MECHANICAL BEHAVIOUR OF ALUMINIUM BASED METAL MATRIX COMPOSITES REINFORCED WITH SiC AND ALUMINA

A
Thesis
Submitted in fulfilment of the requirement for the award of degree of

MASTER OF ENGINEERING
IN
PRODUCTION & INDUSTRIAL ENGINEERING

Submitted By:
Pulkit Bajaj
Roll No. 800982019
Under the Guidance of

Mr. Yogesh Kumar Singla
Lecturer
M.E.D
Thapar University
Patiala-147004

Mr. Anil Kalra
Lecturer
M.E.D
Thapar University
Patiala-147004

DEPARTMENT OF MECHANICAL ENGINEERING
THAPAR UNIVERSITY
PATIALA-147004, INDIA

CERTIFICATE

This is to certify that the work is in this seminar report entitled "**MECHANICAL BEHAVIOUR OF ALUMINIUM BASED METAL MATRIX COMPOSITES REINFORCED WITH SiC AND ALUMINA** " in partial fulfilment of requirement for the award of the master degree in Production & Industrial submitted in the mechanical engineering department, Thapar University, Patiala, is an authentic record of the initial work carried out by me under the guidance of Mr. Yogesh Kumar Singla, Lecturer Mechanical Engineering Department, Thapar University, Patiala and Mr. Anil Kalra, Lecturer, Mechanical Engineering Department, Thapar University, Patiala.

The matter embodied in this report has not been submitted in part or full to any other university or institute for the award of any degree.

Pulkit Bajaj

Dated: **(Pulkit Bajaj)**

This is to certify that above declaration made by the student concerned is correct to the best of my knowledge & belief.

Mr. Yogesh Kumar Singla
Lecturer,
M.E.D
Thapar University
Patiala-147004

Mr. Anil Kalra
Lecturer,
M.E.D
Thapar University
Patiala-147004

Dr. Ajay Batish
Professor & Head (MED)
Thapar University
Patiala-147004

Dr. S.K Mohapatra
Dean of Academic Affairs
Thapar University
Patiala-147004

ACKNOWLEDGEMENT

I am highly grateful to the authorities of Thapar University, Patiala for providing this opportunity to carry out the thesis work.

I would like to express a deep sense of gratitude and thank profusely to my thesis guide Mr. Anil Kalra (Lecturer) & Mr. Yogesh Singla (Lecturer) for his sincere & invaluable guidance and suggestions which inspired me to submit thesis report in the present form.

I am highly thankful to Dr. Rahul Chhibber for their invaluable guidance & morale boosting support from time to time. I am also thankful to Dr. Ajay Batish, Head of Department, Department of Mechanical Engineering, Dr. S.K Mohapatra, Dean of Academic Affairs and other faculty members and workshop staff of Mechanical Engineering Department, Thapar University, Patiala for their intellectual support.

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

Pulkit Bajaj
(800982019)

ABSTRACT

Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion resistance and wear, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of applications both from scientific and technological viewpoints. The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and Ceramics.

Present work is focused on the study of behaviour of Aluminium Cast Alloy (LM6) with SiC and Al_2O_3 composite produced by the stir casting technique. Different % age of reinforcement is used. Tensile test, Hardness Test, Impact test performed on the samples obtained by the stir casting process. X-ray Diffraction was performed to know the presence of the phases of reinforced material.

Hardness tester is employed to evaluate the interfacial bonding between the particles and the matrix by indenting the hardness with the constant load and constant time. X-ray Diffraction was performed to know the presence of the phases of reinforced material. Scanning electron microscopy was done to know the distribution of SiC/Alumina particles in Aluminium alloy.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 INTRODUCTION

The aim involved in designing metal matrix composite materials is to combine the desirable attributes of metals and ceramics. The addition of high strength, high modulus refractory particles to a ductile metal matrix produce a material whose mechanical properties are intermediate between the matrix alloy and the ceramic reinforcement. [1] Aluminium is the most abundant metal in the Earth's crust, and the third most abundant element, after oxygen and silicon. It makes up about 8% by weight of the Earth's solid surface. Due to easy availability, High strength to weight ratio, easy machinability, durable, ductile and malleability Aluminium is the most widely used non-ferrous metal in 2005 was 31.9 million tonnes. [2]

1.1.1 Advantages of Aluminium

I. Light Weight, Strong and Long-lasting

Aluminium is a very light metal with a specific weight of 2.7 gm/cm^3, about a third that of steel. For example the use of aluminium in vehicles reduces dead-weight and energy consumption while increasing load capacity. Its strength can be adapted to the application required by modifying the composition of its alloys. The application of light weight, strong and long lasting aluminium alloy is shown in Figure 1.1 & 1.2. [3]

Figure 1.1: Aluminium Used In Ship [3]

Figure 1.2: Aluminium Used In Aeroplane [3]

II. Highly Corrosion Resistant

Aluminium naturally generates a protective oxide coating and is highly corrosion resistant. It is particularly useful for applications where protection and conservation are required. The application of highly corrosion resistance aluminium alloy is shown in Figure 1.3 & 1.4[3].

Figure 1.3: Aluminium Used in Marine [3]

Figure 1.4: Aluminium Used in Industries [3]

III. Excellent Heat and Electricity Conductor

Aluminum is an excellent heat and electricity conductor and in relation to its weight is almost twice as good a conductor as copper. This has made aluminium the most commonly used material in major power transmission lines. The application of excellent heat and electricity conductor is shown in Figure 1.5. [3]

Figure 1.5: Aluminium Used in Wires [3]

IV. Good Reflective Properties

Aluminium is a good reflector of visible light as well as heat, and that together with its low weight makes it an ideal material for reflectors, for example, light fittings or rescue blankets. The application of good reflective properties is shown in Figure 1.6. [3].

Figure 1.6: Aluminium Used in Rescue Blanket [3]

V. Very Ductile

Aluminium is ductile and has a low melting point and density. In a molten condition it can be processed in a number of ways. Its ductility allows products of aluminium to be basically formed close to the end of the product. The application of ductility is shown in Figure 1.7. [3]

Figure 1.7: Aluminium Used as Bar [3]

VI. Completely Impermeable and Odourless

Aluminium foil, even when it is rolled to only 0.007 mm thickness, is still completely impermeable and let's neither light aroma nor taste substances out. Moreover, the metal itself is non-toxic and releases no aroma or taste substance which makes it ideal for packaging sensitive products such as food or pharmaceuticals. [3] The application of completely impermeable and odourless aluminium alloy is shown in Figure 1.8. [3]

Figure 1.8: Aluminium Used in Packaging [3]

VII. Totally Recyclable

Aluminium is 100 percent recyclable with no downgrading of its qualities. The re-melting of aluminium requires little energy: only about 5 percent of the energy required to produce the primary metal initially is needed in the recycling process. [3] Pure Aluminium has also some limits according to properties so to enhance Aluminium properties aluminium alloys are used.

1.2 ALUMINIUM ALLOYS

Selecting the right alloy for a given application entails considerations of its tensile strength, density, ductility, formability, workability, weld ability, and corrosion resistance. Aluminium alloys are alloys in which aluminium (Al) is the predominant metal.

The typical alloying elements are copper, magnesium, manganese, silicon, and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost effective products due to its low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al-Si, where the high levels of silicon (4.0% to 13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required. Wrought aluminium alloys are used in the shaping processes: rolling, forging, extrusion, pressing, stamping. Cast Aluminium alloys are comes after sand casting, permanent mould casting, die casting, investment casting, centrifugal casting, squeeze casting and continuous casting. Aluminium alloys are classified as shown in Figure 1.9. [4]

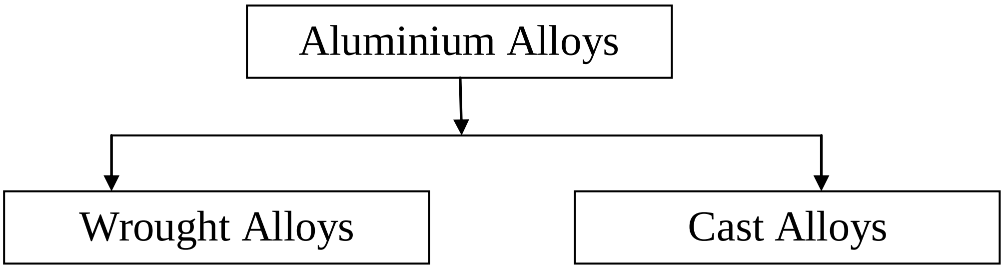


Figure 1.9: Classification of Aluminium Alloy

1.2.1 Cast Aluminium Alloys

Aluminium and its alloys are used in a variety of cast and wrought form and conditions of heat treatment. Forgings, sections, extrusions, sheets, plate, strip, foils and wire are some of the examples of wrought form while castings are available as sand, pressure and gravity die-castings e.g. Al-Si and Al-Mg alloys. [4] The designation of Cast Aluminium alloy is shown in Table 1.1.

Table 1.1: Designation of Cast Aluminium alloys [4]

Alloy Designation	Details
1XX.X	99% pure Aluminium
2XX.X	Cu containing alloy
3XX.X	Si, Cu/Mg containing alloy
4XX.X	Si containing alloy
5XX.X	Mg containing alloy
6XX.X	Zn containing alloy

1.2.2 Wrought Aluminium Alloys

To meet various requirements, aluminium is alloyed with copper, manganese, magnesium, zinc and silicon as major alloying elements. The designation of wrought aluminium alloy is shown in Table 1.2. [4]

Table 1.2: Designation of Wrought Aluminium alloys [4]

Alloy designation	Details
1XXX	99% pure Aluminium
2XXX	Cu containing alloy
3XXX	Mn containing alloy
4XXX	Si containing alloy
5XXX	Mg containing alloy
6XXX	Mg and Si containing alloy
7XXX	Zn containing alloy
8XXX	Other alloys

1.3 DESIGNATION OF ALUMINIUM ALLOYS

The Aluminium Association of America has classified the wrought aluminium alloys according to a four-digit system. The classification is adopted by the International Alloy Development System (IADS). Table 1.3 gives the basis of designation of wrought and cast aluminium alloys in the four-digit system. The first digit identifies the alloy type the second digit shows the specific alloy modification. The last two digits indicate the specific aluminium. Aluminium Alloy in present Thesis work is shown in Table 1.4.

Table 1.3: Temper Designation System [5]

Letter	Condition of alloy
F	As-fabricated
O	Annealed
T4	Solution treated
T6	Solution treated and aged

Table 1.4: Alloys conforms to British Standards 1490 LM6 Cast Aluminium [5]

Chemical Composition	Weight Percentage
Copper	0.1
Magnesium	0.10 max.
Silicon	11
Iron	0.6
Manganese	0.5 max
Nickel	0.1 max
Zinc	0.1 max
Tin	0.05 max
Titanium	0.2 max
Aluminium	Remainder

1.4 APPLICATION OF ALUMINUM ALLOY

The application of aluminium alloy is shown in Table 1.5

Table 1.5: Application of Aluminium alloys [6]

Aluminium Alloy	Alloy Characteristics	Common Use
1050/1200	Non heat-treatable. Good formability, weld ability and corrosion resistance	Food and Chemical Industry
2014	Heat-treatable. High strength. Non wieldable. Poor corrosion resistance	Airframes
5251/5052	Non-heat-treatable. Medium strength work hardening alloy. Good weld ability, formability and corrosion resistance.	Vehicle paneling, structures exposed to marine atmospheres, mine cages.
6063	Heat-treatable. Medium strength alloy. Good weld ability and corrosion resistance. Used for intricate profiles.	Architectural extrusions (internal and external) window frames, irrigation pipes.
6061/6082	Heat-treatable. Properties very similar to 6082. Preferable as air quenchable, therefore has less distortion problems. Not notch sensitive.	Stressed structural members, bridges, cranes, roof trusses, beer barrels
7075	Heat-treatable. Age hardens naturally, therefore will recover properties in heat-affected zone after welding. Susceptible to stress corrosion..	Armored vehicles, military bridges, motor cycle and bicycle frames

1.5 INTRODUCTION TO COMPOSITE MATERIALS

Composites are materials in which two phases are combined, usually with strong interfaces between them. They usually consist of a continuous phase called the matrix and discontinuous phase in the form of fibers, whiskers or particles called the reinforcement.

Considerable interest in composites has been generated in the past because many of their properties can be described by a combination of the individual properties of the constituent phases and the volume fraction in the mixture.

Composite materials are gaining wide spread acceptance due to their characteristics of behaviour with their high strength to weight ratio. The interest in metal matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Like all composites, aluminium matrix composites are not a single material but a family of materials whose stiffness, density and thermal and electrical properties can be tailored. composites materials are high stiffness and high strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc. The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. [7]

1.6 CLASSIFICATION OF COMPOSITES

Particulate composites consist of particles immersed in matrices such as alloys and ceramics. They are usually isotropic since the particles are added randomly. Particulate composites have advantages such as improved strength, increased operating temperature and oxidation resistance etc. Typical examples include use of aluminium particles in rubber, silicon carbide particles in aluminium. Flake composites provide advantages such as high out-of plane flexural modulus, higher strength, and low cost. [7]

1.6.1 Natural Composites

Several natural materials can be grouped under natural composites. E.g. bones, wood, shells, pearlite (steel which is mixture of a phase FeC). The example of Natural composites are shown in Figure 1.10 & 1.11.

Figure 1.10: Abalone shell ($CaCO_3$) [7]

Figure 1.11: Scallop shell [7]

1.6.2 Man-Made Composites

Man-made composites are produced by combining two or more materials in definite proportions under controlled conditions. e.g. Mud mixed straw to produce stronger mud mortar and bricks, Plywood, Chipboards, Decorative laminates etc. [7] The example of Man made composites are shown in Figure 1.12.

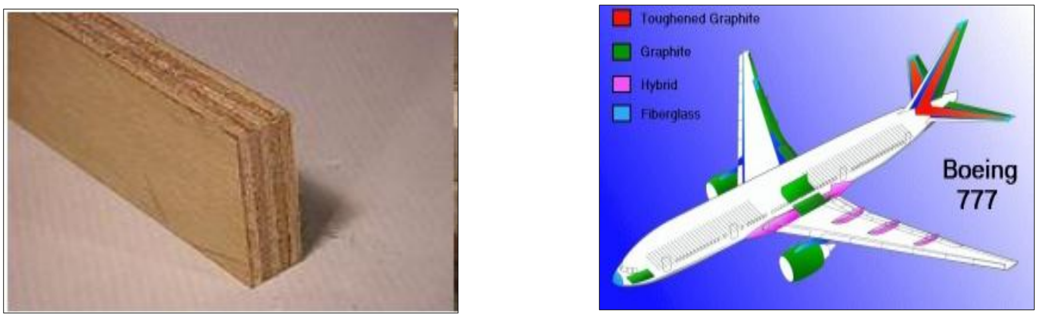


Figure 1.12: Man made composites used in Airplane and Plywood [7]

1.7 MATRIX (PRIMARY PHASE)

The selection of suitable matrix alloys is mainly determined by the intended application of the composite material.

I. For the development of light metal composite materials that are mostly easy to process, conventional light metal alloys are applied as matrix materials. Mainly Aluminium Alloy is used for Light weight Composites.

II. The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together.

III. In structural applications, the matrix is usually a lighter metal such as Aluminium, magnesium, or titanium, and provides a compliant support for the reinforcement. In high temperature applications, cobalt and cobalt-nickel alloy matrices are common. [8]

1.8 REINFORCEMENT (SECONDARY PHASE)

The reinforcement material is embedded into the matrix. The reinforcement does not always serve a purely structural task (reinforcing the compound), but is also used to change physical properties such as wear resistance, friction coefficient, or thermal conductivity. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of poly crystaline diamond tooling (PCD). Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers are embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength. One of the first MMCs used boron filament as reinforcement. Discontinuous reinforcement uses "whiskers", short fibers, or particles. The most common reinforcing materials in this category are alumina and silicon carbide [8].

Examples of some current application of composites include the tires, diesel piston, brake-shoes and pads. Examples of different reinforcement of aluminium alloy are shown in Table 1.6. The Al_2O_3 and SiC are used as reinforcement in present experimental work. Comparison between reinforced & unreinforced aluminium alloy is done in Table 1.7.

Table 1.6: Reinforcement of Aluminium Alloy [8]

Non Metallic	**Metallic**
Alumina	Beryllium
Boron	Niobium
Silicon Carbide	Stainless Steel

Table 1.7: Comparison between Reinforced & Un- Reinforced Aluminium Alloy [8]

Advantages	**Disadvantages**
Compared to Un- Reinforced Aluminium Alloys	
Higher Specific Strength	Lower toughness and ductility
Higher Specific Stiffness	More Expensive and complicated Production Method
Improved High Temperature Creep Resistance	
Improved Wear Resistance	
Compared To Polymer Matrix Composites	
Higher Transverse Strength	Less developed Technology
Higher Toughness	Smaller Database Technology
Higher Damage Tolerance	Higher Cost
Improved Environmental Resistance	
Higher Electrical and Thermal Conductivity	
Higher Temperature Capability	
Compared Ceramic Matrix Composites	
Higher Toughness and Ductility	Inferior High Temperature Capability
Ease of Fabrication	
Lower Cost	

1.9 PROCESSING OF MMCS

Accordingly to the temperature of the metallic matrix during processing the fabrication of MMCs can be classified into three categories:

(a) Liquid phase processes,

(b) Solid state processes, and

(c) Two phase (solid-liquid) processes

1.9.1 Liquid Metal Techniques

Liquid state fabrication of Metal Matrix Composites involves incorporation of dispersed phase into a molten matrix metal, followed by its Solidification. In order to provide high level of mechanical properties of the composite, good interfacial bonding (wetting) between the dispersed phase and the liquid matrix should be obtained. Wetting improvement may be achieved by coating the dispersed phase p articles (fibers). Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix. The simplest and the most cost effective method of liquid state fabrication is Stir Casting [9].

The methods of liquid state fabrication of Metal Matrix Composites are:

- Stir casting
- Infiltration
- Gas Pressure Infiltration
- Squeeze Casting Infiltration
- Pressure Die Infiltration
- Deposition Processes

1.9.1.1 Stir Casting Process

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 [9]. The Stir Casting set up is shown in Figure 1.13.

Figure 1.13: Stir casting set up

1.9.1.2 Infiltration

Infiltration is a liquid state method of composite materials fabrication, in which a preformed dispersed phase e.g. ceramic particles, fibers, are soaked in a molten matrix metal, which fills the space between the dispersed phase inclusions. The motive force of an infiltration process may be either capillary force of the dispersed phase or an external pressure applied to the liquid matrix phase. Infiltration is one of the methods of preparation of tungsten-copper composites. [9]

The principal steps of the technology are as follows:

- Tungsten powder preparation with average particle size of about 1-5 micron.
- Optional step: Coating the powder with nickel. Total nickel content is about 0.04%.
- Mixing the tungsten powder with a polymer binder.
- Compacting the powder by a molding method. Compaction should provide the predetermined porosity level of the tungsten structure.
- Solvent rebinding and sintering the green compact at 1204-1315°C in hydrogen atmosphere for 2 hrs. Placing the sintered part on a copper plate or powder in the infiltration/sintering furnace.
- Infiltration of the sintered tungsten skeleton porous structure with copper at 110-1260 °C in either hydrogen atmosphere or vacuum for 1 hour.

1.9.1.3 Gas Pressure Infiltration

Gas pressure infiltration is a forced infiltration method of liquid phase fabrication of metal matrix composites, using a pressurized gas for applying pressure on the molten metal and forcing it to penetrate into a preformed dispersed phase [9].

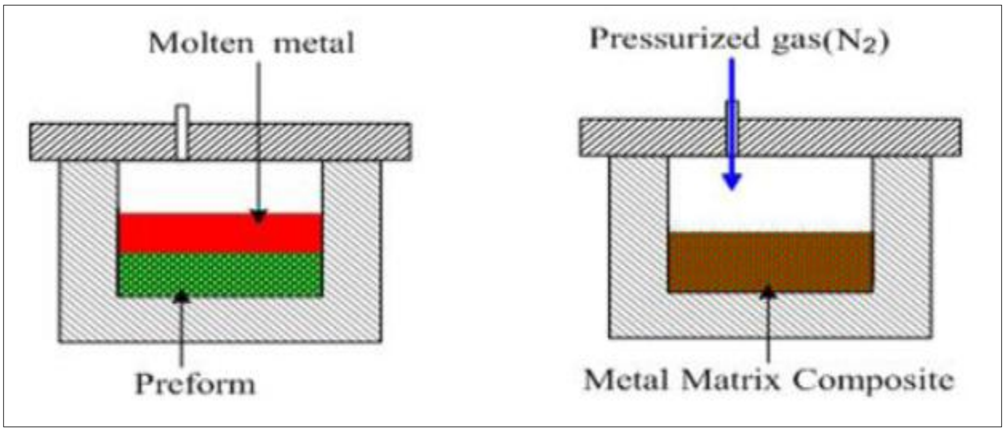


Figure 1.14: Gas Pressure Infiltration [9]

Gas Pressure Infiltration method is used for manufacturing large composite parts. This method allows using non-coated fibers due to short contact time of the fibers with the hot metal. In contrast to the methods using mechanical force, Gas Pressure Infiltration results in low damage of the fibers. The Figure 1.14 shows the Schematic view of Gas pressure infiltration.

1.9.1.4 Squeeze Casting Infiltration

Squeeze casting infiltration is a forced infiltration method of liquid phase fabrication of metal matrix composites, using a ram for applying pressure on the molten metal and forcing it to penetrate into a dispersed phase, placed into the lower fixed mold part. Squeeze casting [9]. Infiltration method is similar to the squeeze casting technique used for metal alloys casting. Figure 1.15 shows the Schematic view of squeeze casting Infiltration.

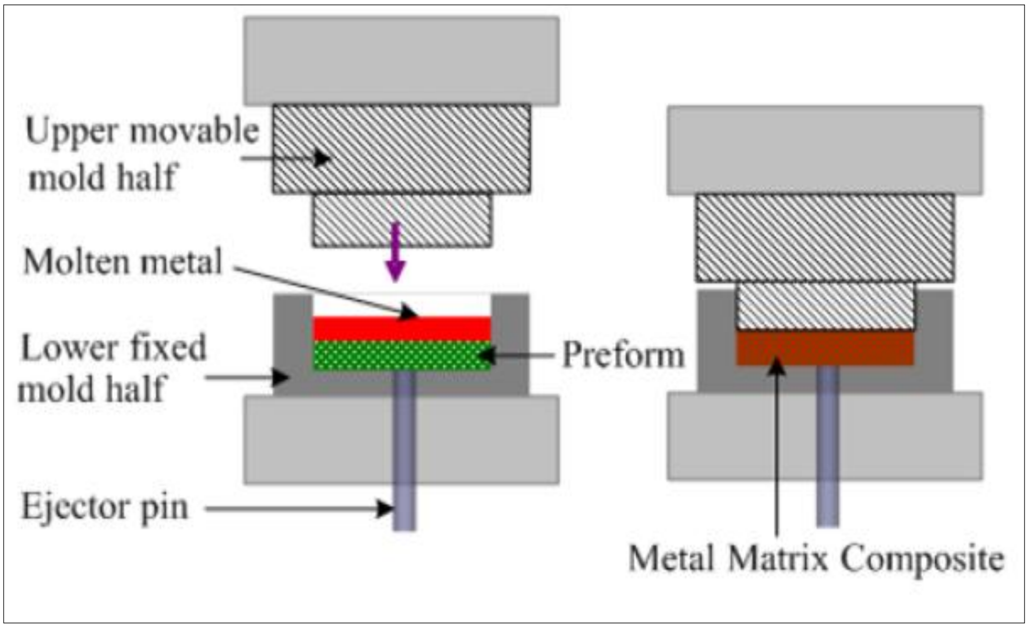


Figure 1.15: Squeeze Casting Infiltration [9]

Squeeze casting infiltration process has the following steps:

- A perform of dispersed phase is placed into the lower fixed mold half.
- A molten metal in a predetermined amount is poured into the lower mold half.
- The upper movable mold half (ram) moves downwards and forces the liquid metal to infiltrate the perform.
- The infiltrated material solidifies under the pressure.
- The part is removed from the mold by means of the ejector pin.

1.9.1.5 Pressure Die Infiltration

Pressure Die Infiltration is a forced infiltration method of liquid phase fabrication of Metal Matrix Composites, using a Die casting technology, when a preformed dispersed phase is placed into a die which is then filled with a molten metal entering the die through a sprue and penetrating into the perform under the pressure of a movable piston.[9]

1.10 SILICON CARBIDE AS REINFORCEMENT

Silicon Carbide is the only chemical compound of carbon and silicon. It was originally produced by a high temperature electro-chemical reaction of sand and carbon. Silicon carbide is an excellent abrasive and has been produced and made into grinding wheels and other abrasive products for over one hundred years. Today the material has been developed into a high quality technical grade ceramic with very good mechanical properties [10].

It is used in abrasives, refractoriness, ceramics, and numerous high-performance applications. The material can also be made an electrical conductor and has applications in resistance heating, flame igniters and electronic components. Silicon carbide is composed of tetrahedral of carbon and silicon atoms with strong bonds in the crystal lattice. This produces a very hard and strong material. Silicon particles are shown in Figure 1.16. [10]

Figure 1.16: Silicon Carbides as reinforcement [10]

1.10.1 Properties of Silicon Carbide

- Low density
- High strength
- Low thermal expansion
- High thermal conductivity
- High hardness
- High elastic modulus

- Excellent thermal shock resistance
- Superior chemical inertness

Detailed properties of SiC are shown in Table 1.8.

Table 1.8: Properties of Silicon Carbide

Properties	Value	Properties
Melting Point (°C)	2200-2700	Linear coefficient of expansion (10^{-6} K)
Limit of application (°C)	1400-1700	Fracture toughness (MPa-$m^{1/2}$)
Moh's Hardness	9	Crystal structure
Density (g/cm^3)	3.2	Linear coefficient of expansion (10^{-6} K)

1.11 ALUMINA AS REINFORCEMENT

Aluminium oxide, commonly referred to as alumina, possesses strong ionic inter atomic bonding giving rise to its desirable material characteristics. It can exist in several crystalline phases which all revert to the most stable hexagonal alpha phase at elevated temperatures. This is the phase of particular interest for structural applications and the material available from Accuratus. Alpha phase alumina is the strongest and stiffest of the oxide ceramics. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for a wide range of applications. High purity alumina is usable in both oxidizing and reducing atmospheres to 1925°C. Weight loss in vacuum ranges from 10^{-7} to 10^{-6} g/cm^2 sec over a temperature range of 1700° to 2000°C.

It resists attack by all gases except wet fluorine and is resistant to all common reagents except hydrofluoric acid and phosphoric acid. The composition of the ceramic body can be changed to enhance particular desirable material characteristics [11]. An example would be additions of chrome oxide or manganese oxide to improve hardness and change color. Other additions can be made to improve the ease and consistency of metal films fired to the ceramic for subsequent brazed and soldered assembly. Alumina particles are shown in Figure 1.17.

Figure 1.17: Alumina as reinforcement [11]

1.11.1 Properties of Alumina

Detailed properties of Alumina are shown in Table 1.9 are shown on next page. [11]

Table 1.9: Properties of Alumina

99.5% Aluminium Oxide		
Mechanical	**Unit of measure**	**SI Unit**
Density	gm/cc (lb/ft^3)	3.89
Porosity	%	0
Elastic	GPa	375
Shear	GPa	152
Bulk	GPa	228
Poisson's	-	0.22
Fracture	MPa•m$^{1/2}$	4
Hardness	Kg/mm^2	1440
Compressive	MPa	2600

1.12 TENSILE STRENGTH

Tensile properties dictate how the material will react to forces being applied in tension. A tensile test is a fundamental mechanical test where a carefully prepared specimen is loaded in a very controlled manner while measuring the applied load and the elongation of the specimen over some distance. Tensile tests are used to determine the modulus of elasticity, elastic limit, elongation, proportional limit, and reduction in area, tensile strength, yield point, yield strength and other tensile properties. The main product of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Since both the engineering stress and the engineering strain are obtained by dividing the load and elongation by constant values (specimen geometry information), the load-elongation curve will have the same shape as the engineering stress-strain curve. The stress-strain curve relates the applied stress to the resulting strain and each material has its own unique stress-strain curve. [12]

A typical engineering stress-strain curve is shown below Figure 1.18. If the true stress, based on the actual cross-sectional area of the specimen, is used, it is found that the stress-strain curve increases continuously up to fracture. They are tabulated for common materials such as alloys, composite materials, ceramics, plastics, and wood. Tensile strength is defined as a stress, which is measured as force per unit area. [12]

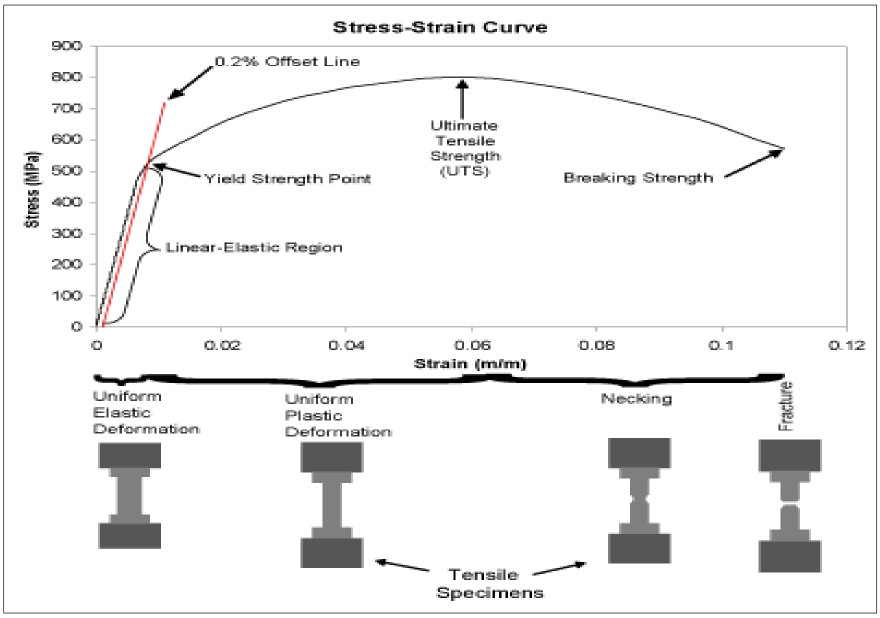


Figure 1.18: Stress Strain Curve of Ductile Material [12]

1.12.1 Yield Point

In ductile materials, at some point, the stress-strain curve deviates from the straight-line relationship and Law no longer applies as the strain increases faster than the stress. From this point on in the tensile test, some permanent deformation occurs in the specimen and the material is said to react plastically to any further increase in load or stress. The material will not return to its original, unstressed condition when the load is removed. In brittle materials, little or no plastic deformation occurs and the material fractures near the end of the linear-elastic portion of the curve [12].

With most materials there is a gradual transition from elastic to plastic behavior, and the exact point at which plastic deformation begins to occur is hard to determine. Therefore, various criteria for the initiation of yielding are used depending on the sensitivity of the strain measurements and the intended use of the data. For most engineering design and specification applications, the yield strength is used. The yield strength is defined as the stress required producing a small, amount of plastic deformation. The offset yield strength is the stress corresponding to the intersection of the stress-strain curve and a line parallel to the elastic part of the curve offset by a specified strain (in the US the offset is typically 0.2% for metals and 2% for plastics).

To determine the yield strength using this offset, the point is found on the strain axis (x-axis) of 0.002, and then a line parallel to the stress-strain line is drawn. This line will intersect the stress-strain line slightly after it begins to curve, and that intersection is defined as the yield strength with a 0.2% offset. A good way of looking at offset yield strength is that after a specimen has been loaded to its 0.2 percent offset yield strength and then unloaded it will be 0.2 percent longer than before the test. Even though the yield strength is meant to represent the exact point at which the material becomes permanently deformed, 0.2% elongation is considered to be a tolerable amount of sacrifice for the ease it creates in defining the yield strength [12].

Some materials such as gray cast iron or soft copper exhibit essentially no linear-elastic behavior. For these materials the usual practice is to define the yield strength as the stress required to produce some total amount of strain.

- **True elastic limit** is a very low value and is related to the motion of a few hundred dislocations. Micro strain measurements are required to detect strain on order of 2 x 10 -6 in/in.
- **Proportional limit** is the highest stress at which stress is directly proportional to strain. It is obtained by observing the deviation from the straight-line portion of the stress-strain curve.
- **Elastic limit** is the greatest stress the material can withstand without any measurable permanent strain remaining on the complete release of load. It is determined using a tedious incremental loading-unloading test procedure. With the sensitivity of strain measurements usually employed in engineering studies (10 - 4in/in), the elastic limit is greater than the proportional limit. With increasing sensitivity of strain measurement, the value of the elastic limit decreases until it eventually equals the true elastic limit determined from micro strain measurements.
- **Yield strength** is the stress required to produce a small-specified amount of plastic deformation. The yield strength obtained by an offset method is commonly used for engineering purposes because it avoids the practical difficulties of measuring the elastic limit or proportional limit.[12]

1.12.2 Ultimate Tensile Strength

The ultimate tensile strength (UTS) or, more simply, the tensile strength, is the maximum engineering stress level reached in a tension test. The strength of a material is its ability to withstand external forces without breaking. In brittle materials, the UTS will at the end of the linear-elastic portion of the stress-strain curve or close to the elastic limit. In ductile materials, the UTS will be well outside of the elastic portion into the plastic portion of the stress-strain curve. [12]

On the stress-strain curve above, the UTS is the highest point where the line is momentarily flat. Since the UTS is based on the engineering stress, it is often not the same as the breaking strength. In ductile materials strain hardening occurs and the stress will continue to increase until fracture occurs, but the engineering stress-strain curve may show a decline in the stress level before fracture occurs. This is the result of engineering stress being based on the original cross-section area and not accounting for the necking that commonly occurs in the test specimen. The UTS may not be completely representative of the highest level of stress that a material can support, but the value is not typically used in the design of components anyway [12].

For ductile metals the current design practice is to use the yield strength for sizing static components. However, since the UTS is easy to determine and quite reproducible, it is useful for the purposes of specifying a material and for quality control purposes. On the other hand, for brittle materials the design of a component may be based on the tensile strength of the material. [12]

1.12.2 Measures of Ductility (Elongation and Reduction of Area)

The ductility of a material is a measure of the extent to which a material will deform before fracture. The amount of ductility is an important factor when considering forming operations such as rolling and extrusion. It also provides an indication of how visible overload damage to a component might become before the component fractures. Ductility is also used a quality control measure to assess the level of impurities and proper processing of a material. [12]

The conventional measures of ductility are the engineering strain at fracture (usually called the elongation) and the reduction of area at fracture. Both of these properties are obtained by fitting the specimen back together after fracture and measuring the change in length and cross-sectional area. Fracture or breaking Point of ductile or brittle material is shown in Figure 1.19. [12]

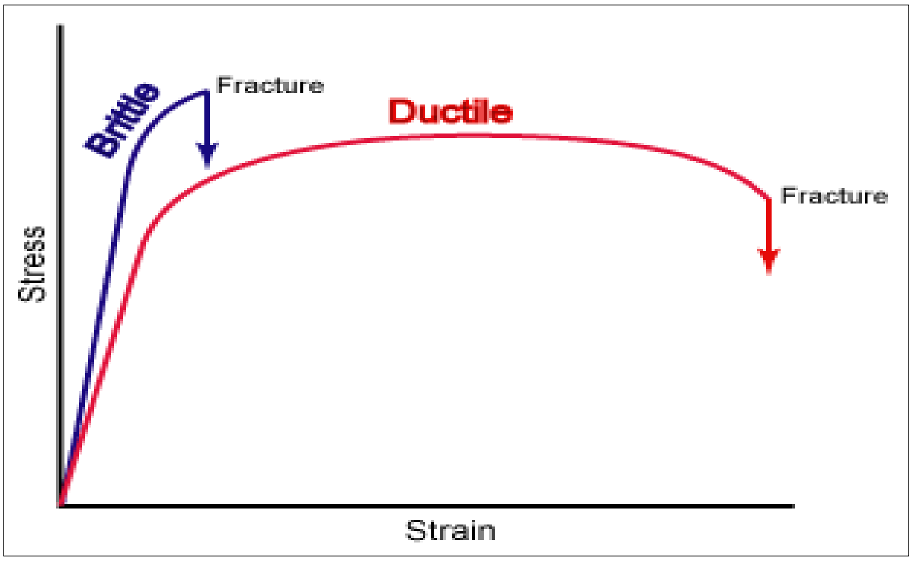


Figure 1.19: Fracture Point of Ductile and Brittle material[12]

Elongation is the change in axial length divided by the original length of the specimen or portion of the specimen. It is expressed as a percentage. Because an appreciable fraction of the plastic deformation will be concentrated in the necked region of the tensile specimen, the value of elongation will depend on the gage length over which the measurement is taken. The smaller the gage length the greater the large localized strain in the necked region will factor into the calculation. Therefore, when reporting values of elongation, the gage length should be given. One way to avoid the complication from necking is to base the elongation measurement on the uniform strain out to the point at which necking begins. This works well at times but some engineering stress-strain curve are often quite flat in the vicinity of maximum loading and it is difficult to precisely establish the strain when necking starts to occur. Reduction of area is the change in cross-sectional area divided by the original cross-sectional area. This change is measured in the necked down region of the specimen. Like elongation, it is usually expressed as a percentage. [12]

1.13 HARDNESS

Hardness is the resistance of a material to localized deformation. The term can apply to deformation from indentation, scratching, cutting or bending. In metals, ceramics and most polymers, the deformation considered is plastic deformation of the surface. For elastomers and some polymers, hardness is defined at the resistance to elastic deformation of the surface. The lack of a fundamental definition indicates that hardness is not be a basic property of a material, but rather a composite one with contributions from the yield strength, work hardening, true tensile strength, modulus, and others factors. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be nondestructive tests when the marks or indentations produced by the test are in low stress areas. There are a large variety of methods used for determining the hardness of a substance. A few of the more common methods are introduced below. [13]

1.14 TOUGHNESS

The ability of a metal to deform plastically and to absorb energy in the process before fracture is termed toughness. The emphasis of this definition should be placed on the ability to absorb energy before fracture. Recall that ductility is a measure of how much something deforms plastically before fracture, but just because a material is ductile does not make it tough. The key to toughness is a good combination of strength and ductility. A material with high strength and high ductility will have more toughness than a material with low strength and high ductility. Therefore, one way to measure toughness is by calculating the area under the stress strain curve from a tensile test. This value is simply called “material toughness” and it has units of energy per volume. Material toughness equates to a slow absorption of energy by the material. There are several variables that have a profound influence on the toughness of a material. These variables are:

- Strain rate (rate of loading)
- Temperature
- Notch effect

A metal may possess satisfactory toughness under static loads but may fail under dynamic loads or impact. As a rule ductility and, therefore, toughness decrease as the rate of loading increases. Temperature is the second variable to have a major influence on its toughness. As temperature is lowered, the ductility and toughness also decrease. The third variable is termed notch effect, has to due with the distribution of stress. [14]

1.14.1 Impact Toughness

The impact toughness of a material can be determined with a Charpy or Izod test. Impact properties are not directly used in fracture mechanics calculations, but the economical impact tests continue to be used as a quality control method to notch sensitivity and for comparing the relative toughness of engineering materials. For both tests, the specimen is broken by a single overload event due to the impact of the pendulum. A stop pointer is used to record how far the pendulum swings back up after fracturing the specimen. The impact toughness of a metal is determined by measuring the energy absorbed in the fracture of the specimen.

This is simply obtained by noting the height at which the pendulum is released and the height to which the pendulum swings after it has struck the specimen. The height of the pendulum times the weight of the pendulum produces the potential energy and the difference in potential energy of the pendulum at the start and the end of the test is equal to the absorbed energy. Since toughness is greatly affected by temperature, a Charpy or Izod test is often repeated numerous times with each specimen tested at a different temperature. This produces a graph of impact toughness for the material as a function of temperature.

Impact toughness versus temperature graph for steel is shown in the Figure 1.20. It can be seen that at low temperatures the material is more brittle and impact toughness is low. At high temperatures the material is more ductile and impact toughness is higher. Izod Charpy test machine is used in Figure 1.21. [14]

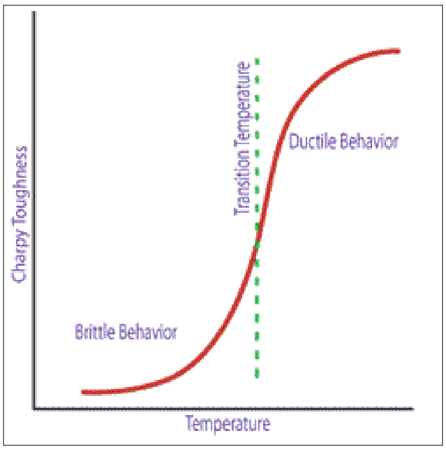


Figure 1.20: Temperature Vs Toughness Graph [14]

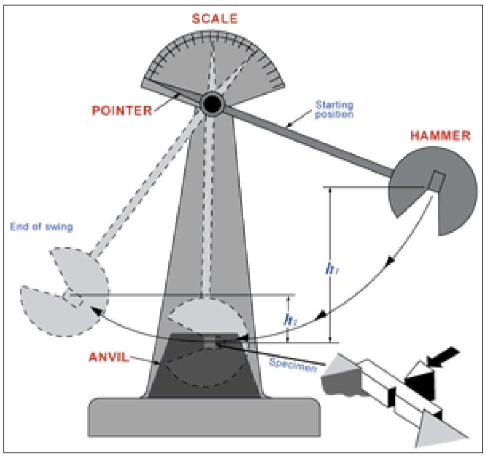


Figure 1.21: Izod Charpy Test Machine [14]

1.15 X-RAY POWDER DIFFRACTION

X-ray diffraction relies on the dual wave/particle nature of X-rays to obtain information about the structure of crystalline materials. A primary use of the technique is the identification and characterization of compounds based on their diffraction pattern.The dominant effect that occurs when an incident beam of monochromatic X-rays interacts with a target material is scattering of those X-rays from atoms within the target material. In materials with regular structure (i.e. crystalline), the scattered X-rays undergo constructive and destructive interference. This is the process of diffraction. The diffraction of X-rays by crystals is described by Bragg's Law, $n\lambda=2d \sin\Theta$. The directions of possible diffractions depend on the size and shape of the unit cell of the material. The intensities of the diffracted waves depend on the kind and arrangement of atoms in the crystal structure. However, most materials are not single crystals, but are composed of many tiny crystallites in all possible orientations called a polycrystalline aggregate or powder. When a powder with randomly oriented crystallites is placed in an X-ray beam, the beam will see all possible inter atomic planes. If the experimental angle is systematically changed, all possible diffraction peaks from the powder will be detected. The focusing (or Bragg-Brentano) diffractometer is the most common geometry for diffraction instruments.

This geometry offers the advantages of high resolution and high beam intensity analysis at the cost of very precise alignment requirements and carefully prepared samples. Additionally, this geometry requires that the source-to-sample distance be constant and equal to the sample-to-detector distance. Alignment errors often lead to difficulties in phase identification and improper quantification. A mis-positioned sample can lead to unacceptable specimen displacement errors. Sample flatness, roughness, and positioning constraints preclude in-line sample measurement. Additionally, traditional XRD systems are often based on bulky equipment with high power requirements as well as employing high powered X-ray sources to increase X-ray flux on the sample, therefore increasing the detected diffraction signals from the sample. These sources also have large excitation areas, which are often disadvantageous for the diffraction analysis of small samples or small sample features.

Polycapillary X-ray optics can be used to overcome many of these drawbacks and constraints to enhance XRD applications. Polycapillary collimating optics convert a highly divergent beam into a quasi-parallel beam with low divergence. They can be used to form a Parallel Beam XRD instrument geometry which greatly reduces and removes many sources of errors in peak position and intensity inherent to the parafocusing geometry, such as sample position, shape, roughness, flatness, and transparency. Polycapillary focusing optics collect X-rays from a divergent X-ray source and direct them to a small focused beam at the sample surface with diameters as small as tens of micrometers for micro X-ray diffraction applications of small samples or small specimen features. Both types of polycapillary optics direct very high X-ray intensities to the sample surface, such that XRD systems employing optics can use low power X-ray sources, reducing instrument size, cost, and power requirements. [15]

X-ray diffraction using X-ray optics has been applied to many different types of applications including thin film analysis, sample texture evaluation, monitoring of crystalline phase and structure, and investigation of sample stress and strain.

When a focused X-ray beam interacts with these planes of atoms, part of the beam is transmitted, part is absorbed by the sample, part is refracted and scattered, and part is diffracted. This high voltage accelerates the electrons, which then hit a target, commonly made of copper. When these electrons hit the target, X-rays are produced. The wavelength of these X rays is characteristic of that target. These X-rays are collimated and directed onto the sample, which has been ground to a fine powder (typically to produce particle sizes of less than 10 microns). A detector detects the X-ray signal; the signal is then processed either by a microprocessor or electronically, converting the signal to a count rate. Changing the angle between the X-ray source, the sample, and the detector at a controlled rate between preset limits is an X-ray scan. When an X-ray beam hits a sample and is diffracted, we can measure the distances between the planes of the atoms. [15]

1.16 SCANNING ELECTRON MICROSCOPE (SEM)

SEM stands for scanning electron microscope. The SEM is a microscope that uses electrons instead of light to form an image. Since their development in the early 1950's, scanning electron microscopes have developed new areas of study in the medical and physical science communities. The SEM has allowed researchers to examine a much bigger variety of specimens.SEM working i.s shown in Figure 1.22 & 1.23

The scanning electron microscope has many advantages over traditional microscopes. The SEM has a large depth of field, which allows more of a specimen to be in focus at one time. The SEM also has much higher resolution, so closely spaced specimens can be magnified at much higher levels. Because the SEM uses electromagnets rather than lenses, the researcher has much more control in the degree of magnification. All of these advantages, as well as the actual strikingly clear images, make the scanning electron microscope one of the most useful instruments in research today.

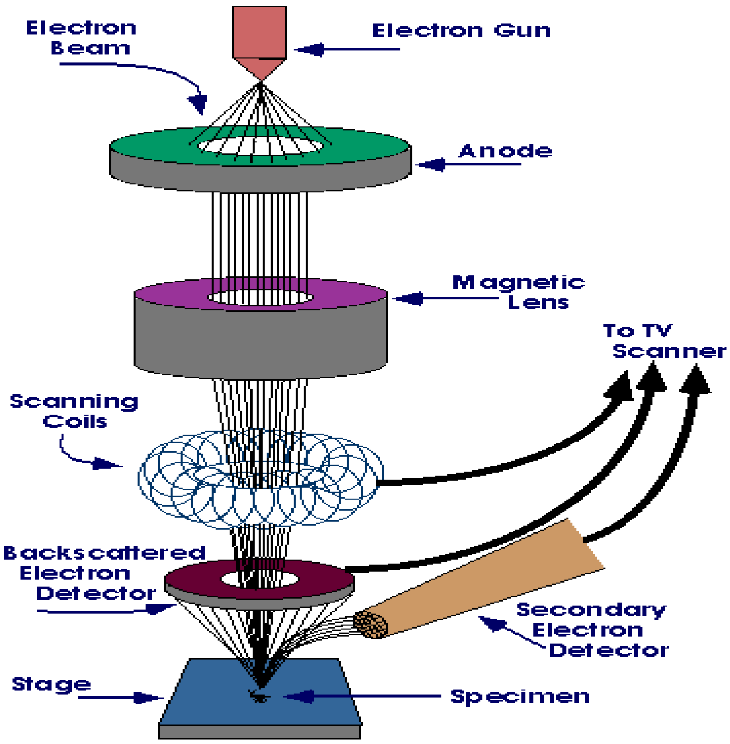


Figure 1.22: SEM working [16]

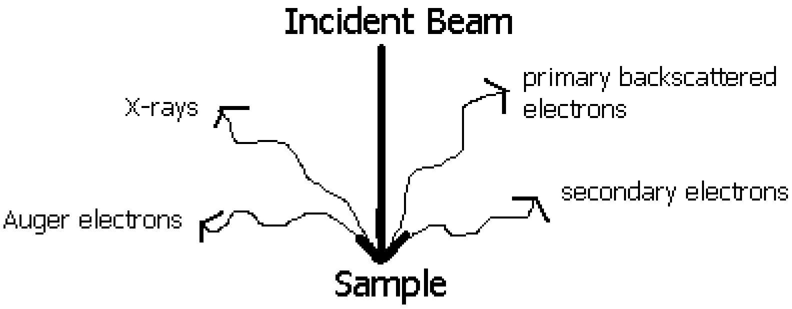


Figure 1.23: SEM beam [16]

Detectors collect these X-rays, backscattered electrons, and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen. This produces the final image. [16]

CHAPTER 2 LITERATURE REVIEW

This chapter presents a review of the literature data available on the effect of various reinforcement types, their size and volume fraction, ageing behavior with Al based MMC's. Metal matrix composites are a combination of two phases, matrix and the reinforcement. Matrices can be selected from a number of Aluminium alloys e.g. AA 2000, 6000, 7000, A356 and many reinforcement types SiC, B_4C, Al_2O_3, AlN, and C etc. are available in different sizes, morphologies (particulates, short fibers, long fibers and platelets) and volume fractions. These reinforcements can be combined with the different matrices, resulting in large composite systems. Furthermore, several different processing routes, such as powder metallurgy, stir casting, squeeze casting, hot extrusion etc.

N. Chawla, J.J. Williams, G. Piotrowski, and R. Saha [2003] [12]

Authors investigated the tensile strength processes in discontinuously reinforced aluminium (DRA).In this experiment author varies the average particle size (6-23 micro meter), Heat treatment is also given. Conclusion of this paper is that as particle size increases Tensile strength decreases. Heat treatment increases the tensile strength.

Manoj Singla, D. Deepak Dwivedi, Lakhvir Singh, Vikas Chawla[2009] [17]

In this author studied to develop aluminium based silicon carbide particulate MMCs with an objective to develop a conventional low cost method of producing MMCs and to obtain homogenous dispersion of ceramic material. To achieve these objectives two method of stir casting technique has been adopted and subsequent property analysis has been made. Aluminium (98.41% C.P) and SiC (320-grit) has been chosen as matrix and reinforcement material respectively. Experiments have been conducted by varying weight fraction of SiC (5%, 10%, 15%, 20%, 25%, and 30%), while keeping all other parameters constant. An increasing trend of hardness and impact strength with increase in weight percentage of SiC has been observed. The best results (maximum hardness 45.5 BHN & maximum impact strength of 36 N-m.) have been obtained at 25% weight fraction of SiCp.

I. A. Ibrahim, F. A. Mohamed, E. J. Lavernia [2001] [18]

In this review author studied the mechanical properties that can be obtained with metal matrix composites by varying reinforcement percentage by 0, 10, 15, 20% and taking different alloy AA 6061, AA 2014, AA 356. Conclusion of this paper is by increasing reinforcement % age yield strength, ultimate strength is increasing but elongation of a Alloy decreases.

D. J. Lloyd [1994] [19]

This review has primarily been concerned with the factors influencing the micro structural, mechanical properties relationship of composites shows the effect of different reinforcement. In this author study different reinforcement effect on different alloy are considered. Conclusions of this paper are elongation of composites decreases as increases percentage of reinforcement and tensile strength are increases.

L. Ceschini , G. Minak , A. Morri [2005] [20]

In this paper, the tensile properties and the low-cycle fatigue behavior of the 7005 aluminium alloy reinforced with 10 volume % of Al_2O_3 particles and 6061 aluminium alloy reinforced with 20 volume % of Al_2O_3 particles were studied. The tensile ductility was strongly affected by the material in homogeneity, mainly related to the particles size and distribution. No significant variation of the tensile strength and ductility with temperature was observed up to 150^oC, while at 250^oC strength significantly decreased, and ductility increased.

S.V. Prasad and R. Asthana[2004] [21]

This paper gives an overview of the tribological behavior of Al MMCs reinforced with hard particles, short fibers, and solid lubricants, and the technologies for producing automotive parts from these novel materials. The emphasis has been on developing affordable Al MMCs, reinforced with SiC and Al2O3, that will reduce the weight and increase the engine efficiency, and thereby reduce fuel consumption and vehicle emissions.. Considerable reduction in wear and friction is achieved by use of these particulates. Furthermore, increased cylinder pressures (and therefore, higher engine performance) are possible because Al MMCs can withstand high mechanical and thermal loads, and reduce heat losses by permitting closer fit that can be achieved because of lower thermal expansion coefficient of Aluminum MMCs.

P.K Rohatgi, J.K Kim, R.Q.Guo, D.P.Robertson, and M.Gajdardziska[2002] [22]

Investigated the effect of aging characteristics of aluminium alloy A356 and an aluminium alloy A356 containing hollow spherical fly ash particles were studied using optical microscopy, transmission electron microscopy (TEM), energy dispersive X-ray (EDX) spectroscopy, hardness tests, and compressive tests.. As the density of the composite is lower than that of the base alloy due to the presence of hollow particles, the composites have a higher specific strength and specific hardness compared to the matrix. Even though the hardness of the as-cast composite was higher than that of the base alloy, no significant change in the aging kinetics was observed, due to the presence of spherical fly ash particles in the matrix. Aging times of the order of 104 to 105 seconds were required to reach the peak hardness (92 HRF) and compressive strength (376 MPa) in both the A356–5 wt. % fly ash composite and the matrix alloy.

The possible effects of shape and hollowness of particles, the interface between the matrix and the particles, the low modulus of the particles, and the micro cracks formed on the surface o f hollow fly ash particles on the kinetics of the age hardening of aluminium alloy A356.

S. Balasivanandha Prabu,L. Karunamoorthy, S. Kathiresan, B. Mohan[2006] [23]

In the present study, high silicon content aluminium alloy–silicon carbide metal matrix composite material, with 10% SiC were successfully synthesized, using different stirring speeds and stirring times. The microstructure of the produced composites was examined by optical microscope and scanning electron microscope. The Brinell hardness test was performed. Increase in stirring speed and stirring time resulted in better distribution of particles.

The hardness test results also revealed that stirring speed and stirring time have their effect on the hardness of the composite. The uniform hardness values were achieved at 600 rpm with 10 min stirring. But beyond certain stir speed the properties degraded again.

M. Kok[2004] [24]

In this author examined AA 2024 aluminium alloy metal matrix composites (MMCs) reinforced with three different sizes and weight fractions of Al_2O_3 particles up to 30 wt. % were fabricated by a vortex method and subsequent applied pressure. The effects of Al_2O_3 particle content and size of particle on the mechanical properties of the composites such as hardness and tensile strength were investigated. Scanning electron microscopic observations of the microstructures revealed that the dispersion of the coarser sizes of particles was more uniform while finer particles led to agglomeration of the particles and porosity. The results show that the hardness and the tensile strength of the composites increased with decreasing size and increasing weight fraction of particles.

G. B. Veeresh Kumar1, C. S. P. Rao, N. Selvaraj, M. S. Bhagyashekar[2010] [25]

Author examine the base matrix and the reinforcing phase for the present studies selected were AA 6061, AA 7075 and particles of Al_2O_3 and SiC of size 20 μm. It can be observed that the densities of composites are higher than that of their base matrix, further the density increases with increased percentage of filler content in the composites. it can be observed that the tensile strength of the composites are higher than that of their base matrix also it can be observed that the increase in the filler content contributes in increasing the tensile strength of the composite. In microstructure studies it can be observed that, the distributions of reinforcements in the respective matrix are fairly uniform.

Daniel B. Miracle [2000] [26]

In Air Force Research Laboratory author studied 6092/SiC/17.5p & 2009/SiC/15p-T4 for F16 aircraft Door and body purposes. It can be observed that the densities of composites are higher than that of their base matrix, further the density increases with increased percentage of filler content in the composites.

A. Daouda, W. Reif [2002] [27]

The author had studied the influence of Al2O3 particulates on the precipitation and hardening behavior of the A356 Al_2O_3 composites**.** It was found that the $MgAl_2O_3$ spinel formed at the interface led to Mg depletion in the matrix and subsequently to lesser age hardening in the composites. Therefore, it was necessary for the composite matrix to have a higher Mg concentration prior to casting to achieve the same level of hardening in the composite as in the unreinforced. The hardening kinetics is enhanced by Al2O particulates because the precipitation preferentially develops on the dislocation lines that increased due to coefficient of thermal expansion mismatch between the matrix and reinforcement.

Hailong Wang [2008] [28]

The author was investigated; SiC particulate-reinforced Al composites were prepared by powder metallurgy (PM) method and conventional atmospheric sintering. Scanning electron microscope (SEM), X-ray diffraction (XRD) techniques were used to characterize the sintered composites. The effect of temperature on the density, hardness, strength, and microstructure of composites. Detailed failure behavior was analyzed. They had found that the segregation of SiC appeared at higher temperature. The highest micro hardness of 80MPa occurred at 700◦ C. The strength tended to increase with the increasing temperature due to the formation of Al_2Cu. Both ductile and brittle fracture features were observed.

Z. M. El-Baradie [2007] [29]

Investigated 7020 aluminium alloy unreinforced and reinforced with 5 and 10% volume fraction SiC particulates. The aging behaviour of the unreinforced and reinforced materials was studied for both natural and artificial aging at 170°C. The results show that the incorporation of 5 and 10 vol. % of SiCp can be improved considerably by natural or artificial aging. Also, the effect of deformation for both unreinforced and composite alloys was studied. The results show that the deformation altered the aging precipitation sequence significantly the greater the deformation, the higher the dislocation densities and hence, the faster the precipitation. Generally, deformation accelerated aging and hence, peak hardness occurred earlier. Also, appreciable increase in hardness and faster kinetics were obtained by the introduction of thermomechanical processing to these alloys.

2.2 GAPS FOUND FROM LITERATURE

The extensive review of literature carried out for the present study reveals that a lot of work has been reported to enhance the properties of Aluminium metal matrix composites through stir casting or by any other process. The work carried out by different researchers can be categorized in to the following broad classes:

I. Very limited amount of work has been reported which explains the factors affecting mechanical properties like Tensile strength and Impact strength of Aluminium matrix composites.

II. Very limited work on combined effect of Alumina and Silicon Carbides on aluminium metal matrix composites properties have done.

CHAPTER 3 PROBLEM FORMULATION

3.1 OBJECTIVES OF PRESENT WORK

The problem is to study the tensile strength behaviour of Al-SiC/Alumina metal matrix composite (MMC) of aluminium alloy of grade LM6 with addition of varying percentage composition of SiC particles and Alumina made by stir casting technique. The tensile strength and Toughness, Hardness like mechanical properties will also be taken into consideration. For the achievement of the above, an experimental set up is prepared where all the necessary inputs were made. The aim of the experiment is to study the effect of variation of the percentage composition to predict the mechanical properties of the metal matrix composites (MMC). The experiment was carried out by preparing the sample of different percentage composition by stir casting technique. The present work emphasizes the literature review of Al-Si alloys and its composites. There are many manufacturing processes to form composites commercially. But the technique adopted here is rapid solidification process. The stir forming is newly developed technique and still under progress for its commercialization in developing countries like India. The objectives of present proposal are as follows:

- To prepare the cost-effective MMC material by taking Al-Si alloy with matrix ceramic particulate like silicon carbide as reinforced phase using stir casting technique.
- To analyze the micro structural characteristics of the as cast material.
- Tensile strength, Impact strength & Hardness measurements of the as prepared MMCs.

4.1 EXPERIMENTAL SET UP USED IN STIR CASTING OPERATION

Equipments used to perform the Stir Casting operation and testing of composites is shown in Table 4.1.

Table 4.1: List of Equipment used for Stir Casting Operation

S. No.	Equipments Used	S. No.	Equipments Used
1	Radial drilling machine	6	Universal Testing Machine
2	Graphite Crucible/ mould	7	Hardness testing machine
3	Graphite Stirrer	8	Scanning electron microscope
4	Muffle Furnace	9	Power Hacksaw
5	Stainless steel rod (SS316) of diameter 12mm, Length 600mm	10	Impact Toughness Machine

The equipments used during experimental work are shown in Figure 4.1 to Fig. 4.9.

I. Muffle Furnace

Muffle Furnace was used to heat the material to desired temperatures by conduction, convection, or blackbody radiation from electrical resistance heating elements. A muffle furnace (sometimes, retort furnace) in historical usage is a furnace in which the subject material is isolated from the fuel and all of the products of combustion including gases and flying ash. In our muffle furnace which is shown in Figure 4.1 maximum temperature of 1100°C. was achieved.

Figure 4.1: Muffle Furnace

II. Stirrer

The function of a stirrer was to agitate liquids for speeding up reactions. Stirrer was designed to homogenous mixing of liquid, oilment, solution, viscous material and solid-liquid.

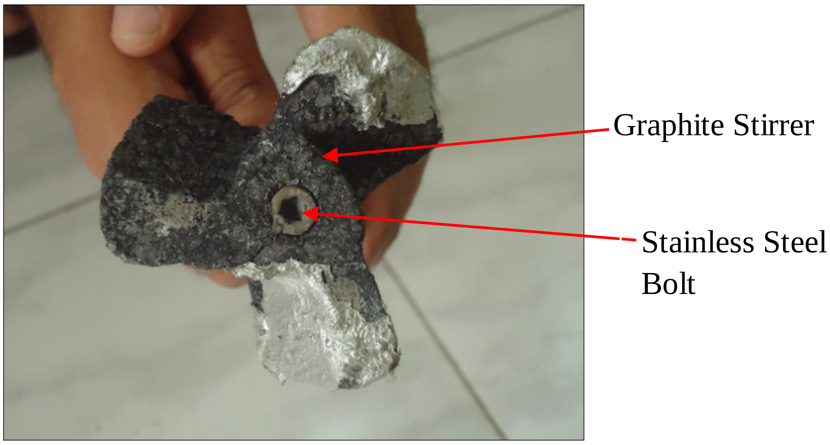


Figure 4.2 : Graphite Stirrer

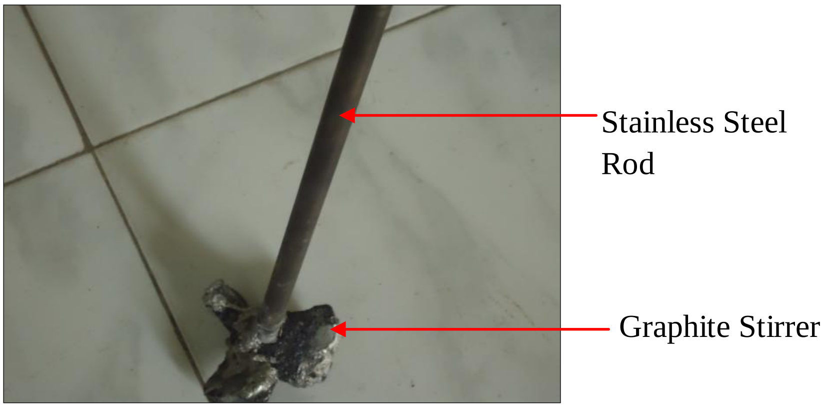


Figure 4.3 : Full View of Graphite Stirrer with Steel Rod

III. Sieve Analysis Tester

A sieve analysis was used to assess the particle size distribution of a granular material. The size distribution is often of critical importance to the way the material performs in use. A sieve analysis can be performed on any type of non-organic or organic granular materials including sands, crushed rock, clays, granite, feldspars, coal, soil, a wide range of manufactured powders, grain and seeds, down to a minimum size depending on the exact method. In this experiment SiC and Alumina particles of 100 micron size were used. Sieve analysis Tester was shown in Figure 4.4. was used to get desired granular size.

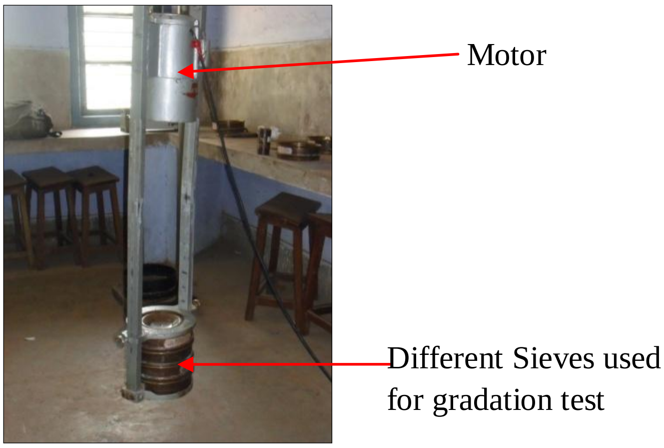


Figure 4.4: Sieve Analysis Tester

IV. Belt Grinder

Belt Grinder was used for resistant technology purposes to give a smooth, shiny finish to manufactured products (Aluminium Composites). Belt Grinder is shown below in Figure 4.5.

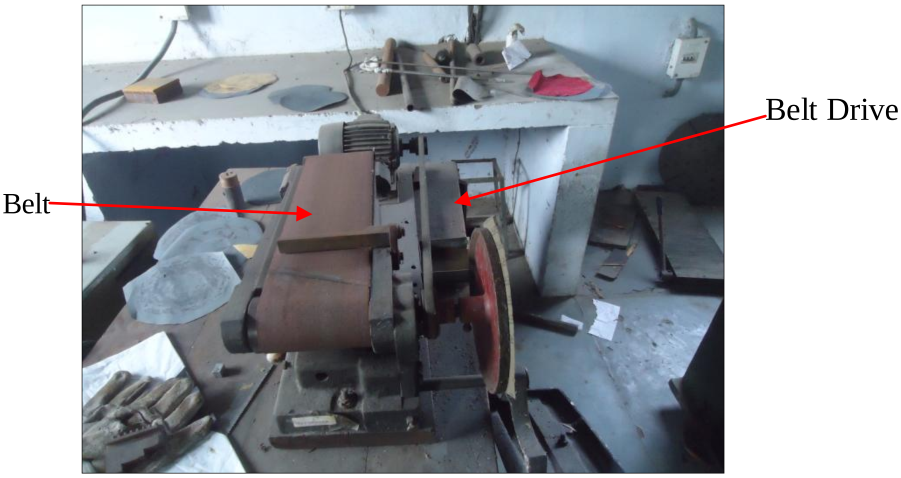


Figure 4.5: Belt Grinder:

V. Power Hack Saw

A power hacksaw (or electric hacksaw) was a type of hacksaw that was powered either by its own electric motor. A hacksaw is a fine-tooth saw with a blade under tension in a frame, used for cutting materials such as Aluminium alloy into small pieces so is to keep the alloy into crucible. Power hacksaw is shown in Figure 4.6.

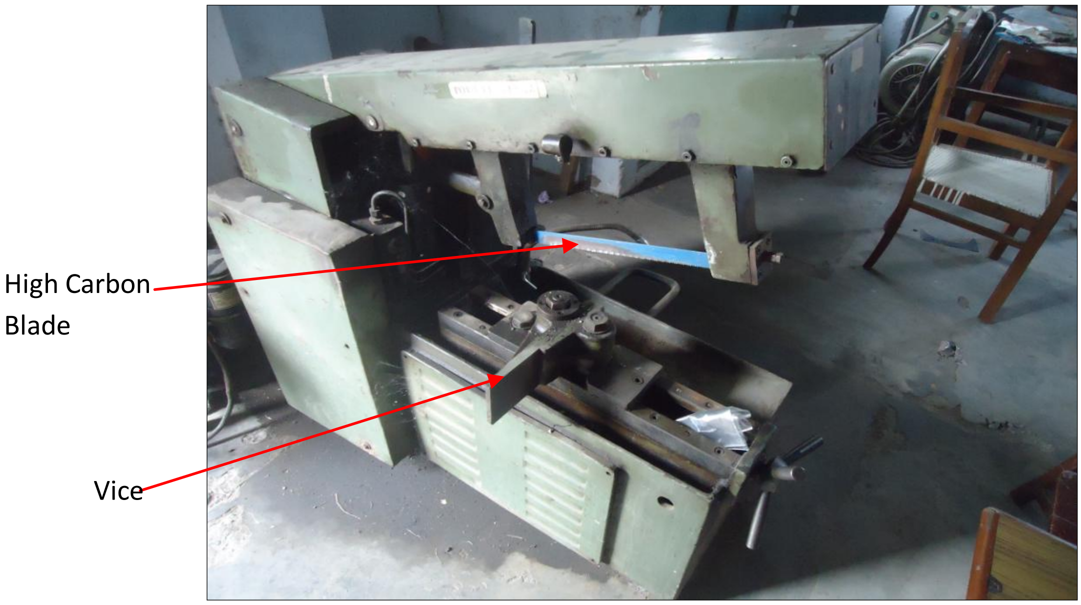


Figure 4.6: Power Hack Saw

VI. Drilling Machine

This machine was used for rotating Stirrer at different speeds as shown in Figure 4.7.

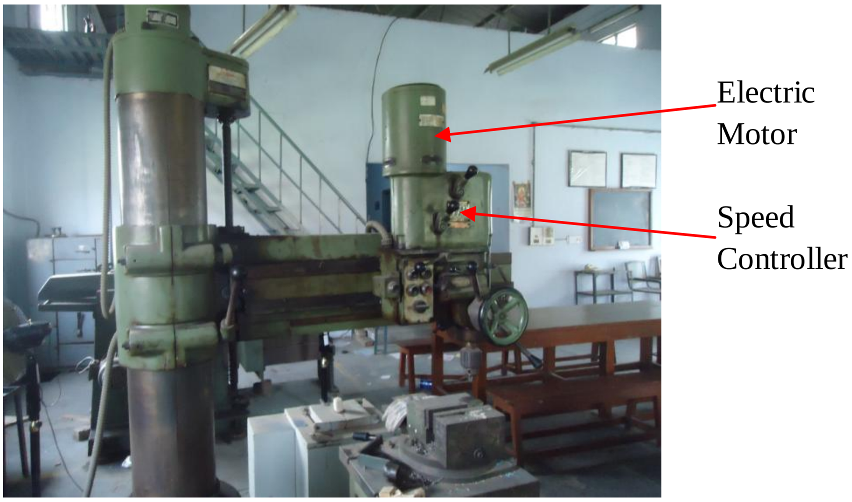


Figure 4.7: Drilling Machine used for Stirring Purpose

VIII. Graphite Crucible

A crucible is a refractory container used for metal, glass, and pigment production as well as a number of modern laboratory processes, which can withstand temperatures high enough to melt or otherwise alter its contents. Historically, they have usually been made of clay, but they can be made of any material with a higher temperature resistance than the substances they are designed to hold. Graphite crucible is shown in Figure 4.8.

Figure. 4.8: Graphite Crucible used to keep molten metal in muffle furnace

4.2 EXPERIMENTAL PROCEDURE

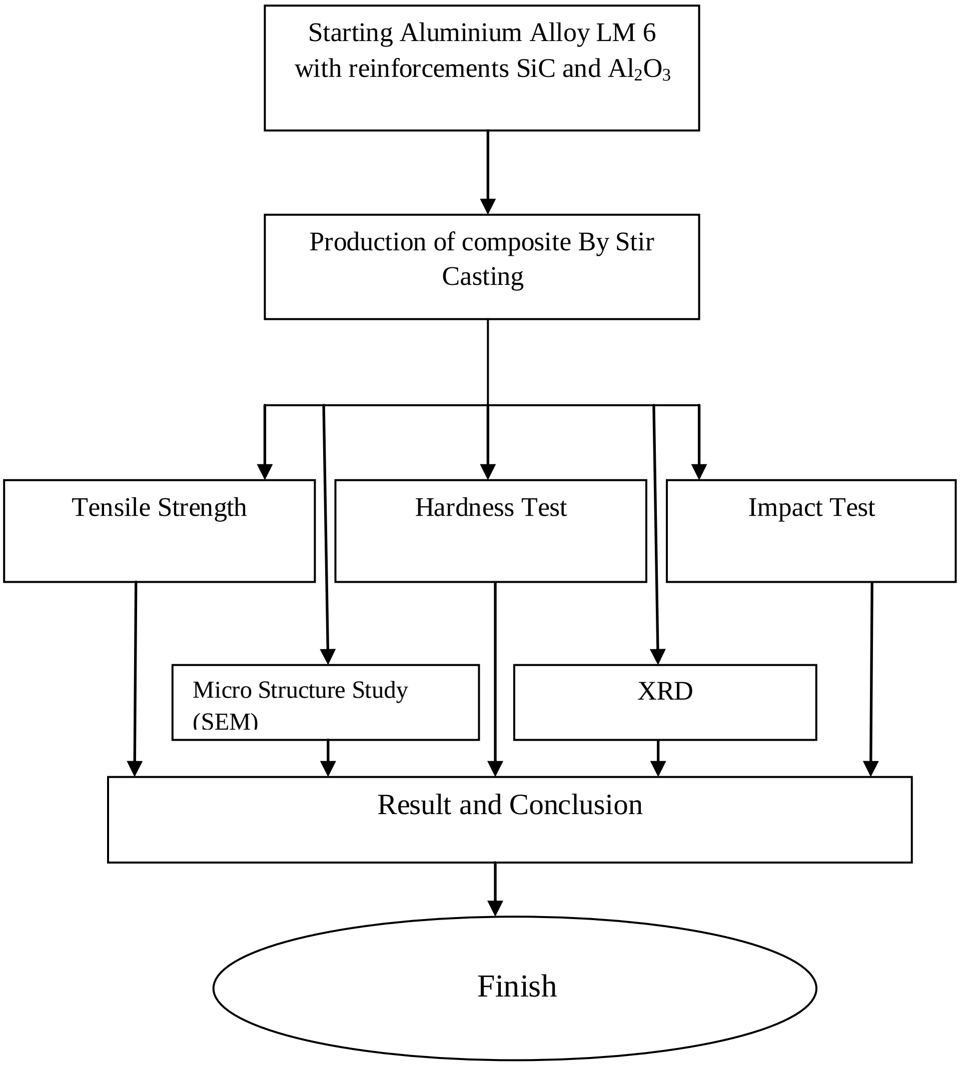


Figure 4.9: Flow Chart Experimental Techniques followed

4.2.1 Preparation of Samples

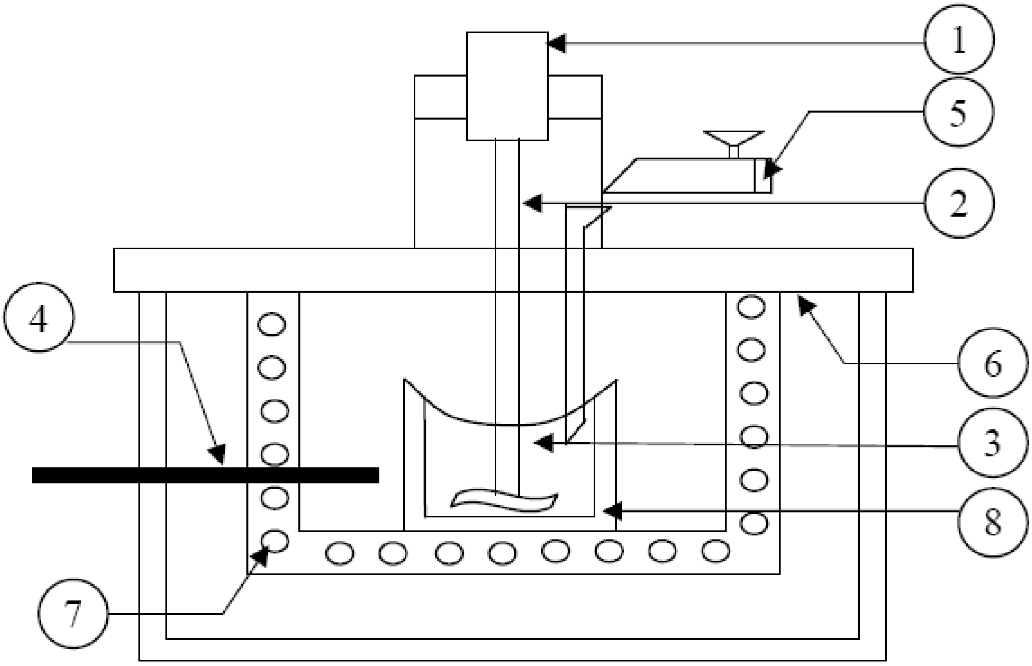


Figure 4.10: Schematic view of setup of Stir Casting [23]

1. Motor
2. Shaft
3. Molten Aluminium
4. Thermocouple
5. Particle Injection Chamber
6. Insulation Hard Chamber
7. Furnace
8. Graphite Crucible

Aluminium Alloy was melted in a crucible by heating it in a muffle furnace at 800°C for three to four hours. The silicon carbide particles and Alumina particles were preheated at 1000^oC and 900^oC respectively for one to three hours to make their surfaces oxidised. The furnace temperature was first raised above the liquidus temperature of Aluminium near about 750^oC to melt the Al alloy completely and was then cooled down just below the liquidus to keep the slurry in Semi solid state. Automatic stirring was carried out with the help of radial drilling machine for about 10 minutes at stirring rate of 290 RPM. At this stage, the preheated SiC particles and Alumina particles were added manually to the vortex. In the final mixing processes the furnace temperature was controlled within 700 ± 10^oC. After stirring process the mixture was pour in the other mould to get desired shape of specimen as shown in Figure 4.10. The presence of reinforcement throughout the specimen was inspected by cutting the casting at different locations and under microscopic examination. Same process was used for specimens with different compositions of SiC and Alumina. Compositions of samples are shown in Table 4.2.

Figure 4.10: Mould and cast product after casting

4.2.2 Following procedure was followed after the casting preparation

1. Specimens, prismatic in shape with dimensions 10 mm × 10 mm × 10 mm for SEM, XRD, Tensile strength specimen , Impact strength specimen 55×10×10, micro structure and with dimensions 300 mm x 60mm x 30 mm (l x b x t) respectively were cut from the cast composite.
2. Hardness of specimen was measured on hardness testing machine.
3. The SEM and XRD analysis was done for the samples.
4. Tensile Strength measure in Universal Testing Machine
6. Analyzing the microstructure of the specimens by SEM before the corrosion and after the corrosion.
7. Impact strength measure by Izod & Charpy Machine

Table 4.2: Composition of Samples

Composition				
Sample No.	Aluminium(gm)	SiC(gm)	Zircon(gm)	Remarks
1	1100	0	0	Weight of sample=1000 gm
2	990	26	0	SiC=2.5%
3	1050	55	0	SiC=5%
4	925	75	0	SiC=7.5%
5	1100	122	0	SiC=10%
6	975	0	25	Alumina=2.5%
7	990	0	52	Alumina =5%

8	1050	0	85	Alumina =7.5%
9	900	0	100	Alumina =10%
10	1020	27	27	SiC=2.5%+ Alumina =2.5%
11	1120	62	62	SiC=5%+ Alumina =5%
12	950	84	84	SiC=7.5%+ Alumina =7.5%
13	900	108	108	SiC=10%+ Alumina =10%

CHAPTER 5 RESULTS AND DISCUSSION

5.1 IMPACT TEST RESULTS

The Charpy impact test, also known as the Charpy v-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness.

Table 5.1: Results of Impact Test

Serial No	Composites	Trial						Average Force Nm
		1	2	3	4	5	Total Force Nm	
1	Aluminum Alloy (LM6)	6.2	6.1	5.9	5.6	5.5	29.3	5.86
2	LM6 + 2.5 % SiC	7.3	7.2	7.3	6.8	6.7	35.3	7.06
3	LM6 + 5 % SiC	8.2	8	7.5	7.8	7.6	39.1	7.82
4	LM6 + 7.5 % SiC	8.8	7.9	7.5	8.6	7.6	40.4	8.08
5	LM6 + 10 % SiC	8.5	8.7	8.8	9.7	9.2	44.9	8.98
6	LM6 + 2.5 % Al_2O_3	6.5	6.5	6.7	6.8	6.6	33.1	6.62
7	LM6 + 5 % Al_2O_3	6.7	6.8	6.9	7.0	7.0	34.4	6.88
8	LM6 + 7.5 % Al_2O_3	7.1	7.0	7.0	6.9	7.2	35.2	7.04
9	LM6 + 10 % Al_2O_3	7.5	7.2	7.1	7.2	7.1	36.1	7.22
10	LM6 + (2.5+2.5) % SiC+Al_2O_3	8.0	7.8	7.6	7.7	7.8	38.9	7.78
11	LM6 + (5+5) % SiC+Al_2O_3	8.2	8.5	8.9	9.2	9	43.8	8.76
12	LM6 + (7.5+7.5) % SiC+Al_2O_3	8.8	9.1	9.3	9.1	9.5	45.8	9.16
13	LM6 + (10+10) % SiC+Al_2O_3	9.2	9.3	9.4	9.0	9.9	46.8	9.36

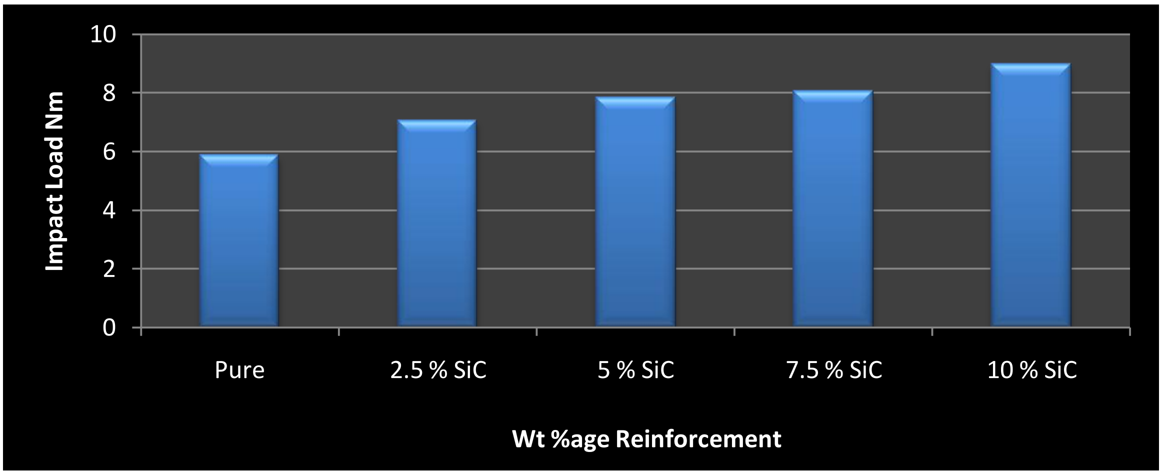


Figure 5.1: Comparison of Impact Strength with %age variation of SiC

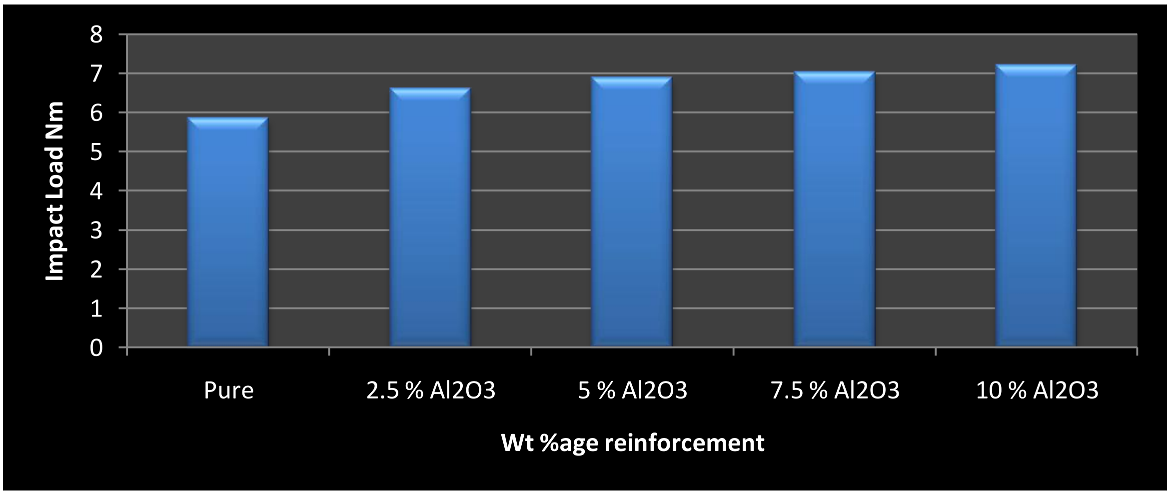


Figure 5.2: Comparison of Impact Strength with %age variation of Al_2O_3

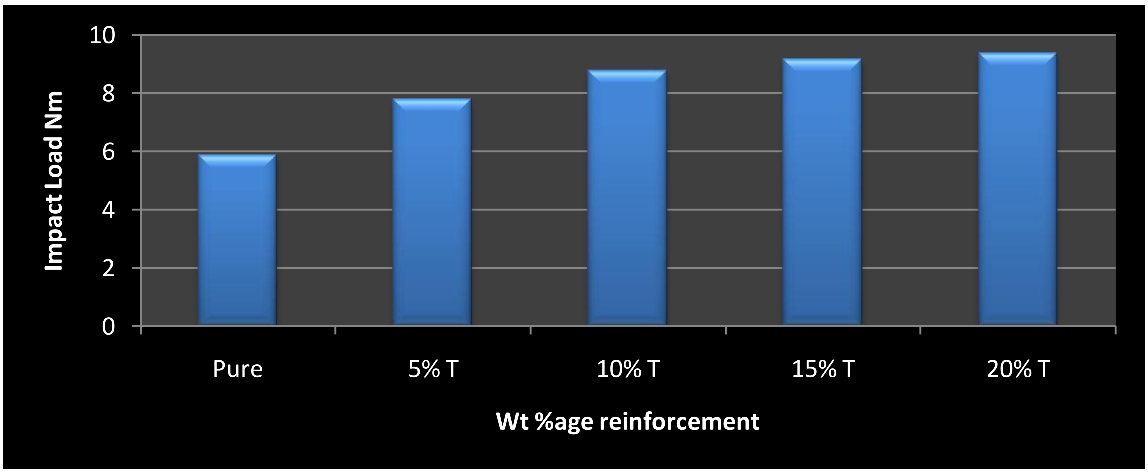


Figure 5.3: Comparison of Impact Strength with %age variation of mixture Al_2O_3 & SiC

Figure 5.1-5.3 shows that with the increase in SiC & Al_2O_3 constituent Impact strength is increases w.r.t base metal. This is due to proper dispersion of SiC & Al_2O_3 into the matrix or strong interfacial bonding in between the Al alloy LM6 and SiC& Alumina interfaces.

5.2 HARDNESS TEST

A Rockwell hardness tester machine used for the hardness measurement. The surface being tested generally requires a metallographic finish and it was done with the help of 100, 220, 400, 600 and 1000 grit size emery paper. Load used on Rockwell's hardness tester was 200 grams at dwell time 20 seconds for each sample. The result of Rockwell's hardness test for simple alloy without reinforcement (Sample No.1) and the wt.% variation of different reinforcements such as SiC/ Al_2O_3 and Al alloy LM6 (Sample No. 2-13) are shown in Table number 5.2.

Table 5.2: Results of hardness Test

Sample No	Sample Name	Hardness Rockwell Hardness				Mean Hardness
	LM 6 +	Trial 1	Trial 2	Trial 3	Trial 4	
1	Pure	53.7	52.7	54.5	51.9	53.2
2	2.5 % SiC	56.7	59.5	56.1	60.1	58.1
3	5 % SiC	50	48	53	51	51.0
4	7.5 % SiC	86.3	89.3	85.8	89.8	87.8
5	10 % SiC	91.2	90.7	91.7	91.3	91.2
6	2.5 % Al_2O_3	76.5	74.3	75.2	75.6	75.4
7	5 % Al_2O_3	85.2	83.2	86.6	86.6	85.4
8	7.5 % Al_2O_3	89.9	89.4	91.6	87.6	89.6
9	10 % Al_2O_3	91.6	98.8	92.5	101.3	95.8
10	2.5 + 2.5 % T	69.8	69.8	71.5	67.1	69.2
11	5 + 5 % T	85.9	85.6	85.4	85.8	85.6
12	7.5 + 7.5 % T	107.2	106.1	109.4	110.5	108.2
13	10 + 10 % T	119.0	122.0	118.0	121.0	120.0

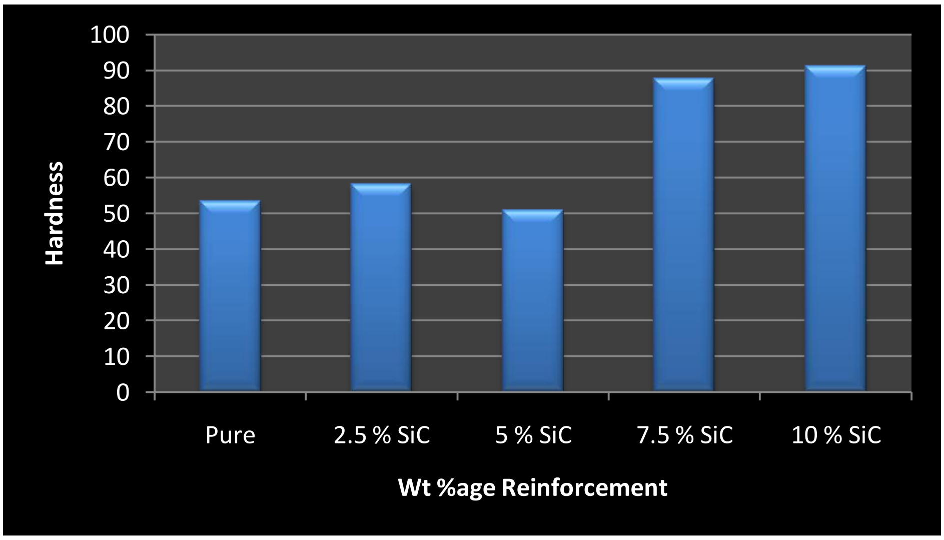


Figure 5.4: Comparison the hardness with wt. % variation of SiC

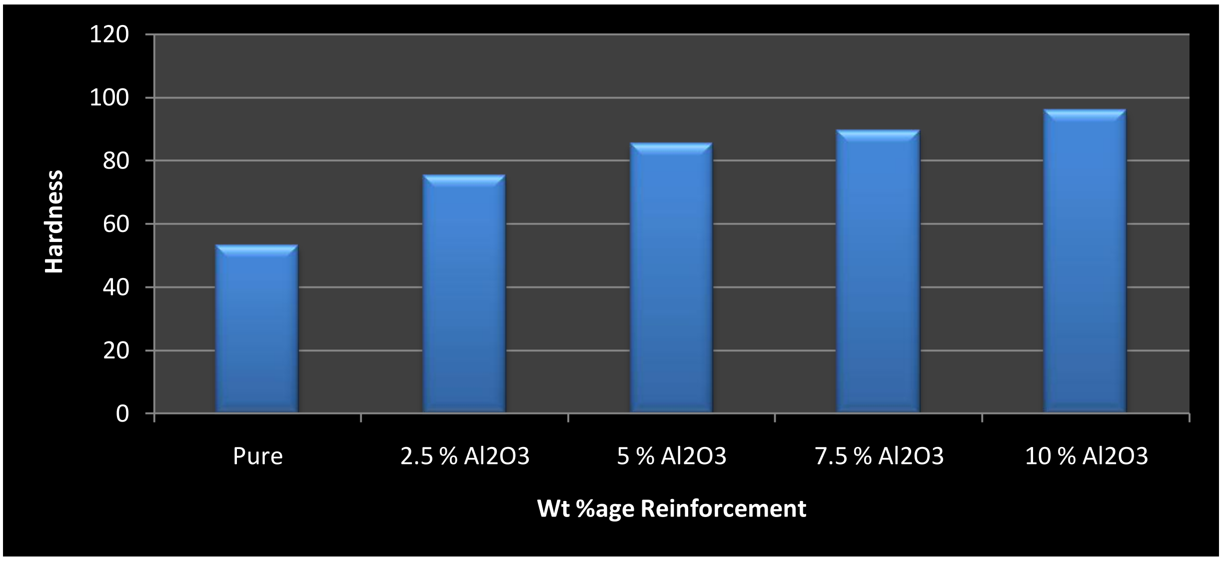


Figure 5.5: Comparison the Hardness with wt. % variation of Al_2O_3

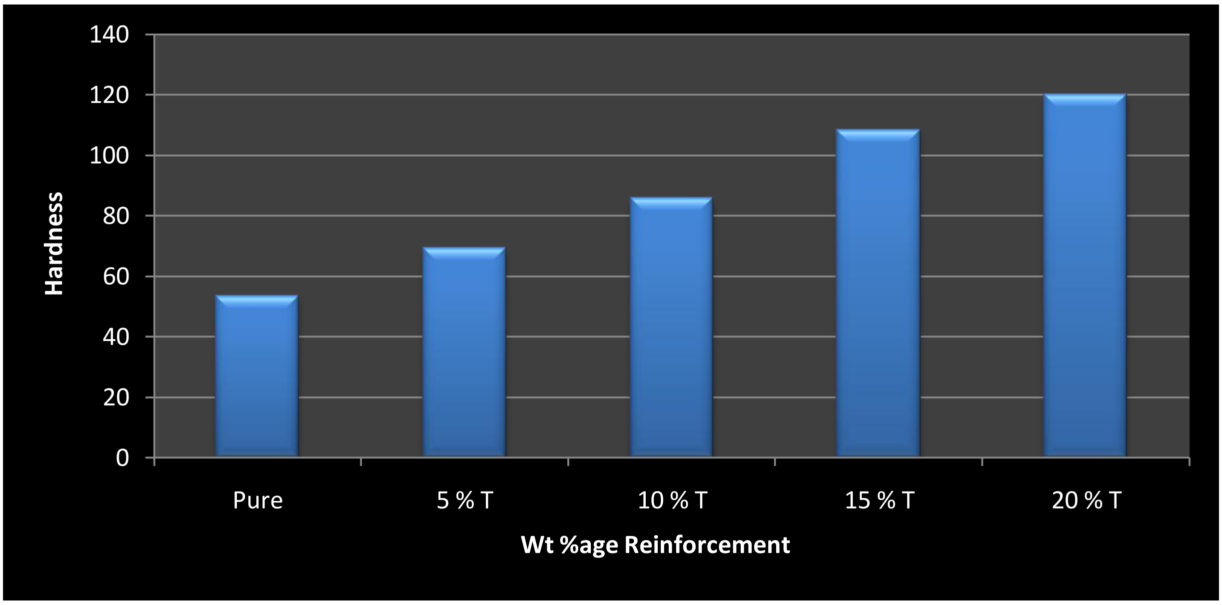


Figure 5.6: Comparison the Hardness with wt. % variation of combined Al_2O_3 & SiC

In Figure number 5.4,5.5,5.6 results predict that uniform increase in hardness is also seen. This is due to increase in resistance to deformation by adding SiC and Alumina as reinforcment in LM6 alloy.

5.3 TENSILE STRENGTH TEST

Tensile tests were used to assess the mechanical behavior of the composites and matrix alloy. The composite and matrix alloy rods were machined to tensile specimens with a diameter of 6mm and gauge length of 30 mm. Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before necking, which is when the specimen's cross-section starts to significantly contract.

Figure 5.7: Tensile Strength Specimens of different composition

Table 5.3: Tensile Strength Results

Alloy (LM6)	Yield Strength N/mm^2	UTS N/mm^2	Elongation (%)
Pure	65	180	9
2.5% SiC	78	220	7.5
5% SiC	85	245	5.5
7.5% SiC	112	250	3.2
10% SiC	150	310	2.1
2.5 % Al_2O_3	75	190	8.1
5 % Al_2O_3	88	201	6.5
7.5 % Al_2O_3	105	250	3.9
10 % Al_2O_3	140	290	2.8
2. 5% SiC + 2.5 %Al_2O_3	100	240	6.8
5% SiC + 5 %Al_2O_3	170	270	4.5
7. 5% SiC + 7.5 %Al_2O_3	190	320	3.1
10 % SiC + 10 %Al_2O_3	220	370	1.4

5.3.1 Stress vs. Strain Curves

During tensile testing of a material sample, the stress–strain curve is a graphical representation of the relationship between stress, derived from measuring the load applied on the sample, and strain, derived from measuring the deformation of the sample, i.e. elongation, compression, or distortion. The slope of stress-strain curve at any point is called the tangent modulus; the slope of the elastic (linear) portion of the curve is a property used to characterize materials and is known as the Young's modulus. The area under the elastic portion of the curve is known as the modulus of resilience.

I. Stress vs. Strain Curves for Pure LM 6 Alloys

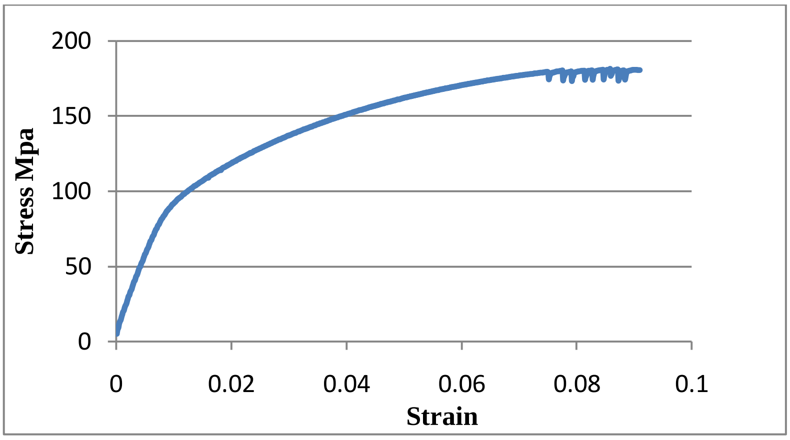


Figure 5.8: Stress vs. Strain Curves for LM 6 Alloys

II. Stress vs. Strain Curves for LM 6 Alloys with 2.5% SiC

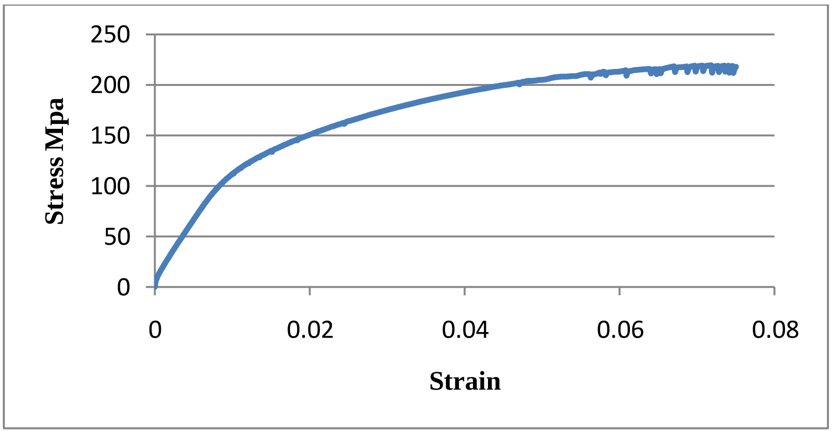


Figure 5.9: Stress vs. Strain Curves for LM 6 Alloys with 2.5 % SiC

III. Stress vs. Strain Curves for LM 6 Alloys with 5% SiC

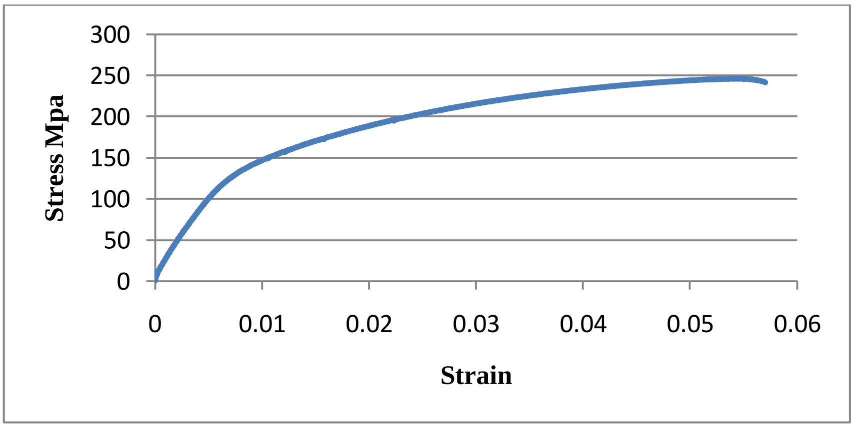


Figure 5.10: Stress vs. Strain Curves for LM 6 Alloys with 5 % SiC

IV. Stress vs. Strain Curves for LM 6 Alloys with 7.5% SiC

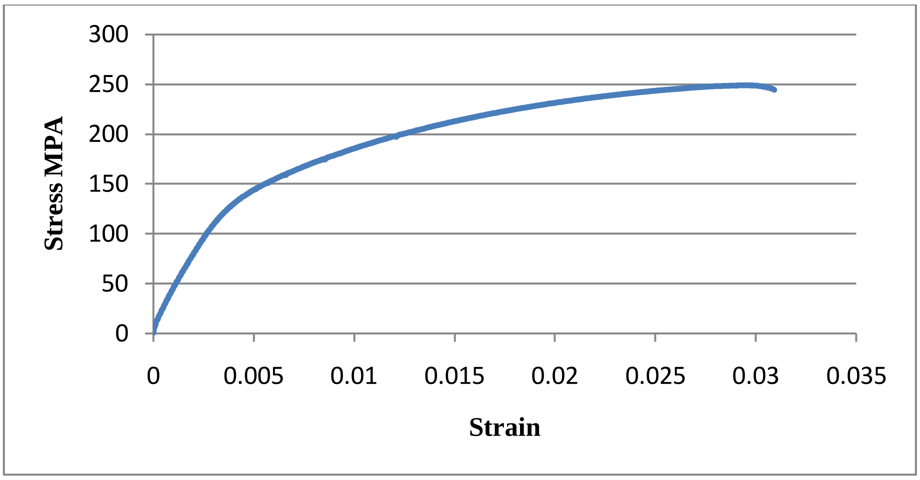


Figure 5.11: Stress vs. Strain Curves for LM 6 Alloys with 7.5 % SiC

V. Stress vs. Strain Curves for LM 6 Alloys with 10% SiC

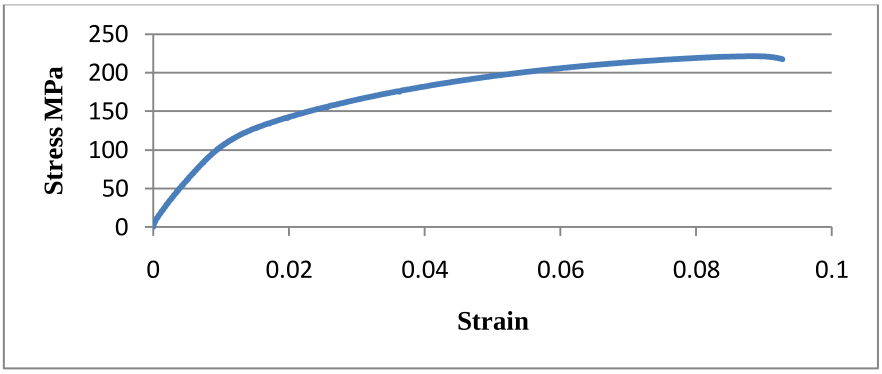


Figure 5.12: Stress vs. Strain Curves for LM 6 Alloys with 10% SiC

VI. Stress vs. Strain Curves for LM 6 Alloy with 2.5% Al_2O_3

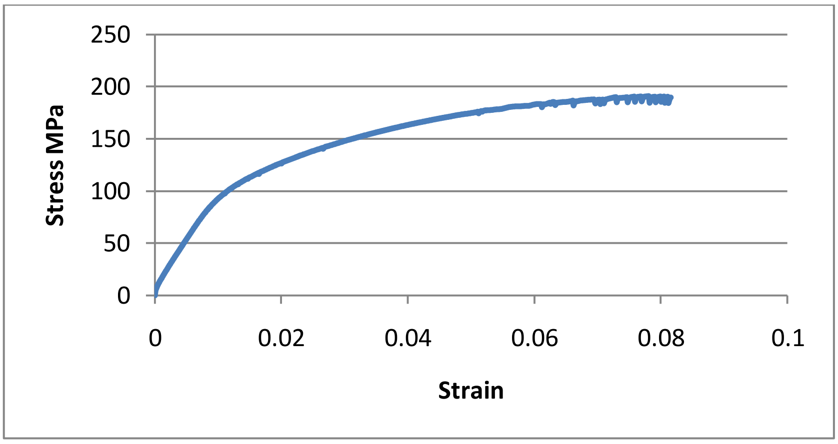


Figure 5.13: Stress vs. Strain Curves for LM 6 Alloy with 2.5% Al_2O

VII. Stress vs. Strain Curves for LM 6 Alloy with 5% Al_2O_3

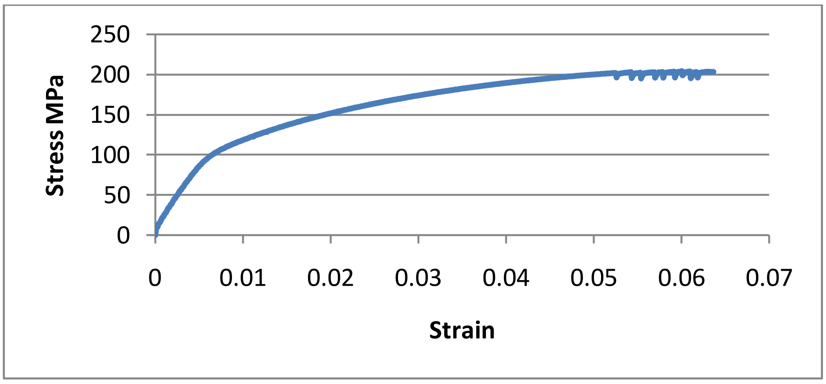


Figure 5.14: Stress vs. Strain Curves for LM 6 Alloy with 5% Al_2O_3

VIII. Stress vs. Strain Curves for LM 6 Alloy with 7.5% Al_2O_3

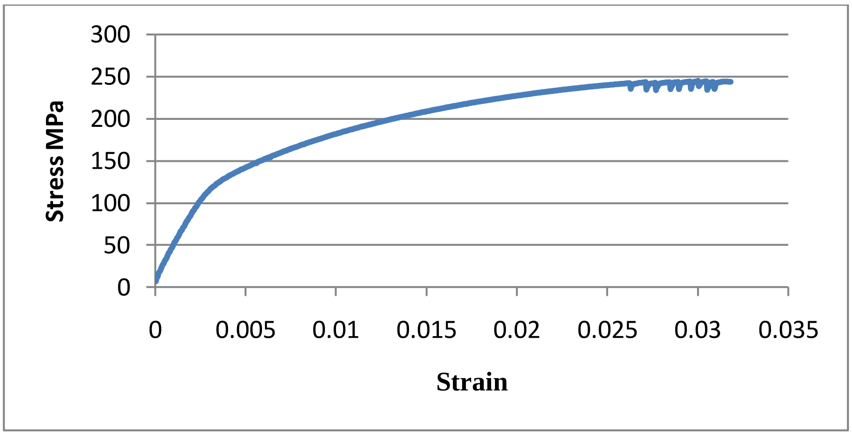


Figure 5.15: Stress vs. Strain Curves for LM 6 Alloy with 7.5% Al_2O_3

IX. Stress vs. Strain Curves for LM 6 Alloy with 10% Al_2O_3

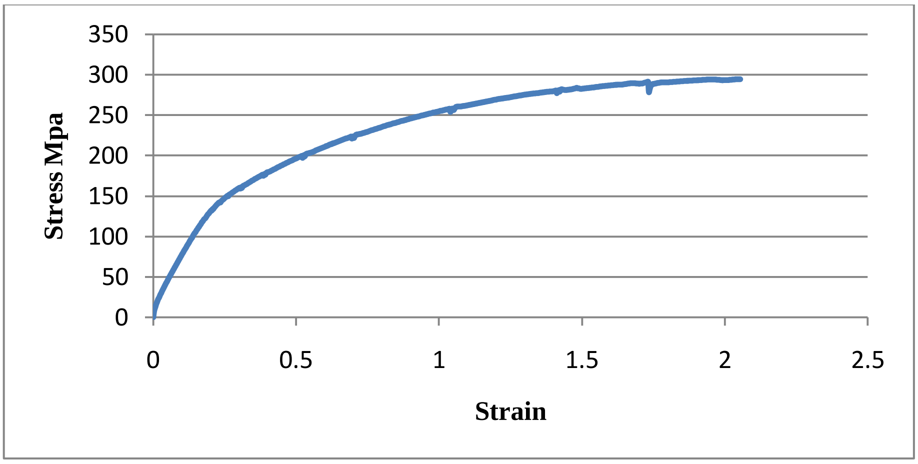


Figure 5.16: Stress vs. Strain Curves for LM 6 Alloy with 10% Al_2O_3

X. Stress vs. Strain Curves for LM 6 Alloy with 5% T (SiC & Al_2O_3)

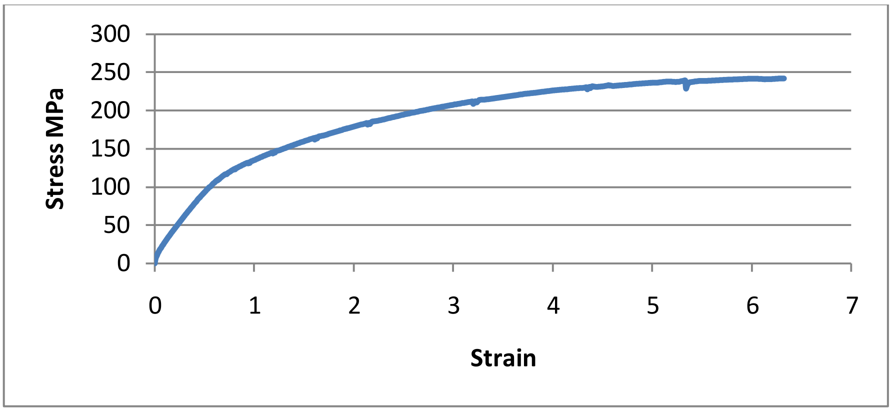


Figure 5.17: Stress vs. Strain Curves for LM 6 Alloy with 5% T (Sic & Al_2O_3)

XI. Stress vs. Strain Curves for LM 6 Alloy with 10% (SiC &Al_2O_3)

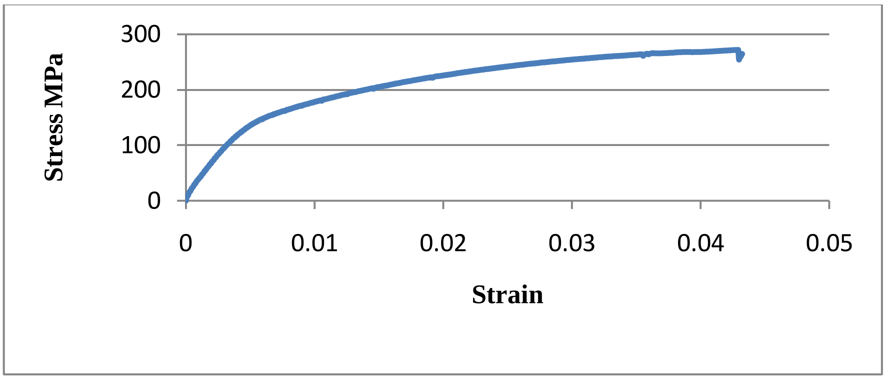


Figure 5.18: Stress vs. Strain Curves for LM 6 Alloy with 10% T (SiC & Al_2O_3)

XII. Stress vs. Strain Curves for LM 6 Alloy with 15% T (SiC & Al_2O_3)

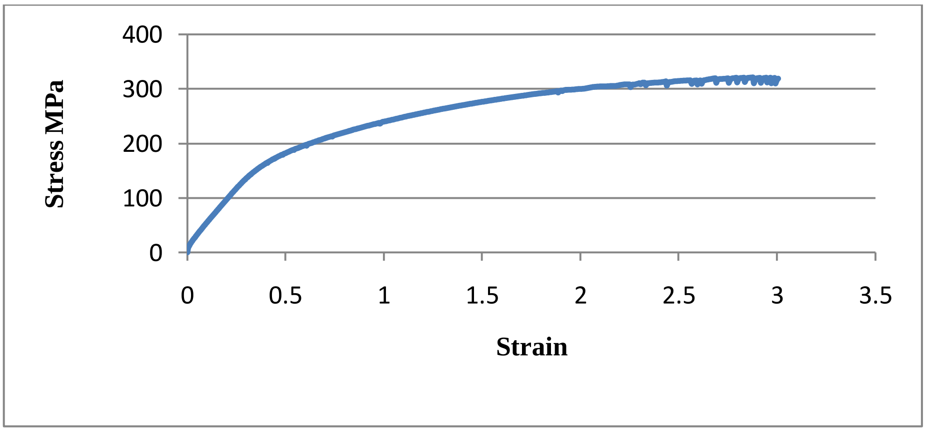


Figure 5.19: Stress vs. Strain Curves for LM 6 Alloy with 15% T (SiC & Al_2O_3)

XIII. Stress vs. Strain Curves for LM 6 Alloy with 20%T (SiC & Al_2O_3)

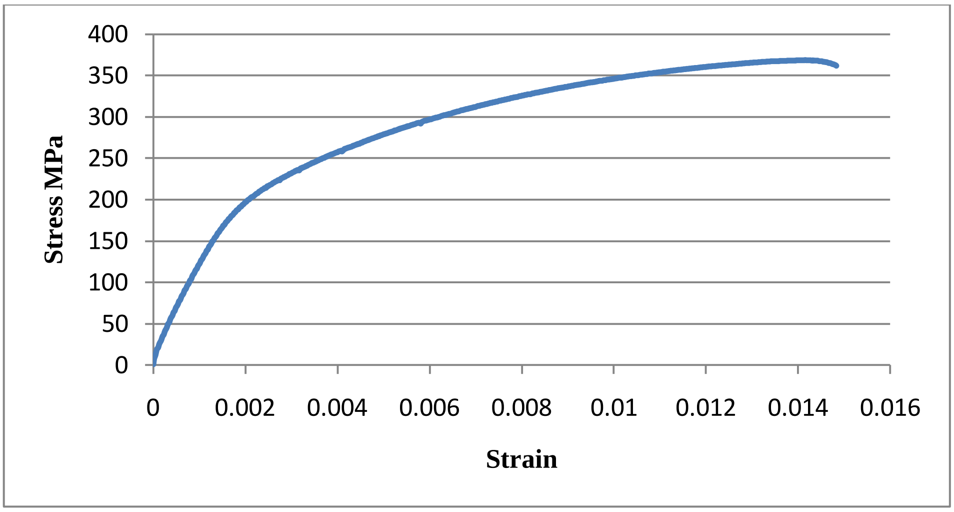


Figure 5.20: Stress vs. Strain Curves for LM 6 Alloy with 20% T (SiC & Al_2O_3)

It exhibits a very linear stress–strain relationship up to a well defined yield point. The linear portion of the curve is the elastic region and the slope is the modulus of elasticity or Young's Modulus. As deformation continues, the stress increases on account of strain hardening until it reaches the ultimate strength. Until this point, the cross-sectional area decreases uniformly because of Poisson contractions. The actual rupture point is in the same vertical line as the visual rupture point. The work hardening rate increases with increasing volume fraction of reinforcement (and decreasing matrix volume). The lower ductility can be attributed to the earlier onset of void nucleation with increasing amount of reinforcement.

5.3.2 Yield Strength Comparison

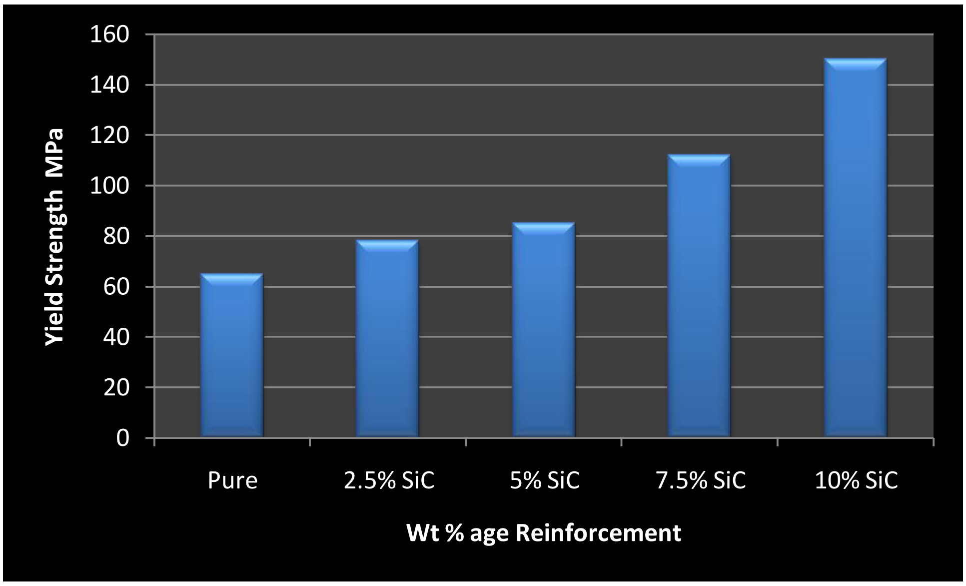


Figure 5.21: Comparison the Yield Strength with wt. % variation of SiC

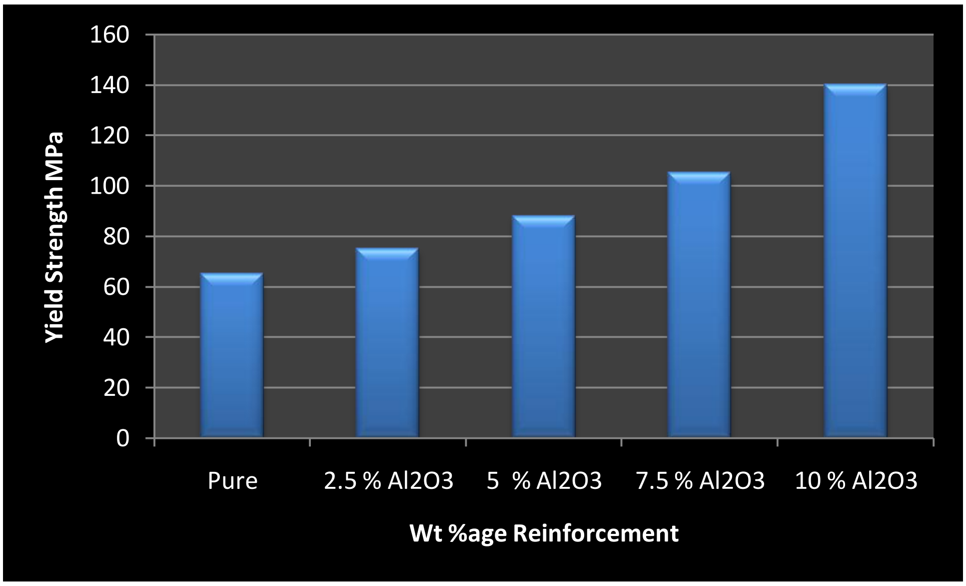


Figure 5.22: Comparison the Yield Strength with wt. % variation of Al_2O_3

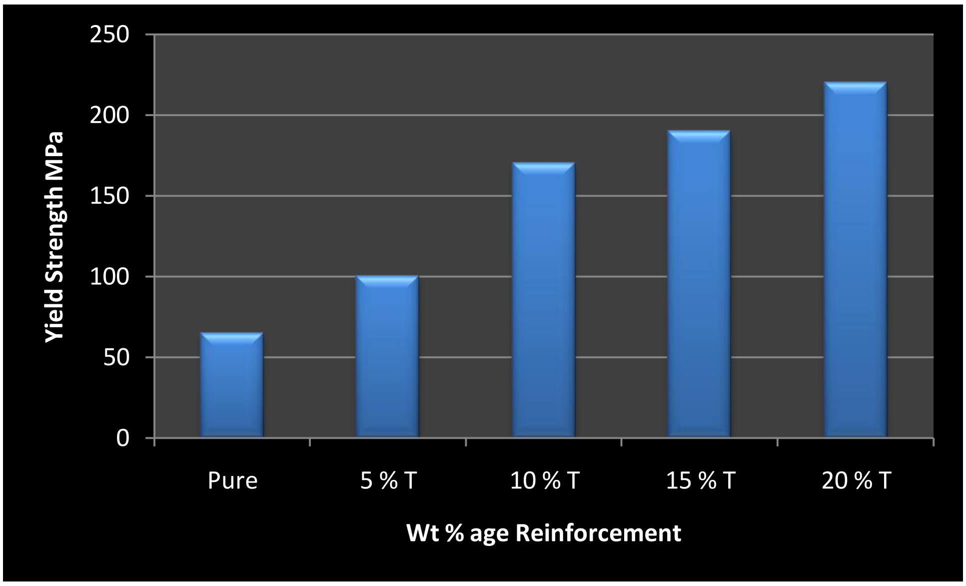


Figure 5.23: Comparison the Yield Strength with wt. % variation of Al_2O_3 & SiC

As shown in Figure number 5.21,5.22,5.23 results predict that as the reinforcement wt.% Yield Strength is increases. This happens may be due to dispersion of SiC & Alumina which create hinderance to dislocation motion. To move this defect (plastically deforming or yielding the material), a larger stress must be applied. This may results increase in tensile strength of reinforced LM6 alloy.

5.3.3 Ultimate Tensile Strength Result

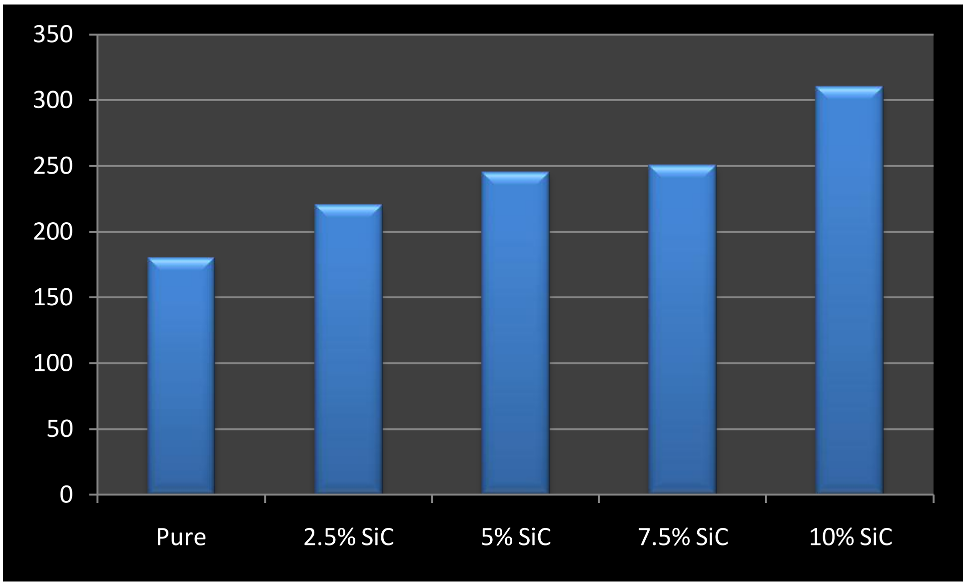


Fig. 5.24: Comparison of the Ultimate Tensile Strength with wt. % variation of SiC

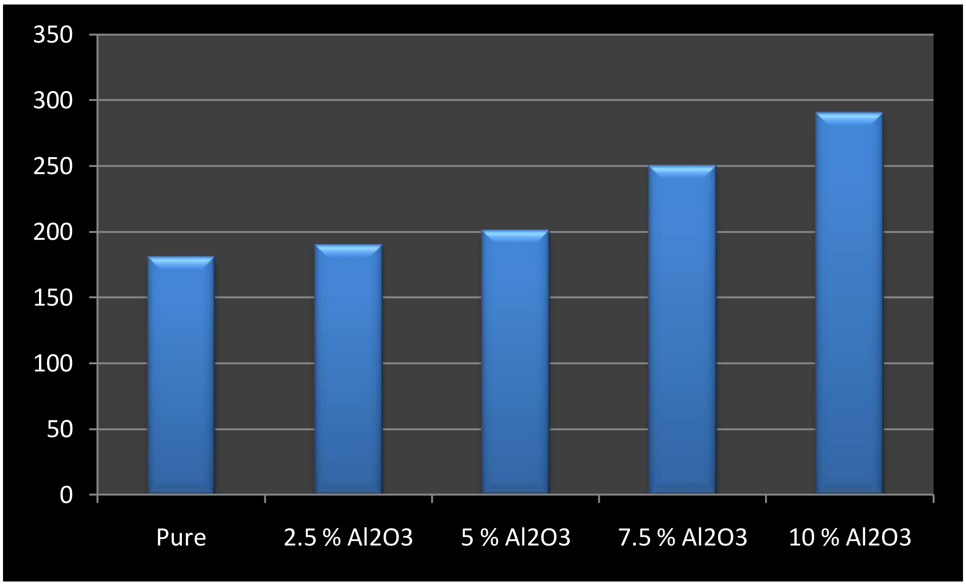


Fig. 5.25: Comparison of the Ultimate Tensile Strength with wt. % variation of Al_2O_3

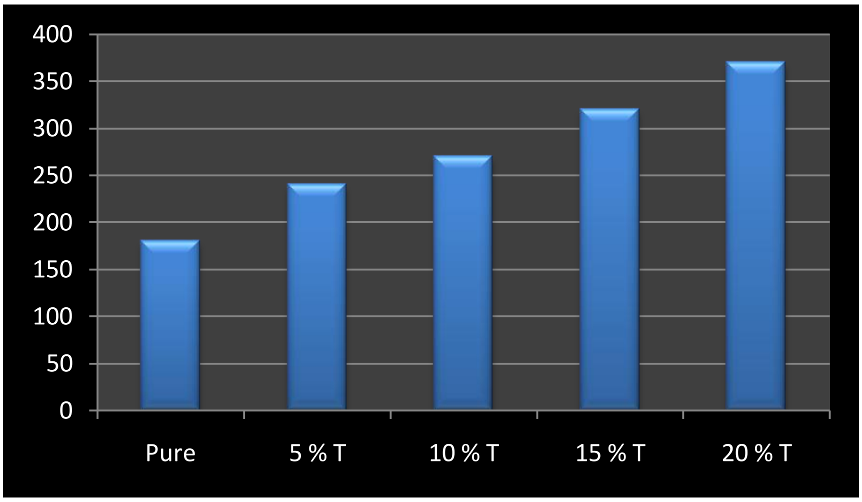


Figure 5.26: Comparison of the Ultimate Tensile Strength with wt. % variation of SiC & Al_2O_3 mixture

As shown in Chart (Figure number 5.24,5.25,5.26) results predict that as the reinforcement wt.% UTS is also increases. This happens may be due to dispersion of SiC & Alumina which create hinderance to dislocation motion. This may results increase in tensile strength of reinforced LM6 alloy.

5.3.4 Length Elongation Comparison

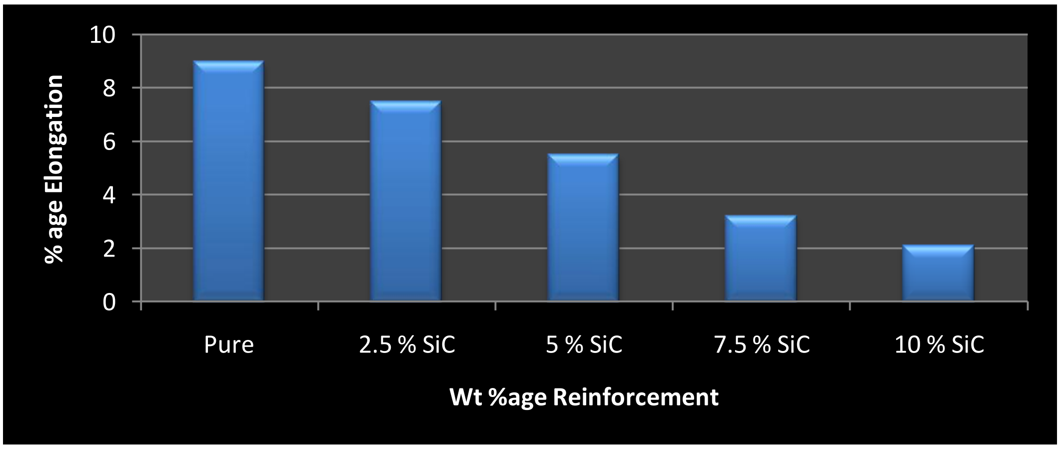


Figure 5.27: Comparison the Elongation with wt. % variation of SiC

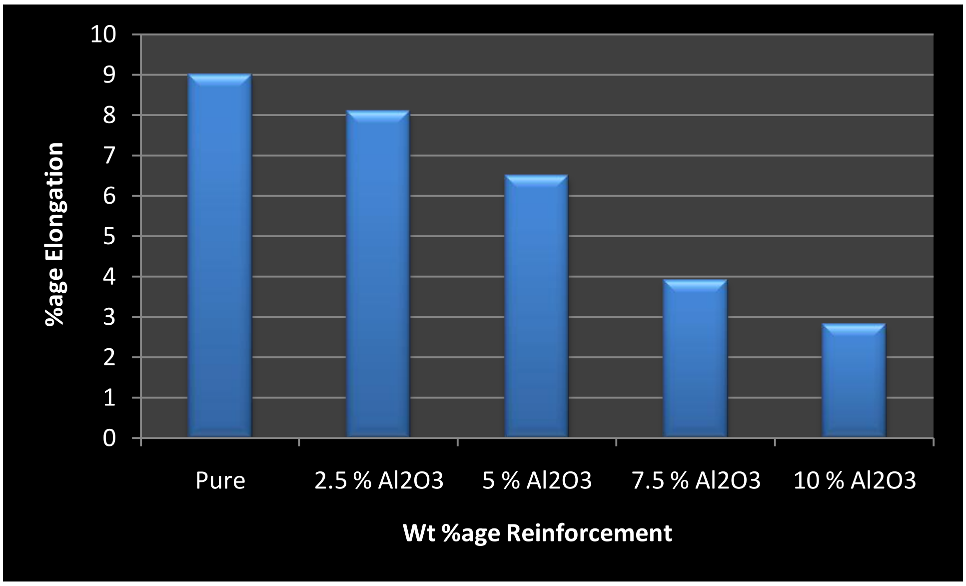


Figure 5.28: Comparison the Elongation with wt. % variation of Al_2O_3

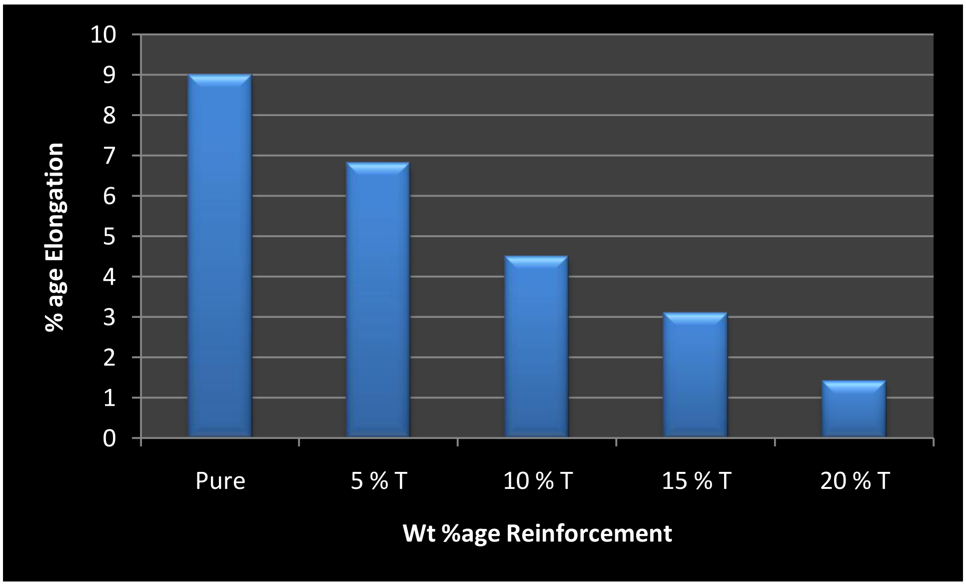
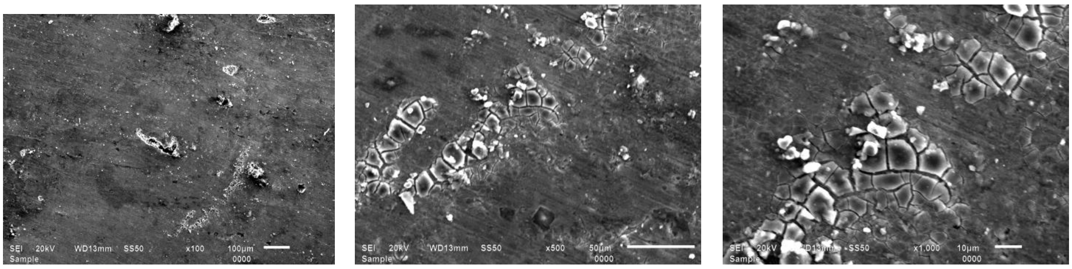


Figure 5.29: Comparison the Elongation with wt. % variation of Mixture of SiC & Al_2O_3

As shown in Figure Number 5.27-5.29 results predict that as the wt. of SiC & Al_2O_3 increases elongation is decreases. This is due to decrease in ductility because of increase in tensile strength as shown above.

5.4 RESULTS OF SEM

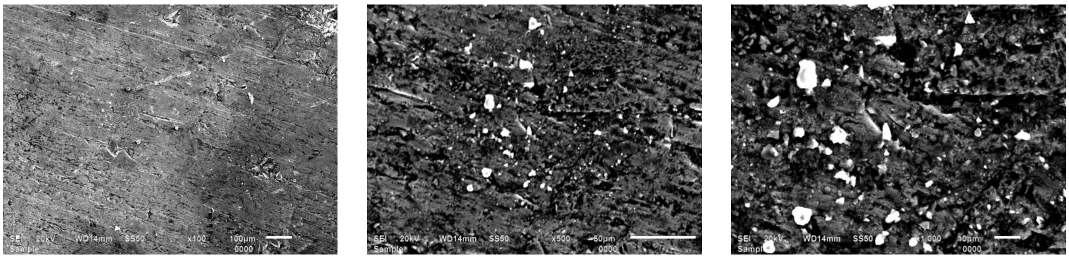
I. 2.5 % Alumina is mixed with LM6 Alloy



100 X **500 X** **1000 X**

Figure 5.30: Microscopic View of 2.5 % SiC Reinforced in LM6 100 X, 500 X, 1000 X

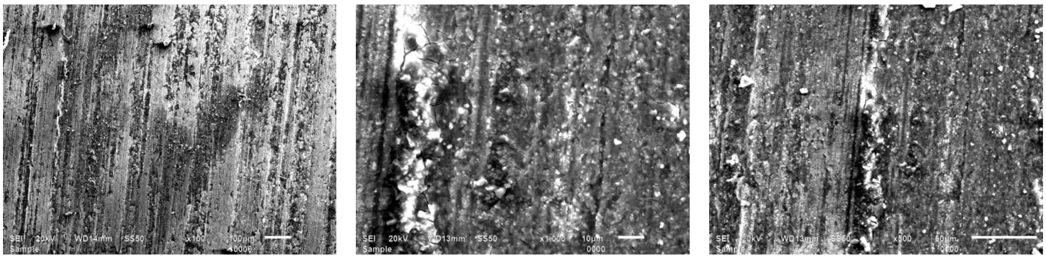
II. 7.5 % SiC is Mixed with Alloy LM 6



100X **500 X** **1000 X**

Figure 5.31: Microscopic View of 7.5 % SiC Reinforced in LM6 100 X, 500 X, 1000X

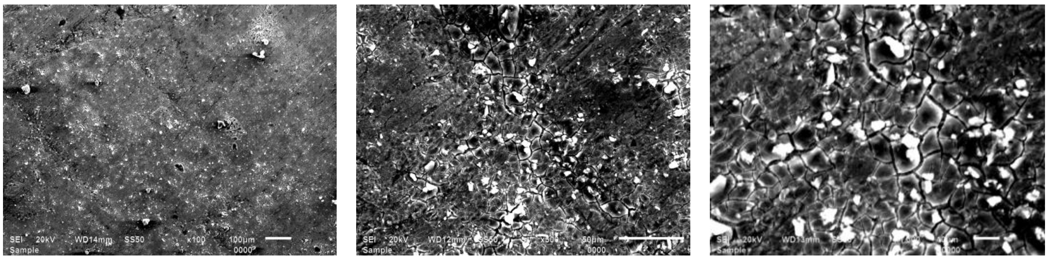
III. 10 % Al_2O_3 is mixed with Alloy LM 6



100 X **500 X** **1000 X**

Figure 5.32: Microscopic View of 10 % Alumina Reinforced 100 X, 500 X, 1000 X

IV. 7.5 % Al_2O_3 and SiC with LM 6



100 X **500 X** **1000 X**

Figure 5.33: Microscopic View of 15 % SiC & Al_2O_3 Reinforced in 100 X, 500 X, 1000 X

Figures 5.30, 5.31, 5.32, 5.33 are presented with the microphotographs of Cast LM 6-SiC and Alumina composites respectively. From figures it can be observed that, the distributions of reinforcements in the respective matrix are fairly uniform. Further these figures reveal the homogeneity of the cast composites. The microphotograph also clearly revels the increased filler contents in the composites. Cracks are also seen in the microstructure.

5.5 XRD ANALYSIS RESULT

An X-ray diffraction (XRD) pattern of aluminium alloy matrix composites and aluminium alloy were shown in given figure numbers 5.43- 5.51. X-ray diffraction of different samples was carried out by X'PERT PRO of PAN ANALYTICAL using CuK α radiation. In XRD, the physical content of the constituents present in the samples are indicated in the form of a graphs and tables shows the name and percentage of element/ compound present in respective Samples.

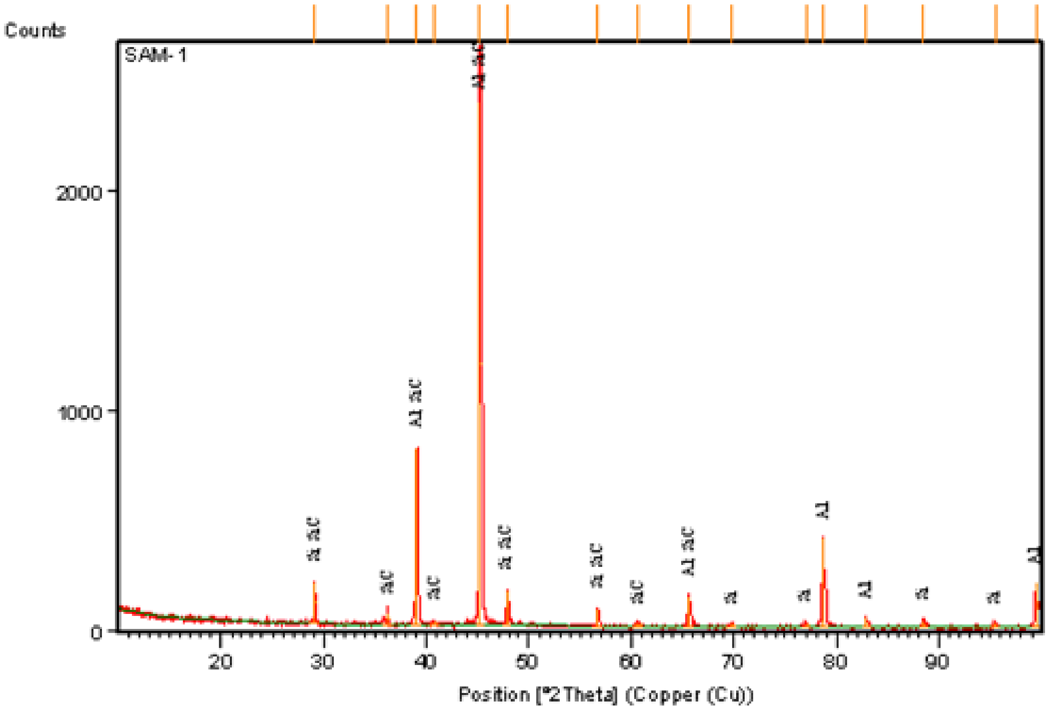


Figure 5.34: X-ray diffraction pattern of the alloy with 2.5% wt. SiC

Table 5.4: X-ray diffraction of the alloy with 2.5 % wt. SiC

Ref.Code	**Score**	**Compound Name**	**Scale Factor**	**Weight fraction (%)**
01-089-2837	47	Aluminium	0.507	**82.9**
01-074-6395	47	Silicon	0.036	5.1
03-065-3163	12	Silicon Carbide	0.007	**5.1**

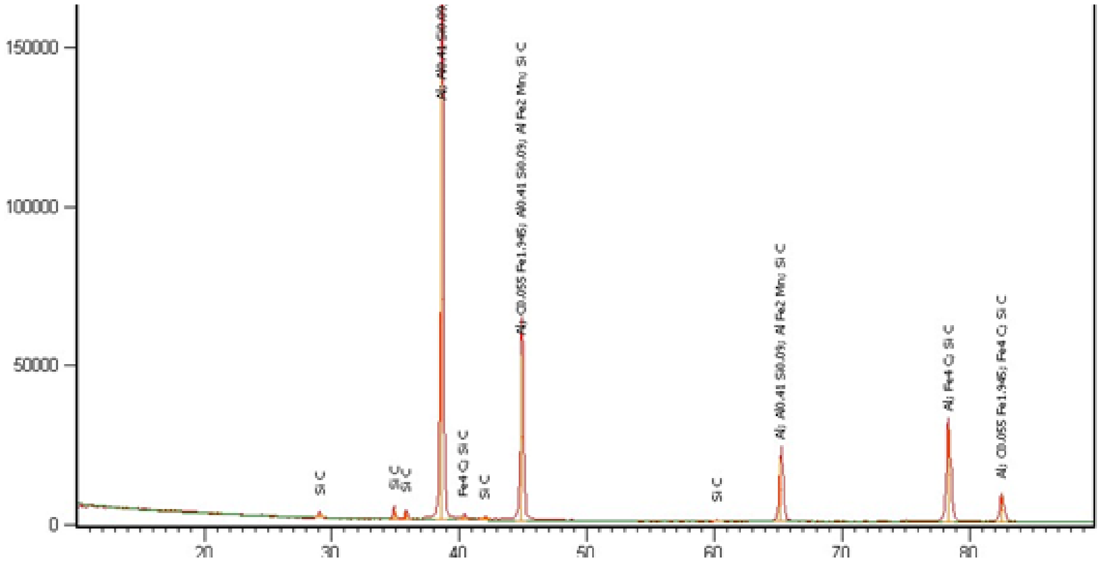


Figure 5.35: X-ray diffraction pattern of the alloy with 5% wt. SiC

Table 5.5: X-ray diffraction of the alloy with 5% wt. SiC

Ref.Code	Score	Compound Name	Scale Factor	Weight fraction (%)
01-075-0921	47	Aluminium	0.507	26
01-071-3901	47	Silicon	0.036	5.1
03-075-4411	12	Silicon Oxide	0.007	15
01-071-4624	20	Silicon	.105	25
01-080-0369	21	Aluminium Oxide	.075	19
01-067-0256	4	Silicon Oxide	.123	13

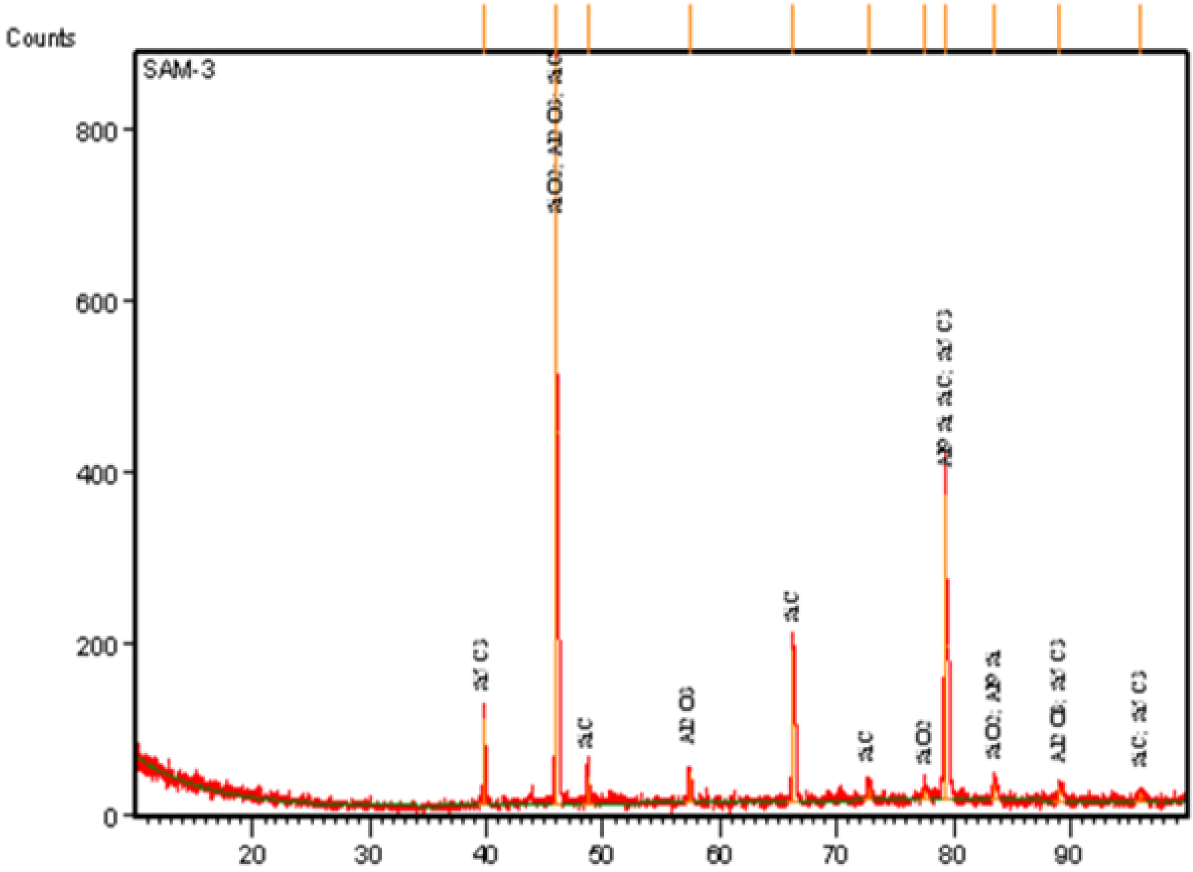


Figure 5.36: X-ray diffraction pattern of the alloy with 7.5 % wt. SiC

Table 5.6: X-ray diffraction of the alloy with 7.5% wt. SiC

Ref.Code	**Score**	**Compound Name**	**Scale Factor**	**Weight fraction (%)**
01-074-6550	52	Silicon Oxide	0.606	32.5
01-089-3072	39	Aluminum Oxide	0.171	19.0
03-065-8554	11	Silicon Aluminum	0.013	**30**
01-073-1663	10	Silicon Carbide	0.031	4.5
01-077-1084	12	Silicon Carbide	0.008	4

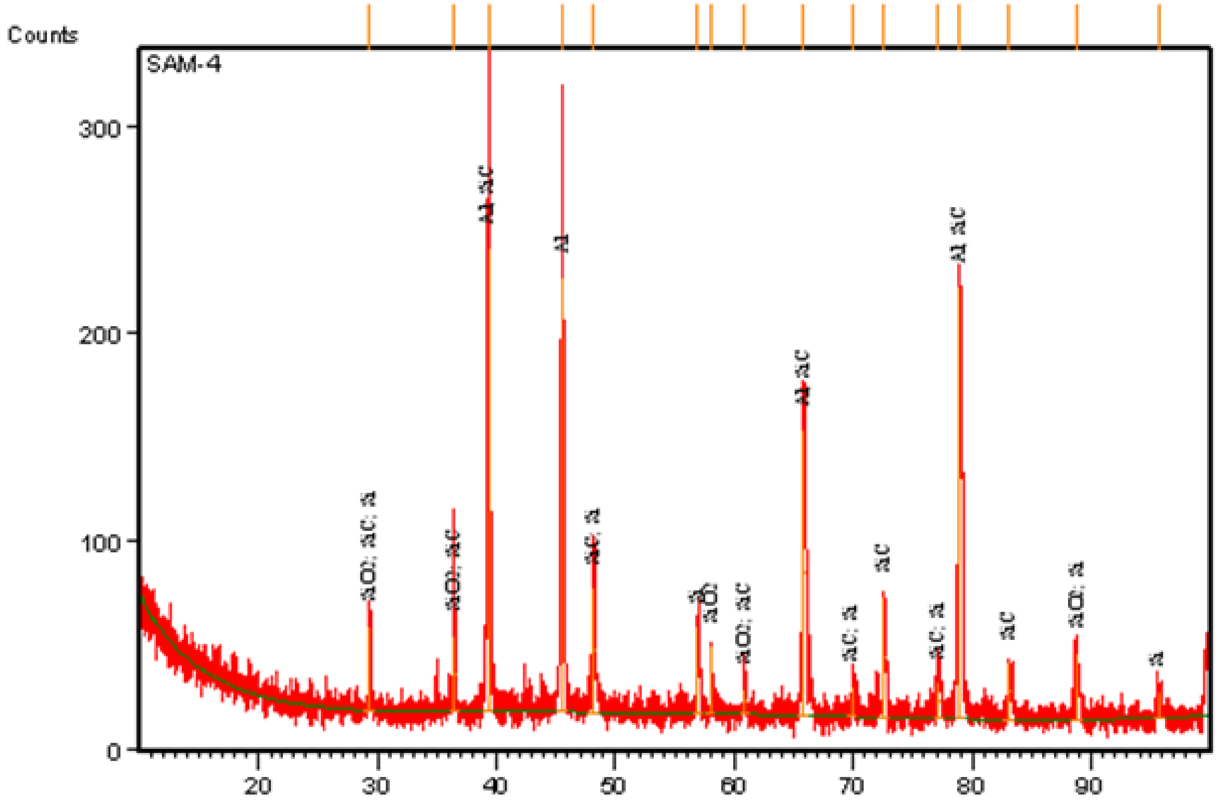


Figure 5.37: X-ray diffraction pattern of the alloy with 10% wt. SiC

Table 5.7: X-ray diffraction of the alloy with 10% wt. SiC

Ref.Code	**Score**	**Compound Name**	**Scale Factor**	**Chemical Formula**	**Weight Fraction (%)**
03-065-2869	48	Aluminium	0.606	Al	70.0
01-075-3170	39	Silicon Oxide	0.171	SiO_2	15.0
01-073-6302	16	Silicon Carbide	0.013	SiC	9.O
01-045-1363	8	Silicon	0.031	Si	1.0

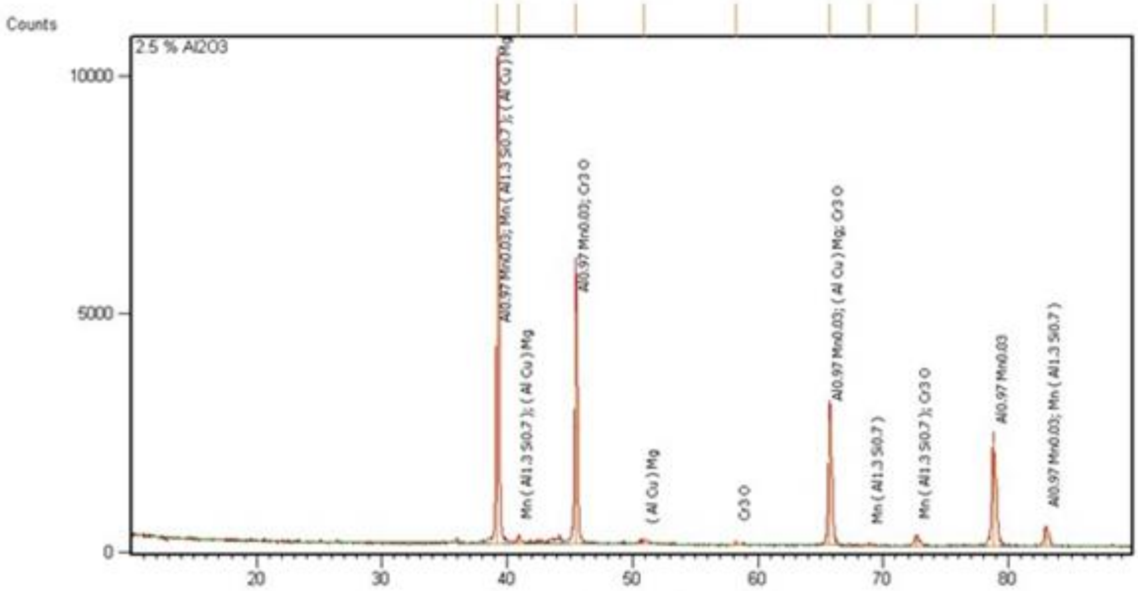


Figure 5.38: X-ray diffraction pattern of the alloy with 2.5% wt. Al_2O_3

Table 5.8: **X**-ray diffraction pattern of the alloy with 2.5% wt. Al_2O_3

Ref.Code	**Score**	**Compound Name**	**Scale Factor**	**Weight fraction (%)**
01-071-4624	35	Aluminium	0.782	**54.5**
01-074-6395	12	Silicon	0.171	6
03-065-3163	3	Silicon Oxide	0.015	**30**
01-073-0368	5	Alumina Oxide	0.125	8

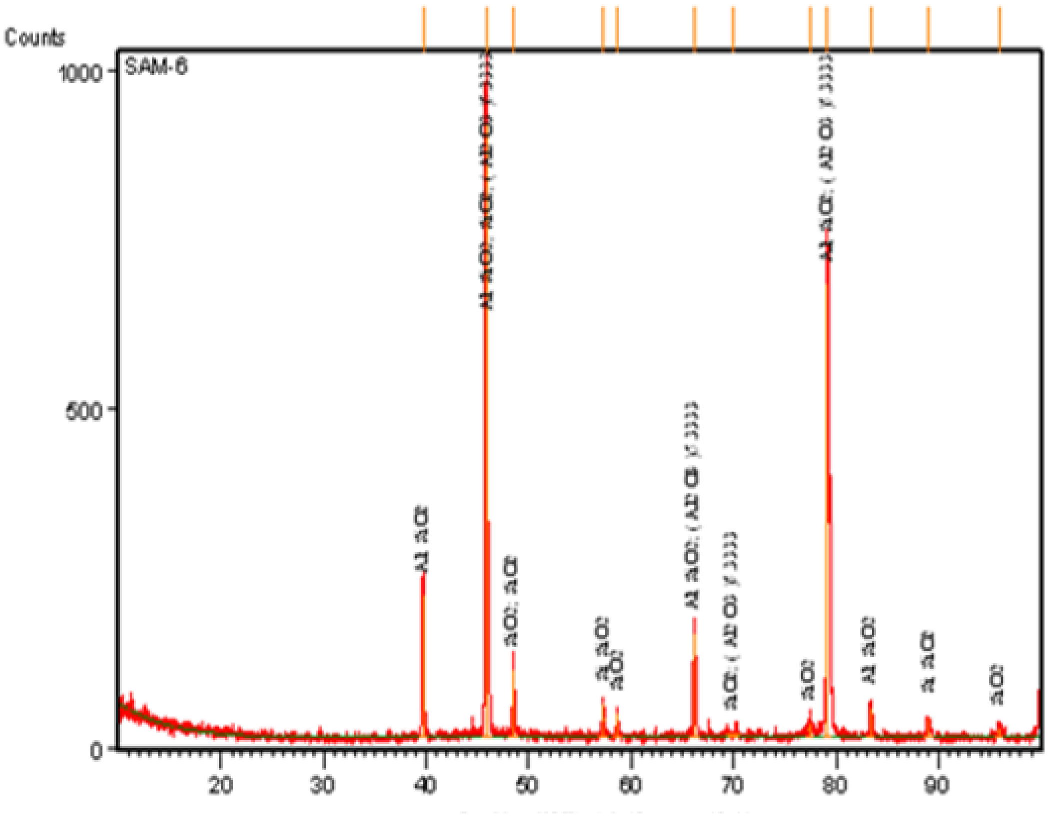


Figure 5.39: X-ray diffraction pattern of the alloy with 5% wt. Al_2O_3

Table 5.9: X-ray diffraction of the alloy with 5 % wt. Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Weight fraction (%)
01-071-4624	19	Aluminium	0.868	**54.5**
01-074-6395	7	Silicon	0.171	6
03-065-3163	3	Silicon Oxide	0.013	**30**
01-073-0368	4	Alumina Oxide	0.031	5.1

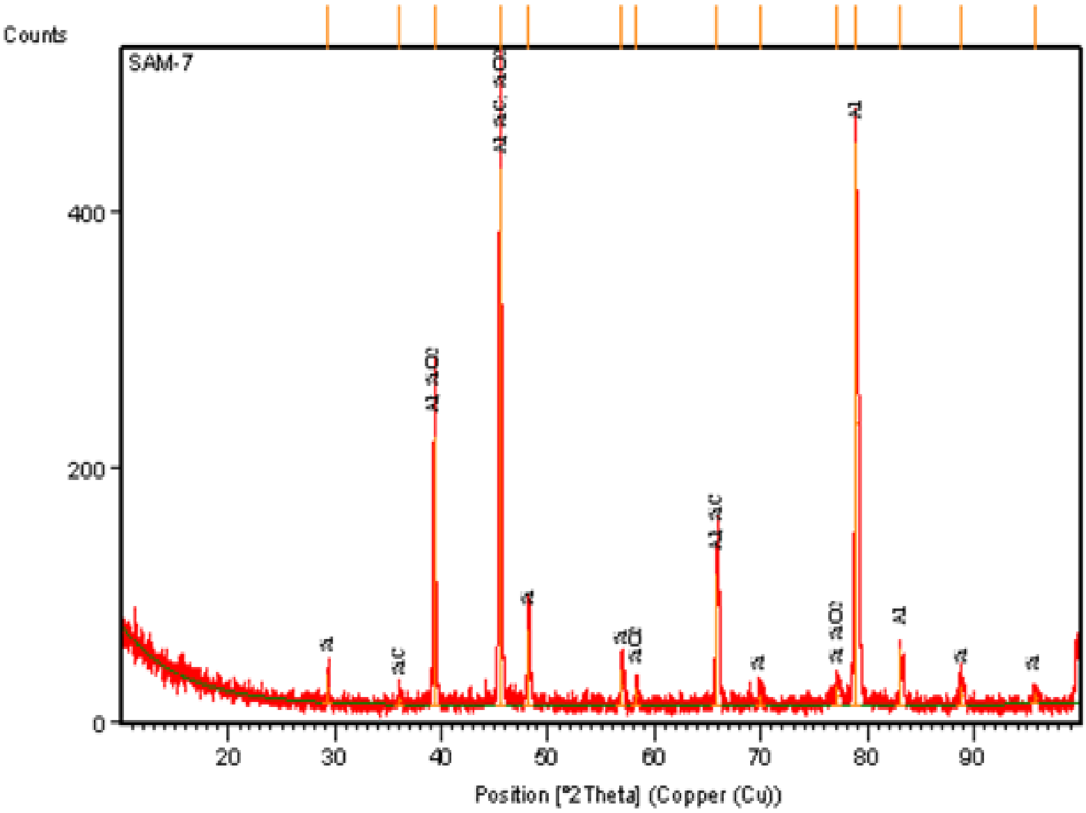


Figure 5.40: X-ray diffraction pattern of the alloy with 7.5 % wt. Al_2O_3

Table 5.10- X-ray diffraction of the alloy with 7.5 % wt. Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-089-2837	53	Aluminium	0.606	Al	5
01-089-2955	24	Silicon	0.171	SiO_2	81.2
01-075-1541	13	Alumina Oxide	0.013	SiC	**12**
01-079-1913	2	Silicon Oxide	0.031	Si	1.0

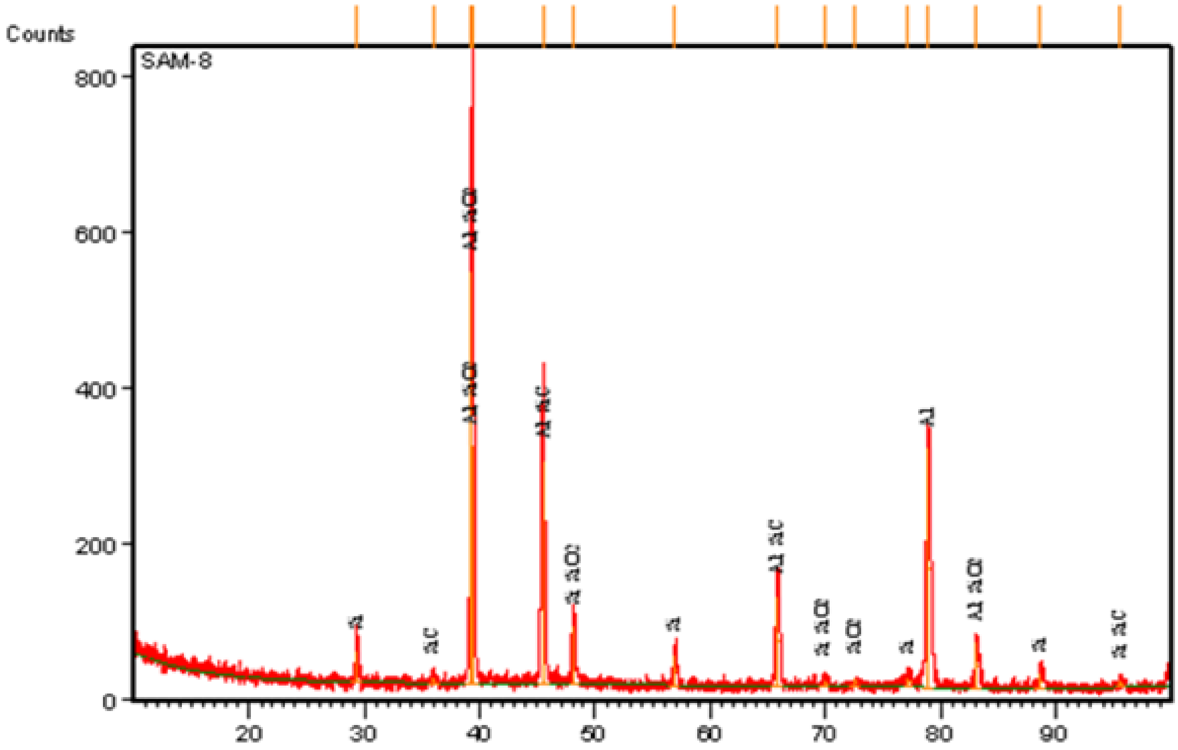


Figure 5.41: X-ray diffraction pattern of the alloy with 10 % wt. Al_2O_3

Table 5.11: X-ray diffraction pattern of the alloy with 10 % wt. Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-089-2837	33	Aluminium	0.606	Al	4
01-089-2955	44	Silicon	0.171	SiO_2	81.2
01-075-1541	4	Alumina Oxide	0.013	SiC	11
01-079-1913	3	Silicon Oxide	0.031	Si	2.0

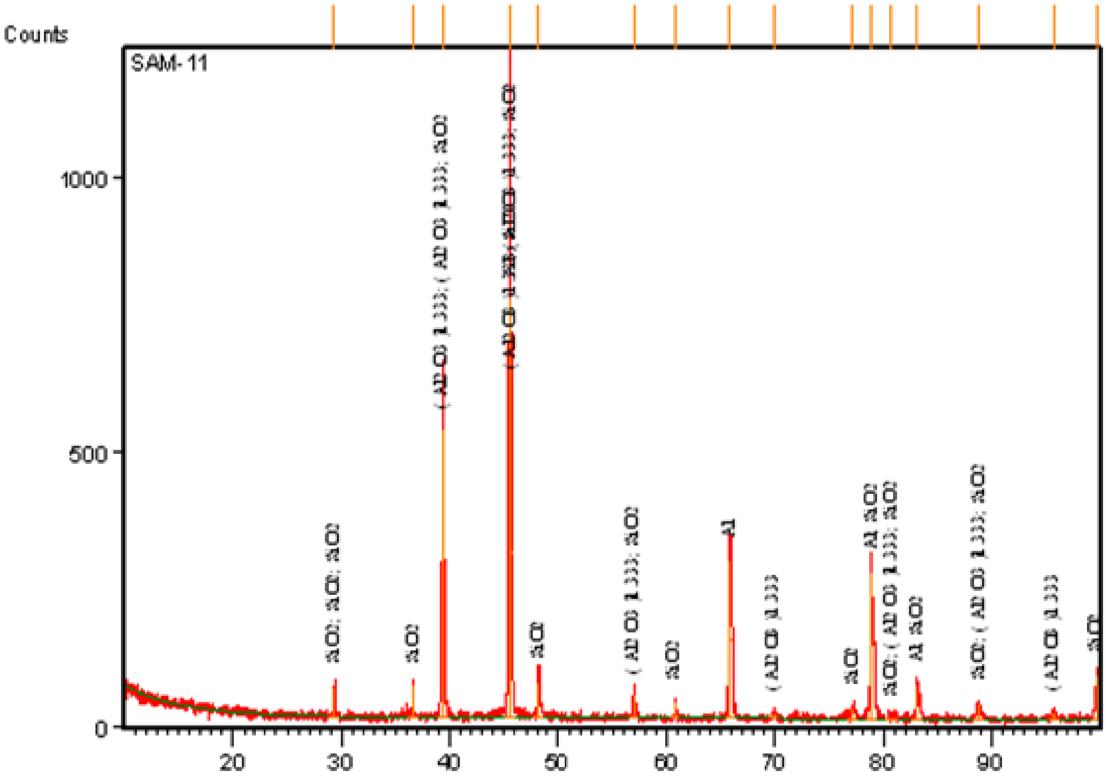


Figure 5.42: X-ray diffraction pattern of the alloy with 5% wt. SiC & Al_2O_3

Table 5.12: X-ray diffraction of the alloy with 5% wt. SiC & Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-089-2837	33	Alumina Oxide	0.678	AlO_2	81.2
01-089-2955	44	Aluminium	0.052	Al	6
01-075-1541	4	Silicon Oxide	0.034	SiO_2	11
01-079-1913	3	Silicon	0.035	Si	4

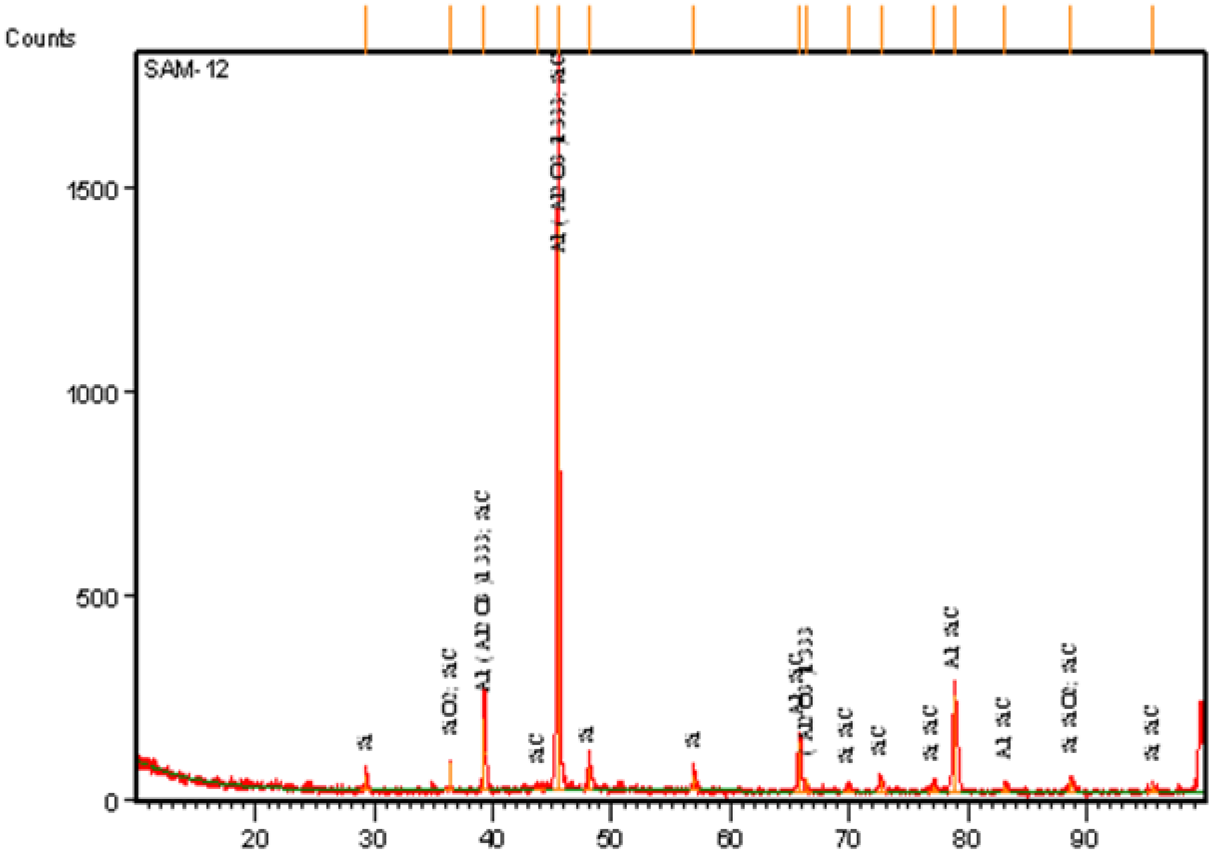


Figure 5.43: X-ray diffraction pattern of the alloys with 10% wt. Al_2O_3 & \SiC

Table 5.13: X-ray diffraction pattern of the alloys with 10 % wt. Al_2O_3 & \SiC

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-076-2837	33	Alumina Oxide	0.678	AlO_2	75
01-065-2955	44	Aluminium	0.052	Al	18
01-085-1541	4	Silicon Oxide	0.034	SiC	2
01-099-1913	3	Silicon	0.035	Si	1

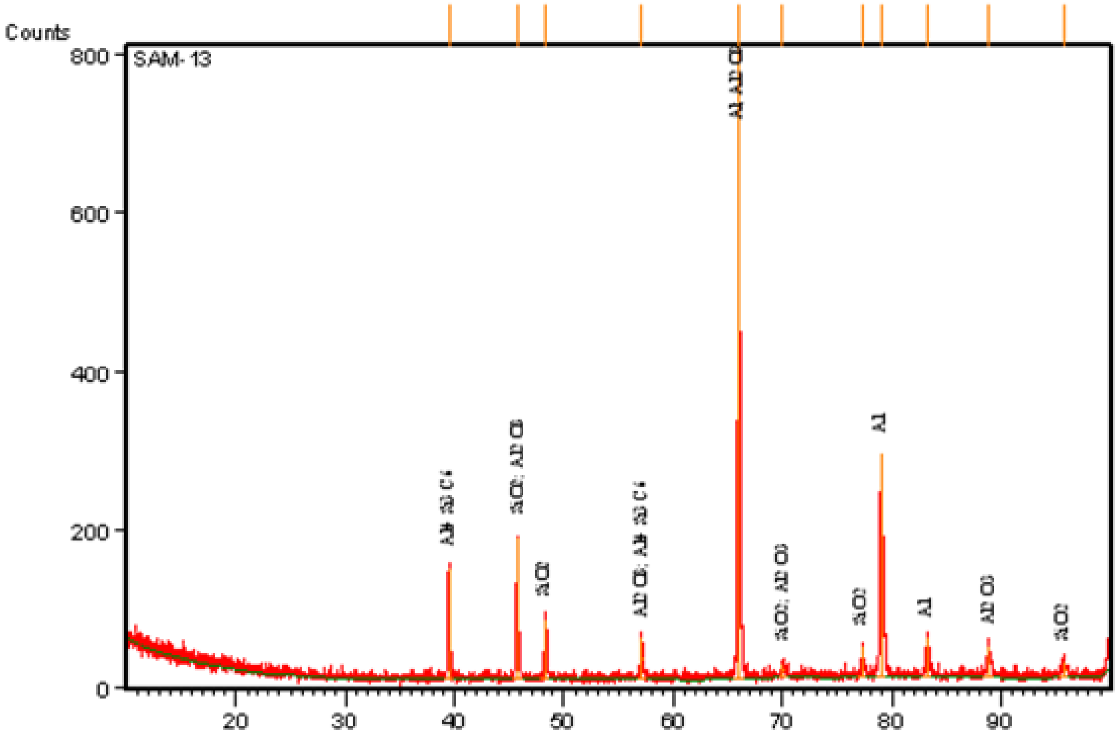


Figure 5.44: X ray diffraction pattern of the alloy with 15 % wt. of SiC & Al_2O_3

Table 5.14: X-ray diffraction pattern of the alloy with 15 % wt. of SiC & Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-056-8554	37	Silicon Aluminium	0.567	SiAl	45
01-067-2339	48	Silicon	0.271	SiO_2	12
01-078-3072	5	Alumina Oxide	0.513	SiC	8
01-089-1916	7	Silicon Oxide	0.031	Si	11
01-085-3072	4	Alumina Oxide	0.013	SiC	21

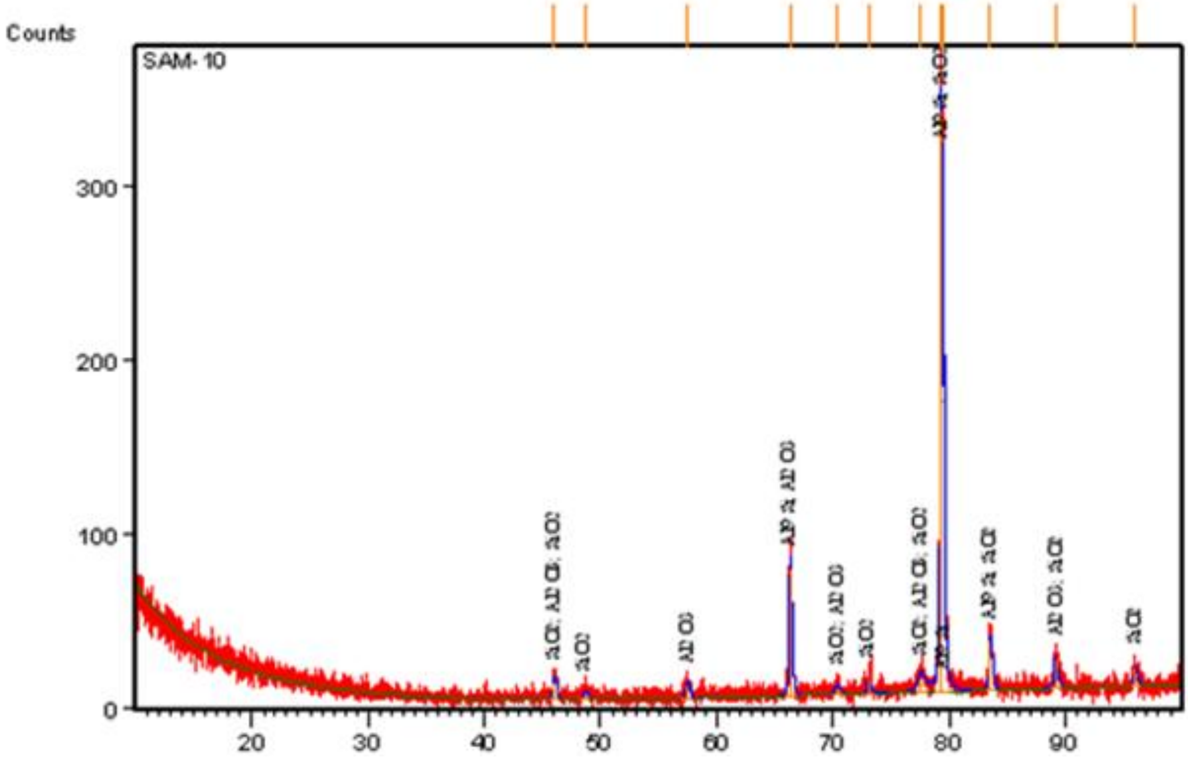


Figure 5.45: X-ray diffraction pattern of the alloy with 20% of SiC & Al_2O_3

Table 5.15: X-ray diffraction pattern of the alloy with 20 % wt. of SiC & Al_2O_3

Ref.Code	Score	Compound Name	Scale Factor	Chemical Formula	Weight fraction (%)
01-086-8554	33	Silicon Aluminium	0.606	Al	69
01-086-2339	44	Silicon	0.171	SiO_2	12
01-089-3072	4	Alumina Oxide	0.013	SiC	8
01-079-1916	3	Silicon Oxide	0.031	Si	8.0

In X-ray diffraction (Figure. 5.45), eleven peaks have been obtained in the 2θ span ranging from 10 to 90. Applying extinction rules, these peaks and associated d-values have been found to correspond to the aluminium matrix composite are given in Table 5.15. The peaks in the pattern can be indexed to a mixture of different compounds such as Al, SiC and Al_2O_3. Minor peaks attributed to impurity.

CHAPTER 6 CONCLUSIONS

6.1 CONCLUSIONS

The conclusions drawn from the present investigation are as follows:

1. The results confirmed that stir formed Al alloy LM 6 with SiC/Al_2O_3 reinforced composites is clearly superior to base Al alloy LM 6 in the comparison of tensile strength, Impact strength as well as Hardness.
2. Dispersion of SiC/Al_2O_3 particles in aluminium matrix improves the hardness of the matrix material.
3. It is found that elongation tends to decrease with increasing particles wt. percentage, which confirms that silicon carbide and alumina addition increases brittleness.
4. Aluminium matrix composites have been successfully fabricated by stir casting technique with fairly uniform distribution of SiC & Al_2O_3 particles.
5. It appears from this study that UTS and Yield strength trend starts increases with increase in weight percentage of SiC and Al_2O_3 in the matrix.
6. The Hardness increases after addition of SiC, Al_2O_3 particles in the matrix.
7. XRD results showed the presence SiC, Al_2O_3 particles in alloy matrix. The oxide phases like Al_2O_3 and SiO etc. have dispersed uniformly throughout in the MMC thus strengthening the resulting composite.
8. Impact strength is increase by adding SiC & Al_2O_3.
9. Stir casting process, stirrer design and position, stirring speed and time, particle-preheating temperature, particle incorporation rate etc. are the important process parameters.

6.2 SCOPE OF FUTURE WORK

1. This can further be extended by varying geometrical angle of Stirrer & by varying stirring speed.

2. Heat treatment can be done to improve the properties.

3. Results can be varied by varying reinforcement Grain Size.

REFERENCES

[1] Hashim J et al., "*Metal matrix composites: production by the stir casting method*", Journal of Materials Processing Technology 92-93 (1999) 1-7.

[2] *http://en.wikipedia.org/wiki/Aluminium.htm* on date 1/4/*2011*

[3] *http://www.eaa.net/eaa/education/TALAT/index.htm* on date 6/5/2011.

[4] Seymour G. Epstein, "*Aluminum and Its Alloys*", the Aluminum Association, Inc. 2001

[5] *http://www.azom.com/article.aspx?ArticleID=310* on date 7/4/2011

[6] J. R. Davis, "*Aluminum and aluminum alloys*", ASM International, 1993

[7] Sanjeev kumar, *"Effect of thermal ageing on Al-SiC Metal Matrix"*, ME Thesis Thapar University Patiala, 2010.

[8] Sudipt Kumar et al, "*production and characterisation of Aluminium-Fly Composites using Stir Casting Method*", Department of Metallurgical & Materials Engineering National Institute of Technology Rourkela, 2008.

[9]http://www.substech.com/dokuwiki/doku.php?id=liquid_state_fabrication_of_metal_matrix_composites.htp on date 15/4/2011

[10] DIVECHA, A P et al, "*Silicon carbide reinforced aluminum - A formable composite*" Journal of Metals. Vol. 33, pp. 12-17. Sept. 1981

[11] C. M. Friend, "*The effect of matrix properties on reinforcement in short alumina fibre-aluminium metal matrix composites*" Journal of Materials Science ,Volume 22, Number 8, 3005-3010,Journal of Materials Science Volume 22, Number 8, 3005-3010, DOI: 10.1007/BF01086505

[12] N. Chawla et al, "*Tensile and fatigue fracture of Discontinuously Reinforced Aluminum*" D, Advances in Fracture Research, (2001), pp. 1-6.

[13] D Tabor, "The hardness of metals" Oxford University Press, 1951

[14] Toshiro Kobayashi," Springer, 2004 - Technology & Engineering - 275 pages"

[15] *http://www.mrl.ucsb.edu/mrl/centralfacilities/xray/xray-basics/index.htm*, 11/5/2011.

[16] Joseph Goldstein, Scanning electron microscopy and x-ray microanalysis, Plenum Publishers, 2001.

[17] Manoj Singla, "*Development of Aluminium Based Silicon Carbide Particulate Metal Matrix Composite",* Journal of Minerals & Materials Characterization & Engineering, Vol. 8, No.6, pp 455-467, 2009.

[18] I.A.Ibrahim et al, "*Particulate reinforced metal matrix composites - a review",* Journal of materials science 26 (1991) 1137-1156.

[19] D.J.Lloyd, "*Particle reinforced aluminium and magnesium matrix composites"*, International Materials Reviews 1994 Vol. 39 No.1.

[20] L.Ceschini, "*Tensile and fatigue properties of the AA6061/20% volume* Al_2O_3p *and AA7005/10% volume* Al_2O_3p *composites",* Composites Science and Technology 66 (2006) 333–342.

[21] S.V. Prasad, "*Aluminum metal–matrix composites for automotive applications: tribological considerations",* Tribology Letters, Vol. 17, No. 3, October 2004.

[22] P.K. Rohatgi et al, "*Scatter and Statistical Analysis of Tensile Properties of Cast SiC Reinforced A359 Alloys*", Materials Science and Engineering A, vol. 398, Issues 1-2, Pages 1-14, April 2005.

[23] S. Balasivanandha Prabu, "*Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite",* Journal of Materials Processing Technology 171 (2006) 268–273.

[24] M. Kok, "*Production and mechanical properties of* Al_2O_3 *particle-reinforced 2024 aluminium alloy composites",* Journal of Materials Processing Technology 161 (2005) 381–387.

[25] G.B.Veeresh Kumar, "*Studies on Al6061-SiC and Al7075-*Al_2O_3 *Metal Matrix Composites",* Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.1, pp.43-55, 2010.

[26] Daniel.Miracle, "*Aeronautical Applications of Metal-Matrix Composites",* Air Force Research Laboratory, Light Met. Age, Vol 57 (No. 1, 2), 1999, p 117–121.

[27] A.Daouda, "*Influence of Al2O3 particulate on the ageing response of A356 Al-based composites"*, Journal of Materials Processing Technology 123 (2002) 313–318.

[28] W.Q. Song, P. Krauklis, A.P. Mouritz, S. Bandyopadhyay, "*The effect of thermal ageing on the abrasive wear behaviour of age-hardening 2014 Al/SiC and 6061 Al/SiC composites"*, Wear, Volume 185, Issues 1-2, June 1995.

[29] Z. M. El-Bradie, A. N. Abd El-Azim, "*Ageing behavior of aluminium alloy Glass particulate composites*", Journal of Materials Processing Technology, Volume 66, Issues 1-3, April 1997.