A Thesis

On

EFFECT OF THERMAL AGEING ON Al -SiC METAL MATRIX COMPOSITE

Thesis submitted in the partial fulfillment of the requirements for the award of the Degree of

MASTER OF ENGINEERING

IN

(PRODUCTION AND INDUSTRIAL ENGINEERING)

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CERTIFICATE

This is to certify that the work done in this thesis report titled **"EFFECTS OF THERMAL AGEING ON Al-SiC METAL MATRIX COMPOSITE"** submitted in partial fulfilment of requirement for the award of the **Master of Engineering Degree in Production and Industrial Engineering** in the Mechanical Engineering Department of Thapar University, Patiala, is an authentic record of work carried out by me under the guidance of **Dr. V. P. Agrawal**, Visiting Professor, Mechanical Engineering Department, Thapar University, Patiala and **Mr.Kishore Khanna** Assistant Professor 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.

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

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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.

Present work is focused on the study of age hardening behaviour of Aluminium alloy (6351) - 9%wt SiC composite produced by the stir casting technique. Water and Brine solution has been used as the quenching media. Thermal ageing has been done at different temperature, time and quenching media. Micro hardness and wear tests were performed on the samples obtained from the stir casting process. The results of ageing demonstrate that the micro hardness of the composite depend on the quenching medium in which they are heat treated and peak hardness depends on quenching media and ageing time durations. X-ray Diffraction was performed to know the presence of the phases of reinforced material. Optical micrography was done to know the distribution of SiC particles in aluminium alloy.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO THE COMPOSITE MATERIALS

Composite Materials can be defined as a combination of two or more dissimilar materials having a distinct interface between them such that the properties of the resulting materials are superior to the individual constituting components.

The possibility of taking advantage of particular properties of the constituent materials to meet specific demands is the most important motivation for the development of composites. This definition is very large, and includes a lot of materials such as the Roman ways (constituted of different layers of stones, chalk and sand), wood, concrete etc. A more restrictive definition is used by industries and materials scientists: a composite is a material that consists of constituents produced via a physical combination of pre-existing ingredient materials to obtain a new material with unique properties when compared to the monolithic material properties. This definition distinguishes a composite from other multiphase materials which are produced by bulk processes where one or more phases result from phase transformation.

Generally, a composite material is composed of reinforcement. 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.

1.1.1 Matrix phase

The primary phase, having a continuous character, is called matrix. Matrix is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it.

Functions of matrix to take the load and transfers it to the reinforcement and it binds or holds the reinforcement and protects the same from mechanical or chemical damage that might

occur by abrasion of their surface. Matrix also separates the individual fibres and prevents brittle cracks from completely across the section of the composite

1.1.2 Dispersed (reinforcing) phase

The second phase is imbedded in the matrix in a discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase.

Many of common materials (metal alloys, doped Ceramics and Polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents.

The following are some of the reasons why composites are selected for certain applications:

- High strength to weight ratio (low density high tensile strength)
- High creep resistance
- High tensile strength at elevated temperatures
- High toughness

Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile, or tough, material. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material. The downside is that such composites are often more expensive than conventional materials. Examples of some current application of composites include the diesel piston, brake-shoes and pads, tires and the Beechcraft aircraft in which 100% of the structural components are composites.

The strength of the composite depends primarily on the amount, arrangement and type of fibre (or particle) reinforcement in the resin. Typically the higher the reinforcement content, the greater the strength. In some cases, glass fibres are combined with other fibres, such as carbon or aramid to create a "hybrid" composite that combines the properties of more than

one reinforcing material. In addition, the composite is often formulated with fillers and additives that change processing or performance parameters.

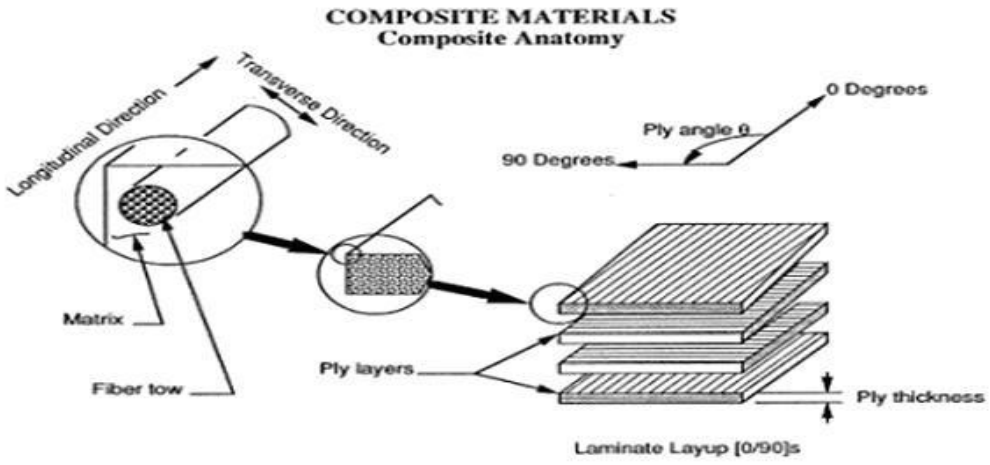


Figure 1.1 Laminate Composite Anatomy

1.2 CLASSIFICATION OF COMPOSITES

There are two classification systems of composite materials. One of them is based on the matrix material (metal, ceramic and polymer) and the second is based on the material structure.

i.2.1 Classification of composites I

i. Metal matrix composites (MMC)

Metal matrix composites (MMCs), like all composites, consist of at least two chemically and physically distinct phases, suitably distributed to provide properties not obtainable with either of the individual phases. Generally, there are two phases, e.g. a fibrous or particulate phase in a metallic matrix. A metal matrix composite (MMC) combines into a single material a metallic base with a reinforcing constituent, which is usually non-metallic and is commonly a ceramic. By definition, MMC's are produced by means of processes other than conventional metal alloying. Like their polymer matrix counterparts, these composites are often produced by combining two pre-existing constituents.

Common types of MMC are

- Aluminum Matrix Composites (AMC)
- Magnesium Matrix Composite
- Titanium Matrix Composite
- Copper Matrix Composites

Aluminum is the most popular matrix for the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminum matrix composites (AMCs) have been widely studied since the 1920s and are now used in sporting goods, electronic packaging, armours and automotive industries. They are usually reinforced by Al_2O_3, SiC, and carbon. As proposed by the American Aluminum Association the AMCs should be designated by their constituents: accepted designation of the matrix / abbreviation of the reinforcement's designation / arrangement and volume fraction in % with symbol of type (shape) of reinforcement. For example, an aluminum alloy AA6061 reinforced by particulates of alumina, 22 % volume fraction, is designated as "AA6061/Al_2 O_3/22p".

Aluminum Matrix Composites are manufactured by the following fabrication methods

- Powder metallurgy
- Stir casting
- Squeeze casting

ii. Ceramic matrix composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and imbedded fibres of other ceramic material (dispersed phase). Ceramic Matrix Composites are designed to improve toughness of conventional ceramics, the main disadvantage of which is brittleness. Ceramic Matrix Composites are reinforced by either continuous (long) fibers or discontinuous (short) fibers. Short-fiber (discontinuous) composites are produced by conventional ceramic processes from an oxide (alumina) or non-oxide (silicon carbide) ceramic matrix reinforced by whiskers of silicon carbide (SiC), titanium boride (TiB2), aluminum nitride (AlN), zirconium oxide (ZrO2) and other ceramic fibers. Most of CMC are reinforced by silicon carbide fibers due to their high strength and stiffness. Whiskers incorporated in a short-fiber

Ceramic Matrix Composite improve its toughness resisting to cracks propagation. However a character of failure of short-fiber reinforced materials is catastrophic.

Long-fiber composites are reinforced either by long monofilament of long multifilament fibers. The best strengthening effect is provided by dispersed phase in form of continuous monofilament fibers, which are fabricated by chemical vapor deposition (CVD) of silicon carbide on a substrate made of tungsten (W) or carbon (C) fibers. Monofilament fibers produce stronger interfacial bonding with the matrix material improving its toughness.

iii. **Polymer Matrix Composites (PMC)**

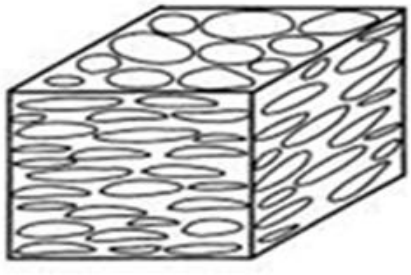
Polymer Matrix Composite (PMC) is the material consisting of a polymer (resin) matrix combined with a fibrous reinforcing dispersed phase. Polymer Matrix Composites are very popular due to their low cost and simple fabrication methods. Use of non-reinforced polymers as structure materials is limited by low level of their mechanical properties such as tensile strength of one of the strongest polymers - epoxy resin is 20000 psi (140 MPa). In addition to relatively low strength, polymer materials possess low impact resistance.

1.2.2 Classification of composite materials II

i. Particulate Composites

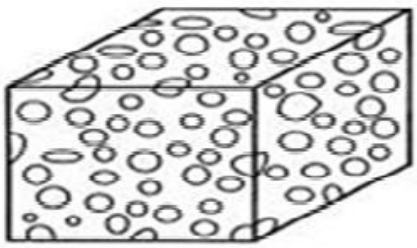
These are of two types

- Particulate Composites with random orientation of particles.
- Composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.



Flake Reinforcement

Figure 1.2



Partical Reinforcment

Figure 1.3

- Effect of the dispersed particles on the composite properties depends on the particles dimensions. Very small particles (less than 0.25 micron in diameter) finely distributed in the matrix impede the movement of dislocations and deformation of the material. Such strengthening effect is same to the precipitation hardening. In contrast to the precipitation hardening, which disappears at elevated temperatures when the precipitated particles dissolve in the matrix, dispersed phase of particulate composites is usually stable at high temperatures, so the strengthening effect is retained. Many of composite materials are designed to work in high temperature applications. Large dispersed phase particles have low strengthening effect but they are capable to share load applied to the material, resulting in increase of stiffness and decrease of ductility. Hard particles dispersed in a softer matrix increase wear and abrasion resistance. Soft dispersed particles in a harder matrix improve machinability (lead particles in steel or copper matrix) and reduce co efficient of friction.

ii. Fibrous Composites

Short fibre reinforced composites. Short fibre reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibres.

- Composites with random orientation of fibers.
- Composite with preferred orientation of fibers.

Long-fibre reinforced composites. Long-fibre reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibres.

- Unidirectional orientation of fibres.
- Bidirectional orientation of fibres.

Figure 1.4: Fiber composite

Effect of the strength increase becomes much more significant when the fibers are arranged in a particular direction and a stress is applied along the same direction. The strengthening effect is higher in long-fiber reinforced composites than in short-fiber reinforced composites. Short-fiber reinforced composites, consisting of a matrix reinforced with a dispersed phase in form discontinuous fibers have a limited ability to share load. Load applied to a long-fiber reinforced composite, is carried mostly by the dispersed phase - fibers. Matrix in such materials serves only as a binder of the fibers keeping them in a desired shape and protecting them from mechanical or chemical damages.

iii. Laminate Composites

When a fibre reinforced composite consists of several layers with different fibre orientations, it is called multilayer composite.

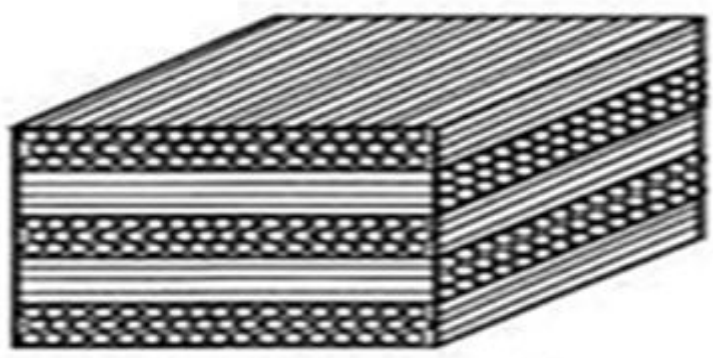


Figure 1.5: Laminated Composite

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer composite. Laminate composites provide increased mechanical strength in two directions and only in one direction, perpendicular to the preferred orientations of the fibers or sheet, mechanical properties of the material are low.

iv. Sandwich structured composite

A sandwich structure results from the assembly by bonding or welding of two thin facings or skins on a lighter core that is used to keep the two skins separated.

Their properties are

- Very light weight
- Very high flexural rigidity
- Excellent thermal insulation characteristics

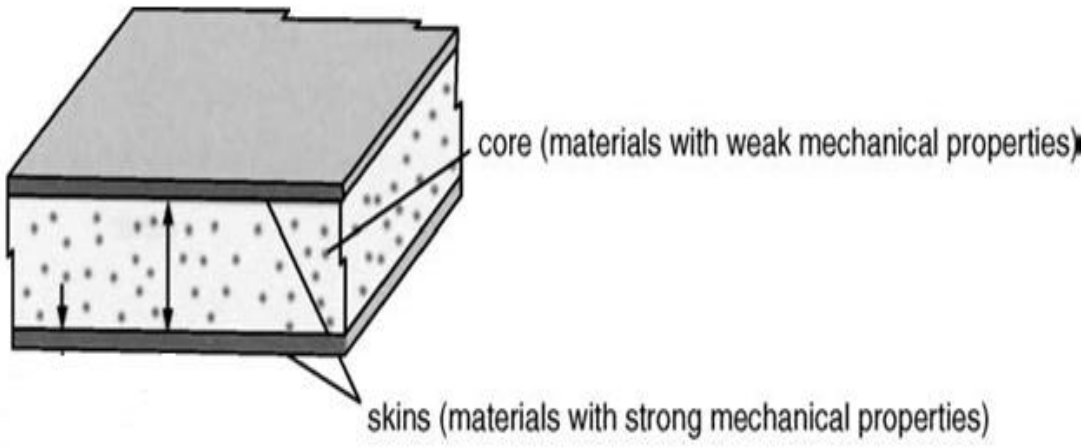


Figure 1.6: Sandwich Structure Composite [21]

1.3 WHY COMPOSITES

The demands on material performance are so great and diverse that no one material is able to satisfy them e.g. lightweight yet strong & stiff structure. Composite material systems results in a performance unattainable by the individual constituents. Composite material offer advantage of a flexible design that can be tailored to the design requirements.

If we make comparison of metals like steel and aluminium with composites. The reason for choosing the aluminium and steel is that they are widely used in industry. So one can figure out that in comparison by weight composites are much lighter than other two metals. Similarly in comparison of thermal expansion the composites are low which is good for places where high temperature working is required. In case of stiffness & strength the composites are ahead of the aluminium & steel.

1.4 PROCESSING OF COMPOSITES

Metal matrix composites can be made by liquid, solid state processes.

1.4.1 Liquid state fabrication of Metal Matrix Composites

This process 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 particles. Proper coating not only reduces interfacial energy, but also prevents chemical interaction between the dispersed phase and the matrix.

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

i. Stir Casting

Stir casting is a liquid state method of composite materials fabrication, in which a dispersed phase is mixed with a molten matrix metal by means of mechanical stirring. Stir casting is the simplest and the most cost effective method of liquid state fabrication. The method using stirring metal composite materials in semi-solid state is called rheocasting. High viscosity of the semi-solid matrix material enables better mixing of the dispersed phase the liquid composite material is then cast by conventional casting methods and may also be processed by conventional Metal forming technologies.

Stir casting is characterized by the following features are

- Content of dispersed phase is limited.
- Distribution of dispersed phase throughout the matrix is not perfectly homogeneous.

ii. 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.

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 debinding 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.

iii. 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.

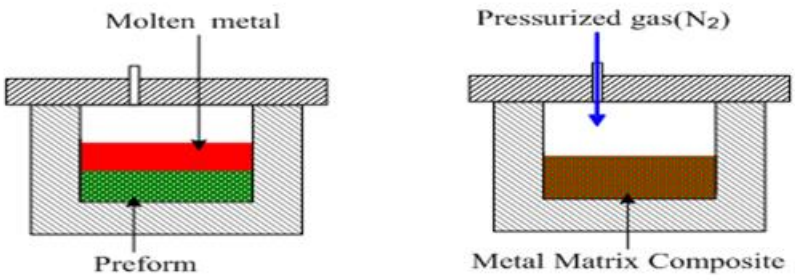


Figure 1.7: Gas Pressure Infiltration [20]

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.

iv. 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 Infiltration method is similar to the squeeze casting technique used for metal alloys casting.

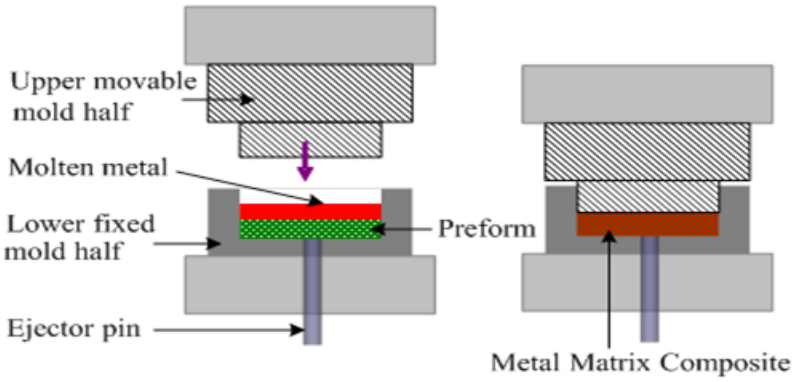


Figure 1.8: Squeeze Casting Infiltration [20]

Squeeze casting infiltration process has the following steps are

- A preform 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 preform.
- The infiltrated material solidifies under the pressure.
- The part is removed from the mold by means of the ejector pin.

This method is used for manufacturing simple small parts like automotive engine pistons from aluminium alloy reinforced by alumina short fibers.

v. 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 preform under the pressure of a movable piston.

vi. **Deposition Processes**

In deposition processes, droplets of molten metal are sprayed together with the reinforcing phase and collected on a substrate where the metal solidification is completed. This technique has the main advantage that the matrix microstructure exhibits very fine grain sizes and low segregation, but has several drawbacks such as this technique can only be used with discontinuous reinforcements, high costs, and the products are limited to the simple shapes that are obtained by extrusion, rolling or forging.

1.4.2 Solid State Fabrication of Metal Matrix Composites

Solid state fabrication of Metal Matrix Composites is the process in which metal matrix composites are formed as a result of bonding matrix metal and dispersed phase due to mutual diffusion occurring between them in solid states at elevated temperature and under pressure. Low temperature of solid state fabrication process depresses undesirable reactions on the boundary between the matrix and dispersed phases.

Metal Matrix Composites may be deformed also after sintering operation by rolling, forging, pressing, drawing or extrusion. The deformation operation may be either cold or hot. Deformation of sintered composite materials with dispersed phase in form of short fibers results in a preferred orientation of the fibers and anisotropy of the material properties.

There are two principal groups of solid state fabrication of metal matrix composites

- Diffusion bonding
- Sintering

i. Diffusion bonding

Diffusion Bonding is a solid state fabrication method in which a matrix in form of foils and a dispersed phase in form of long fibers are stacked in a particular order and then pressed at elevated temperature. The finished laminate composite material has a multilayer structure.

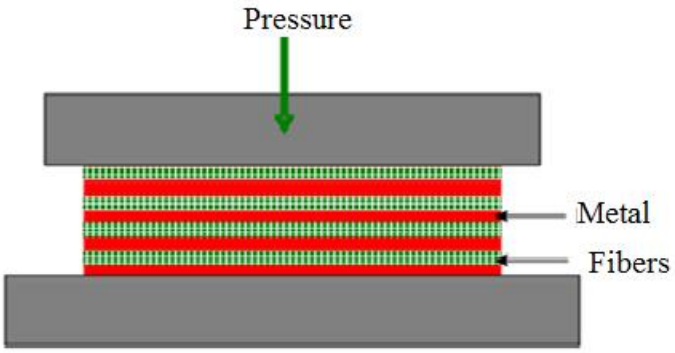


Figure 1.9: Diffusion bonding [20]

Variants of diffusion bonding are roll bonding and wire/fiber winding. Roll bonding is a process of combined rolling strips of two different metals e.g. steel and aluminum alloy resulted in formation of a laminated composite material with a metallurgical bonding between the two layers. Wire/fiber winding is a process of combined winding continuous ceramic fibers and metallic wires followed by pressing at elevated temperature.

ii. Sintering

Sintering fabrication of metal matrix composites is a process, in which a powder of a matrix metal is mixed with a powder of dispersed phase in form of particles or short fibers for subsequent compacting and sintering in solid state. Sintering is the method involving consolidation of powder grains by heating the "green" compact part to a high temperature below the melting point when the material of the separate particles diffuse to the neighboring powder particles. In contrast to the liquid state fabrication of metal matrix composites, sintering method allows obtaining materials containing up to 50% of dispersed phase. When sintering is combined with a deformation operation, the fabrication methods are called

- Hot Pressing Fabrication of Metal Matrix Composites
- Hot Powder Extrusion Fabrication of Metal Matrix Composites

a. Hot Pressing Fabrication of Metal Matrix Composites

Pressing Fabrication of Metal Matrix Composites – sintering under a unidirectional pressure applied by a hot press.

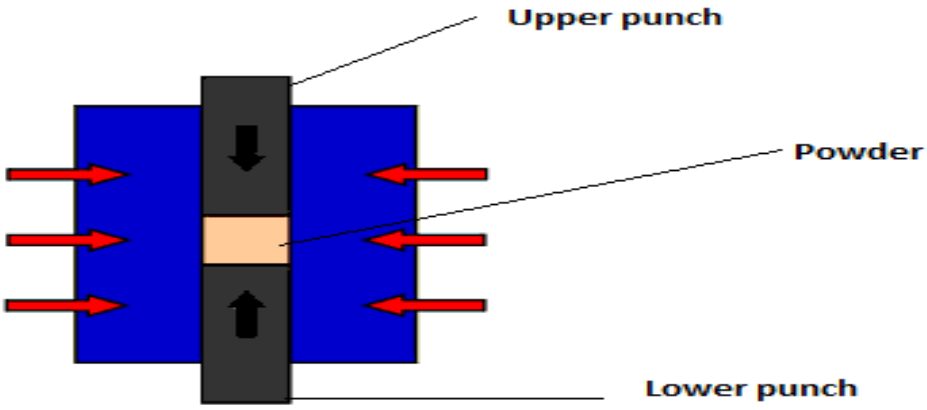


Figure 1.10: Hot Pressing [20]

b. Hot powder extrusion fabrication of metal matrix composites

Extrusion Fabrication of Metal Matrix Composites sintering under a pressure applied by an extruder at elevated temperature. There are two main type extrusion process first is forward extrusion and second is backward extrusion.

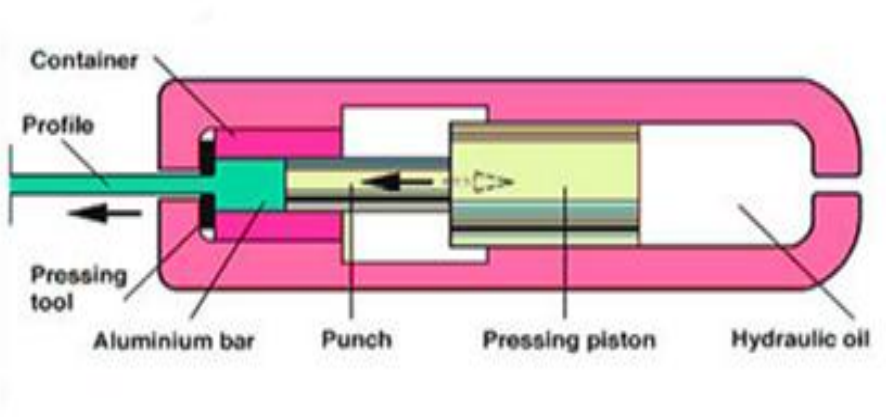


Figure 1.11: Hot Forward Extrusion

1.5 ALUMINIUM AND ITS ALLOYS

The three main alloys of importance in engineering and aerospace applications are the aluminium alloys, steels and nickel alloys. Titanium, magnesium and copper alloys are also significant. Aluminium alloys with great durability and high strength, some with a tensile strength as good as that of constructional steels, are available to the designer in the form of extruded profiles, rolled sheet and plate, castings and forgings. The majority of these alloys consist of aluminium with carefully controlled additions of copper, magnesium, silicon, manganese, zinc and more recently lithium. Aluminium alloys are the dominant materials for airframe structures. There are three main classes of aluminium alloys used in aerospace applications, though only the wrought heat-treated alloys have sufficient strength for structural components.

1.5.1 Casting 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

1.5.1 Wrought Aluminium Alloys: to meet various requirements, aluminium is alloyed with copper, manganese, magnesium, zinc, nickel and silicon as major alloying elements. These alloying additions improve the properties of aluminium when added in desired percentages. 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) and by most of the countries in the world. Table 1-1 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

Table 1.1 Designation of Wrought Aluminium alloys

Alloy Designation	Detail
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
9XXX	Unassigned

Table 1.2 Designation of Cast Aluminium alloys

Alloy Designation	Details
1XXX	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
7XX.X	Sn containing alloy

The condition of temper of Aluminium alloys be denoted by specific letters as shown below

Table 1.3 Temper Designation System

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

1.5.3 Heat Treatable Aluminium Alloys: Heat treating in its broadest sense, refers to any of the heating and cooling operations are performed for the purpose of changing the mechanical properties, the metallurgical structure, or the residual stress state of a metal Product . When the term is applied to aluminum alloys, however, its use frequently is restricted to the specific operations employed to increase strength and hardness of the precipitation hardenable wrought and cast alloys. These usually are referred to as the "heat-treatable" alloys to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling. The Aluminium alloys of this class belong to systems with limited solubility in solid state. These are precipitation hardenable alloys. The main characteristic of these alloys system is temperature dependent equilibrium solid solubility, which increases with rise in temperature. In addition the other requirements are possibility of retaining single phase supersaturated solid solution by quenching, and precipitation of coherent/partially coherent phase by decomposition of the super saturated solid solution. The examples of this group are:

1. Aluminum-copper systems with strengthening from $CuAl_2$
2. Aluminum-copper-magnesium systems (magnesium intensifies precipitation)
3. Aluminum-magnesium-silicon systems with strengthening from Mg2Si
4. Aluminum-zinc-magnesium systems with strengthening from MgZn2

1.5.4 Non-Heat treatable Aluminium alloys: These alloys do not respond to heat treatment, because they consist of a homogeneous solid solution with or without non-coherent precipitate(s) and show low strength and high ductility. These alloys may be stress hardened. Commercially pure Aluminium (1100), Al-Mn (3003), and Al-Si alloys are examples of this class. These alloys are used as sheet, bar, plates,

1.5 Thermal Ageing

Aluminium alloys which are heat treatable belong to systems with limited solubility in solid state. These are precipitation hardenable alloys. The main characteristics of this type of alloy system are temperature-dependent equilibrium solid solubility, which increases with rise in temperature. Ageing is done for greater hardness and is achieved by the phenomenon of precipitation [22]. If precipitation is done at room temperature with respect to time then it is called natural ageing, whereas, precipitation at high temperature is referred to as artificial

ageing, “age hardening” or just “ageing”. The maximum hardness and strength is developed when an alloy is aged at a suitable temperature which normally ranges between 80 °C and 300 °C. Ageing time may vary from 4 hours to 24 hours.

The spontaneous decomposition of supersaturated solid solution takes place during ageing treatment. Higher the ageing temperature and higher the degree of super saturation more intensive will the ageing be. Besides mechanical properties, chemical properties are also affected by ageing. This happens due to the metastable structures of alloy which are formed during ageing of supersaturated of solid solution obtained by the solution treatment. The rise in temperature changes the atomic position with corresponding change in the forces associated with inter atomic bonds. At the same time distribution of second phase particles also changes.

Following steps are associated with the process of precipitation hardening in most of the aluminium alloys

i. The first stages preceding the formation of particles of the precipitating phase consists of rearrangement of atoms within the crystal lattice. This constitutes the formation of clusters and Guinier-Preston zones (GP-I). During this process, mechanical properties are improved due to development of micro strains in the lattice.

ii. Formation of transition structure in the form of modified Guinier-Preston zones (GP-II) and intermediate this may give to maximum strengthing in the alloy.

iii. Formation of stable phase from transition phases whose particles have common boundaries with the grain of the matrix.

iv. Growth of the larger particles at the expense of neighboring smaller particles. Due to this, stress relief takes place in the lattice usually at higher ageing temperature, which causes considerable decrease in strength and increase in ductility of the alloy.[22]

CHAPTER 2

LITERATURE REVIEW

2.1 REVIEW OF LITERATURE

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. 2000, 6000, 7000, and many reinforcement types SiC, B4C, 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.E. Bekheet et al.[1] [2002] Studied the effect of particulate silicon carbide (SiCp) which are reinforced in 2024 aluminum alloy shows that reinforcement and cold working before artificial aging have accelerated the reaction kinetics of the precipitation-hardening process of the composite. The presence of SiC particles refined the structure of the matrix. The higher the percentage of SiCp, the smaller is the grain size of the matrix. The precipitation behavior of the composite alloy is greatly different from the unreinforced 2024 Al alloy. The peak hardness of composites is slightly higher than that for 2024 Al alloy. The time required to attain the peak hardness is very much affected by the existence and amount of SiCp.

Y. Sahin et al.[2] [2003] Presented that aluminium alloy composites containing various particle sizes of 10 and 20 wt. % SiC particles were prepared by molten metal mixing and squeeze casting method under argon gas. The stirring was carried out with graphite impeller during addition of particle. The molten mixture was poured into a die when the stirring was completed and metal matrix composites were produced by applying the pressure. Optical microscopic examination, hardness, density and porosity measurement were carried out. Moreover, metal matrix composites were machined at various cutting speeds under a fixed depth of cut and feed rate using different cutting tools. It is observed that there was a reasonably uniform dispersion of particles in the matrix alloy. The density decreased with

decreasing particle sizes, but porosity decreased considerably with increasing particle size. In addition, the tool life decreased considerably with increasing cutting speeds for all tests.

P.K. Rohatgi et al.[3] [2002] Investigated the effect of aging characteristics of aluminum alloy A356 and an aluminum 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 of hollow fly ash particles on the kinetics of the age hardening of aluminum alloy A356.

Rajesh Sharma et al.[4][2007] Observed that the influence of solutionizing temperature during artificial age hardening treatment (T6) of cast Al–Mg on abrasive wear resistance Increase as solution temperature increases. Alloys were prepared by controlled melting and casting. After that artificial aging is done. All the alloys were solutionized at 450 ºC, 480 ºC, 510 ºC, and 550 ºC for 8 h followed by water quenching (30 ºC) and aging hardening at 170 ºC for 12 h. Abrasive wear tests were conducted against 320 grade SiC polishing papers at 5 N and 10 N normal loads. It was observed that the silicon content and solution temperature affected the wear resistance significantly. Increase in normal load increases the wear rate irrespective of alloy compositions and conditions. Alloy composition and its condition influence the wear rate. Increasing silicon content reduces the abrasive wear rate under identical sliding conditions. Heat treatment of all three alloys improved abrasive wear resistance.

Z. M. El-Baradie et al.[5] [2007] 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. The results show that the application of TMT is highly recommendable to improve the strength of both the unreinforced and composite alloys.

W.Q. Song et al.[6] [1995] Examines the changes to the abrasive wear resistance of aluminium-based composites when heat-treated to different ageing conditions. The composites studied were the age-hardenable aluminium alloys 2014 Al or 6061 Al reinforced with 3 μm or 20 μm SiC particles. The materials were aged at temperatures between 50°C and 250°C, and changes to the wear resistance were measured using a pin-on-drum machine. When aged at the lowest temperatures (between 50–150°C), transmission electron microscopy revealed the presence of the solute clusters (e.g. GP zones) and small coherent precipitates in the aluminium alloy matrices, and these were easily sheared by mobile dislocations. Consequently, the hardness and abrasive wear resistance of these under-aged composites were measured to be relatively low. Raising the ageing temperature to 200°C increased the hardness and abrasion resistance of the composites to the peak-aged condition and this was associated with the precipitation of small intermetallic compounds which were incoherent with the crystal structures of the aluminium alloy matrices. At 250°C the composites were over-aged, and this resulted in a reduction in hardness and wear resistance due to the coarsening of the intermetallic precipitates. The composites containing 20 μm SiC particles were slightly more wear resistant than those containing 3 μm Sic.

Hailong Wang et al.[7] [2008] 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 behaviour 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.

J.J. Gracio et al.[8] [2004] Investigated the effect of artificial aging behavior of 6022-T4 alloy It was found that 6022-T4 alloy can be substantially hardened through a short aging treatment at temperatures in excess of 200 ºC. The strain hardening curves of the 6022 alloy in different aging conditions were measured using the simple shear test and analysed in terms of their respective microstructures. The under-aged and pre-peak-aged exhibited a good combination of strength and strain hardening while the peak-aged alloy was characterized by maximum strength, albeit with a drastic reduction in strain hardening ability.

S.B. Hassan et al.[9] [2009] Studied the microstructure and ageing behavior of Al–Si–Fe/Mg alloys produced through sand-casting route is presented. 4.0–6.0 wt% Mg was added to Al–Si–Fe alloy. Standard mechanical properties test samples were prepared from the sand cast 25 mm diameter by 45 mm rods. Thermal ageing was done for 6 h at 200 °C. The ageing characteristics of these alloys were evaluated using tensile properties, hardness values, impact energy and microstructure as criteria. The thermal aged samples exhibited higher yield strength, tensile strength and hardness values as the weight percent of magnesium increased up to 5 wt% in the Al–Si–Fe/Mg alloys as compared to as-cast samples. The optimum values were obtained at 5 wt. % Mg. Lower percent elongation, reduction in area and impact energy values were obtained for age-hardened Al–Si–Fe/Mg alloy samples as compared to as-cast samples. The increases in hardness values and strength during ageing are attributed to the formation of coherent and uniform precipitation in the metal lattice. It was found that the age-hardened showed acceleration in ageing compared to the as-cast alloy. However, the 5 wt% Mg addition to the alloy showed more acceleration to thermal ageing treatment. These results show that better mechanical properties are achievable by subjecting the as-cast Al–Si–Fe/Mg alloys to thermal ageing treatment.

P. Appendino et al.[10] [1999] studied the kinetics of natural aging and precipitation hardening (T4 and T6 tempers) were compared in 6061 aluminium alloy (AA) and 6061 AA−14vol.%SiC particle composite. Aging processes have been studied by hardness measurements and differential scanning calorimetry (DSC). The latter technique is used as a screening tool to follow the aging sequence in fact, the DSC thermogram depicts characteristic features of different heat treatments undergone by samples. DSC curves for both 6061 AA and 6061AA-SiCp, after solution treatment, display the same aging path; on the contrary, the two materials differ in solution temperature, which is about 30 °C higher in

the case of the composite. The precipitation hardening (at 180°C) occurs faster in the composite than in 6061 alloy. The latter presents a broad hardness peak ranging between 4 and 10 h of aging while the composite shows a sharp peak after about 4 h. Probably this behaviour is due to the high dislocation density close to the metal matrix-SiC particle interface. In these strongly deformed zones nucleation processes are accelerated. The aging kinetics at room temperature for the composite is slower than for the 6061 AA. In fact the two materials show the same aging rate when solution treatment in the case of the composite is complete. On the contrary, the composite ages more slowly than 6061 AA. Hence the high dislocation density at the interface, between composite constituents, does not affect T4 treatment.

Byung-Chul et al.[11] [1999] made hybrid composites with different ratios of SiCw and SiCp (SiCw : SiCp=1:1, 1:2, and 1:3) were fabricated by the powder-metallurgy route and were solution treated followed by aging treatment. Mechanical properties of the hybrid composites reinforced with both SiC whiskers (SiCw) and SiC particles (SiCp) were investigated. The peak aging time for the hybrid composites was determined from the measurement of matrix hardness. Accelerated aging occurred in the hybrid composites and the peak aging time (5 h) was similar in all the hybrid composites. The hybrid composite with SiCw : SiCp=1:1 showed the highest ultimate tensile strength. The work hardening rate of under-aged hybrid composite with SiCw : SiCp=1:1 was higher than that of over-aged one.

Guiqing Wang et al.[12] [2004] was investigated the effect of Be addition on the aging behavior of UNS 03370 (Al11Si3Cu0.3Mg) was investigated by micro-hardness measurement, differential scanning calorimetry (DSC) and transmission electron microscope (TEM) analysis. Age hardening analysis shows Be additions to an Al11Si3Cu0.3Mg alloy accelerates the age hardening rate and increases the peak hardness by 15 HV during aging at 160 °C. DSC shows that Be additions lead to an endothermic peak corresponding to the dissolution of Gunier Preston zones (GP I) disappear with exothermic peaks corresponding to precipitation of GP II zones and the ‘ λ and/or ‘ θ phases shift to low temperature. DSC and TEM analyses show that GP II zones are more effective than λ and/or θ on hardening the alloy, and Be addition increases the homogeneous nucleation density of GP II zones. The possible Be atoms participating in the precipitation process during aging and the high Be-vacancy λ binding energy can explain the effect of Be on aging behavior of Al-11Si-3Cu-0.3Mg alloy.

H.K. Shivanand et al.[13] [2006] Studied the improvement in abrasive wear rate of as-cast and heat-treated Al (6061) alloy reinforced with 9% by weight of SiC particulate and 0, 1, 3 and 5% by weight of E-glass fiber subjected to different ageing durations. The liquid melt technique route is used to produce the castings. Castings were machined to the ASTM standards and T6 heat-treatment process is carried out. All the specimens were artificially aged to different durations like 1, 3, 5 and 7 h at a temperature of 175 ºC. It was found that the heat-treatment T65h was the one that provided the matrix greater hardness and therefore it was the one, which shows the heat-treated specimens, are the high wear resistance. The wear rate of the Al-based hybrid composites do not depend on type of reinforcement, but wear rate of the hybrid composites decreases with increasing the weight percentage of reinforcing materials. The abrasive wear resistance of Al-based hybrid composites may be controllably altered by thermal ageing. As-cast hybrid composites and 1 h aged hybrid composites provided relatively low resistance. Maximum wear resistance was achieved when the hybrid composites aged at 5 h condition, when the Al alloy contained a large number of coherent precipitates.

Halil Demir et al.[14] [2009] The effect of aging on machinability behavior in 6061 Al-alloy was studied in artificially aged conditions and found that an increase in hardness of SHTA (solution heat treated and aged) 6061 Al-alloy with increase in aging time at 180 ºC can be explained by a diffusion assisted mechanism which causes an increase in the density of GP zones, distortion of lattice planes and hindering of dislocation movement by the impurity atoms. The strengthening effect can also be as a result of interference with the motion of dislocation, due to the formation of precipitates. Further increase in aging time decreases the hardness of the alloy. This could be due to coalescence of the precipitates into larger particles which will cause fewer obstacles to the movement of dislocation and hence the hardness starts to decrease. Unlike cutting forces, aging at different times for 180 ºC affected surface roughness of workpieces considerably. This is due to its highest hardness value as the result of aging and easy disposal of the chips during machining.

L. Ceschini et al.[15] [2008] studied the effect of the hot isostatic pressing (HIP) process on the fatigue resistance of sand-cast A356 (Al–Si–Mg) and A204 (Al–Cu–Mg) aluminium alloys w by means of rotating bending tests. Many solidification defects, such as gas pores and shrinkage cavities, were present in both alloys in the sand-cast before HIP. The HIP process had a negligible effect on microstructural features (such as grain size, SDAS, and intermetallic compounds), whereas it significantly reduced the solidification defects. The

non-HIP processed A204 alloy showed a slightly lower fatigue resistance than the A356 alloy, due to the presence of many branched shape shrinkage cavities, especially along grain boundaries. For both aluminium alloys, the HIP process led to a reduction in fatigue data scattering and an increase in fatigue resistance, equal to about 40% for A356 and 70% for A204. In the HIP processed condition, when the alloys can be considered pore-free, the A204 showed a 20% higher fatigue resistance than the A356 alloy.

Umit Cocen et al.[16] [2002] had investigated the effect of hot extrusion on the strength and ductility of particulate silicon-carbide-reinforced aluminium alloy (Al–5% Si–0.2% Mg) composites. Cast ingots of the matrix alloy and the composites were extruded at 500° C at an extrusion ratio of 10:1. The microstructures and mechanical properties of the composite samples and the matrix alloy had investigated in the as-cast state and after extrusion, and are compared with the mechanical properties of hot-forged composites of the same composition. The extruded microstructures have more uniform distribution of the SiC particles and the eutectic silicon by comparison with as-cast microstructures. Evaluation of the mechanical properties show that the extruded samples have strength and ductility values superior to those of the as-cast counterparts. In the extruded samples the addition of increasing amounts of particulate SiC increases the yield and tensile strength and decreases the ductility. The ductility level of the extruded samples is found to be higher than those of the forged and as cast samples.

C. Badini et al.[17] [*1990*] was investigated that the results of a Differential Scanning Calorimetry (DSC) investigation on precipitation hardening in solubilized 6061 aluminum alloy and its composites reinforced with SiC whiskers are reported. The exothermic and endothermic effects in DSC traces of these materials (in the solubilized state) have been attributed to phase formation and reversion on the base of the 6061 AA ageing sequence described in previous TEM studies. Apparent activation energies have been calculated according to the Ozawa method in non-isothermal conditions. The ageing sequence in composites is analogous to that of 6061 AA. It was found that the SiC whiskers reinforcement accelerates many steps of the ageing sequence.

Chen Zhenhua et al.[18] [2006] was investigated wear behaviors of spray-deposited Al–Si/SiC composites, with Si contents between 9 and 20% and 15 vol.% SiC particles, were investigated by using a ring-on-ring test at room temperature under dry conditions. The wear rate of spray-deposited Al–Si/SiCp composites is decreased with increasing Si content, and

the wear resistance can be further improved by heat treatment and densification and the degree of plastic deformation of the subsurface is greatly affected by the hardness of the composite, and this will affect the formation and stability of the transfer layer.

A. Daoud et al.[19] [2002] had studied The influence of Al_2O_3 particulates on the precipitation and hardening behaviour of the A356 Al– Al_2O_3 composites**.** It was found that the $MgAl_2O_4$ 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 Al_2O particulates because the precipitation preferentially develops on the dislocation lines that increased due to coefficient of thermal expansion mismatch between the matrix and reinforcement.

2.2 SUMMARY AND GAP IN LITERATURE REVIEW

A lot of work has been done in aluminium matrix composite at different types of reinforcements, different sizes and manufactured either by stir casting or by sintering technique then aged at various temperature and time durations. Alloy composition and its condition influence the wear rate. Heat treatment of all composites and Al alloys improved abrasive wear resistance. [4] With increase in temperature hardness and wear resistance also increases and hardness will increase initially with ageing time and after a peak value it tends to decrease. In case of the hybrid composites the wear rate do not depend on type of reinforcement, but wear rate of the hybrid composites decreases with increasing the weight percentage of reinforcing materials. The abrasive wear resistance of Al-based hybrid composites will be controllably altered by thermal ageing. [13] In case of silicon-carbide-reinforced aluminium alloy extruded samples the addition of increasing amounts of particulate SiC increases the yield and tensile strength and decreases the ductility. The ductility level of the extruded samples is found to be higher than those of the forged and as cast samples. [16]

CHAPTER 3

PROBLEM FORMULATION

3.1 PROPOSED WORK

The problem is to study the effect of thermal ageing on Al-SiC metal matrix composite (MMC) of aluminium alloy of grade 6351with addition of 9% SiC particles made by stir casting technique. The change in physical and mechanical properties will also be taken into consideration.

For the achievement of the above, an experimental set up is being prepared where all the necessary inputs are to be made. The aim of the experiment is to study the effect of parameters, as ageing temperature, ageing time durations and to predict the rate of change of physical and mechanical properties of the metal matrix composites (MMC). The sample will be held in experimentation for pre-decided time periods and then change in the properties will be analyzed. The natural ageing of Al-SiC metal matrix composites will take long time so artificial ageing method is chosen.

3.2 OBJECTIVES

1. To study the effect of aging temperature and time durations on abrasion resistance, microhardness and getting maximum hardness from different combinations of time and temperature.
2. Analyze for microstructure to study the change in material properties as a result of the experimentation.

CHAPTER 4

EXPERIMENTAL DETAILS

4.1 Composite Material

Composite is made up of two materials aluminium alloy of grade 6351 and reinforced with SiC particles of grain size 50-100 μm by stir casting route.

Aluminum alloy is used as matrix in the synthesis of composite. Chemical composition of used alloy is given in table 4.1.

Table 4.1 Composition of 6351 aluminium alloy

Element	Si	Fe	Cu	Mn	Mg	Zn	Ti	Al
Wt%	1.2	0.5	0.10	0.6	0.7	0.20	0.20	rest

4.2 Quenching media

For quenching aluminium alloy and composite materials water and salt brine solution (8%).

4.3 Experimental Procedure

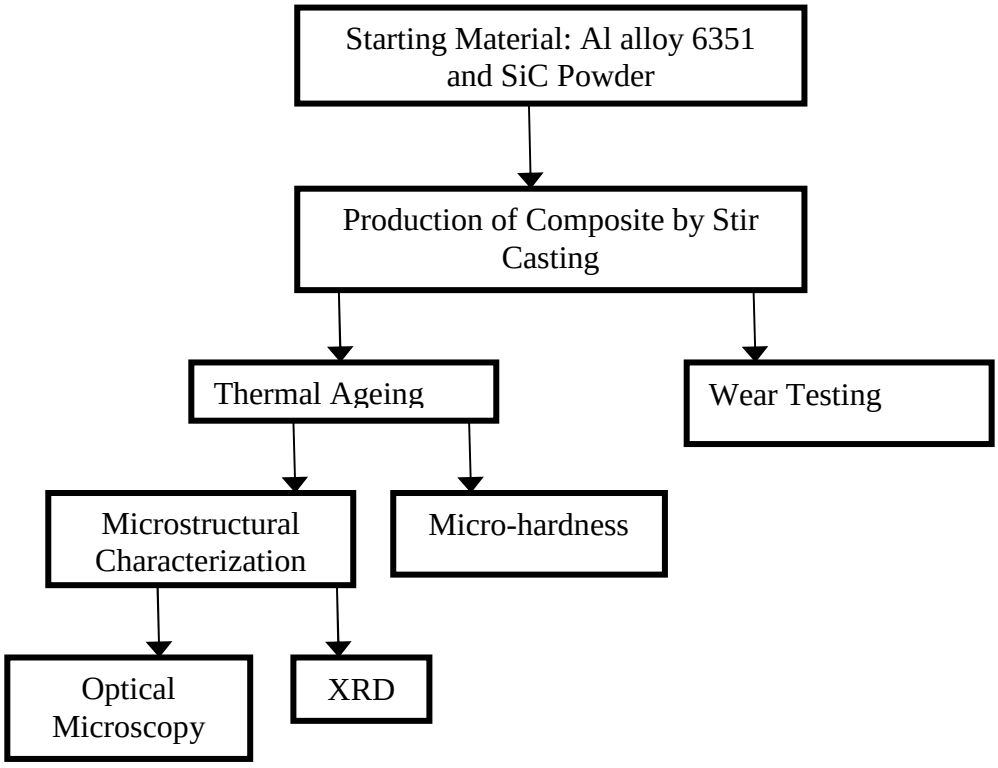


Figure 4.1 - Experimental Techniques followed

4.3 Processing

Stir casting setup consist of digital control muffle furnace (fig. 4.2) and a stirrer (fig.4.3) made of graphite connected to electric motor with speed range of 22-840 rpm. SiC particles were artificially oxidized in air at 1000 ◦C for 150 min to form a layer of SiO2 on them and improve their wettability with molten aluminium. This treatment helps the incorporation of the particles while reducing undesired interfacial reactions. Batches of the matrix alloy were melted in a clay-bonded graphite crucible of 1.5 kg capacity using a small muffle furnace. The temperature of the alloy was first raised to about 800 °C and then stirred at 540 rpm using an impeller fabricated from graphite and driven by a variable ac motor.

Figure 4.2 Muffle Furnace

The temperature of the furnace was gradually lowered until the melt reached a temperature in the liquid solid range while stirring was continued. Then the stirrer was positioned just below the surface of the slurry and the oxidized particles were added uniformly at a rate of 20 g/min over a time period of approximately 3–5 min and speed is lowered to 260 rpm. At the end of charging the slurry was allowed to mix in the semisolid state isothermally for another 15 min while the stirrer was positioned near the bottom of the crucible.

Figure 4.3 Graphite stirrer

Figure 4.4 Crucible

4.4 Synthesis of Composite

The synthesis of composite is done by stir casting route. The parameters which are important in this work are stirrer design, preheating temperature for particulate and stirring speed. These parameters are discussed below.

4.4.1 Stirrer Design

It is very important parameter for stir casting process. It is essentially requires for vortex formation for the uniformly dispersion of particles. There is different type of stirrer some 90º

form the shaft and some are bent at 45º. There is a no uniform dispersion of particles in case of no vortex formation.

4.4.2 Particle Preheating Temperature

Preheating of particulate is necessary to avoid moisture from the particulate otherwise there is chance of agglomeration of particulate due moisture and gases. Along this SiC particles are heated at 1000ºC to form a oxide layer on the SiC particles which make it chemically more stable and by the oxide layer formation wettability will increase so particles will effectively embedded in aluminium matrix and less number of porosities in casting. After oxide layer formation preheating of particulate is done on temperature of 400° C.

4.4.3 Stirring Speed

In stir casting process stirring is very important parameter for consideration. In the process stirring speed was 240 rpm which was effectively producing vortex without any spattering. Stirring speed is decided by fluidity of metal if metal having more fluidity then stirring speed will be low. It is also found that at less speed, dispersion of particulates are not proper because of ineffective vortex.

4.5 Thermal Ageing Studies

The hardness measurements were done by Vickers microhardness tester. Four sets of readings taken for each sample for better accuracy.

The following steps in age hardening treatment of the base aluminium alloy and composite material: -

1. *Solutionising*: heating the alloy to a temperature at about 540°C to obtain a single-phase solid solution.
2. *Quenching*: the solutionised alloy is cooled rapidly to retain the high temperature Single-phase supersaturated solid solution at room temperature.
3. *Ageing*: age hardening by holding the quenched alloy at elevated temperature 180°C and 200°C.

After solution heat treatment of alloy and composite samples microhardness is measured with microhardness tester and after each ageing microhardness is measured.

4.6 Parameter Matrix

On the basis of type of material, ageing temperature and quenching media the parameter matrix is as follows

Sample No.	Type	Quenching Media	Ageing Temperature (ºC)
1	C1	W	180
2	C1	W	210
3	C1	B	180
4	C1	B	210
5	C2	W	180
6	C2	W	210
7	C2	B	180
8	C2	B	210

Table 4.2 Parameter Matrix

C1= Aluminum alloy
C2=Aluminum alloy 9 wt% SiC particles
T1 = 180 ºC
T2 = 210 ºC
QM1 = Water
QM2 = Brine Solution (8% NaCl)

4.7 Microhardness Tester

Micro hardness testing is a method for measuring the hardness of a material on a microscopic scale. A precision diamond indenter is impressed into the material at loads from a few grams to 1 kilogram. The impression length, measured microscopically, and the test load are used to calculate a hardness value.

The indentations are typically made using either a square-based pyramid indenter (Vickers hardness scale) or an elongated, rhombohedral-shaped indenter. The tester applies the selected test load using dead weights. The length of the hardness impressions are precisely measured with a light microscope using either a video image or computer software. A hardness number is then calculated using the test load, the impression length, and a shape factor for the indenter type used for the test.

Figure 4.5 Microhardness Tester

4.8 X-ray Diffraction (XRD)

X-ray diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined. Max von Laue, in 1912, discovered that crystalline substances act as three-dimensional diffraction gratings for X-ray wavelengths similar to the spacing of planes in a crystal lattice. X-ray diffraction is based on constructive interference of monochromatic X-

rays and a crystalline sample. These X-rays are generated by a cathode ray tube, filtered to produce monochromatic radiation, collimated to concentrate, and directed toward the sample.

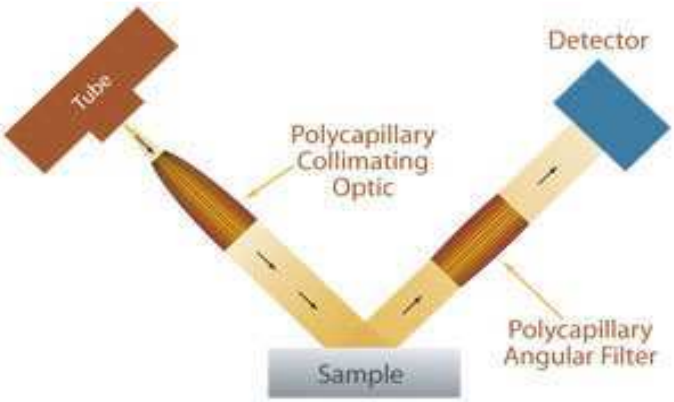


Figure 4.6 X-Ray Diffraction mechanisms

The interaction of the incident rays with the sample produces constructive interference (and a diffracted ray) when conditions satisfy Bragg's Law ($n\lambda=2d \sin \theta$). This law relates the wavelength of electromagnetic radiation to the diffraction angle and the lattice spacing in a crystalline sample. These diffracted X-rays are then detected, processed and counted. By scanning the sample through a range of 2θangles, all possible diffraction directions of the lattice should be attained due to the random orientation of the powdered material. Conversion of the diffraction peaks to d-spacings allows identification of the mineral because each mineral has a set of unique d-spacings. Typically, this is achieved by comparison of d-spacings with standard reference patterns. All diffraction methods are based on generation of X-rays in an X-ray tube. These X-rays are directed at the sample, and the diffracted rays are collected. A key component of all diffraction is the angle between the incident and diffracted rays. X-ray diffractometers consist of three basic elements: an X-ray tube, a sample holder, and an X-ray detector. X-rays are generated in a cathode ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced. These X-rays are collimated and directed onto the sample. As the sample and detector are

rotated, the intensity of the reflected X-rays is recorded. When the geometry of the incident X-rays impinging the sample satisfies the Bragg Equation, constructive interference occurs and a peak in intensity occurs. A detector records and processes this X-ray signal and converts the signal to a count rate which is then output to a device such as a printer or computer monitor. The geometry of an X-ray diffractometer is such that the sample rotates in the path of the collimated X-ray beam at an angle θ while the X-ray detector is mounted on an arm to collect the diffracted X-rays and rotates at an angle of 2θ.

4.9 Wear Test

Sliding wear tests were conducted in pin-on-disc wear testing apparatus under constant applied load of 2kg at a fixed sliding speed of 1 m/s against EN32 steel disc. The pin samples were 30 mm in length and 8 mm in diameter. The surfaces of the pin sample ground using emery paper prior to test. In ordered to ensure effective contact of fresh surface with the steel disc, the fresh samples were subjected to sliding on emery paper of 240 grit size. During sliding, the load is applied on the specimen through cantilever mechanism and the specimens brought in intimate contact with the rotating disc at a track radius of 100 mm. The samples were cleaned with acetone and weighed (up to an accuracy of 0.01 mg using microbalance) prior to and after each test. The wear rate was calculated from the weight loss technique and expressed in terms of volume loss per unit sliding distance.

Figure 4.7 Wear testing machine

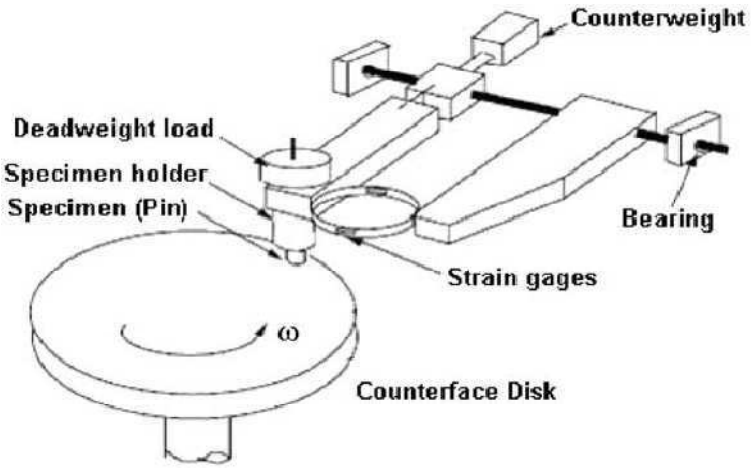


Figure 4.8 Schematic of the pin-on-disk apparatus.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Microstructure of Aluminium Alloy and Composite

Microstructure was visualized with the help of optical microscope. For the sample preparation, first of all sample were cut down into small cuboids shapes then the sample grinded on different grit size paper sequentially by 180,220,320,400,600,1000,1500 and 2000. After grinding, the samples were polished by alumina paste and then etched in etchant (kellars reagant). The samples were visualized on different magnifications.

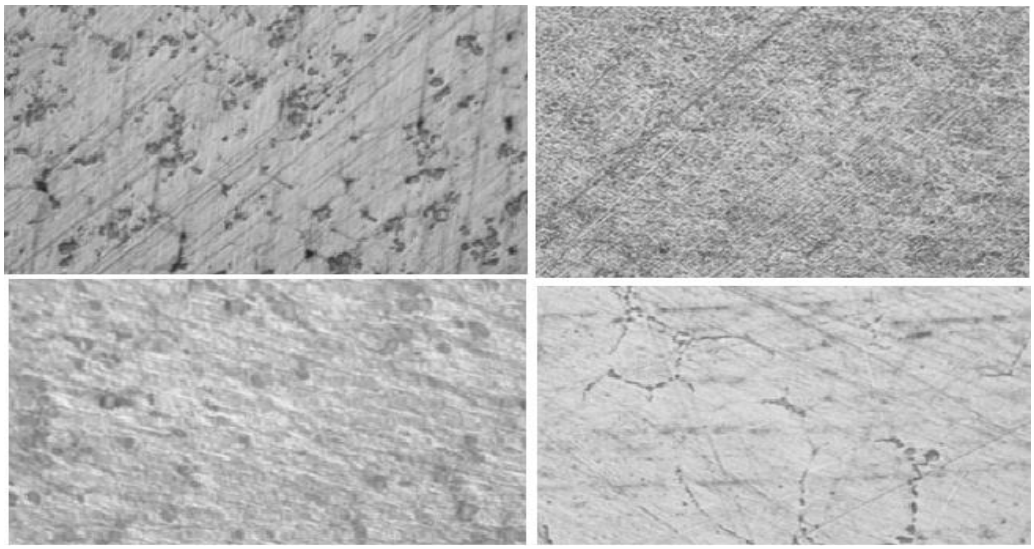


Figure 5.1 Microstructure image of aluminum matrix at different magnifications

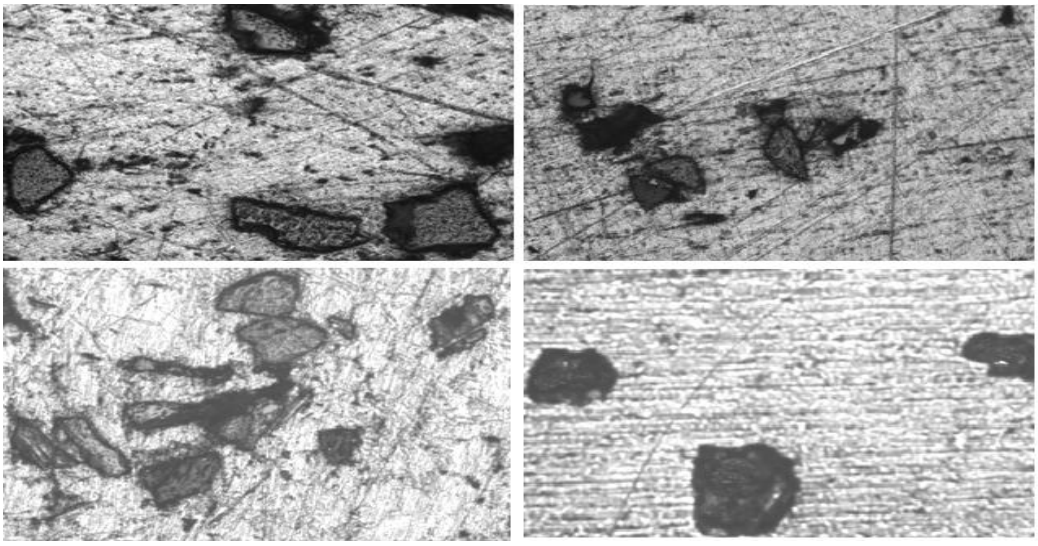


Figure 5.2 Microstructure image of aluminum composite

5.2 X-ray Diffraction

An X-ray powder diffraction (XRD) pattern of aluminum alloy and aluminum matrix composite is shown in Figure 4.7 and Figure 4.8. X-ray diffraction of the aluminum alloy was carried out using X'PERT PRO of PAN ANALYTICAL

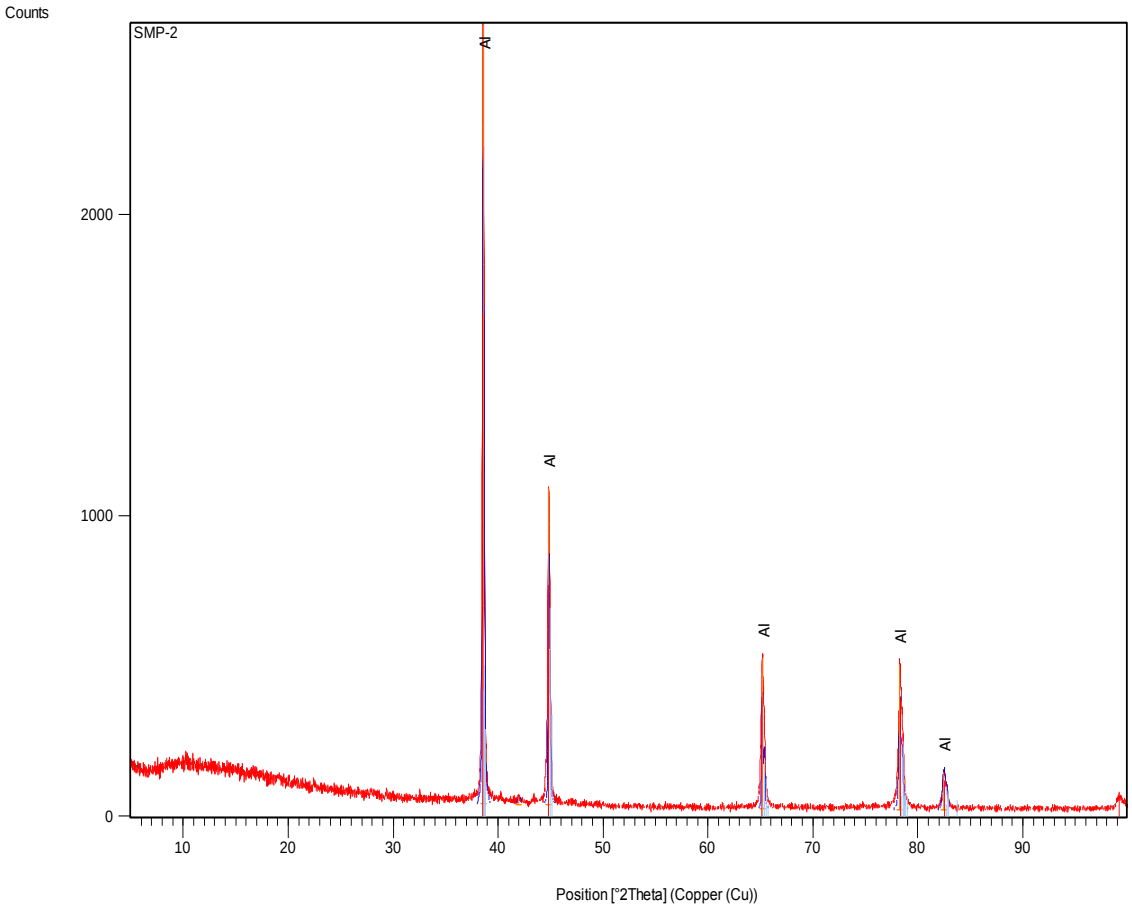


Figure 5.3: X-ray diffraction pattern of the alloy

Table 5.1 XRD results of alloy

Pos. [°2Th.]	Rel. Int. [%]	Assignment
38.5828	100	Al

44.328	42.78	Al
61.185	19.43	Al
78.2786	19.43	Al
82.4746	4.90	Al

In X-ray diffraction (Figure. 5.3), five peaks have been obtained in the 2θ span ranging from 10 to 100. Applying extinction rules, these peaks and associated d-values have been found to correspond to the aluminium matrix composite are given in Table 5.1. The peaks in the pattern can be indexed to aluminium other element has low percentage so they are not seen in any peak above.

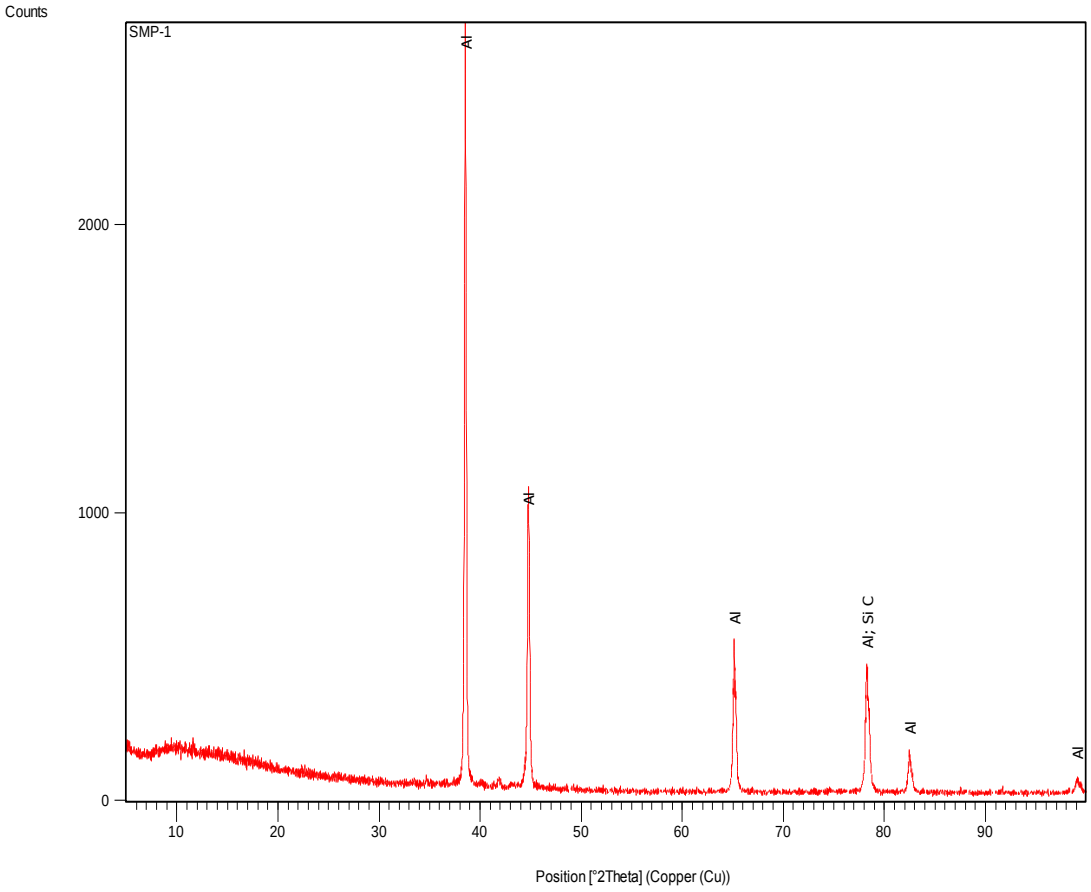


Figure 5.4 X-ray diffraction pattern of the alloy with SiC particles

Table 5.2 XRD results of alloy reinforced with SiC particles

Pos. [°2Th.]	Rel. Int. [%]	Assignment
38.5202	100.00	Al
41.8349	1.20	Al
44.7330	34.60	Al
65.1341	19.66	Al
78.2423	16.34	Al, SiC
78.5043	10.25	Al, SiC
82.4666	65.30	Al
99.0523	1.20	Al

In X-ray difrracetion (Figure. 5.4), eight peaks have been obtained in the 2θ span ranging from 10 to 100. Applying extinction rules, these peaks and associated d-values have been found to correspond to the aluminium matrix composite are given in Table 5.2. The peaks in the pattern can be indexed to a mixture of different compounds, minor peaks attributed to impurity.

5.3 Ageing Studies of the composite

A micro hardness tester MVH-1is used for the micro hardness measurement. The samples are grinded from top and bottom side for appropriate measurement. The load applied is of 200 gm at dwell time of 20 second.

Table 5.3 Ageing Conditions

Solutionizing Temperature	540ºC
Solutionizing Time (hour)	2 hours
Ageing Temperature	180ºC and 210
Ageing Time (hour)	2 4 6

Table 5.4 Microhardness data of aluminium alloy after Water and brine solution quenching.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 1	25.45	25.39	28.49	27.28	26.65
Sample 2	26.37	26.59	27.65	26.70	26.83
Sample 5	29.09	30.35	29.37	30.65	29.81
Sample 6	29.17	27.34	28.45	28.82	28.44

The above table 5.4 consist of value of hardness measurement of aluminium alloy after solution treatment at 540°C and then quenched in water and brine solution to room temperature. Samples 1 and 2 are water quenched and samples 5 and 6 are brine quenched.

Table 5.5 Microhardness data of composite after Water and brine solution quenching.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 3	28.06	31.97	30.19	28.86	29.77
Sample 4	32.53	30.06	31.14	29.30	30.07
Sample 7	35.79	38.51	38.32	37.01	37.41
Sample 8	37.60	38.70	39.49	38.93	38.68

The above table 5.5 consist of value of hardness measurement of composite after solution treatment at 540°C and then quenched in water and brine solution to room temperature. Sample 3 and 4 are water quenched and sample 7 and 8 brine solution quenched.

Table 5.6 Microhardness data of the alloy after 2 hours

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 1	31.20	32.13	32.37	31.17	31.72
Sample 2	28.39	28.87	29.03	27.45	28.44
Sample 5	38.50	38.37	39.34	36.53	38.19
Sample 6	37.73	35.24	36.55	35.42	36.24

The above table 5.6 consist of value of hardness measurement of alloy after thermal ageing at 180ºC and 210ºC and for 2 hours. Samples are put in the oven and remained there for 2 hours and then cooled in air after that microhardness is measured. Samples 1 and 3 are aged at 180ºC and sample 2 and 4 are aged at 210ºC.

Table 5.7 Microhardness data of the composite after 2 hours ageing.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 3	34.43	35.58	34.73	34.25	34.71
Sample 4	32.67	34.09	33.83	33.12	33.43
Sample 7	40.57	41.31	41.02	41.41	41.08
Sample 8	41.38	39.53	40.31	40.62	40.46

The above table 5.7 consist of value of hardness measurement of alloy after thermal ageing at 180ºC and 210ºC and for 2 hours. Samples 5 and 7 are aged at 180ºC and sample 6 and 8 are aged at 210ºC.

Table 5.8 Microhardness data of the alloy after ageing of 4 hours.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 1	29.65	30.17	29.38	30.47	29.90
Sample 2	35.67	35.21	35.01	36.34	35.56
Sample 5	38.28	39.18	39.03	40.01	39.34
Sample 6	41.16	42.01	43.09	42.32	42.14

The above table 5.8 consist of value of hardness measurement of alloy after ageing of 4 hours at 180°C and 210° C.

Table 5.9 Microhardness data of the composite after ageing of 4 hours.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 3	42.36	40.12	41.74	40.93	41.28
Sample 4	42.83	43.32	43.26	43.81	43.21
Sample 7	43.36	42.28	41.35	42.17	42.30
Sample 8	47.37	48.72	48.07	48.31	48.13

The above table 5.9 consist of value of hardness measurement of composite after ageing of 4 hours at 180°C and 210° C.

Table 5.10 Microhardness data of the aluminium alloy after ageing 6 hours.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 1	29.26	30.01	30.69	31.44	30.35
Sample 2	32.19	32.27	32.10	33.41	32.40
Sample 5	38.03	38.11	37.61	36.20	37.48

Sample 6	43.25	40.29	42.04	40.11	41.50

The above table 5.10 consist of value of hardness measurement of alloy after ageing of 6 hours at 180°C and 210° C.

Table 5.11 Microhardness data of the composite after ageing of 6 hours.

Sample no.	Trial 1	Trial 2	Trial 3	Trial 4	Average
Sample 3	41.65	39.55	40.41	40.72	40.51
Sample 4	38.48	39.16	39.53	40.05	39.30
Sample 7	38.63	36.28	37.43	37.15	37.37
Sample 8	42.23	44.52	43.12	43.43	43.50

The above table 5.11 consist of value of hardness measurement of composite after ageing of 4 hours at 180°C and 210° C.

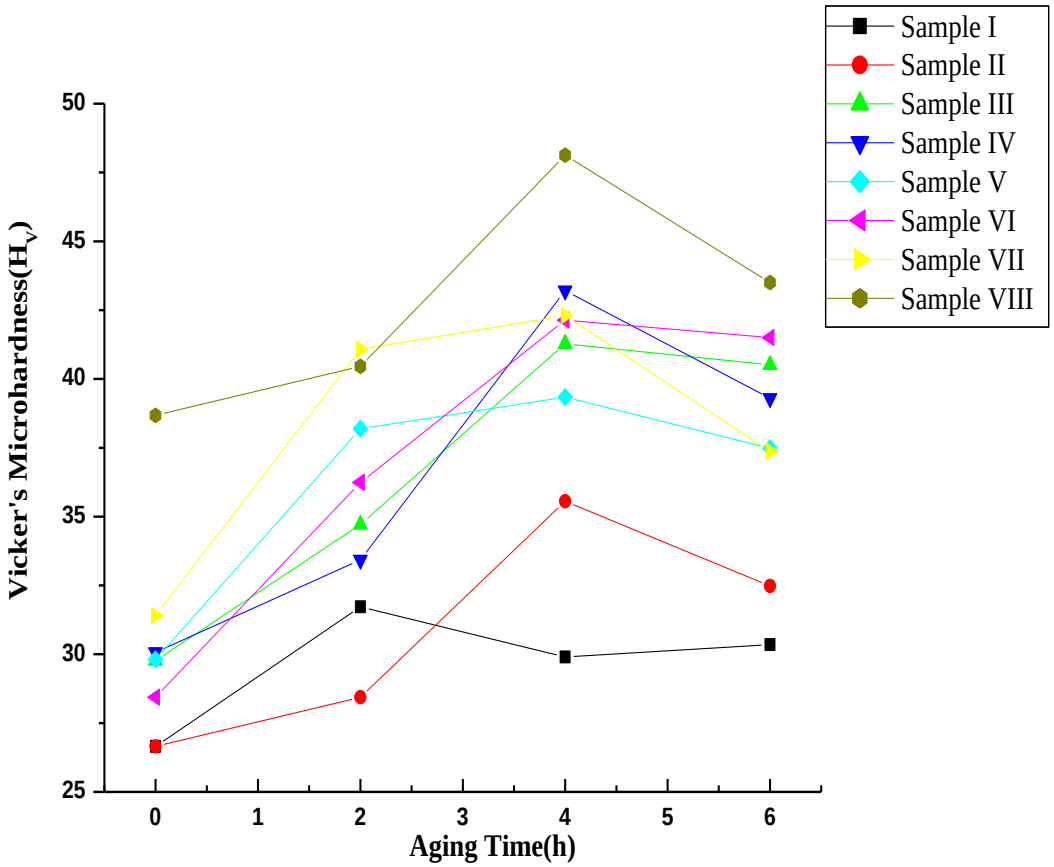


Figure 5.5: Micro hardness of alloys and composites as a function of aging time

In the figure 5.5 maximum micro hardness of specimen achieved after 4 hours of ageing and temperature 210ºC this could be due to uniform precipitation hardening. The graph depict that is decreasing after 4 hours in all samples.

5.4 Wear Test

A pin-on-disc tribometer is used to perform the wear experiment. The alloy and composite samples are cleaned thoroughly with acetone. Each sample is then weighed using a Digital balance having an accuracy of ±0.1 mg. After that the sample is mounted on the pin holder of the tribometer ready for wear test. For all experiments, the sliding speed is adjusted to 1 m/s.

The specific wear rates for the materials were obtained by

$$W = \Delta w / L\rho F$$

Where W denotes specific wear rates in mm^3/N-m, Δw is the weight loss measured in grams, L is the sliding distance in meters, ρ is the density of the worn material in g/mm^3, and F is the applied load in N. Weight loss of the alloy and composite samples in grams is shown in tables 5.12 and 5.13.

Table 5.12 Data of cumulative wear loss of alloy

Sliding distance (m)	Wear loss of S1	Wear loss of S2	Wear loss of S3	Wear loss of S4
300	0.029	0.025	0.027	0.028
600	0.031	0.026	0.027	0.028
900	0.031	0.027	0.028	0.030
1200	0.032	0.028	0.028	0.030
1500	0.032	0.028	0.029	0.030
1800	0.033	0.029	0.030	0.031
2100	0.034	0.030	0.030	0.032
2400	0.034	0.030	0.031	0.032

S1 = alloy quenched in water, aged at 180° C

S2 = alloy quenched in water, aged at 210° C

S3 = alloy quenched in brine, aged at 180° C

S4 = alloy quenched in brine, aged at 210° C

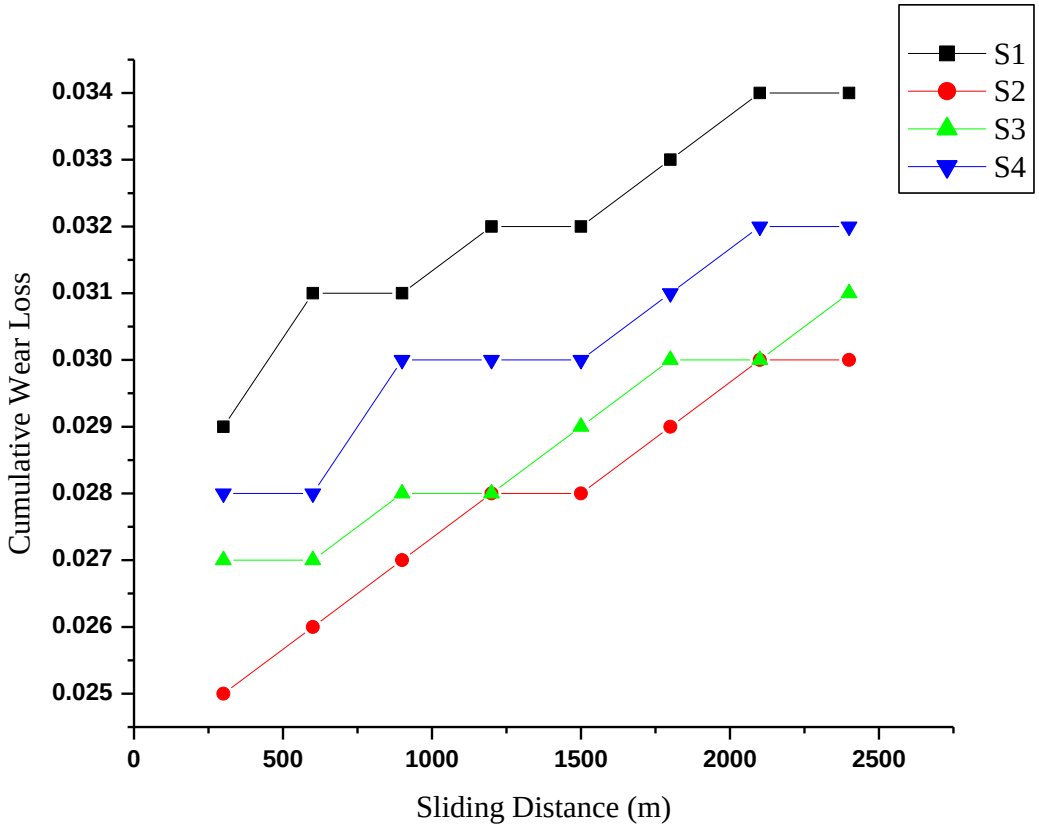


Figure 5.6 Cumulative wear loss of alloy as a function of sliding distance

The graph in figure5.6 shows the cumulative wear loss of alloy specimen after solution treatment at 540°C and then quenched in water and brine solution. After quenching the specimens, ageing is done at 180°C and 210°C for 4 hours. It depicts that wear loss is increasing, when the sliding distance is increases.

Table 5.13 Data of cumulative wear loss of composite

Sliding distance (m)	Wear loss of S5	Wear loss of S6	Wear loss of S7	Wear loss of S8
300	0.021	0.019	0.020	0.018
600	0.021	0.019	0.021	0.018
900	0.022	0.020	0.021	0.020

1200	0.023	0.021	0.022	0.020
1500	0.024	0.021	0.022	0.021
1800	0.024	0.023	0.024	0.023
2100	0.025	0.024	0.025	0.023
2400	0.026	0.025	0.026	0.024

S5 = composite quenched in water, aged at 180° C

S6 = composite quenched in water, aged at 210° C

S7 =composite quenched in brine, aged at 180º C

S8 = composite quenched in brine, aged at 210° C

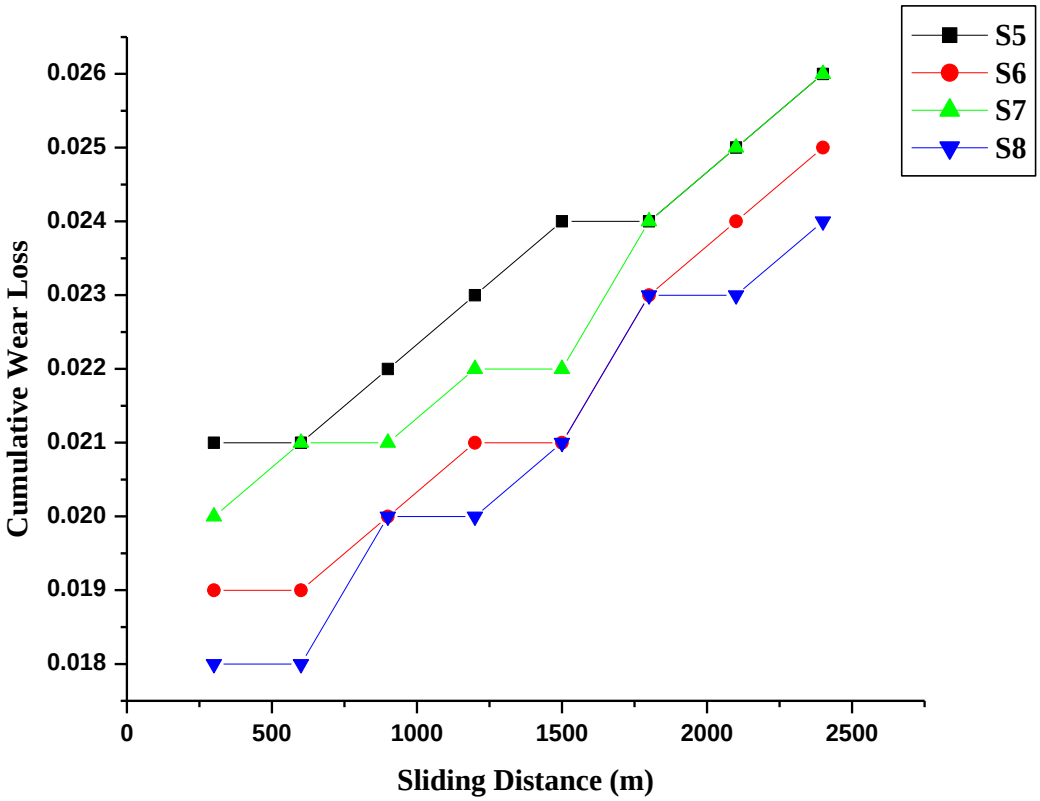


Figure 5.7: Cumulative wear loss of composite as a function of sliding distance

The graph in figure5.7 shows the cumulative wear loss of composite specimen after solution treatment at 540°C and then quenched in water and brine solution. After quenching the specimens, ageing is done at 180°C and 210°C for 4 hours. It depicts that wear loss is increasing, when the sliding distance is increases.

CONCLUSIONS

From the experiments conducted following conclusions have been obtained

1. The synthesis of aluminium alloy aluminium alloy and SiC Particles can be done by stir casting route.
2. Optical micrography shows that SiC particle is uniformly distributed in aluminium alloy matrix.
3. XRD results showed the presence SiC particles in alloy matrix.
4. The micro hardness increases after reinforcement of SiC particles.
5. Wear resistance increases with addition of SiC particles.
6. For synthesizing of composite by stir casting process, stirrer design and position, stirring speed and time, particle-preheating temperature, particle incorporation rate, are the important process parameters.
7. With increasing the microhardness by SiC particles wear resistance is increased.

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