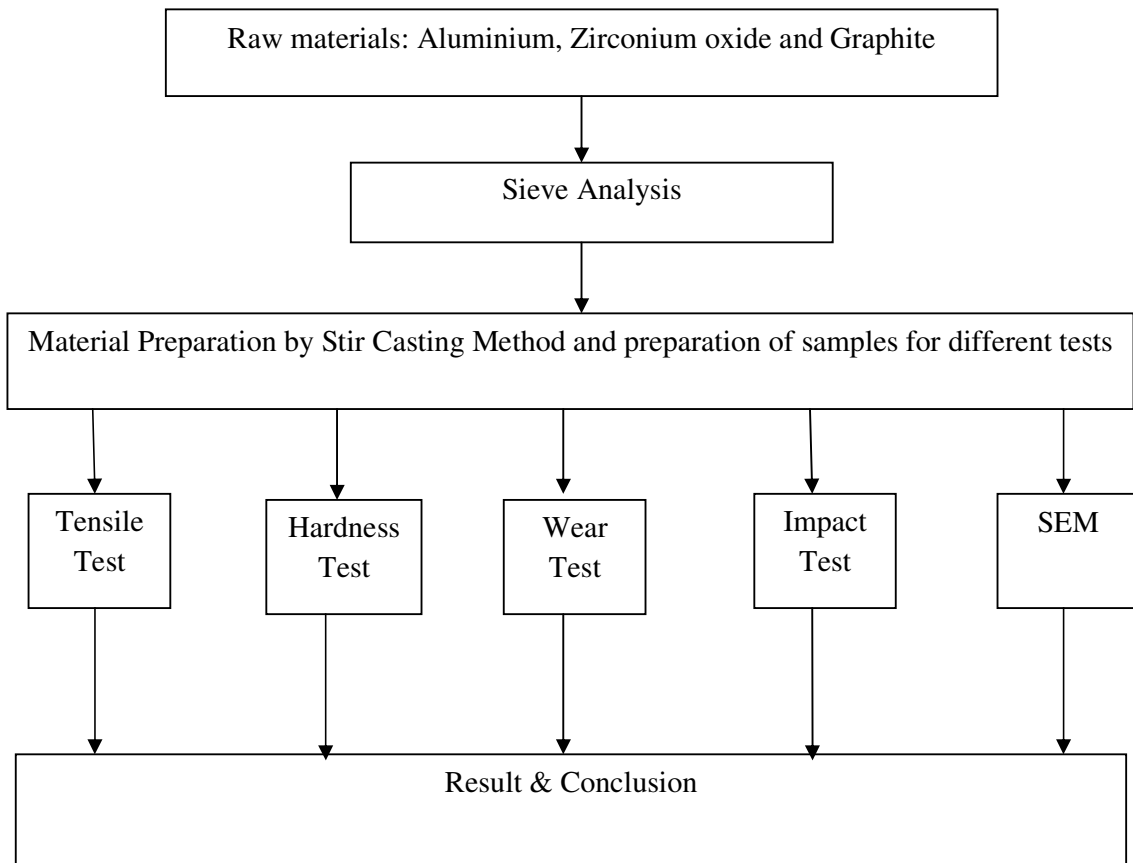
Material used: Aluminium, Zirconium oxide and Graphite

So, it is proposed to investigate the properties of Zirconium oxide and graphite on aluminium metal matrix composites. Test performed to check the properties of Al metal matrix are:

- Tensile strength
- Rockwell hardness test
- Impact test
- Wear and friction test

SEM is performed to check the distribution of the material.

### EXPERIMENTAL TECHNIQUES FOLLOWED:



**Figure 3.1:** Flow chart of experimental techniques

# Chapter 4

## DETAIL OF EXPERIMENTS

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### 4.1 Raw Materials

The matrix material used for the experimental work is aluminum 6061 in which varying amount of zirconium oxide and graphite have been added. The average particle size of the Zirconium Oxide and graphite are 250  $\mu\text{m}$  and 53  $\mu\text{m}$ , respectively. The chemical composite of Al-6061 is given in the table 4.1.

**Table 4.1:** Composition of Aluminium 6061 [26]

Component	Amount (wt. %)
Aluminium	95.8-98.6%
Manganese (Mn)	0.15%
Iron (Fe)	0.70%
Copper (Cu)	0.15 - 0.40%
Magnesium (Mg)	0.15%
Silicon (Si)	0.4 - 0.8%
Zinc (Zn)	0.25%
Chromium (Cr)	0.4 - 0.35%
Others (Total)	0.05- 0.15%

The various instruments or machine used during the preparation and testing of aluminium metal matrix composites are as follows:

1. Stir casting apparatus
2. Pin on disk machine
3. Rockwell hardness machine
4. Tensile testing machine
5. Charpy Impact testing machine
6. Sieve Shaker
7. SEM

The 9 samples prepared by stir casting process with different amount of  $ZrO_2$  and Gr particles in aluminium metal matrix are shown in table.

**Table 4.2:** Composition of samples

<b>Samples</b>	<b>Aluminium (wt. in grams)</b>	<b>Zirconium Oxide (wt. in grams)</b>	<b>Graphite (wt. in grams)</b>
1	1000	50	30
2	1000	100	30
3	1000	150	30
4	1000	50	50
5	1000	100	50
6	1000	150	50
7	1000	50	70
8	1000	100	70
9	1000	150	70

## **4.2 Oven**

Oven was used to preheat the material (Zirconium Oxide and Graphite) and to remove the moisture content. The graphite and Zirconium Oxide particles were preheated to about  $250^{\circ}C$  for 2 hours and then placed near the stir casting apparatus. The oven was available in Sand lab, Thapar University.



**Figure 4.1:** Oven

### **4.3 Stir Casting process**

The process of Stir casting (as shown in Figure 1.4) was performed for making the MMC samples. Stir Casting is a fluid state system for composite materials creation in which ceramic particles or short filaments are blended with a molten matrix metal by means of mechanical stirring. The fluid composite material is then casted by conventional casting strategies.

Stir Casting is described by the following features:

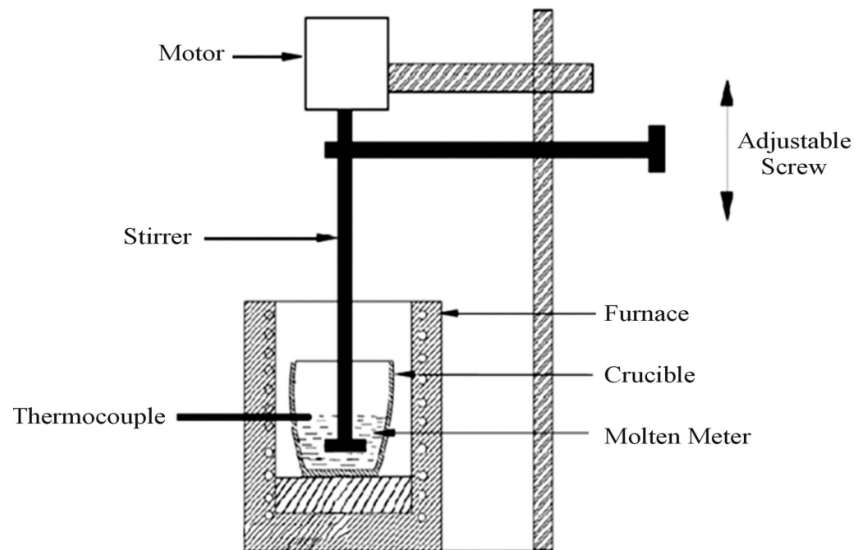
- Content of dispersed stage is limited (usually not more than 30 vol. %).
- The technique is simple and cost-effective.



**Figure 4.2:** Clay graphite crucible of 1 kg Al melt capacity. [34]



**Figure 4.3:** Inside View of Stir Casting Furnace.



**Figure 4.4:** Mechanical stirrer used for the mixing of the MMC. [33]



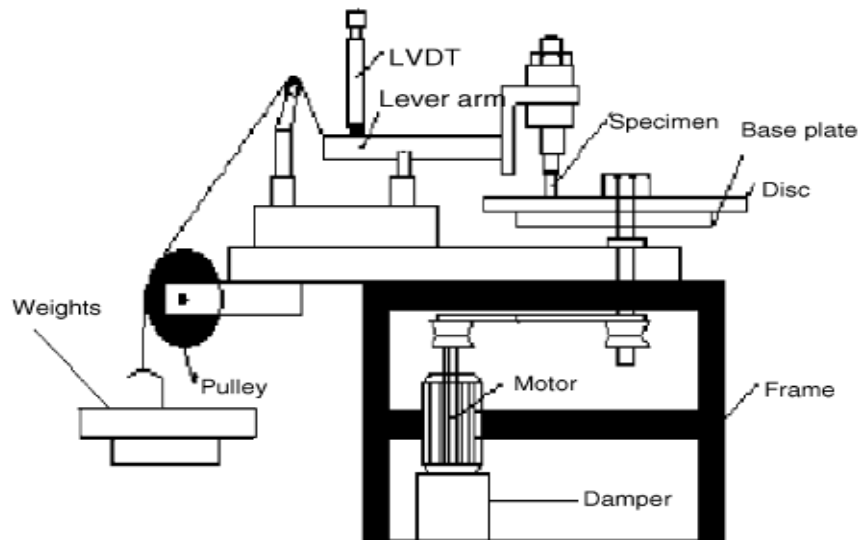
**Figure 4.5:** Moulds for preparation of samples.

The process of stir casting was performed for preparing Aluminium metal matrix composite. 1 Kg of aluminum 6061 was melted in the resistance furnace in which temperature was raised up to 850°C. The graphite and Zirconium Oxide particles were preheated to 250°C for duration of 2 hours to remove the moisture content. Different amounts of graphite and Zirconium Oxide particles were added to the molten metal.

The melt was maintained at a temperature of 790°C and was stirred with the help of a mild steel stirrer. The stirring was carried out for 4 min at an impeller speed of 400 rpm. Finally, the melt with the reinforced particulates was poured into the mould and left for solidification.

#### 4.4 Wear and Friction Test

The dry sliding wear tests were conducted using a pin-on-disc apparatus at room temperature as per the ASTM G99- 95 standards. Pins with 10 mm diameter and 50 mm height have been used for the Wear test. A single pan electronic weighing machine with an accuracy of 0.001 g was used to measure the weight of the specimen. The wear of the composites were studied as a function of sliding Speed and applied load. The Track diameter was kept constant at 100 mm. After running through different speed and weight, the specimen was removed, cleaned and weighed to determine the weight loss.



**Figure 4.6:** The schematic view of the pin-on-disc apparatus used in this study [6]

#### **4.5 Rockwell Hardness Test (B-Scale):**

This test is performed for measuring the hardness values of the prepared specimen at load of 100 kgf. The diameter of the steel ball is 1.588mm. The indenter is first moved down into position on the part surface of the work piece. A minor load is applied and a zero reference position is established. After that the major load is applied for duration of 10 seconds. The major load is then discharged. However, the minor load is left applied. Six readings were taken on each specimen to eliminate possibility of error and mean value was taken as the hardness of the composites



**Figure 4.7:** Rockwell hardness apparatus

## 4.6 Tensile Test

Tensile strength tests were carried out on Al MMCs using a computerized UTM machine as per ASTM E-8 standard.

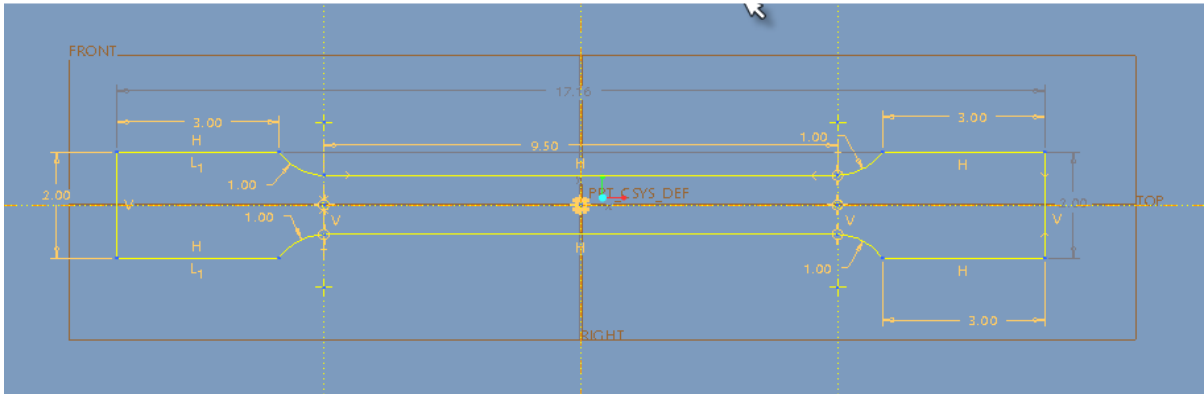


**Figure 4.8:** UTM machine Available in Civil Department, Thapar University.

Ultimate Tensile strength is calculated by dividing the load at breaking point by the original minimum cross-sectional area. The result is expressed in Mega Pascal's (MPa).

$$\text{Ultimate Tensile strength} = \frac{\text{Load at break}}{(\text{Original width}) (\text{Original thickness})}$$

The test pieces are made as per ASTM E-8 standards as shown in figure 4.9.



**Figure 4.9:** ASTM E8 Standards dimensions



**Figure 4.10:** Samples made for Tensile Testing as per the ASTM E-8 standards

#### **4.7 Impact Test (Charpy)**

Impact test is performed to determine the resistance to failure ratio of a material when it is subjected to a sudden force. The test is performed for the measurement of impact energy. This test is mainly used for assessing the relative toughness of materials or impact toughness. The size of the test piece used is 55x10x10 mm with V-shaped notch of 2 mm depth on one side and the angle considered for the notch corresponds to 45°. In this test, test piece is stroked with the striker which is located at the end of the pendulum. The test piece is placed and the striker is used to strike the test piece quickly behind the notch.



**Figure 4.11:** Impact test (Charpy) Available in SOM lab, Thapar University, Patiala



**Figure 4.12:** Samples made for impact test



**Figure 4.13:** Broken piece of Impact test sample

#### **4.8 Sieve Shaker**

A sieve analysis is a practice or procedure used to assess the particle size distribution of a granular material. [30] Particle size analysis for the  $ZrO_2$  and Gr particles was done using Sieve Shaker available at Sand Testing Lab at Thapar University.

100g Graphite and Zirconium Oxide was taken for this analysis. This weighed sample of  $ZrO_2$  and Gr was entered into the top sieve which has the biggest screen openings. Each lower sieve in the column had smallest openings than the one above. At the base is a round pan, called the receiver. The column was placed in a mechanical shaker. Then the shaking was conducted for 15 minutes. After the shaking was completed, than the material on each sieve was weighed.

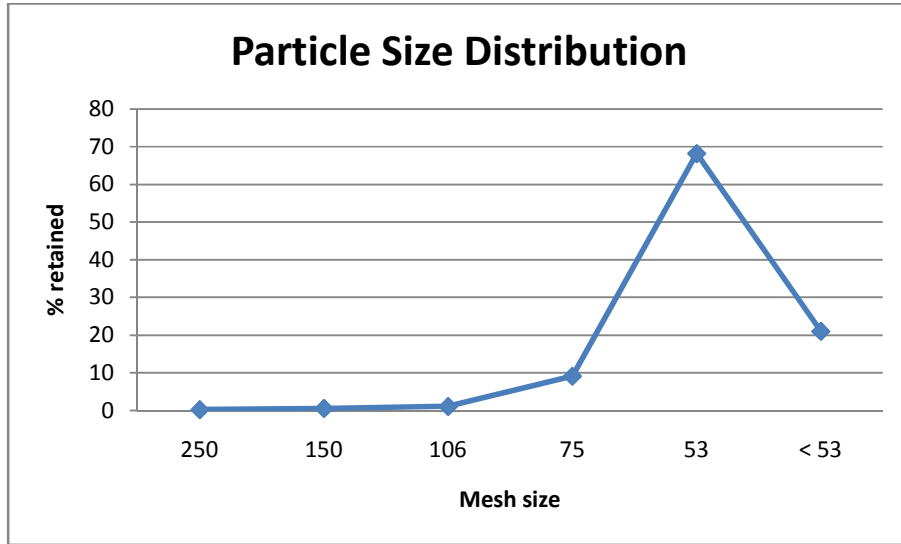


**Figure 4.14:** Sieve Shaker available at Sand Testing Lab at Thapar University.

The weighted of the sample of each sieve was then divided by the total weight to get the percentage retained on each sieve. Following Figures show the Particle size distribution of the Sieve test conducted:

**Table 4.3:** Distribution of graphite Size

Graphite Particle size Distribution	
Mesh Size	% retained
< 53	20.96
53	68.15
75	9.06
106	1.02
150	0.52
250	0.17

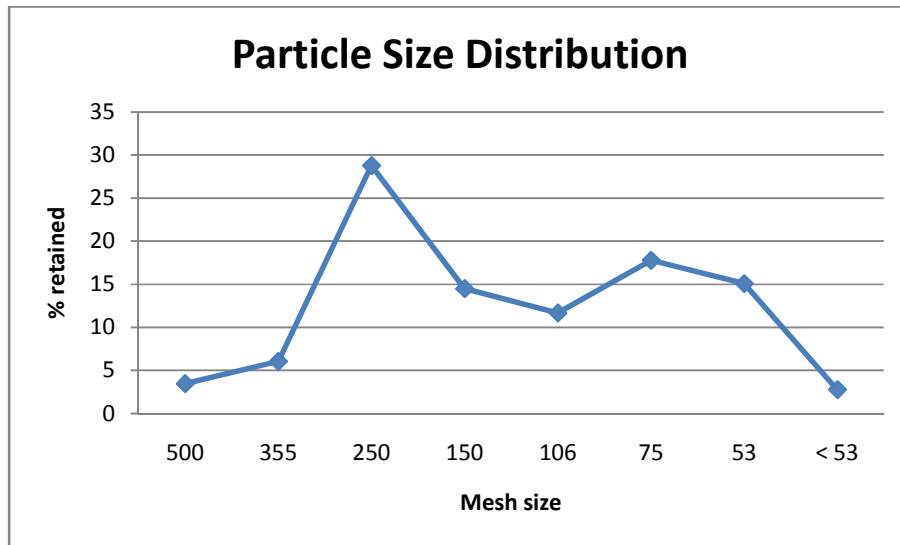


**Figure 4.15:** Mesh size vs. % retained of Graphite

The average particle size of Graphite is found out to be 53 microns.

**Table 4.4:** Distribution of Zirconium oxide Particle size

Zirconium oxide Particle size Distribution	
Mesh size	% retained
500	3.45
355	6.03
250	28.77
150	14.49
106	11.66
75	17.77
53	15.07
< 53	2.76



**Figure 4.16:** Mesh size Vs % retained of Zirconium Oxide

The average Zirconium Oxide particle size is found out to be 250 microns.

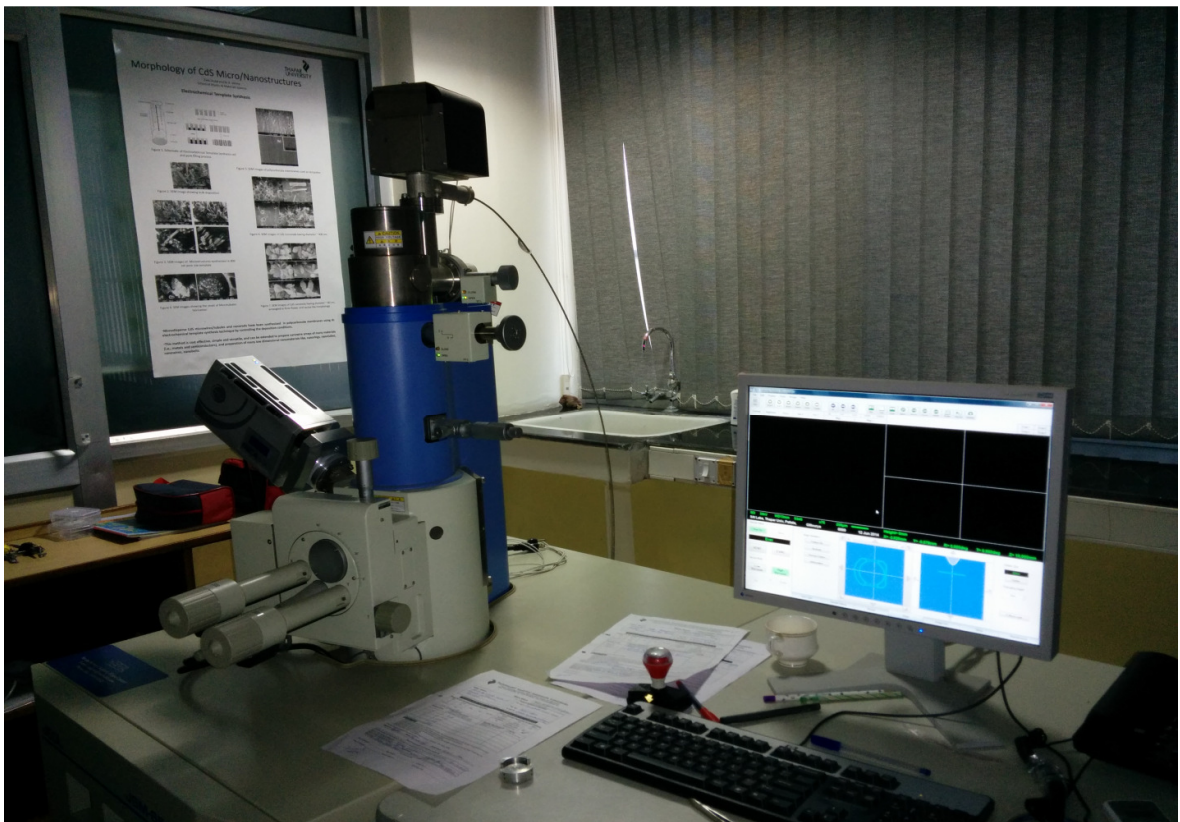
## **4.9 Scanning Electron Microscope Apparatus**

A (SEM) is a type of electron microscope that is used to produce images of a sample by scanning it with a focused beam of electrons. The electrons interface with atoms in the example creating different signals. These signals hold data about the surface topography and arrangement of the examples. SEM can achieve the determination better than 1 nanometer. Specimens can be observed in high-low vacuum in wet conditions.

The number of secondary electrons is a function of the angle between the surface and the beam. On a flat surface, the trail of secondary electrons is mostly contained by the example, however on a tilted surface, the trail is partially uncovered and more electrons are emitted. [31]



**Figure 4.17:** Sample prepaid for SEM test.



**Figure 4.18:** SEM apparatus.

# Chapter 5

## RESULTS AND DISCUSSION

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In this dissertation, Aluminium metal matrix has been prepared using different quantities of graphite and zirconium oxide. Various tests have been performed to investigate the properties of graphite and zirconium oxide in Aluminium metal matrix composites. The tests performed are as follows:

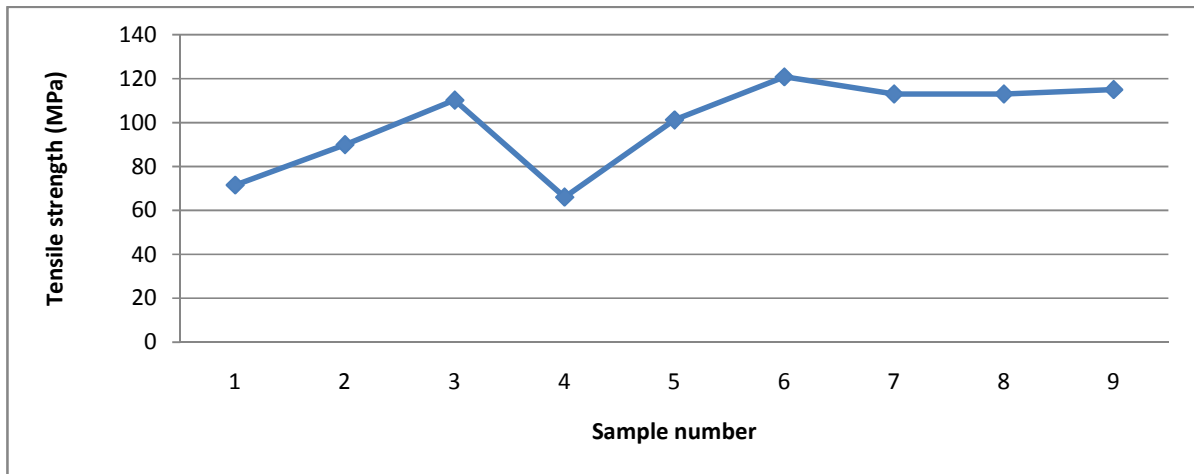
### 5.1 Tensile Test

**Table 5.1:** Result of tensile test

Sample Number	ZrO <sub>2</sub> wt. %	Gr wt. %	Ultimate tensile strength (MPa)
1	5	3	71.5
2	10	3	89.9
3	15	3	110.2
4	5	5	66.0
5	10	5	101.2
6	15	5	120.8
7	5	7	113
8	10	7	113
9	15	7	115

Tensile strength test was carried out on Al MMCs using a computerized Universal testing machine as per the ASTM E-8 standard. 9 samples were made by stir casting methods. Initially, the weight of graphite was maintained constant. Its contribution was 3wt. % in pure aluminium 6061. Quantity of ZrO<sub>2</sub> was varied from 5wt% to 15wt%. It was observed that as the concentration of ZrO<sub>2</sub> increased, ultimate tensile strength also increased from 71.5 MPa to 110.2 MPa. The contribution of graphite was further increased to 5wt%. It was kept constant

and again, the concentration of  $ZrO_2$  was varied from 5wt% to 15wt%. Similar pattern in tensile strength was observed i.e. the tensile strength increased from 66 MPa to 120.8 MPa. Again the contribution of the graphite was further increased to 7 wt%. It was kept constant and the concentration of  $ZrO_2$  was varied from 5wt% to 15 wt%. The tensile strength increased from 113.0 MPa to 115.0 MPa.



**Figure 5.1:** Variation of tensile strength



**Figure 5.2:** The broken samples of MMC using a computerized UTM testing machine as per the ASTM E-8 standards

No variation in tensile strength is observed for sample 7 and sample 8 i.e. it remains constant at 113 MPa. The highest value of tensile strength observed is 120.8 MPa and the corresponding values of  $ZrO_2$  and graphite are 15% and 5 %, respectively. Similarly, the lowest value of tensile strength is 66.0 MPa and the corresponding values of  $ZrO_2$  and graphite are 5% and 5 %, respectively.

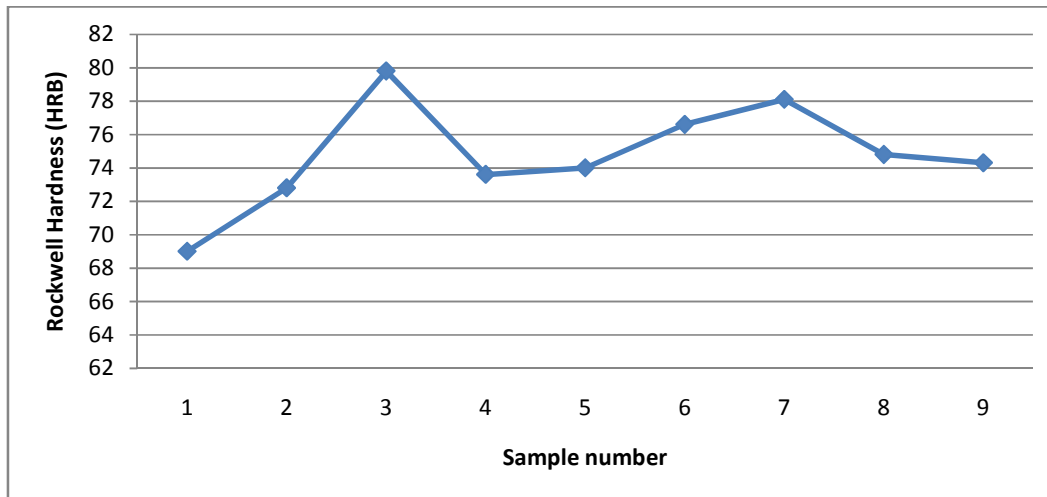
Hence with the addition of zirconium oxide and graphite, the tensile strength varied from 66.0 MPa to 120.8 MPa. The tensile strength is improved, with the addition of ZrO<sub>2</sub>.

## 5.2 Rockwell Hardness Test Scale B Load 100Kg

**Table 5.2:** Results of Rockwell Hardness

Sample No.	Zr wt. %	Gr wt. %	HRB	Avg. HRB
1	5	3	70,72,68,64,68,72	69
2	10	3	75,73,73,70,73,73	72.8
3	15	3	80,83,81,77,78,80	79.8
4	5	5	72,72,75,77,74,72	73.6
5	10	5	73,76,75,74,73,74	74.1
6	15	5	78,73,75,76,79,75	76
7	5	7	74,79,76,80,79,81	78.1
8	10	7	69,74,74,75,79,76	74.5
9	15	7	75,78,74,72,72,75	74.3

Hardness test was carried out on Al MMCs using a Rockwell hardness machine scale B with the load of 100 kgf. Nine samples were made by stir casting methods. From the graph, it can be observed that as the content of ZrO<sub>2</sub> is increased, the hardness value of the material is also increased. Six readings were considered for each of the samples. Finally, the average of all the six readings was calculated so as to minimize the error in the hardness for each of the samples considered. The highest value of hardness is 79.8 HRB and the corresponding values of ZrO<sub>2</sub> and graphite are 15% and 3 %, respectively. The lowest value of hardness is 69 HRB and the corresponding values of ZrO<sub>2</sub> and graphite are 5% and 3 %, respectively. It is observed that the hardness of the Al 6061 metal matrix composite increases with the addition of zirconium oxide. The hardness decreases with the addition of graphite particles to the Al MMC [Leng *et al* (2009)].



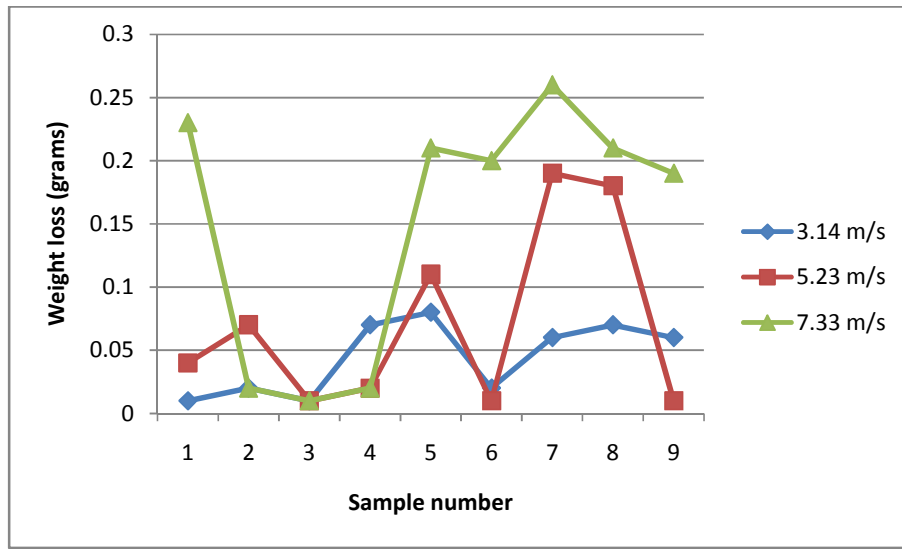
**Figure 5.3:** variation of Rockwell Hardness (HRB)

### 5.3 Wear behavior of the Composites

For different samples, weight loss (in grams) has been measured for different combinations of speed and load, which is given in Table 5.3. Sliding speed is kept at 3.14 m/s, 5.23 m/s and 7.23 m/s whereas applied weight is fixed at 9.8 N, 29.4 N and 49 N. Each experiment has been performed for 15 minutes.

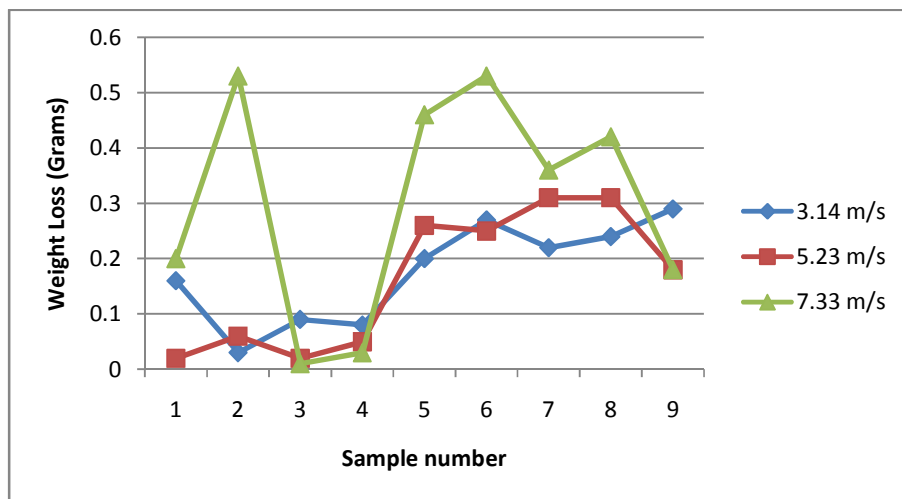
**Table 5.3** Results of wear and friction

Applied load	Sliding Speed m/s	1 5%Zr 3%Gr	2 10% Zr 3% Gr	3 15% Zr 3% Gr	4 5%Zr 5%Gr	5 10%Zr 5% Gr	6 15%Zr 5%Gr	7 5%Zr 7%Gr	8 10%Zr 7%Gr	9 15%Zr 7%Gr
9.8 N	3.14	.01	.02	.01	.07	.08	.02	.06	.07	.06
	5.23	.04	.07	.01	.02	.11	.01	.19	.18	.01
	7.33	.23	.02	.01	.02	.21	.20	.26	.21	.19
29.4 N	3.14	.16	.03	.09	.08	.20	.27	.22	.24	.29
	5.23	.02	.06	.02	.05	.26	.25	.31	.31	.18
	7.33	.20	.53	.01	.03	.46	.53	.36	.42	.18
49 N	3.14	.43	.28	.06	.10	.27	.16	.63	.26	.27
	5.23	.26	.07	.04	.02	.26	.39	.32	.52	.28
	7.33	.50	.55	.03	.15	.56	.73	.45	.68	.20



**Figure 5.4:** Wear rate of the MMC with Load of 9.8 N and different speeds

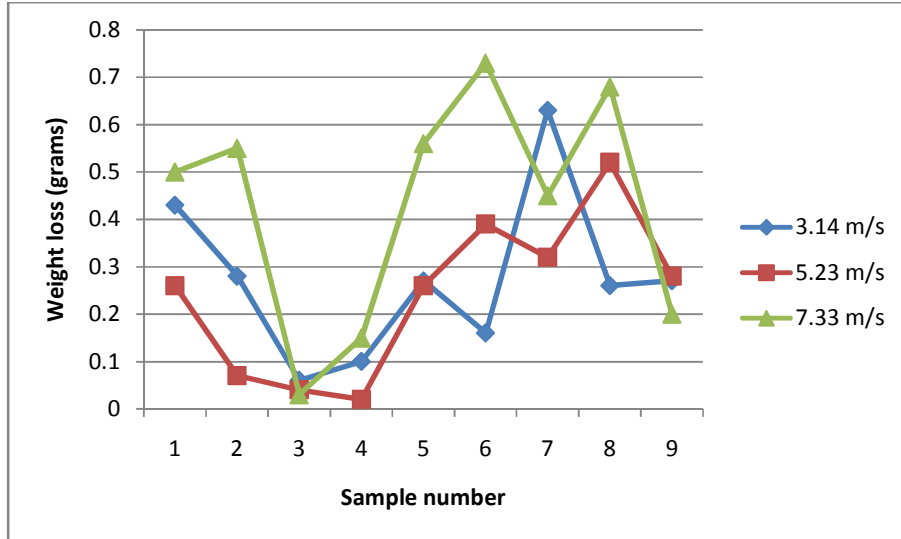
Figure 5.4 shows the weight loss for different samples. Here, a constant load of 9.8 N is applied whereas speed is varied. For each of the speeds, the minimum weight loss occurs at sample number 3 which consists of maximum quantity of ZrO<sub>2</sub> (15%) and minimum quantity of Gr (03%). Also, the maximum weight loss occurs at sample number 7 which consists of minimum quantity of ZrO<sub>2</sub> (05%) and maximum quantity of Gr (07%). As the quantity of graphite increases, weight loss also increases.



**Figure 5.5:** Wear rate of the MMC with Load of 29.4 N and different speeds

Figure 5.5 shows the weight loss for different samples. Here, a constant load of 29.4 N is applied whereas speed is varied. For each of the speeds, the minimum weight loss occurs at sample number 3 which consists of maximum quantity of

ZrO<sub>2</sub> (15%) and minimum quantity of Gr (03%). Also, the maximum weight loss occurs at sample number 6 which is formed by 5 % of Gr and 15% of ZrO<sub>2</sub>. As the quantity of graphite increases, weight loss also increases.



**Figure 5.6:** Wear rate of the MMC with Load of 49 N and different speeds.

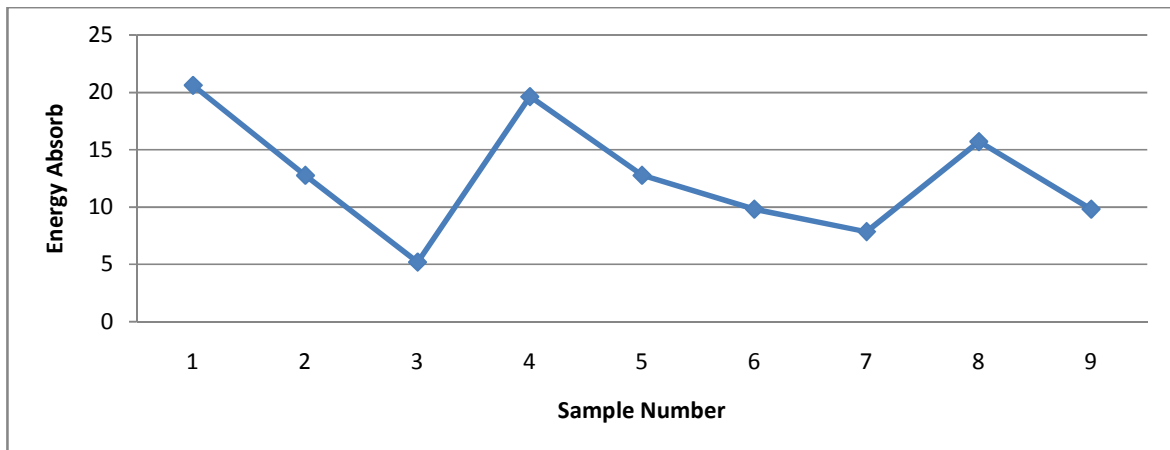
Figure 5.6 shows the weight loss for different samples. Here, a constant load of 49 N is applied whereas speed is varied. For each of the speeds, the minimum weight loss occurs at sample number 3 which consists of maximum quantity of ZrO<sub>2</sub> (15%) and minimum quantity of Gr (03%). Also, the maximum weight loss occurs at sample number 6 which is formed by 5 % of Gr and 15% of ZrO<sub>2</sub>. As the quantity of graphite increases, weight loss also increases.

## 5.4 Impact Test (Charpy)

**Table 5.4:** Results of Impact test (Charpy)

Sample No.	ZrO <sub>2</sub> %	Gr%		Avg.	Energy Absorb (J)
1	5	3	2,2.5,1.9	2.1×9.81	20.601
2	5	5	1.8,1.2,0.9	1.3×9.81	12.753
3	5	7	0.5,0.6,0.5	0.53×9.81	5.19
4	10	3	1.9,2.3,2	2×9.81	19.62
5	10	5	1.4,1,1.5	1.3×9.81	12.753
6	10	7	1.3,1,0.9	1×9.81	9.81
7	15	3	0.5,1.5,0.5	0.8×9.81	7.848
8	15	5	1,2,1.8	1.6×9.81	15.696
9	15	7	1.4,1.3,0.5	1×9.81	9.81

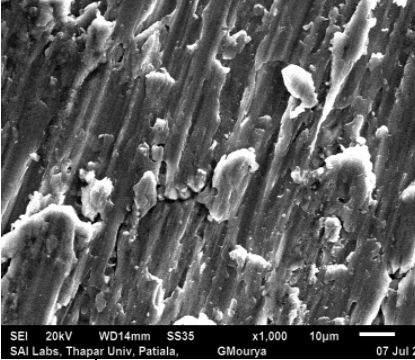
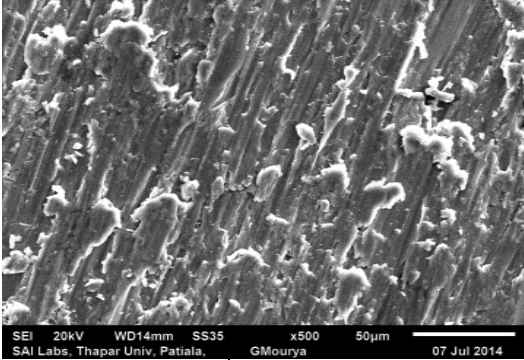
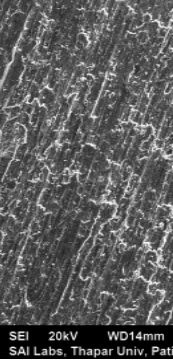
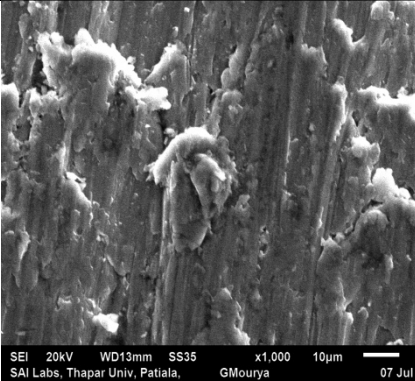
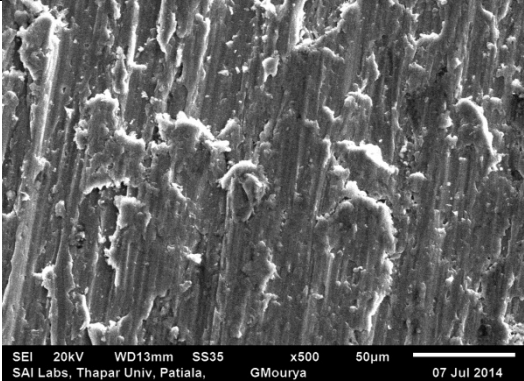
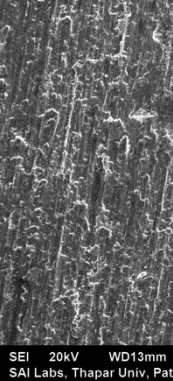
Impact test was carried out on Al MMCs using Charpy impact test. Nine samples were made by stir casting methods. Three readings were considered for each of the samples. Finally, the average of all the three readings was calculated so as to minimize the error in the energy absorbed for each of the samples considered. Initially, the weight of ZrO<sub>2</sub> was maintained constant. Its contribution was 5wt. % in pure aluminium 6061. Quantity of Gr was varied from 3wt% to 7wt%. It was observed that as the concentration of Gr increases, energy absorbed decreases from 20.601 J to 5.19 J.



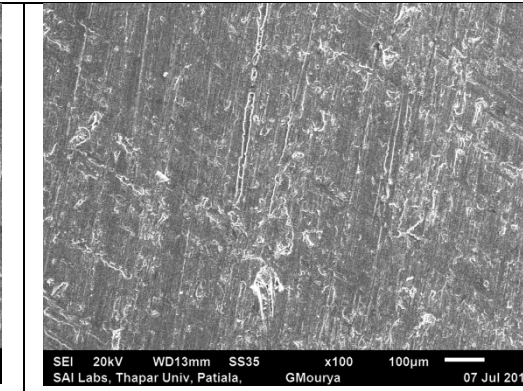
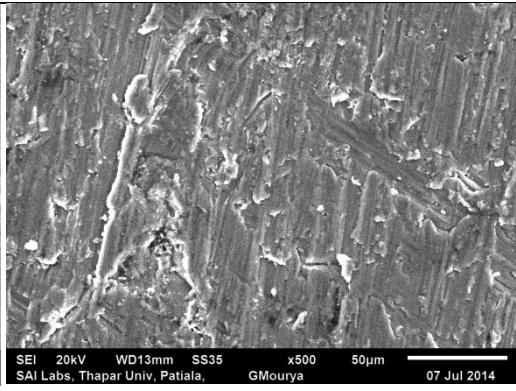
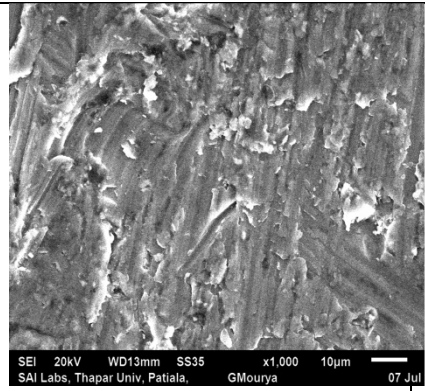
**Figure 5.7:** Variation of Energy absorbed

The contribution of  $\text{ZrO}_2$  was further increased to 10 wt%. It was kept constant and again, the concentration of Gr was varied from 3wt% to 7wt%. Now, the energy absorbed decreased from 19.62 J to 9.81 J. The quantity of the  $\text{ZrO}_2$  was further increased to 15 wt%. It was kept constant and the concentration of Gr. was varied from 3wt% to 7 wt%. However, the energy absorbed in case of sample number 8 is higher than the energy absorbed in case of sample number 9. The highest value of energy absorbed is 20.601 J and the corresponding values of  $\text{ZrO}_2$  and graphite are 5% and 3 %, respectively. The lowest value of energy absorbed is 5.19 J and the corresponding values of  $\text{ZrO}_2$  and graphite are 5% and 7 %, respectively.

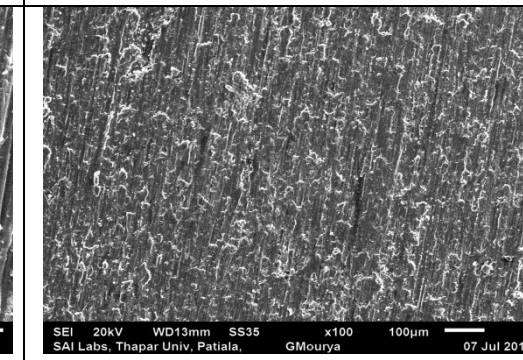
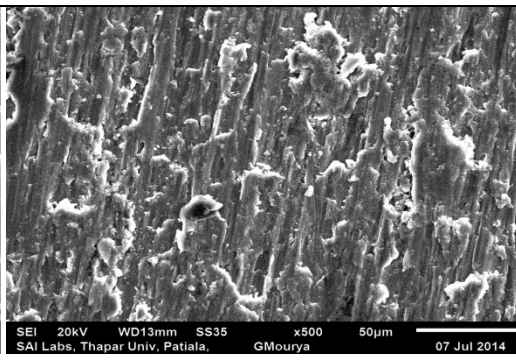
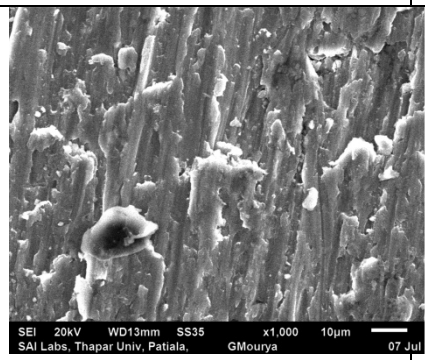
## SEM Results

	x1,000 10 μm	x500 50 μm	x100 100μm
5% wt. ZrO <sub>2</sub> 3 % wt. Gr			
10% wt. ZrO <sub>2</sub> 3 % wt. Gr			

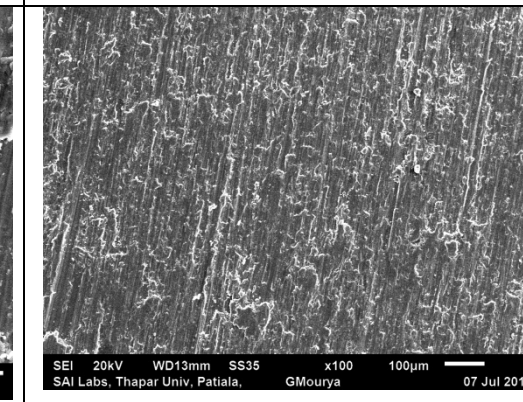
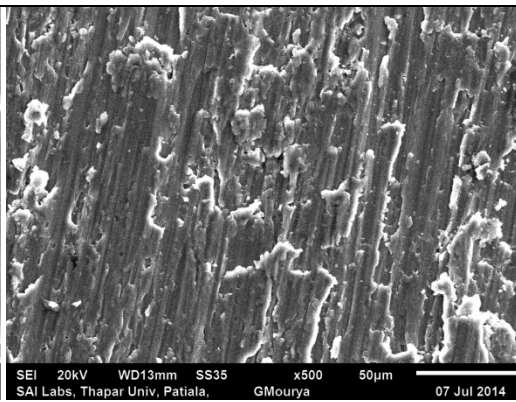
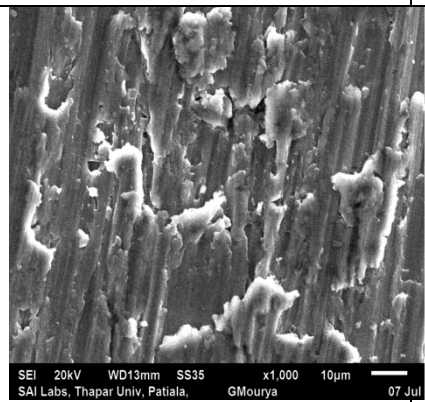
15%  
ZrO<sub>2</sub>  
3% Gr



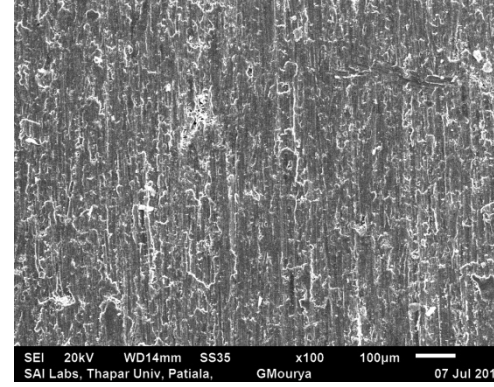
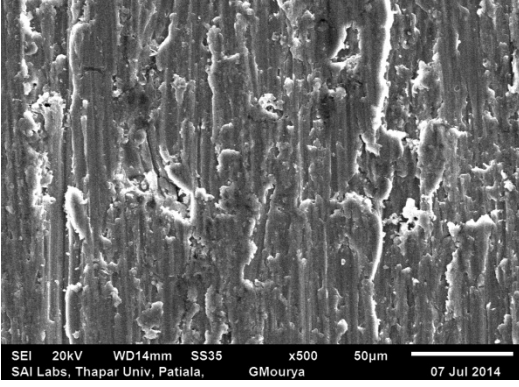
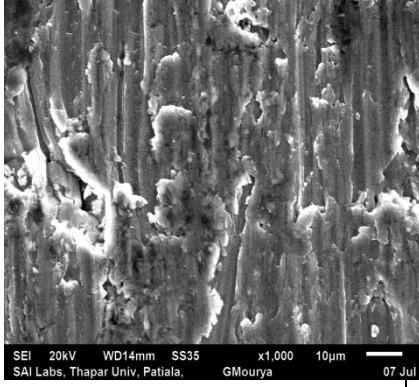
5%  
ZrO<sub>2</sub>  
5% Gr



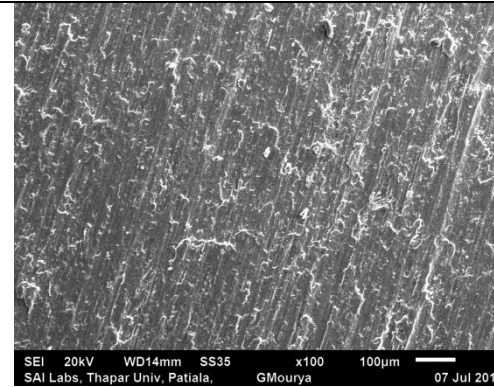
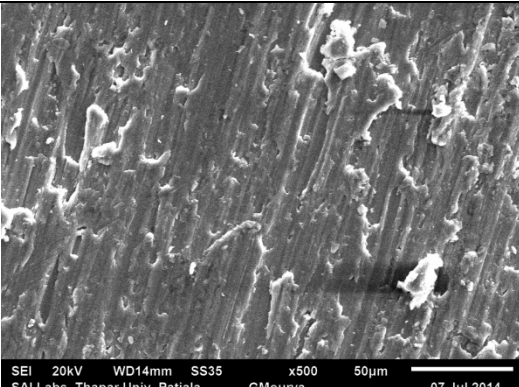
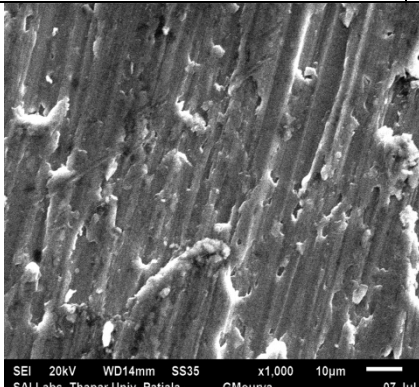
10%  
ZrO<sub>2</sub>  
5% Gr

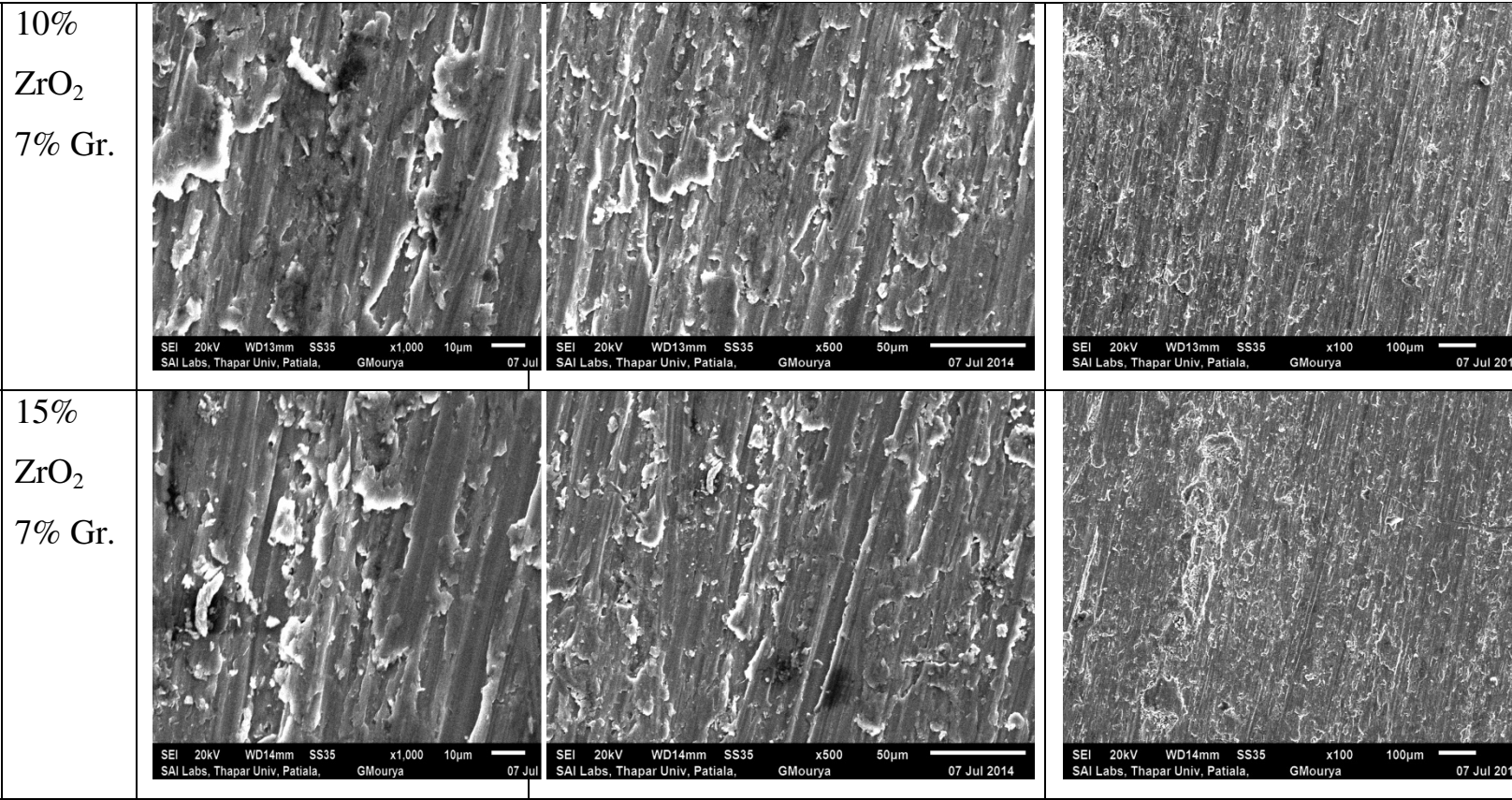


15%  
ZrO<sub>2</sub>  
5% Gr.



5%  
ZrO<sub>2</sub>  
7% Gr.





**Figure 5.8:** SEM images.

From figure 5.8: It is observed that there are aggregates of zirconium oxide particles dispersed in the gray aluminum matrix. Also there are some black points representing Graphite of composites. These micrographs show fine distribution of zirconium oxide particles, what causes more uniform composites. The reason behind fine distribution of zirconium particles is selection of appropriate time and method of mixing. In all graphs, it is seen that there is equal distribution of zirconium oxide and Graphite in aluminium metal matrix composites.

# Chapter 6

## CONCLUSIONS & FUTURE SCOPE

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### 6.1 Conclusions

The following conclusions have been drawn from the work:

- The addition of zirconium affected the Al MMC positively from the point of hardness, tensile strength and wear rate.
- The hardness increases with the increase in contents of  $ZrO_2$  but decreases with increase in graphite content.
- Wear rate can be reduced with an increase in  $ZrO_2$  content.
- $ZrO_2$  also improves the tensile strength of composite.
- Addition of graphite decreases the toughness of material because of its brittle nature.
- SEM shows that there are equally distributions of zirconium oxide and Graphite in aluminium metal matrix composites.

## **6.2 Future Scope**

- The work can be further extended for some more combination of ZrO<sub>2</sub> and graphite.
- Other reinforcement materials can also be tried for further investigation.
- Three point bending test and micro-hardness studies can also be carried out.

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### **Image references**

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# APPENDIX

## Load Vs Time Graphs

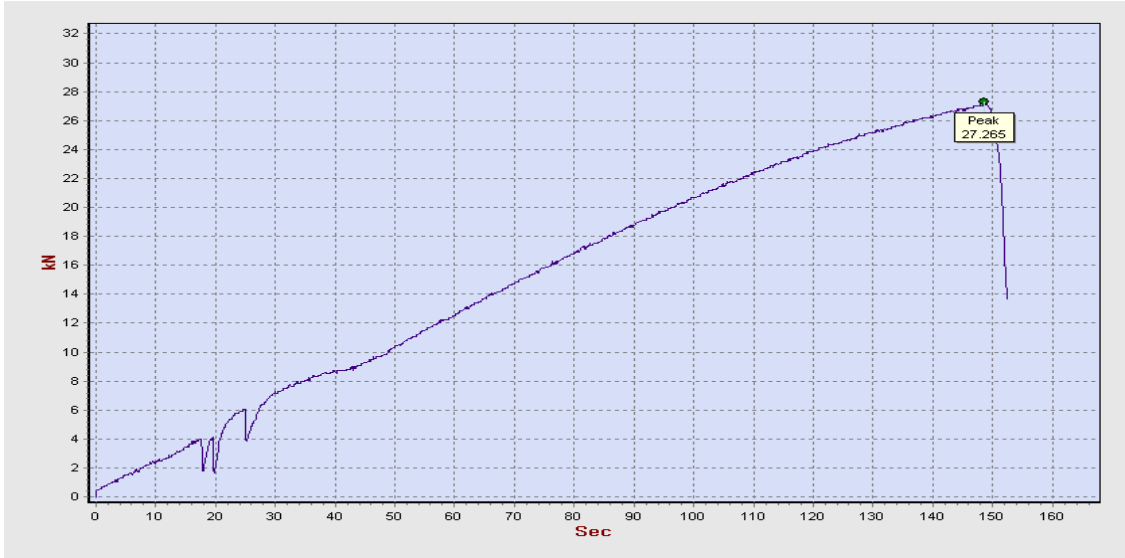


Figure5.1: Load Vs time for sample 1 (ZrO<sub>2</sub> 5% and Graphite 3%)

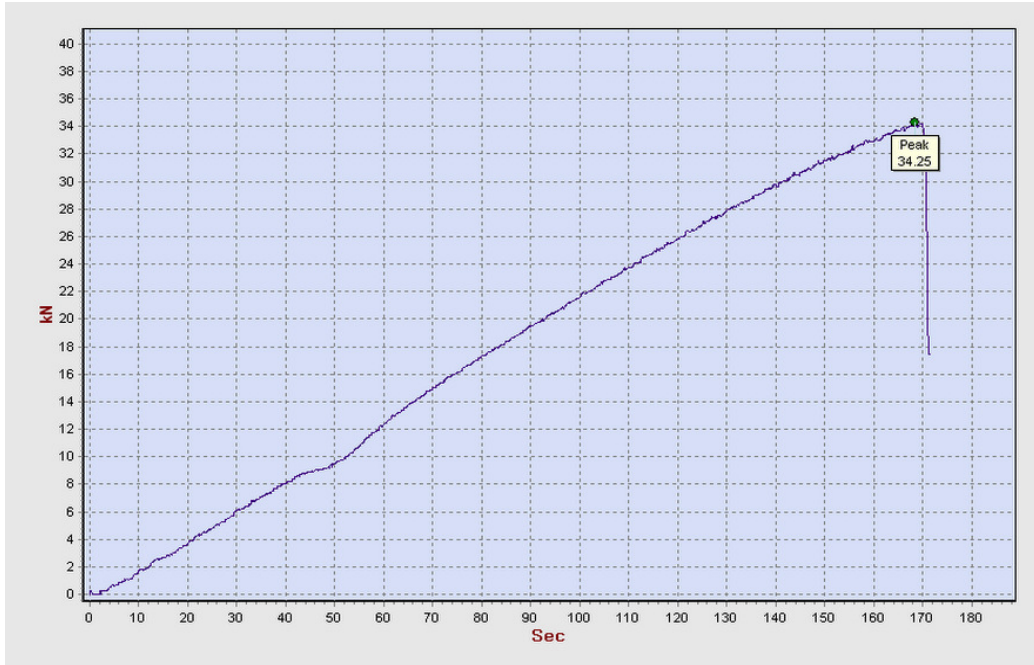


Figure5.2: Load vs time for sample 2 (ZrO<sub>2</sub> 10% and Graphite 3%)

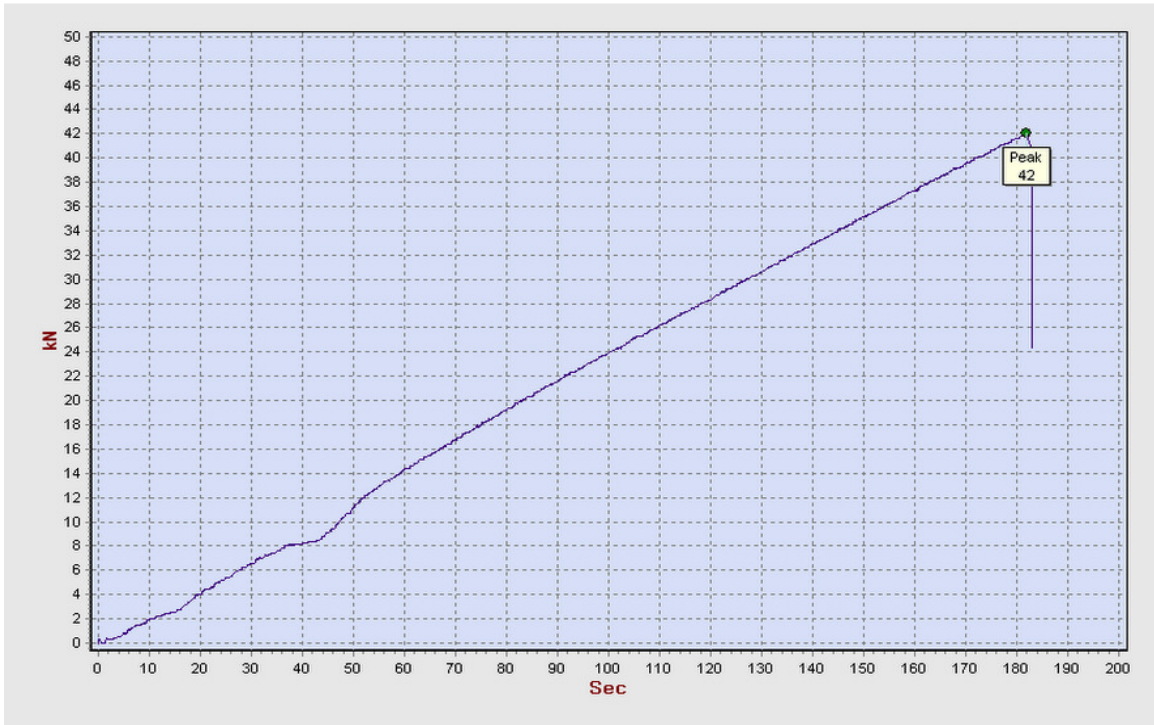


Figure5.3: Load vs time for sample 3 (ZrO<sub>2</sub> 15% and Graphite 3%)

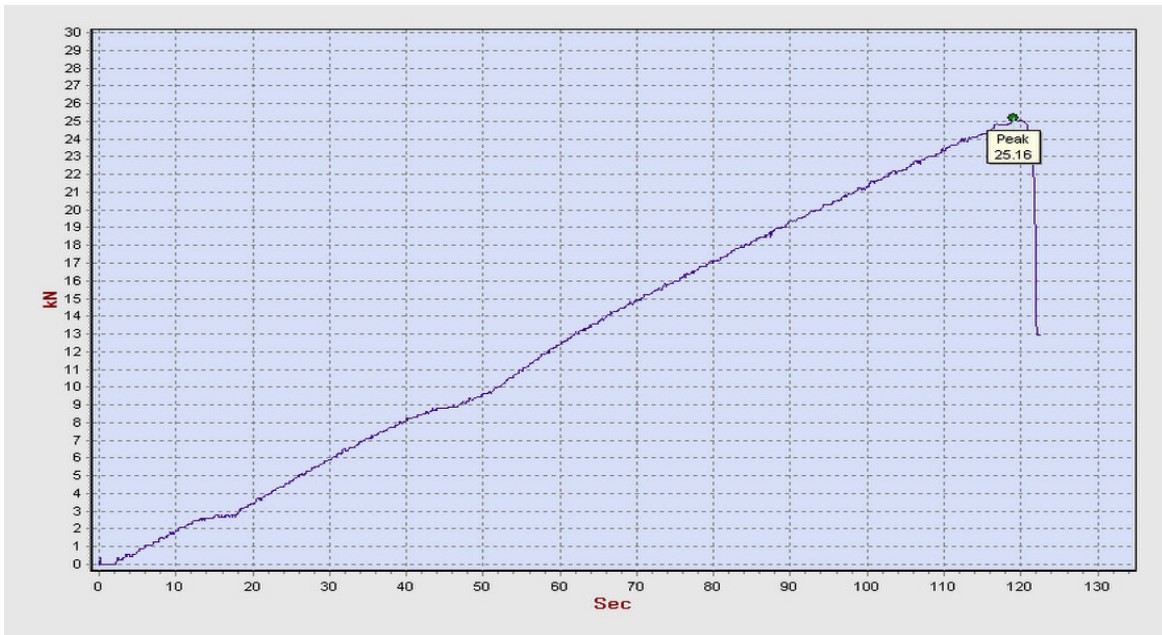


Figure5.4: Load vs time for sample 4 (ZrO<sub>2</sub> 5% and Graphite 5%)

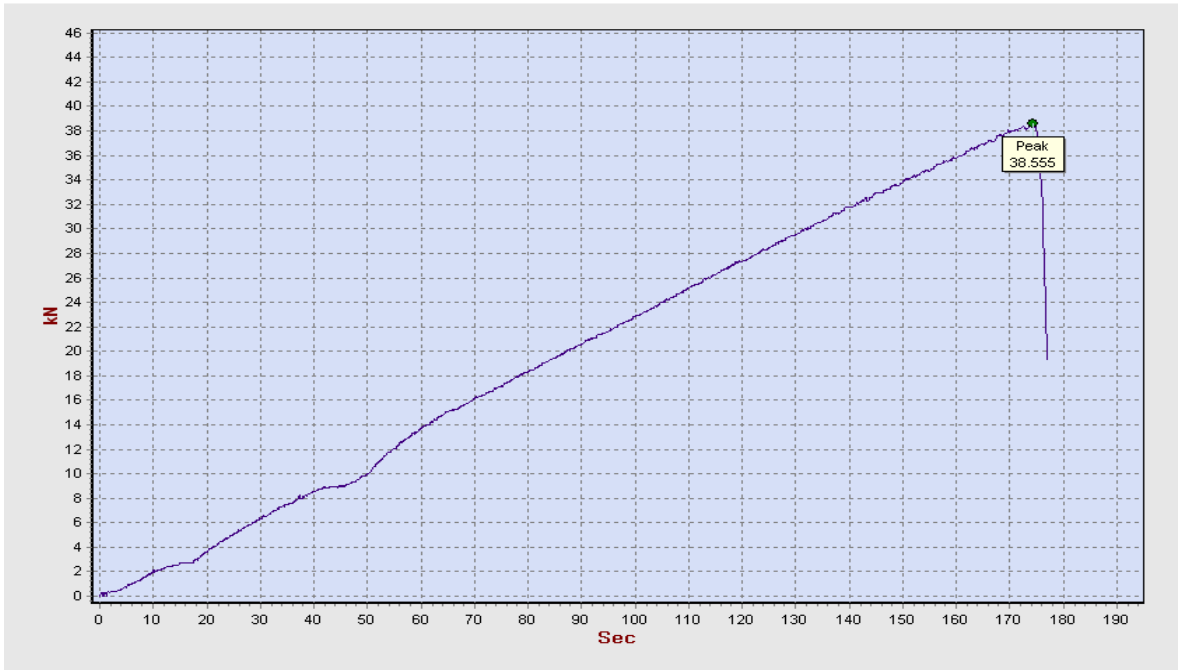


Figure5.5: Load vs time for sample 5(ZrO2 10% and Graphite 5%)

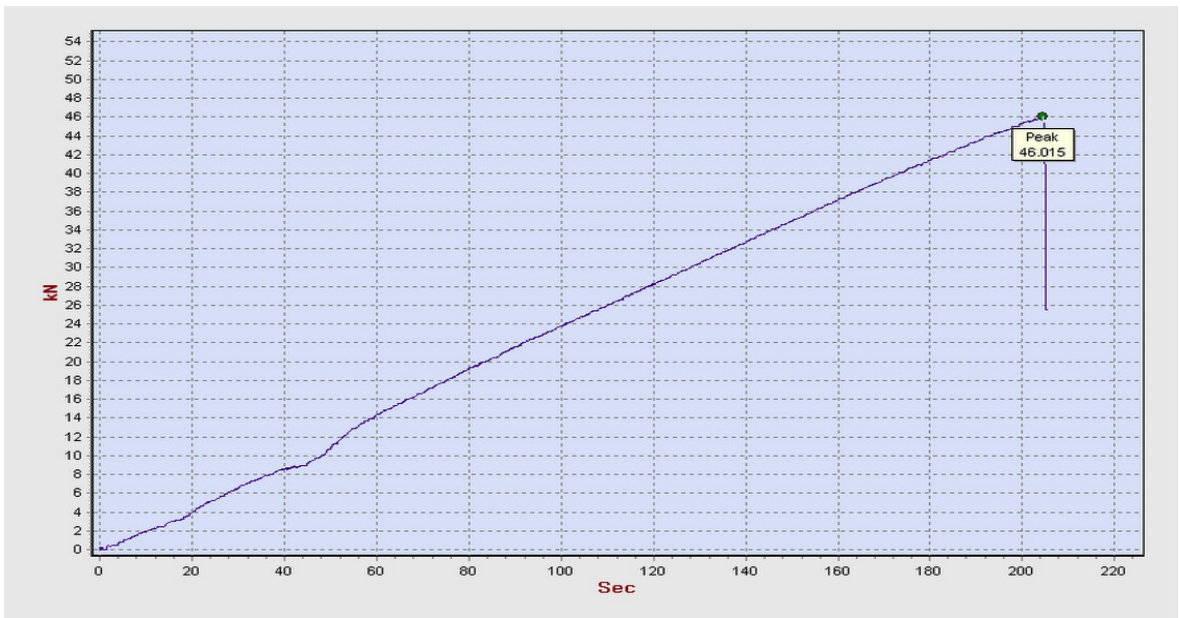


Figure5.6: Load vs time for sample 6(ZrO2 15% and Graphite 5%)

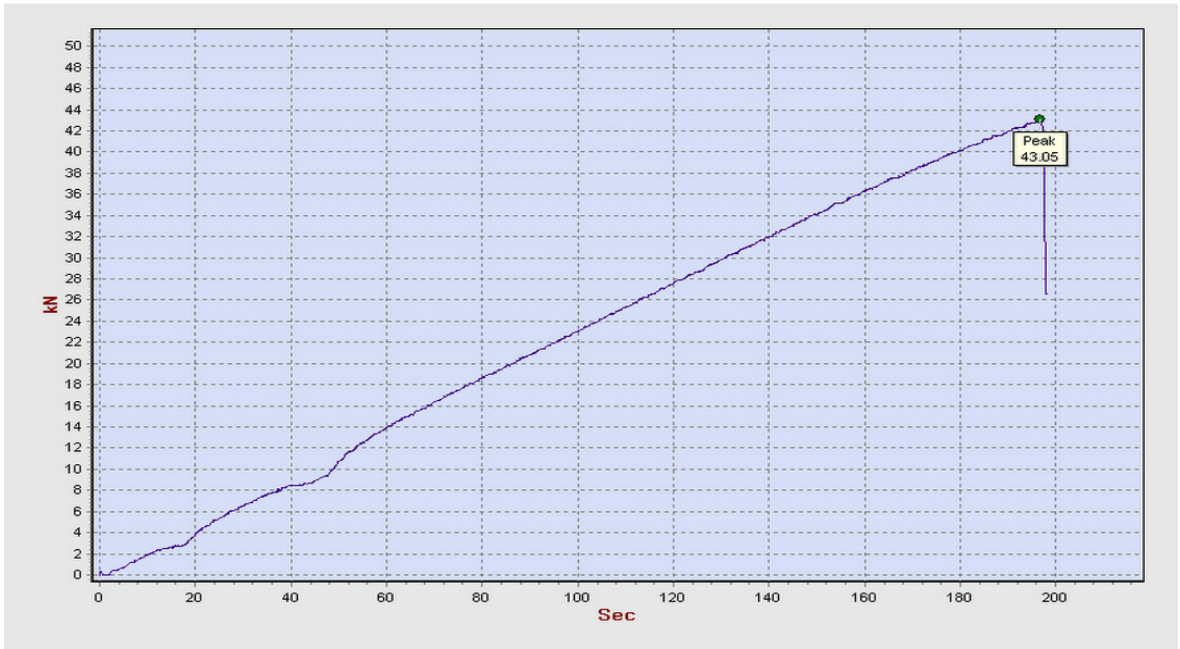


Figure5.7: Load vs time for sample 7 (ZrO<sub>2</sub> 5% and Graphite 7%)

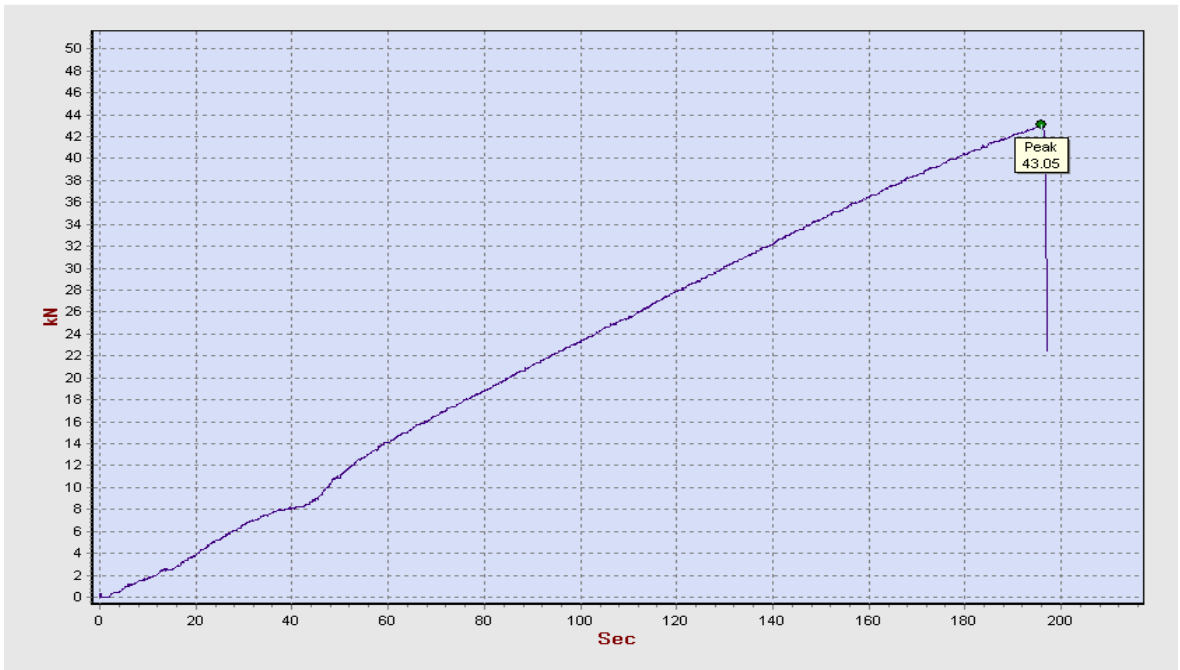


Figure5.8: Load vs time for sample 8 (ZrO<sub>2</sub> 10% and Graphite 7%)

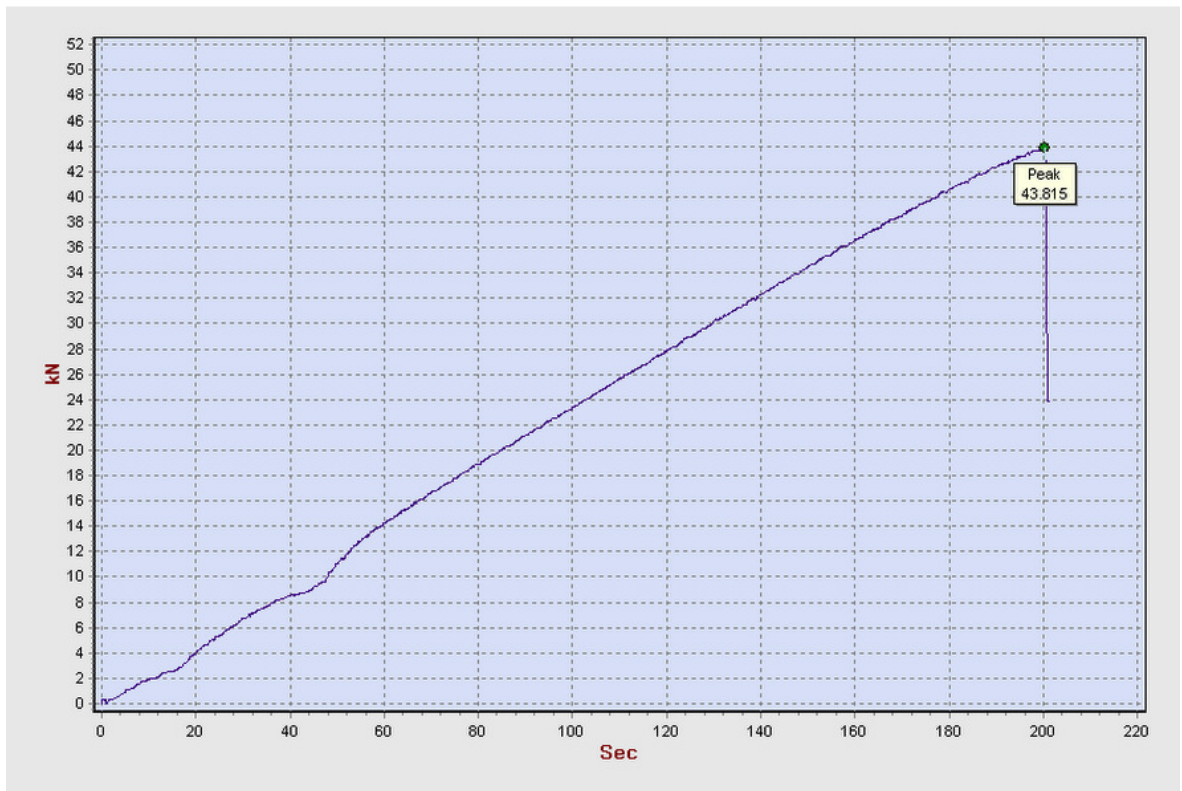


Figure5.9: Load vs time for sample 9 (ZrO<sub>2</sub> 15% and Graphite 7%)