# DEVELOPMENT AND CHARACTERIZATION OF ALUMINIUM SILICON CARBIDE COMPOSITE MATERIALS WITH IMPROVED PROPERTIES

*Capstone Project-II Report submitted in*
*partial fulfillment for the award of the*
*degree of*

**BACHELOR OF TECHNOLOGY**

*Submitted by*

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**IN**

**MECHANICAL ENGINEERING**

**DEPARTMENT OF MECHANICAL & CHEMICAL ENGINEERING**

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GALGOTIAS
UNIVERSITY
(Established under Galgotias University Uttar Pradesh Act No. 14 of 2011)

**JUNE- 2021**

GALGOTIAS
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# DEPARTMENT OF MECHANICAL & CHEMICAL ENGINEERING

## BONAFIDE CERTIFICATE

Certified that this project report **“DEVELOPMENT AND CHARACTERIZATION OF ALUMINIUM SILICON CARBIDE COMPOSITE MATERIALS WITH IMPROVED PROPERTIES”** is the bonafide work of **Sandeep Kumar, Shivam Raj, Shivam, Piyush Badhani** who carried out the project work under my supervision.

SIGNATURE OF SUPERVISOR

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We, hereby declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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This thesis/dissertation/report entitled **DEVELOPMENT AND CHARACTERIZATION OF ALUMINIUM SILICON CARBIDE COMPOSITE MATERIALS WITH IMPROVED PROPERTIES** by Sandeep Kumar, Shivam, Shivam Raj and Piyush Badhani is approved for the degree of Bachelor of Technology in Mechanical Engineering.

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# Statement of Project Report Preparation

1. Thesis title: **DEVELOPMENT AND CHARACTERIZATION OF ALUMINIUM SILICON CARBIDE COMPOSITE MATERIALS WITH IMPROVED PROPERTIES**
2. Degree for which the report is submitted: **BACHELOR OF TECHNOLOGY IN MECHANICAL ENGINEERING**
3. Project Supervisor was referred to for preparing the report.
4. Specifications regarding thesis format have been closely followed.
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7. All sources used have been cited appropriately.
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# ACKNOWLEDGEMENT

I have taken efforts in this project. However, it would not have been possible without the kind support and help of many individuals and organizations. We would like to extend our gratitude to **Prof. P.K.S. Nain**, HEAD, Department of Mechanical Engineering, Galgotias University, **Mr. Pramod Kumar,** Project coordinator and our supervisor **Mr. Lavepreet Singh**, Assistant Professor. We are grateful for their guidance and constant supervision as well as for providing necessary information regarding the project & also for their support in completing the project. I would like to express my gratitude towards my parents & **Department of Mechanical & Chemical engineering** for their kind cooperation and encouragement which helped me in completion of this project. I would like to express my special gratitude and thanks to industry persons for giving me such attention and time. My thanks and appreciation also go to my colleague in developing the project and people who have willingly helped me out with their abilities.

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# ABSTRACT

Aluminium matrix composites (AMCs) promise numerical applications in industries mainly due to their superior strength to conventional materials. The addition of AMC to the metal matrix increases performance compared to conventional engineering materials. This report examines the properties of AMCs and their advantages and disadvantages. Major issues such as production impairment, matrix strength, production costs and reinforcement in the particles are reviewed. The introduction of various ceramics reinforcing elements on AMCs and its micro structural and mechanical properties such as stiffness, compression, durability, wear are also discussed in detail. AMC industrial applications are also reflected in this work. Aluminum metal matrix composites have properties that no other monolithic material can match. Due to their superior strength to conventional materials, aluminium matrix composites (AMCs) have a broad variety of industrial applications. The nature of reinforcing, that can take the form of constant or undefined fibres, has a big influence on the properties of aluminum metal matrix composites. Thus it depends on the fabrication methods for aluminium matrix composites, which are influenced by a number of factors including the type of reinforcement and matrix used, its required degree with surface morphology integrity, as well as physical, mechanical, electro-chemical, and thermal properties. The present report offers a description of the synthesis, mechanical behaviour, and utilisation of aluminium metal matrix composites. The main processing methods for making or production of aluminium metal matrix composites(AMCs) are thoroughly discussed. The development and characterization of Aluminium Silicon Carbide (Al-SiC) composite materials is the subject of this report. Aluminium (Al) was used as the pure matrix material in this report, and Silicon carbide (SiC) was used as the reinforcement material to stabilise the matrix. Stir casting was used to make aluminium matrix composites (AMC) with varying SiC content (0 to 5% wt.%). In stir casting technique, a motor with mild steel four blade stirrer was used with a speed of 550 rpm to stir the molten mold .Mechanical as well as micro structural properties of Al-SiC composites were studied in detail to characterize their properties. In the result, it was found that the mechanical properties have been improved considerably with the addition of SiC in the Al matrix. Also there has been uniform distribution of SiC over the Al matrix and it was possible due to continuous stirring for 20 min in the mould. Micro structural observation also revealed little clustering.

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# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

Materials and innovation that reflect human ability and comprehension are frequently used to distinguish history. In general, scales began well with neolithic period, progressing through the Bronze, Iron, Steel, Aluminum, and Alloy epochs as refinement as well as purification increased, since technology enabled all of these epochs to progress toward the discovery of more composite materials.

From the E glass/Phenolic cockpit canopy constructions of the mid-1940s towards the graphite/polyimide composite used for the spacecraft orbiter, the advancement in cutting-edge composite has been astounding. This development in the evolution of fortifications, grids, and composites manufacturing is due to the knowledge of the potential low weight that can be realised by employing high-level composites, that implies reduced costs but also more efficacy. If advancements in manufacturing process were seen in the first twenty years, precise examination of characteristics and break mechanics reached a point of confluence in the 1960s. Since then, there has been an ever-increasing demand for more current, more stable, stiffer yet lightweight weight in industries such as aerospace, transport, vehicles, and development. Composites are emerging mostly as a result of unprecedented demand from innovators as a result of rapidly propelling workouts in the aeroplane, aircraft, and automobile industries. Such material have such a low explicit gravity, which means they have superior modulus and strength than many customary design materials like as metals. As a result of targeted inquiries into the core idea of material and a fuller sense of their architectural characteristic relationships, innovative composites with improved mechanical and physical capabilities have been developed. Polymer grid composites [1,2], Ceramic framework composites [3, 4], as well as Metal lattice composites [5] are among the enhanced composites used in these inns. Ongoing developments led to composites being used in a growing number of novel applications. The importance of composites as design material being demonstrated by the fact that more than 200 of the more over 1600 design materials currently available in the market are composite [6].

## 1.2 COMPOSITES

### 1.2.1 WHY A COMPOSITES?

Composites, plastics, and earthenware seem to be the most common emerging materials over the last 30 years [7]. Composites have constantly increased in volume and number of applications, invading and conquering emerging business areas. Composites currently account for a sizable percentage of the advanced equipment market, with applications range from very

simple to complex.
While composites have confirmed to be valuable as poundage materials, the current issue is to make them smart. In the composites sector, attempts to make financially appealing reinforced composites have led to a wide range of inventive assembly procedures. It's indeed self-evident, especially in the case of composites, that advancements in assembly technology alone will not be enough to overcome the cost barrier. A concentrated attempt in architecture, composition, measurement, machining, product testing, production, and perhaps even programme management is required for composite to compete with metals. Because of the sheer magnitude of the transportation industry, the composites industry has begun to recognise that business applications of composites promise to give much larger business opportunities than the aviation industry. As a result, in recent times, the shift of advanced composites from aeroplanes to several other corporate applications has been apparent.
The infiltration of such high-level materials has experienced a steady growth in employment and quantity, aided by the introduction of more up-to-date polymer sap foundation elements and elite supporting strands of glass, carbon, and aramid. The increased volume has resulted in a regular cost reduction. Composites reinforcing meant to counteract unstable effects, fuel chambers for petrol gas vehicles, windmill sharp corners, mechanical drive shafts, support light emissions connects, and even paper producing rollers would all benefit from superior FRP. A few models are falls for motors, bended fairing and filets, trades for welded metallic parts, chambers, tubes, conduits, edge regulation groups and so on

Furthermore, the demand for composites for lighter construction materials and much more seismic-safe designs has placed a premium on the use of new and advanced materials that reduce unnecessary weight while retaining shock and vibrations via specific microstructures. Composite are now commonly used to recover/reinforce older designs that need to be upgraded to become seismically safe, or to refurbish spoil cause by seismic motion.

Despite traditional materials (such as steel), the properties of a composites could be planned from various angles. Material and basic layout are both included in the design of a primary part made of composite. Composites features (such as solidity, warm growth, and so on) can be varied repeatedly across a wide range of attributes that are highly impacted by the fashioner. The final item attributes can be adjusted to practically whatever design need with appropriate choice of supporting type.

And and that the use of composite materials would become a rational option in so many cases, the material choice in other would be depending on criteria like as operating lifelong requisites, the number of objects to be delivered (run distance), the intricacy of the item structure, potential exchange funds in gathering expenses, and indeed the fashioner's knowledge and talents in pressing composite materials to their maximum capability. In certain occasions, best outcomes might be accomplished using composites related to conventional materials.

### 1.2.2 What Is A Composite?

On a visible scale, the common composite is an arrangement of materials made out of at least two materials (blended & strengthened).

Support (strands, particles, droplets, and occasionally fillers) are organised in a lattice pattern in a composite (metals, ceramics, or polymers). The lattice holds the resources in place, enabling it to frame the ideal shape while also increasing the on the whole mechanical property of the conceptual platform. When planned appropriately, the original joint material exceeds all the other methods in terms of strength and durability.

According to Jartiz, composites are multiplexing frameworks that provide features that are not possible with surface run. They're strong designs combining at least two materials with different origins, characteristics, and building methods.

Kelly [8] emphasises that composite should not be considered solely as a combination of two components. In terms of greater significance, the mix has distinct characteristics. It is stronger than anyone of the pieces alone or deeply different from all of them in order to determine the strength, heat insulation, or any other appealing feature.

"The composites are contain recycled that differ from amalgams in the sense that the separate segments retain their attributes but are so combined into the composite as to exploit just of their properties and not of their deficiencies," according to Berghezan [9], to obtain a better substance.

Composites, according to Van Suchetclan [10], are material qualities made up of at least two strong phases that are in close proximity on a microscopic level. On an infinitesimal scale, these could also be thought as such homogeneous materials because every portion of them has same material characteristics.

### 1.2.3 Characteristics of the Composites

At least one interrupted stage is installed in a nonstop stage in composite. The'support' or 'building up material' stage is often harder and more grounded than the constant stage, whereas the 'grid' stage is named after the constant stage.

The qualities of composite are inextricably linked to the qualities of their material properties, as well as their distribution and interconnection. The composite attributes could be the volumetric portion quantity of the constituents' attributes, or the constituents could interact synergistically to produce enhanced or superior properties. Apart from of the concept of the individual components, the support calculation (form, size, and size circulation) has a significant impact on the composite's qualities. The characteristics are also influenced by the fixation distribution and orientation of the supports.

The state of the intermittent stage (which can be circular, tube-shaped, or rectangle cross-endorsed crystals or platelets), the shape and size dispersion (which controls the material's surface), and the volume part all play a role in determining the degree of coordination between both the assistance and the lattice, which all help to determine the degree of coordination between assistance as well as the lattice.

Fixation, which is commonly quantified as a volume or weight part, determines the involvement of a particular constituent to the entire attributes of composite. It's not only the most critical boundary determining composite properties, and it's also a highly controlled assembly variable that may be used to change them.

### 1.2.4 Classification of Composites

There are various types of composite materials [11]. Because the geometries of the reinforcing cause the mechanical structure and low performance of composites, classification based upon on shape of a typical unit of reinforcing is useful. A common classification system is shown in Table1.

#### 1.2.4.1 Particulate Composites

The backing is of a molecular nature, as the name implies (platelets are additionally remembered for this class). This can be circular, cubic, tetrahedral, platelet-shaped, or indeed any symmetric or asymmetric shape as long as it is generally equiaxed. After all is said and done, particles aren't particularly effective at increasing crack blockage; nonetheless, they improve the composite's stiffness to a degree. Molecule fillers have been widely used to determine the characteristics of lattice materials, including changing the warm and electronics conductivities, improving execution at high temperatures, reducing erosion, increasing wear and scraped spot resistance, improving machinability, increasing solidity value, and reducing contraction.

#### 1.2.4.2 Fibrous composites

When compared to its cross-sectional measures, the length of a fibre is far more conspicuous. The support's elements determine its capacity to contribute characteristics towards the composites. Filaments can help improve the grid's breaking resistance since a support with a lengthy measure inhibits the growth of ordinary beginning breaks to the support, which can lead to disappointment in some cases, particularly for weaker lattices.

Because massive flaws, which may be present in the mass material, are confined by the small trans elements of the fibre, man-made fibres or strands of non-polymeric materials have a far higher strength along their length. The orientation of the sub-atomic design is responsible for strong strength and solidity in polymer composites.

Strands are difficult to use in application design due to their modest cross-sectional dimensions. In this way, they are put into lattice materials to frame stringy composite. The grid connects the strands, transfers burdens to the filament, and protects them from natural attacks and injury caused by interacting with. In intermittent fiber supported composites, the heap move capacity of the framework is more basic than in ceaseless fiber composites.

## 1.3 COMPONENTS OF A COMPOSITE MATERIAL

In its simplest form, a composite material is one which is made up of at least two elements that act together to provide material qualities that are distinct from those of the individual constituents. In practise, most composites are made up of a bulk material (the "matrix") and some form of reinforcements, which is added to boost the matrix's stiffness and strength.

### 1.3.1 Role of matrix in a composite

Many substances have exceptional tensile strength when arranged in a sinewy structure, but to achieve such capabilities, the filaments must be supported by a suitable matrix. The framework confines the strands from each other to forestall scraped area and development of new surface imperfections and goes about as an extension to hold the filaments set up. A decent matrix ought to have the capacity to twist effectively under applied burden, move the heap onto the filaments and equitably appropriated pressure fixation.

An research into the idea of holding powers in covers [12] reveals that the cement connection between the support and the matrix is prone to breaking once stacking begins. The super strength characteristics of the covers are represented by the friction powers among both.

### 1.3.2 Materials used as matrices in composites

In its simplest form, a composite is one that is made up of at least two elements that act together to provide material qualities that are distinct from those of the individual constituents. In practise, most composites are made up of a bulk material (the matrix) and some form of reinforcement, which is added to boost the matrix's stiffness and strength.

## 1.4 BULK PHASES

### 1.4.1 Metal Matrices

When compared to natural framework, metal lattice composites offer certain desirable features. These include (I) increased strength at higher temperatures, (ii) increased cross-over strength, (iii) improved electrical conductivity, (iv) unequalled warm conductivity, (v) increased disintegration resistance, and so on. Nonetheless, the significant hindrance of metal grid composites is their higher densities and therefore lower explicit mechanical properties contrasted with polymer matrix composites. Another outstanding trouble is the high-energy prerequisite for manufacture of such composites.

Superior has primarily been focused on fiber-supported aluminium and titanium in the avionics industry. Boron and, to a lesser extent, silicon carbide (SiC) have been investigated as support filaments. A variety of ways have been used to supply aluminium composites containing boron. Titanium built up with SiC, boron (covered with SiC) and even with beryllium, utilized for blower sharp edges.

Even if the holding between the strands or stubbles is inadequate, unidirectional aggregation of strands or stubbles in the metal grid can achieve high versatile modulus characteristics. Solid metallic matrixes, rather than flimsy metal or polymer grids, are essential for appropriate cross over elasticity and stiffness.

Because most important fabrication processes entail high temperatures that alter the fibre, carbon/graphite strands have only been used with metal matrixes on a research centre trial scale. In any case, research along similar lines is underway, taking into consideration the composites' capabilities.

### 1.4.2 Polymer Matrices

The matrix materials for the composite are made up of a broad number of polymeric polymers, including thermoplastic and thermosetting. Following table lists a few of the primary benefits and drawbacks of resin composites.

**Table 1**

**Polymeric matrix materials' benefits and drawbacks**

| **Advantages** | **Limitations** |
|---|---|
| Low densities | Low transverse strength |
| Good corrosion resistance | Low operational temperature limits |

| | |
|---|---|
| Low thermal conductivities | |
| Low electrical conductivities | |
| Translucence | |
| Aesthetic Colour effects | |

Resinous fasteners (polymer lattices) are often selected based on adhesive strength, wear resistance, heat resistance, material and moisture resistance, and so on. The pitch's mechanical strength should be comparable to that of the support. It should be simple to choose and use in the production contact, as well as to deal with the help circumstances. Apart from such characteristics, the pitch structure should be capable of soaking and infiltrating into the heaps of filaments that provide support, so replacing the silent gaps and providing those genuine traits capable of improving strand display.

The gum determines the shear, synthetic, and electrical characteristics of a composite. Once again, the tar's concept will determine the usefulness of the coverings in the face of a deteriorating climate.

In general, regardless of how large the volumetric part of the fibre seems (on the order of 0.7), the framework material completely covers the support in composite, and it is the matrix that must endure the negative atmosphere when the composite is exposed to elevated temperature. The strength properties of the composite appear to be degrading, which could be related to the effect of temperature on interfacial interaction. As a result, the composite's elevated temperatures resistance is linked directly to the grid instead of the support. In the quest for high-temperature-resistant polymers, the upper limit of assistance temperatures has been pushed to around 300-3500C. Polyimides, which are now the best in class high temps polymers, can withstand this range of operating temperatures.

The inexact assistance temperature ranges for saps and composites are shown in Tables 2 [13, 14]. It's important to remember that when it comes to the notion of the matrix material, especially with regard to the composite's application temperature, there's no place for wiggle space. On the off chance that the application temperature surpasses 300-3500C metal framework has all the earmarks of being the solitary other option, in any event for the present.

**Table 2**

**Application temperatures of some matrix material**

| **Matrix material** | **Limit of long term exposure, C** | **Limit of short term exposure, C** |
|---|---|---|
| Unsaturated polyesters | 70 | 100 |
| Epoxies | 125 | 200 |
| Phenolics | 250 | 1600 |
| Polyimides | 315 | 400 |

| | | |
|---|---|---|
| Aluminium | 300 | 350 |

## Table - 3

**Trends for temperature application of heat resistant composites**

| **Fibre reinforced Composite** | **Maximum service temperature, C** | **Specific weight gm/cm3** |
|---|---|---|
| Carbon / Epoxy | 180 | 1.4 |
| Boron/Epoxy | 180 | 2.1 |
| Borsic / Aluminium | 310 | 2.8 |
| Carbon/Polyimide | 310 | 1.4 |
| Boron/Polyimide | 310 | 2.1 |
| Carbon/Polyaminoxaline | 350 | 1.4 |
| Carbon/Polybenzimidazole | 400 | 14 |
| Borsic/Titanium | 540 | 3.6 |
| Carbon/Nickel | 930 | 5.3 |
| Whisker/Metals | 1800 | 2.8-5.6 |

### 1.4.3 Ceramic Matrices

High-temperature uses and settings where corrosion seems to be a problem benefit from ceramic fibres such as alumina and SiC (Silicon Carbide). The bulk of uses for reinforcements are in the particulate form due to ceramics' limited stress and shear capabilities (e.g. zinc and calcium phosphate). Ceramic Matrix Composites (CMCs) are materials that use a ceramic as the matrix and are reinforced using small fibres or whiskers consisting of silicon carbide or boron nitride. They are employed in very high temperatures.

## 1.5 REINFORCEMENT

The primary function of reinforcements in a composite is to improve the neat resin system's mechanical characteristics. Every one of the fibres used during composite possess distinct qualities, which influence the composite's qualities in diverse situations. To enable manipulation conceivable, the fibres must be organized into a kind of type of sheets, termed as a fabric, throughout most purposes. Various methodologies for building fibres in sheet, as well as the various fibre orientation that can be used to create various features.

## 1.6 INTERFACE

It possesses qualities that aren't represented by some of the individual elements. An interface is a bounded region or zone in which a disruption, particularly physically, mechanical, chemical, or otherwise, occurs. The fibre must be “wet” by the matrix substance. To enhance wettability, coupling compounds are routinely utilised. Fibers that are well "wetted" increase the surface of the contact. To achieve attractive characteristics in a composite, the load applied must be successfully delivered out from matrix towards the fibres via the interface. This needs a high contact area between the fibres and the matrix, as well as high adherence. Debonding (breakdown at the interface) may not be desired.

## 1.7 METAL MATRIX COMPOSITE

Composite materials are made up of at least two sections: one would be the metal grid, and the other is the support. Although the grid is often described as being made of metal, the matrix is rarely made of pure metal. It is, for the most part, a mix. In the usefulness of the composite the grid and the support are combined as one.

In recent years, the advancement of metal matrix (MMCs) has gotten a lot of attention because of their superior strength and solidity, as well as high wear resistance and creep resistance as compared to its related manufactured combination. The pliable structure allows for the plastic deformation of fractures and stress focuses, which improves the substance's crack toughness.

Factories have long produced cast composite in which the volume and condition of stages are controlled by stage charts, such as Cast iron and Aluminum-silicon combinations. Cutting-edge composites differ in that any volume, form, or size of reinforcement can be incorporated into the lattice. Advanced composite are non-balanced metal-pottery combinations with no thermodynamic constraints upon overall volume rates, forms, or sizes of earthenware stages [15].

Many unique primary uses of metallic composite are attracted to the great durability and impact power of metals and combos such as aluminium, titanium, magnesium, and nickel-chromium combinations that go through plastics deformity under swaying. To increase their qualities, such substances have even been remarkably reinforced by various fortified standards (such as grain limit fortification, cooling rate, powerful organization fortification, and so on). In any event, these techniques have been found to have an impact on strength and solidity at elevated temperatures or even under specific assistance settings. In just this way, another of the major goals of iron frame composite is to create a material with a balanced mix of sturdiness and hardness in order to reduce the material's susceptibility to fractures and faults while potentially maintaining dynamic and static qualities.

This demand ultimately leads to the excellent structure of metal and metal composites using unidirectional or multi - directional weeds or uninterrupted threads. Because of it's extremely high strength of stubbles and strands with distances of less than a few micrometres, the supporting impact occurs. As a result, the discipline of Composite Materials (MMCs) began in the 1960s with the recognition that stubble-built MMCs may compete with long-fiber supported composites in case of mechanical qualities [16].

The perplexing manufacture courses, restricted fabric ability [17, 18] and the little contrast in property upgrade among bristle and particulate support [19] and additionally, the wellbeing dangers related with taking care of SiC hairs [20, 21] have moved the accentuation as of late more towards particulate or slashed filaments instead of stubble support of metals, particularly aluminum, in view of its low weight and great wettability with silicon carbide [22]. Mostly during 1980s, a dramatic shift in metal matrix development occurred, with spasmodic support gradually replacing consistent support such as carbides, nitrides, oxides, and natural materials such as carbon as well as silicon.

Whilst also spastic stubble endorsed MMCs are still being developed for aerospace applications, car sections made from particles in the air and intermittent fibre built up MMCs, which have essentially isotropic properties, are already being mass produced in large quantities, thanks to Toyota's introduction of a diesel combustion chamber in 1983, accompanied by Honda's motor and chamber blocks [23,24].

As a result, the current trend appears to be towards to the development of infrequently supported metal grid composite materials, when compared to uni- and multi-directional constant fibre built up MMCs, and the ease of access to benchmark or near-standard metal working strategies that can be used to shape these MMCs, they have been acquiring wide acceptance mainly since they have lately became more reachable for a moderately low cost [25].. MMCs are really a subtype of irregularly sustained aluminium (DRA) composites, which are formed of high-strength aluminium and its components, which are developed with silicon carbide particles or bristles. Aluminum metal grid composites have an appealing combination of characteristics and fabricability for some fundamental parts that require high-solidity, good stiffness, and light weight [26].

Aluminium [27] is currently the focus of research around the world due to its distinctive combination of good utilization blockage, low thickness, and excellent mechanical qualities. Aluminum composites' unique thermal features, such as metallic conductance with a coefficient of extension that can be custom fit down substantially, expand their use in aerospace and other fields.

As a result, entire families of lightweight material composites that were formerly considered unthinkable have either been available or hovering on the precipice of commercialisation. Duralcan USA, Div. Alcan Aluminum corp., San Diego, California [28], for example, has developed a series of Aluminum grids composite anchored by silicon carbide particles. Timet for McDonnell Douglas developed a high-temperature freak titanium amalgam as a matrix material for the National Aerospace facility. Textron is heated isostatically squeezing titanium composite Ti-6Al-4V supplemented with continuous silicon carbide fibres for turbine motor shafts [29]. Aluminum and rare metals are currently used as structural materials for MMC goods by CERAMTEC AG (Germany). Besides being relatively low-priced in evaluation to certain other light metals (e.g., magnesium and titanium), it has produced excellent results in a variety of automobile and aerospace uses and is known for its ease of handling. Eventually, the structure might be made of nearly any lightweight composite or non-ferrous metal, particularly magnesium. They are likewise growing new clay cutting devices, and furthermore prevalent material for chamber linings.

Even with its greater increased temperature blocking property, titanium [30] has been used in air motors primarily for blowers sharp corners and plates. Magnesium is indeed the best material for producing composites for engine response sections, cylinder, gudgeon pins, and spring coverings [31]. It is additionally utilized in aviation because of its low coefficient of warm extension and high solidness properties joined with low thickness. The usage of Silicon Carbide as an aid in Aluminum composite is principally intended to replace specialised beryllium parts in rocket navigation frameworks since the underpinning exhibition is nicer without the need for particular care in development as requested by the last's hazard [32, 33]. As of late Aluminum-lithium composite has been drawing in the consideration of analysts because of it's acceptable wettability attributes [34].

Effective turn of events and sending of metal framework composites are basic to arriving at the objectives of many progressed aviation drive and force advancement programs. High-temperature, high-warm conductivity, and high-strength materials are required for the specific space impetus and force application. Metal grid composites either meet or are capable of meeting these requirements [35]. Metal structure composites additionally provide good assurance to help car developers meet ongoing and prospective demand issues.

As a result of this writing, it is obvious that the Aluminum metal matrix composites composition may efficiently support SiC, Al2O3, TiB2, boron, and graphite. The supporting Aluminum metal matrix composites chemicals have made significant progress from of the research center to commercialization. In any event, the components that influence the mechanical and physical properties of these substances are a test [36] since they have been receptive to the type as well as nature of support, the way of assembly, and the nuances of creative management of the composites after it starts manufacturing.

Ceramic composites are widely used in situations where large weight investment expenditures are required. Nonetheless, Aluminum composites' fairly weak wear resistance has limited their use in elevated situations. The bulk of the studies to analyse the wear conduct of Aluminum baffles have been conducted, according to the literature available on the subject.

Its protection from wear of MMCs is generally agreed upon, as well as the larger the volumetric portion of particles, the greater the obstructions [37-39]. However, there is an ideal value of the supporting that provides the most extreme contract duration from the material.

The diffraction and wearing demonstrations of supported aluminium composite may be divided into two classes by the head tribological boundaries. Mechanical and real factors are one, and material components are the other [40]. Sliding speed and typical burden have been identified as mechanical and actual aspects, while volume part and type of for constituent materials have been identified. Several researchers have concentrated on the volume part support, which has the most solid impact on wear opposition [41]. MMCs have been planned using various types of fortification as part of the exploration [42-43]. Introducing hard intermetallic into the aluminium matrix improves wear characteristics dramatically, as a result of most of these findings.

## 1.8 NEED FOR THE REINFORCEMENT OF SILICON CARBIDE INTO ALUMINIUM MATRIX

The improvement of supporting framework, particularly composites assembly, can be attributed to a better understanding of the lightweight materials that composites may provide, resulting in cheaper prices and better execution. There seems to be an rise in demand for more contemporary, heavier, stronger, as well as lighter weight in areas such as aviation. Composites are advancing mostly as a result of unusual customised demand arising from rapidly driving activities in the aircraft, flying, and automobile industries. Because the their low explicit gravity, these material outperform several traditional design elements like as metals in terms of effectiveness and modulus. It is currently ready to make new composites with improved mechanical and actual properties as an outcome of far reaching examination into the presence of substances and a more profound comprehension of their design property relationship. Constant advancement has prompted the utilization of composites in a more extensive scope of uses, including elite composites, for example, PMCs, CMCs, and MMCs. The ability to achieve a good mix of solidarity, solidness, strength, and thickness with traditional solid particles is limited. Composites are the most promising materials of continued interest for overcoming these flaws and addressing the ever-increasing need for new technology. Metal grid composites (MMCs) have essentially improved properties over unreinforced compounds, like high explicit strength, explicit modulus, damping force, and high wear obstruction. AMCs have a wide scope of utilizations in our day by day lives. Increased strength and explicit modulus, enhanced solidity, light weight, low warm growth coefficient, high warm conductivity, enhanced electronic characteristics, increased wear obstruction, and improved damping capacities are some of the advantages of using particles fortified AMCs components over un - reinforced materials .Inside the framework, particles, short strands, persistent filaments, and mono fibers would all be able to be utilized as supporting constituents. Aviation, temperature control, modern materials, and car applications like motor cylinders and brake circles currently use it. High solidity and durability, low thickness, high temperature soundness, excellent voltage and warm conductivity, flexible coefficient of warm extension, consuming opposing, expanded wear obstruction, and other important qualities of composites. The support keeps the matrix in place and improves the grid's overall material qualities, allowing it to frame the required stuff. When properly prepared, the most current consolidated material outperforms all of the individual materials. Composite are spectral features structures with features that separate materials cannot match. Rational designs by meticulously mixing many or more comparable elements from diverse organisations, highlights, and shapes.When contrasted with their fashioned amalgam partners, metal lattice composites (MMCs) have gotten a ton of consideration lately as a result of their prevalent strength and solidness, just as their high wear and creep obstruction. Another important goal of lattice composite is to create a combination with a fine balance of strength and hardness that reduces break and deformation weaknesses while improving dynamic and static properties. Complex manufacturing methods, tiny texture restrictions, and a microscopic variation in appropriate framework among brushes, as well as fine molecular upgrade, are all factors to consider. Because of the health risks associated with cleaning SiC stubbles, the focus has recently shifted to particle strands rather than aluminium hair support, which is lightweight and more wettable with silicon carbide. MMCs are a form of DRA constructed of high-strength aluminium amalgams with silicon carbide particulates or bristles. Aluminum metal matrix composites give superb focuses to a few structure components requiring high solidness, high strength, and low weight inferable from the blend of properties and fabricability. Because fundamental performance is excellent and there is no requirement for extraordinary manufacture the board required by that of the last's poisonousness, SiC as a building up in Aluminum Composite is generally planned to substitute some beryllium components in rocket directing frameworks. Aluminum-based composite are commonly used in weight-saving purposes. Mixed Cast is a liquid state composite material creation technology in which a distributed stage (clay particles, short filaments) is accurately merged together with a liquid frame metal. The fluid composite material is projected using traditional projecting tactics, and it can also be treated using standard metal frame processes. The main goal of this work is to use mix projections to create an Al-SiC composite that can be tested mechanically and metallurgically.

# CHAPTER 2

# LITERATURE SURVEY

## 2.1 INTRODUCTION

As part of the thesis study, a literature review is conducted to gain a better understanding of the manufacturing processes, characteristics, and wear behavior of metal matrix composites. Composite structures have consistently demonstrated a cost savings of at least 20% over metal counterpart, as well as lower operational and maintenance costs. As more data on composite structural service life becomes accessible, this can be reliably stated that they are robust, preserve dimensional integrity, withstand stress load, and are simple to maintain and repair. Composite should continue to develop new uses, but as the market for these materials expands, less expensive methods of processing will be required, as well as the chance of recycling [44].

The literature survey is carried out as a part of the thesis work to have an overvi ewof the production processes, properties and wear behaviour of metal matrix comp osits. Composite structures have shown universally a savings of at least 20% over metal counterparts and a lower operational and maintenance cost. As the data on the service life of composite structures is becoming available, it can be safely said that they are durable, maintain dimensional integrity, resist fatigue loading and are easily maintainable and repairable. Composite would continue to develop new uses, but as the market for these materials grows, less expensive processing methods, as well as the possibility of recycling, will be necessary [45].

It has been reported that the energy consumed when aluminium is recycled is only about 5% of that required in the primary production of aluminium [46]. There are, however, certain disadvantages associated with the recycling of aluminium such as the presence of impurities, which to a large extent impair the mechanical proper ties of the recycled material. This problem can be overcome by a careful selection of the constituents and also the fabrication technique, as they can lead to the formation and piling up of intermediate phases that are detrimental [47].

There are many interdependent variables to consider in designing an effective MMC material. Since the upper bound on MMC properties is established by the properti es of the matrix and reinforcement material, careful selection of these components is necessary.

## 2.2 MATERIAL SELECTION

### 2.2.1 Matrix Material

Because the matrix alloy in MMC is responsible for so much more than just distributing glue, it should only be chosen after a thorough examination of its chemical inertness with that of the composite, capacity to wet this same reinforcement, own qualities, qualities, and processing behaviour patterns [ 48].

One very crucial issue to consider in selection of the matrix alloy composition involves the natural dichotomy between wettability of the reinforcement and excessive reactivity with it [49]. Good load transfer from the matrix to the reinforcement depends on the existence of a strongly adherent interface [50, 51]. In turn, a strong interface requires adequate wetting of the reinforcement by the matrix. However, the attainments ofwetting and aggressive reactivity are both favored by strong chemical bonding betweenthe matrix and reinforcement. Adjusting the chemical composition to accomplish this delicate compromise is difficult as many subtleties are involved. To illustrate the complexity, several examples concerning alloying additions to aluminium matrix metal relative to Silicon carbide whiskers, boron reinforced and Graphite reinforced aluminium composites and the effect of insidious impurities from various origins have been documented by numerous investigators [52-66].

As a rule of alloying element addition, the added element should not form intermetalic compounds with the matrix elements and should not form highly stable compounds with the reinforcements. The best properties can be obtained in a composite system when the reinforcement whiskers or particulates and matrix are as physically and chemically compatible as possible. To improve the performance of specific metallic composites, special matrix alloy composition and unique whisker coatings has been developed [67-71].

## 2.3 Why Al Matrix Selection?

MMC materials have a combination of different, superior properties to an unreinforcedmatrix which are; increased strength, higher elastic modulus, higher servic temperature, improved wear resistance, high electrical and thermal conductivity, low coefficientof thermal expansion and high vacuum environmental resistance.These properties can be attained with the proper choice of matrix and reinforcement

Composite materials consist of matrix and reinforcement. Its main function is to transfer and distribute the load to the reinforcement or fibres. This transfer of load dependson the bonding which depends on the type of matrix and reinforcement and the fabrication technique.

The matrix can be selected on the basis of oxidation and corrosion resistance or otherproperties [34]. Generally Al, Ti, Mg, Ni, Cu, Pb, Fe, Ag, Zn, Sn and Si are used as the matrix material, but Al, Ti, Mg are used widely.

Nowadays researchers all over the world are focusing mainly on aluminium [27] because of its unique combination of good corrosion resistance, low density and excellent mechanical properties. The unique thermal properties of aluminium composites such asmetallic conductivity with coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics. Titanium [30] has been used in aeroengines mainly for compressor blades and discs due to its higher elevated temperature resistance. Magnesium is the potential material to fabricate composite for making reciprocating components in motors and for pistons, gudgeon pins and spring caps [31].
It is also used in aerospace due to its low coefficient of thermal expansion and high stiffness properties combined with low density. the choice of Silicon Carbide as the reinforcement in aluminium composite is primarily meant to use the composite in missile guidance system replacing certain beryllium components because structural performance is better without special handling in fabrication demanded by the latter's toxicit [32,33]. Recently aluminiumlithium alloy has been attracting the attention of researchers due to its good wettability characteristics [72].

In addition, literature also reveals that most of the published work has considered aluminium composites with their attractions of low density, wide alloy 23 range, heat treatment capability and processing flexibility. Many of these features are also exhibited by magnesiumbased systems and with its lower elastic modulus. Magnesium often achieves a larger property improvement with reinforcement than aluminium. Also many of the composite fabrication processes are common to both Al and Mg based systems [35, 73].

Magnesium and magnesium alloys are among the lightest candidate materials for practical use as the matrix phase in metal matrix composites. When compared to other currently available structural materials. Magnesium is very attractive because of its uniquecombination of low density and excellent machinability. However, it has been reported by several authors [74] that their low density (35% lower than that of Al) makes them competitive in terms of strength/density values. Magnesium alloys do not compare favorably with aluminium alloys in terms of absolute strength.

The high wettability, design flexibility, and tough bonding at the interface are said to be the major reasons for aluminium's success over magnesium.

## 2.4 Reinforcement

Reinforcement increases the strength, stiffness and the temperature resistance capacity and lowers the density of MMC. In order to achieve these properties the selection depends on the type of reinforcement, its method of production and chemical compatibility with the matrix and the following aspects must be considered while selecting the reinforcement material.

- Size – diameter and aspect ratio:
- Shape – Chopped fiber, whisker, spherical or irregular particulate, flake, etc:

- Surface morphology – smooth or corrugated and rough:
- Poly – or single crystal:
- Structural defects – voids, occluded material, second phases:
- Surface chemistry – e.g. $SiO_2$ or C on SiC or other residual films:
- Impurities – Si, Na and Ca in sapphire reinforcement;
- Inherent properties – strength, modulus and density.

Even when a specific type has been selected, reinforcement inconsistency will persist because many of the aspects cited above in addition to contamination from processing equipment and feedstock may vary greatly [75]. Since most ceramics are available as particles, there is a wide range of potential reinforcements for particle reinforced composites [76-81].

The use of graphite reinforcement in a metal matrix has a potential to create a material with a high thermal conductivity, excellent mechanical properties and attractive damping behaviour at elevated temperatures [82,83]. However,lack of wettabilitybetween aluminium and the reinforcement, and oxidation of the graphite [84,85] lead to manufacturing difficulties and cavitations of the material at high temperature .

Alumina [86] and other oxide particles like $TiO_2$ [87] etc. have been used as the reinforcing particles in Al. Alumina has received attention as a reinforcing phase as it is found to increase the hardness, tensile strength and wear resistance [88,89] of aluminium metal matrix composites. Rohatgi [90] have studied mica, alumina, silicon carbide, clay, zircon, and graphite as reinforcements in the production of composites. Numerous oxides, nitrides, borides and carbides were studied by Zedalis et.al.[91,92] as reinforcements for reinforcing high temperature discontinuously reinforced aluminium (HTDRA). It has been inferred from their studies that HTDRA containing TiC $TiB_2$, $B_4C$, $Al_2O_3$, SiC and $Si_3N_4$ exhibit the highest values of specific stiffness.

It is proven that the ceramic particles are effective reinforcement materials in aluminium alloy to enhance the mechanical and other properties [93,94]. The reinforcement in MMCs are usually of ceramic materials, these reinforcements can be divided into two major groups, continuous and discontinuous. The MMCs produced by them are called continuously (fibre) reinforced composites and discontinuously reinforced composites. However, they can be subdivided broadly into five major categories: continuous fibres, short fibres (chopped fibres, not necessarily the same length), whiskers, particulate and wire (only for metal). With the exception of wires, reinforcements are generally ceramics, typically these ceramics being oxides, carbides and nitrides. these are used because of their combinations of high strength and stiffness at both room and elevated temperatures. Common reinforcement elements are SiC, $A1_20_3$, $TiB_2$, boron and graphite.

#### 2.2.3.1 Continuous fibre reinforcement

According to ASTM [95] the term fibre may be used for any material in an elongated form that has a minimum length to a maximum average transverse dimension of 10:1, a maximum cross sectional area of 5.1X10 $cm^2$ and a maximum transverse dimension of 0.0254 cm. Continuous fibers in composites are usually called filaments, the main continuous fibres include boron, graphite, alumina and silicon carbide.

The fibre is unique for unidirectional load when it is oriented in the same direction as that of loading, but it has low strength in the direction perpendicular to the fibre orientation. As regards cost, continuous fibres are about 200 times higher than discontinuous fibres. Therefore for specific purposes only, that continuous fibre is used. The other advantage of discontinuous fibres is that they can be shaped by any standard metallurgical processes such as forging, rolling, extrusion etc.

#### 2.2.3.2 Short fibres

Short fibres are long compared to the critical length ($l_c = d\ S_f / S_m$ where d is the fibre diameter, $S_f$ is the reinforcement strength and $S_m$ is the matrix strength) and hence show high strength in composites, considering aligned fibres. Nevertheless, misoriented short fibres have been used with some success as AMC (Aluminium Matrix Composite) reinforcement [96]. Short fibres are still used mainly for refractory insulation purposes due to their low strength compared with others, but they are cheaper than fibre and whiskers.

#### 2.2.3.3 Whiskers

Whiskers are characterized by their fibrous, single crystal structures, which have no crystalline defect. Numerous materials, including metals, oxides, carbides, halides and organic compounds have been prepared under controlled conditions in the form of whiskers. Generally, a whisker has a single dislocation, which runs along the central axis.

The relative freedom from discontinuous means that the yield strength of a whisker isclose to the theoretical strength of the material [97].

Silicon carbide, silicon nitride, carbon and potassium titanate whiskers are available already. Among these, silicon carbide whiskers seem to offer the best opportunities for MMC reinforcement. Presently, silicon carbide whisker reinforcement is produced from rice husk, which is a low cost material. The physical characteristics of whiskers are responsible for different chemical reactivity with the matrix alloy [99] and also health hazards posed in their handling. Therefore the inherent interest shown by the researchers in whiskers reinforcement has declined.

#### 2.2.3.4 Particulates

Particulates are the most common and cheapest reinforcement materials.These produce the isotropic property of MMCs, which shows a promising application in structural fields. Initially, attempts were made to produce reinforced Aluminium alloys with graphitepowder, but only low volume fractions of reinforcement had been incorporated (<10%).Presently higher volume fractions of reinforcements have been achieved for various kinds of ceramic particles (oxide, carbide, nitride).

Wear-resistant materials made from SiC particulate-reinforced aluminium matrix composites seem promising. Particulates, on the other hand, have a favourable effect on properties including toughness, durability, and compressive. The selection of reinforcements is guided by a number of factors [100], and is not as random because this set of composite may appear.

**The application**: If the composite is to be used in a structural application, the modulus, strength, and density of the composite will be important, which requires a high modulus, low density reinforcement. Particle shape may be important, since angular particles can act as local stress raisers, reducing ductility. If the composite is to be used in thermal management applications, the coefficient of thermal expansion and thermal conductivity are important. If the composite is to be used in wear resistant applications, hardness is important.

**The method of composite manufacture**: There are two generic methods for composite manufacture, powder metallurgy (P/M) and methods involving molten metal. For composites processed in the molten state, there are different considerations such as compatibility. Alumina is stable in most Mg free Al alloys, but unstable in Mg alloys, reacting to form $Al_2MgO_4$. Reaction of the reinforcement can severely degrade the properties of the composites, so the reinforcement has to be chosen after considering the matrix alloy, and the processing time and temperature.

**Cost:** The cost of the composites is a big consideration when employing particles. As a result, repeatable grade reinforcement must be readily available in the quantities, sizes, and shapes necessary at a low cost.

# CHAPTER 3

# METHODOLOGY

## 3.1 FABRICATION METHODS OF MMCs

Metal-matrix composite (MMC) materials' potential for considerable performance improvements over traditional alloys has been extensively acknowledged in recent years. Their manufacturing expenses, on the other hand, are still quite substantial. MMC materials can be made using a variety of fabrication procedures; there is no one-size-fits-all solution. Fabrication procedures can differ significantly depending on the material and reinforcement used, as well as the types of reinforcement used. The following are the different processing processes utilised to make particle reinforced MMCs.

- Diffusion bonding, hot rolling, extrusion, drawing, explosive welding, PM route, pneumatic impaction, and other solid-phase fabrication methods [101].

- Liquid-metal infiltration, squeeze casting, compocasting, pressure casting, spray codeposition, stir casting, and other liquid-phase production methods[102].

- Rheocasting [103] and Spray atomization are two-phase (solid/liquid) techniques.

Because solid-phase processing takes longer, the liquid-phase fabrication method is usually more efficient [104] than the solid-phase fabrication approach. In various fabrication procedures, the matrix metal is used in diverse forms. Powder is typically utilised in pneumatic impaction and powder metallurgy, while a liquid matrix is utilised in liquid-metal infiltration, plasma spray, spray casting, squeeze casting, pressure casting, gravity casting, stir casting, investment casting, and other processes. Electroforming uses a molecular form of the matrix, while diffusion bonding, rolling, and extrusion utilise vapour deposition and metal foils.

There are certain main manufacturing processes which are used presently in laborat orie as well as in industries are diffusion bonding, the powder metallurgy route, liquid,metal infiltration, squeeze casting, spray codeposition, stir casting and compo casting. Brief Description of these processes is given below.

## 3.2 SOLID PHASE FABRICATION METHODS

There are various methods for fabricating MMC from solid-phase materials, although diffusion bonding and powder metallurgy are the most common.

### 3.2.1 Diffusion bonding

This method is normally used to manufacture fibre reinforced MMC with sheets or foils of matrix material. Figure 1 [104] shows the different steps in fabricating MMC by diffusion bonding. Here primarily the metal or metal alloys in the form of sheets and the reinforcement material in the form of fibre are chemically surface treated for the effectiveness of interdiffusion. Then fibres are placed on the metal foil in predetermined orientation and bonding takes place by press forming directly, as shown by the dotted line. However sometimes the fibres are coated by plasma spraying or ion plating for enhancing the bonding strength before diffusion bonding, the solid line shows this. After bonding, secondary machining work is carried out. the applied pressure and temperature as well as their durations for diffusion bonding to develop, vary with the composite systems. However, this is the most expensive method of fabricating MMC materials.

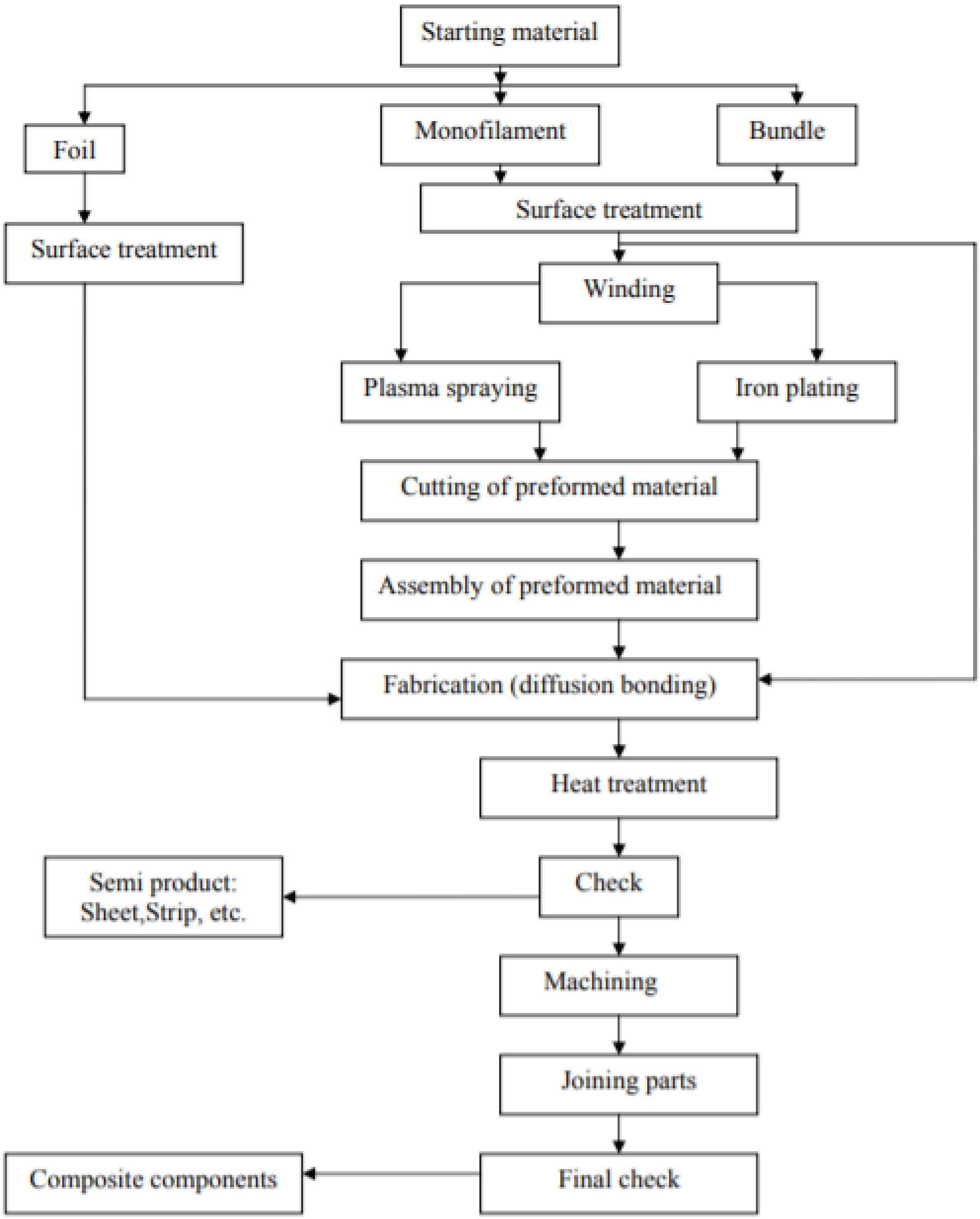

**Fig.1 Flow chart for composite fabrication by diffusion bonding**

### 3.2.2 Powder metallurgy (PM) technique

The PM technique shown in Fig.2 is the most commonly used method for the preparation of discontinuous reinforced MMCs [105]. This technique is used to manufacture MMCs using either particulates or whiskers as the reinforcement materials. In the general process the powders of matrix materials and reinforcement are first blended and fed into a mould of the desired shape. Pressure is then applied to further compact the powder (cold pressing). In order to facilitate the bonding between the powder particles, the compact is then heated to a temperature that is below the melting point but sufficiently high to develop significant solidstate diffusion (sintering). The consolidated product is then used as a MMC material after some secondary operation.

This method is popular because it is reliable compared with other alternative methods, but it also has some demerits. The blending step is a time consuming, expensive and potentially dangerous operation. In addition, it is difficult to achieve an even distribution of particulate throughout the product and the use of powders requires a high level of cleanliness, otherwise inclusions will be incorporated into the product with a deleterious effect on fracture toughness, fatigue life, etc.

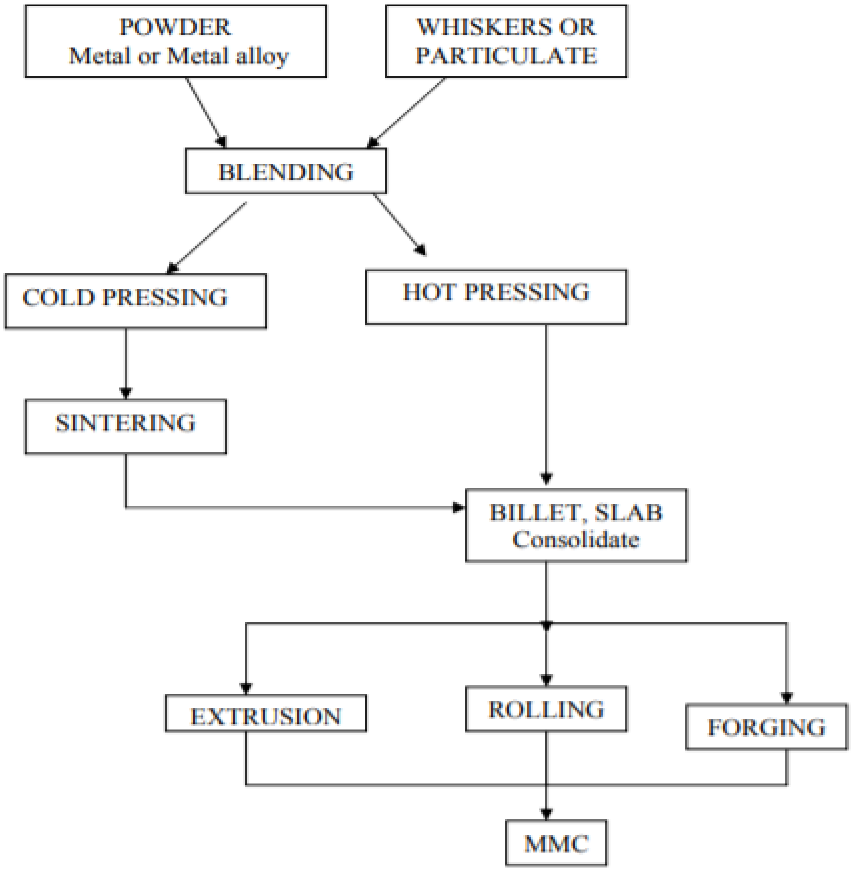

**Fig.2.General flow chart for fabrication of composite by powder metallurgy**

**technique**

### 3.2.3 Liquid phase fabrication techniques

Most of the MMCs are produced by this technique. In this technique, the ceramic particles are incorporated into liquid metal using various processes. the liquid composite slurry is subsequently cast into various shapes by conventional casting techniques or cast into ingots for secondary processing. The process has the major advantage that the production costs of MMCs are very low. The process has the key advantage of having very low MMC production costs. The non-wettability of the particles by liquid aluminium and the resulting denial of the particles from the melt, as well as non-uniform particle dispersion due to favored segregation and significant interfacial reactivity, are the key challenges in such operations.

### 3.2.4 Liquid metal infiltration

This process can also be called fibre infiltration. Fiber tows can be infiltrated by passing through a bath of molten metal. Usually the fibres must be coated in line to promote wetting. Once the infiltrated wires are produced, they must be assembled into a preform and given a secondary consolidation process to produce a component. Secondary consolidation is generally accomplished through diffusion bonding or hot moulding in the two-phase liquid and solid region.

The fabrication process of MMC by vacuum metal infiltration used by Chapman et al. [106] is shown in Fig. 2.3. These authors used Aluminium oxide fibre FP (polycrystalline fibre) of Du Pont Company. In this technique, as the first step, FP is made into a handleable FP tape with a fugitive organic binder in a manner similar to producing a resin matrix composite prepreg. Fibre FP tapes are then laid in the desired orientation, fibre volume loading, and shape, and are then inserted into a casting mold of steel or other suitable material. The fugitive organic binder is burned away, and the mold is infiltrated with molten metal and allowed to solidify. Metals such as Aluminium, magnesium, silver and copper have been used as the matrix materials in this liquid infiltration process because of their relatively lower melting points. This method is desirable in producing relatively small compos ite specimens having unidirectional properties.

### 3.2.5 Squeeze casting

Squeeze casting is a one-step metal forming method that produces close-tolerance, high-integrity finished shapes by rapidly solidifying a measured quantity of liquid metal in a reusable die at high pressures (50 to 100 MPa).

The fabrication process of MMC by squeeze casting is shown in Fig. 3. The preform of the ceramic fibre is preheated to several hundred degrees centigrade below the melting temperature of the matrix and then set into a metal die. the Al or Mg alloy is heated to just above its melting temperature and is then squeezed into the fibre preform by a hydraulic press to form a mixture of fibre and molten metal.

This process can be used for large scale manufacturing but it requires careful control of the process variables, including the fiber and liquid metal preheat temperature, the metal alloying elements, external cooling, the melt quality, the tooling temperature, the time lag between die closure and pressurization, the pressure levels and duration and the plunger speed. Imperfect control of these process variables results in various defects, including freeze choking, preform deformation, fiber degradation, oxide inclusions and other common casting defects. However, in practical use, squeeze casting is the most effective method of constructing machine parts with a complex shape in a short time.

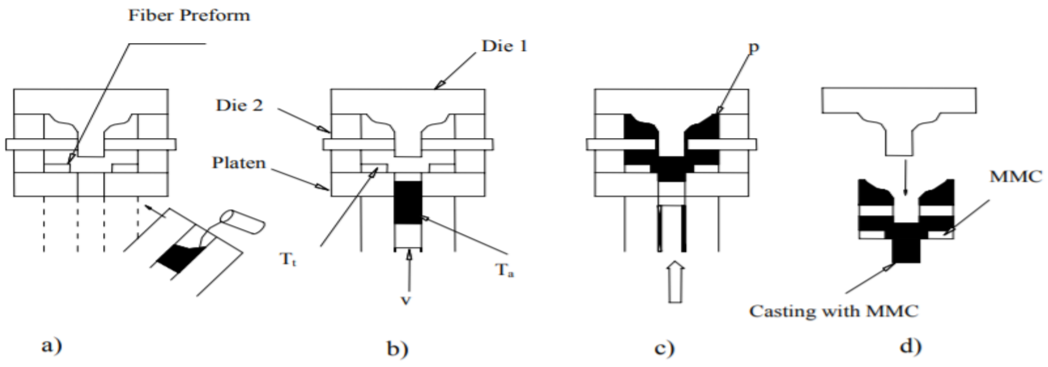

**Fig.3.Sequences of the Squeeze casting process with a vertical machine (a) po uring (b) casting (c) squeezing and (d) ejecting**

### 3.2.6 Spray co-deposition method

Spray-deposition is a low-cost approach for creating particle composites. The Alcan spray deposition method is seen schematically in Figure 4. The alloys to have been spray in a beaker is melted using induction heating. The crucible is pressured, and the metal is expelled throughout a nozzle into an atomizer, where particles (reinforcement) are injected and deposited on a warmed substrate in the line of flight. On the collector, a substantial deposit is built up. When the deposited strip has cooled, it is removed from the substrate and rolled. The final product's shape is determined by the atomizing condition as well as the collector's form and speed.

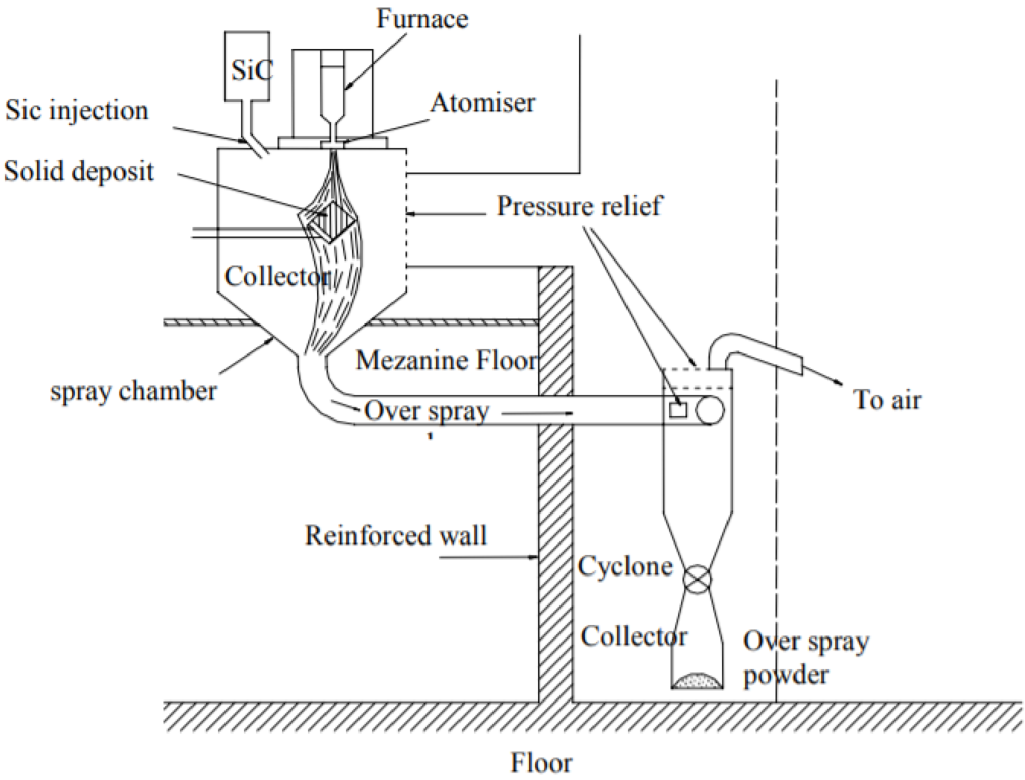

**Fig.4. Schematic of spray deposition equipment**

### 3.2.7 Stir casting

Stir-casting processes, as demonstrated in Fig. 5, are now the most straightforward and marketable method of making MMCs. This method entails mechanically addition the reinforcing particles into a melt bath and then moving the mixture to a formed mould before it solidifies completely. The most important aspect of this technique is to get adequate wetting between the particle reinforcement and the molten metal.

Microstructural inhomogeneity can cause particle agglomeration and sedimentation in the melt and subsequently during solidification. Inhomogeneity in reinforcement distribution in these cast composites could also be a problem as a result of interaction between suspended ceramic particles and moving solid,liquid interface during solidification. This process has the major advantage that the production costs of MMCs are very low.

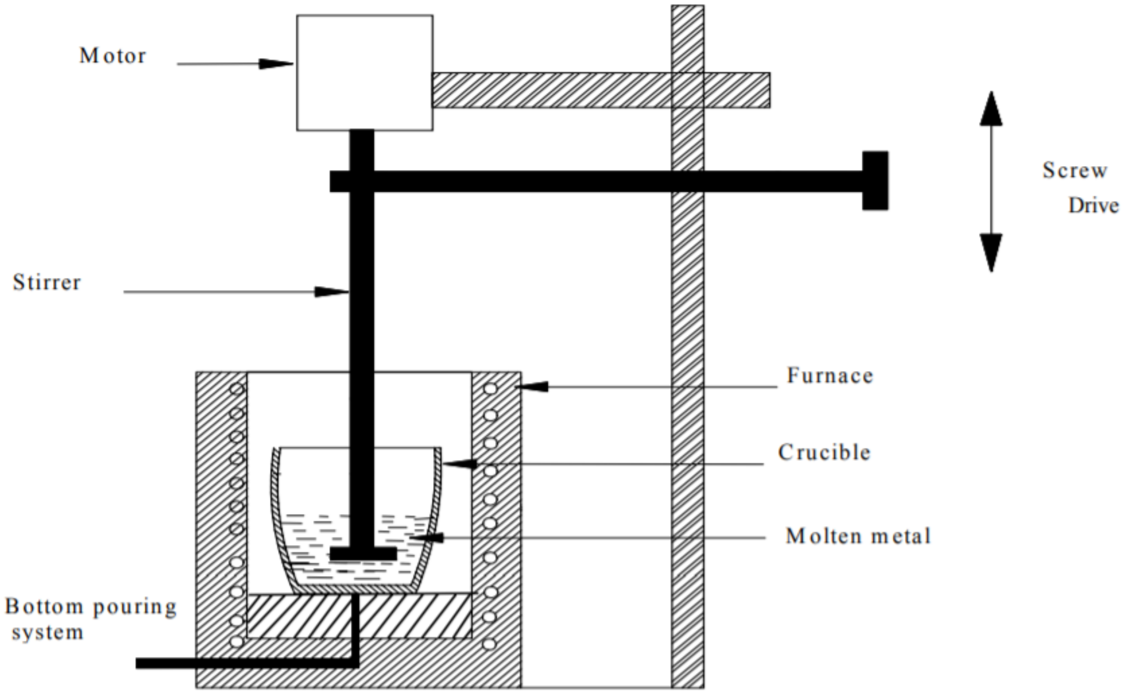

**Fig.5 MMC by casting route through Stir Casting method**

### 3.2.8 Compocasting

This has been the most cost-effective way of producing a composite using discontinuity fibres, except from PM, thermal spraying, diffusion bonding, and high-pressure squeeze casting (chopped fibre, whisker and particulate). This is an upgraded version of the slush- or stir-casting method.

Figure 6 shows the schematic representation of the compo casting apparatus used to make the composites. An inductive power supply (50 kW, 3000 Hz), a water-cooled vacuum chamber with mechanical and diffusion pumps, and a furnace and mixing equipment for agitating the composite make up the device.

First, a metal alloy is placed in the system with the blade assembly in place. Then the chamber is evacuated and the alloy is superheated above its melting temperature and stirring is initiated by the DC motor to homogenize the temperature. The inducing power is lowered gradually until the alloy is 40 to 50% solid, at which point the nonmetallic particles are added to the slurry, However, the temperature is raised during adding in such a way that the total amount of solid, which consists of fibres and solid globules of the slurry, does not exceed 50%. stirring is continued until interface interactions between the particulates and the matrix promote wetting.

The melt is then superheated to above its liquid temperature and bottom poured into the graphite mould by raising the blade assembly. The melt containing the nonmetallic particles is then transferred into the lower half of the press and the top die is brought down to shape and solidify the Composite by applying the pressure. This is used to make the composite of the highest values of volume fractions of reinforcement.

MMCs are less forgiving in terms of processing practise than unreinforced alloys, according to the literature, but with the right technique, desirable combinations of mechanical and physical qualities can be created.

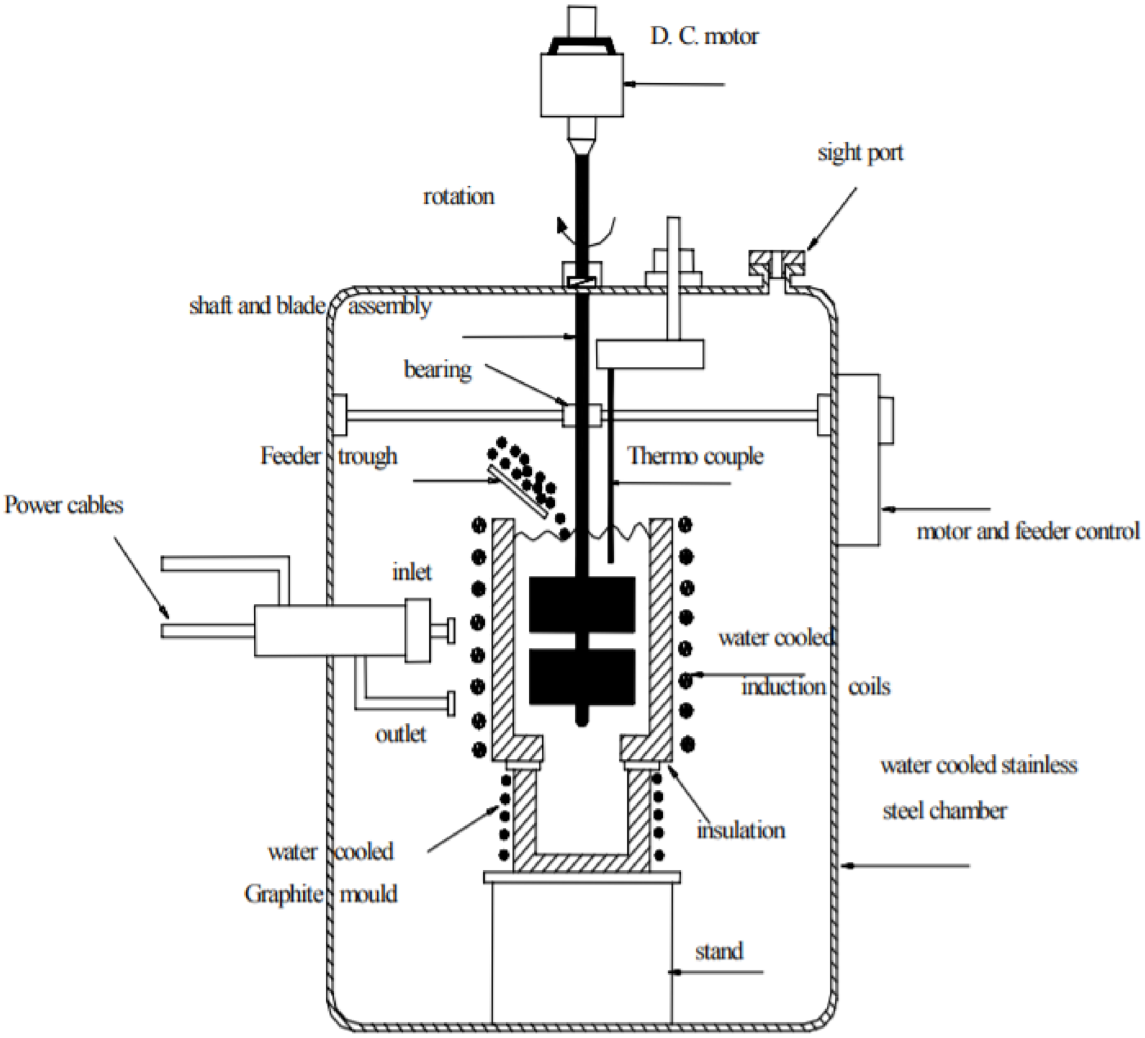

**Fig.6. Compocasting: mixing fibres (or Particulates) with metal**

# CHAPTER 4

# STIR CASTING FABRICATION METHOD

## 4.1 Introduction

Stir casting is one of the many production processes accessible for discontinuity metal matrix composites, and it is presently used economically. Its merits include its simplicity, flexibility, and adaptability to large-scale production, as well as its low price, because it allows for the use of a traditional metal preparation method in theory. This liquid metallurgical approach is perhaps the most cost-effective of all the metal matrix production pathways [107], allowing for the fabrication of very mass production while maintaining high productivity rates. However according Skibo et al [108], the cost of manufacturing composites employing a casting approach is roughly one-third to just one that of comparable technologies, with costs expected to reduce to one-tenth for large volumes manufacturing.

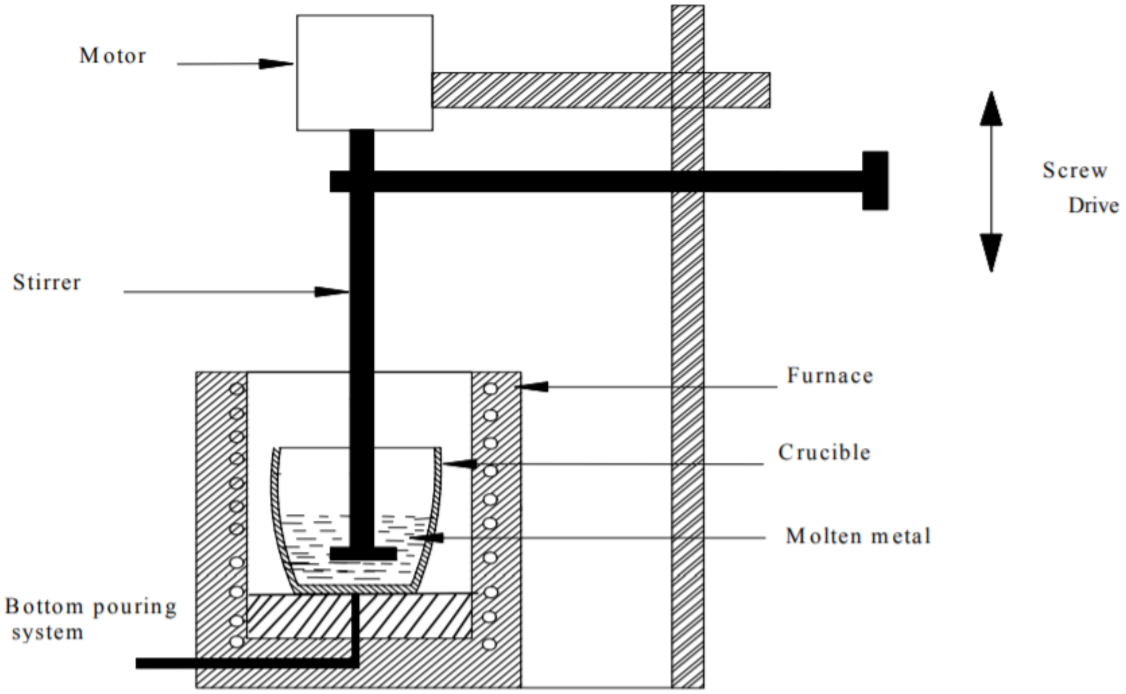

**Fig.7 MMC by casting route through Stir Casting method**

## 4.2 Fabrication Process

In general stir casting of MMCs involves producing a melt of the selected matrix material, followed by the introduction of reinforcing material into the melt,obtaining a suitable dispersion through stirring The next step is the solidification of the melt containing suspended particles to obtain the desired distribution of the dispersed phase in,the cast matrix The schematic diagram of this process is as shown in Figure 8 incomposites produced by this method, particle distribution will change significantly depending on process parameters during both the melt and solidificationstages of the process The addition of particles to the melt drastically changes the viscosity of the melt, and this has implications for casting processes It is important that solidification occur before appreciable settling has been allowed to take place.

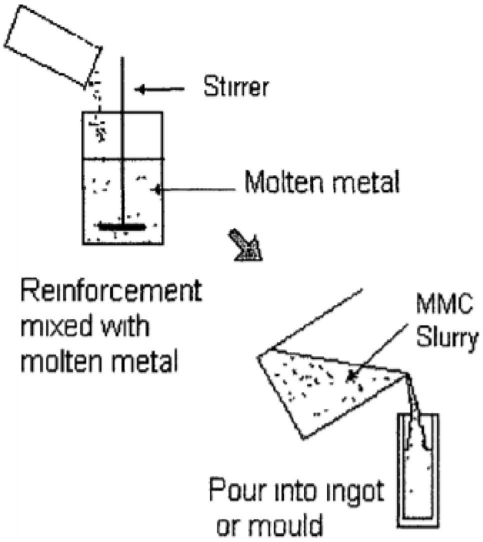

**Fig.8: Schematic diagram of stir casting**

The earlier approaches to producing metal matrix composite used solid particles produced within the melt through a chemical reaction This results in dispersed phases as in precipitation hardening of Al4wt% cu alloy Other approaches to produce metal matrix composites involve the introduction of second phases particles in the metal melt.

The foundry technique involves the mixing of reinforcement particles by sting the molten alloy matrix.

The process is generally earned out at two different ranges of temperature of the melt, beyond the liquidus temperature [109] or at the melt temperature maintained within the partially solid range o f the alloy [110] The technique involving the latter range of temperature is called the compocasting process and it is very effective in making cast composites with higher particle content [111] the reinforcement particles are added gradually while stirring continues at a constant rate.

As per Miwa [112], in order to achieve good integration, the adding rate must be lowered in tandem with size reduction. Salvo [113] takes roughly 5-10 minutes to integrate silicon carbide particle into the melt, while Lee et al [114] added particles at a rate of 4-5g/hour. The particles were sometimes supplied via a nitrogen gas stream [115,116].

The reinforcement particles used normally are one of two types either in as received condition, or heattreated (artificially oxidized) Oxidation has take place at 1000°C for 1 5 hours in air [117] at 1100°C for 12 hours [118] or one and half hours [119], and at 850°C for 8 hour Additionally, gas absorbed on the surface of SiC, which was prepared in air, can be removed by preheating at a certain temperature for a certain period of time For example particles have been heated to 554°C for one hour [120,121], 850°C for 8 hours [122], or at the temperature of 900°C, 799°C [123,124] and 1100°C [125]

Most previous researches have used the matrix metal alloy in the ingot form [126, 127,128] or extruded bar [129] As a starting point the ingot is generally melted to above the liquidus temperature, for example to 50°C above the liquidus temperature [130]. A different approach has been proposed by Young and Clyne [131] and in their work slurry was prepared from powdered material Composite melt may be prepared in a graphite crucible [132,133], silicon carbide crucible [134,35], alumina crucible [136,137], or concrete crucible [138] In order to keep the melt as clean aspossible the ingot is melted under a cover of an inert gas such as nitrogen, or in a vacuum chamber [139] or in a pressure chamber there also helps to minimize the oxidation of the molten metal [140], or reduces porosity (under pressure) McCoy et al [141] prepared composite with the whole apparatus being sealed with a glove box which was filled with nitrogen gas According to Yamada et al [142] the molten aluminium should be subjected to a high vacuum atmosphere to degas hydrogen, before the reinforcement materials are completely added Gupta and Surappa [143] treated the metal ingot in different ways In their work the metal ingot, before melting, was treated with a warm alkaline solution and washed with a mixture of acids, in order to reduce the thickness of the oxide film and to eliminate other surface impurities.

The most significant requirement when using a stir casting technique is continuous stirring of the melt with a motor driven agitator to prevent settling of particles If the particles are more dense than the host alloy, they will naturally sink to the bottom of the melt [144] This means that some method of stirring the melt must be introduced before casting to ensure that the particles are properly distributed throughout the casting Some of the stirrer which are normally be used is shown in Figure 9 .

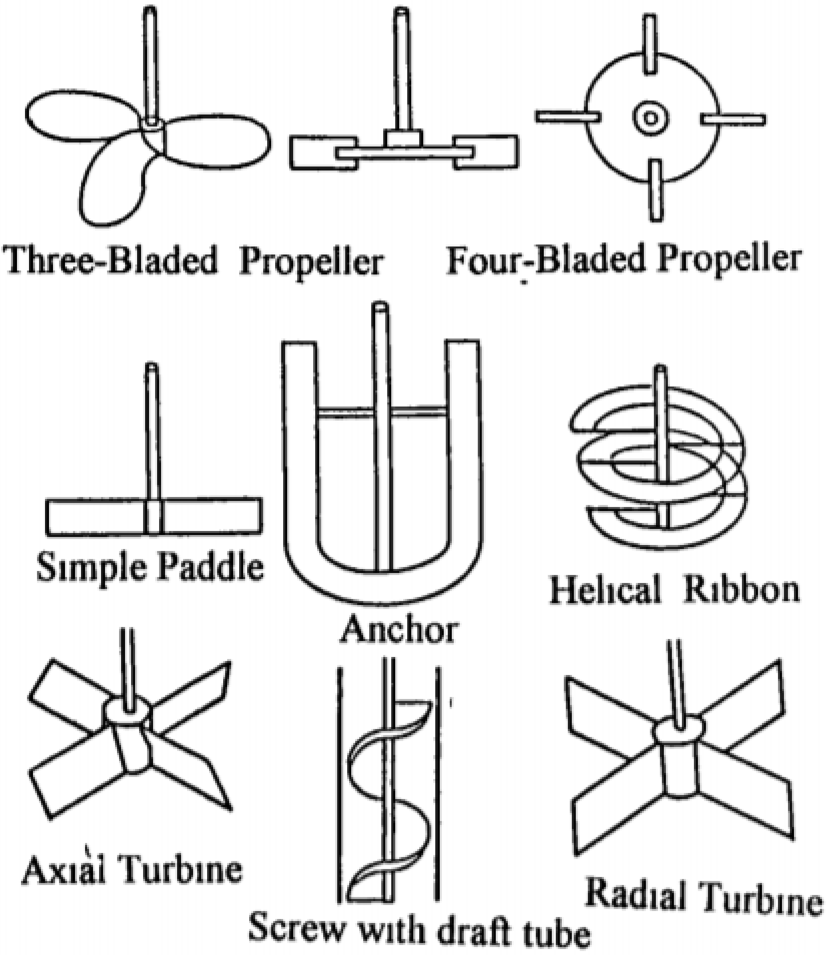

**Figure.9. Several type of stirrer**

## 4.3 Solidification of Metal Matrix Composites

During solidification it is important to have an understanding of particle movements and distribution, as the properties of composite are known to critically depend on the distribution of the reinforcement The solidification synthesis of cast metal,ceramic particle composites involves producing a melt of matrix material, followed by the introduction of the particles into the melt, and the final step is solidification of the melt into a certain shape, such as an ingot or a billet form The solid particles are present virtually in unchanged form, both in the liquid and the solid metal The incorporation of the reinforcement particle will immediately increase the viscosity of the matrix melt For example, if 15 volume percent of reinforcement particles is added into the fully melted matrix mixture, this means that the melt will be occupied by 15 percent of solid particle, or in the other word, the slurry is partially solidified [145].

It is established that the formation of the microstructure in cast particle reinforced composites is mainly influenced by the following phenomena particle pushing or engulfed by the solidification front, particle settling or floatation in the melt, the solidification rate of the melt, and chemical reaction between particles and the matrix.

## 4.4 Particles Pushing or Engulfed

During solidification the reinforcement particle acts as a barrier to solute diffusion ahead of the liquid solid interface, and the growing solid phase will avoid the reinforcement in the same way that two growing dendrites avoid one another The individual particles may be pushed by the moving solid,liquid interface into the last freezing interdendritic regions, or the growing cell may capture them [146] The ceramic particles, which generally have lower thermal conductivity than that of the melt, are often surrounded by the last freezing fraction of the molten alloy during solidification of slurry. This phenomenon has been interpreted by several researchers such as Ulhmann et al [147], m terms of particle pushing by the solidification front, or interaction of particle with a planar solidification front They observed that for every size of particle, there is a critical velocity of solidification front, below which the particles are pushed by the front, and above which the particles areto be engulfed by the solidifying phase [148] There are several prediction model of particle pushing including the Ulhman, Chalmers and Jackson’s model [149] and Bolling and Cisse’s model [150] The first model is a kinetic approach to particle pushing, which assumes that a particle is pushed m front o f the solid,liquid interface Repulsion between the particles and the solid occurs when the sum of the particle,liquid and liquid,solid interfacial free energies is less than the particle,solid interfacial free energy.This model introduced critical velocities,above, which the particles should be entrapped, and below which the particles are rejected by the moving solid-liquid interface.

## 4.5 Post Solidification Processing

The secondary processing will modify the particle distribution According to Lloyd et al, [151] secondary fabrication processes, such as extrusion, can modify the particle distribution but complete declustering cannot be achieved even at the highest extrusion ratio Figure 1 11 shows the effect of extrusion ratio on the particle distribution [152] it shows that extrusion rapidly homogenize the distribution at quite low extrusion ratio, and the particle distribution does not change significantly with greater degree of extrusion However secondary processing may change the particle distribution by cracking,the particle [153] Use of an appropriate reinforcement particle size range, and correct fabrication practice minimises particle fracture.

## 4.6 Problems In Stir Casting

In preparing metal matrix composites by stir casting, there are several factors that need consideration including

I The difficulty of achieving a uniform distribution of reinforcement material
II The poor wettability between the two main substances
III The propensity for porosity in the cast metal matrix composite
IV Chemical reaction between reinforcement maternal and matrix alloy

In order to achieve the optimum properties of the metal matrix composite, the distribution of the reinforcement materials in the matrix alloy must be uniform, and the wettability of bonding between these two substances should be optimized The chemical reaction between reinforcement materials and the matrix alloy and porosity must be avoided or minimised The high AlSiC interface bonding strength is the main reason for the composite relatively high specific mechanical properties A sufficient bond is achieved only when good wetting of the reinforcement by the matrix is obtained, and this is dependent on the surface properties of the two phases [154] It is believed that a strong interface permits transfer and distribution of load from the matrix to the reinforcement, resulting in an increase in elastic modulus and strength [155] Fracture in discontinuously reinforced composites can result mainly from debonding of particles from the matrix [156]

## 4.7 Particle Distribution

Three primary phases, the melting phase, solidification, and post-solidification phase, have a considerable impact on the distribution of particle reinforcement particles alloy. The steps of melting and solidification are intertwined and must be monitored continuously. The post-solidification procedure may aid in the homogenization of particle dispersion in the finished product.

Particle distribution in the matrix material during the melt stage of the casting process mainly depends on the viscosity of the slurry, the extend to which particles are successfully incorporated in the melt, and the characteristics of the reinforcement particles The characteristics of the reinforcement particles influence settling rate, and the effectiveness of mixing in breaking up agglomerates, minimising gas entrapment and attaining distribution of the particles

Casting of particle reinforced metal matrix composites generally occurs in the semi solid state as it is advantageous compared with conventional casting where the alloy is completely melted This is because when the composite slurry is in the temperature range where the matrix itself is partly solid as in compocasting, little or no gravity induced segregation of the ceramic reinforcement occurs, even if the slurry is at rest [157] This occurs as the solid matrix phase has about the same density as the liquid metal, so it neither settles nor floats in the slurry, and holdthe reinforcement in place.

## 4.8 Particle Incorporation

In general there are two types of barrier to particle incorporation into a liquid melt These are mechanical barriers such as a surface oxide film, and thermodynamic barriers, which are usually referred to in terms of wettability Mechanical barriers can be reduced by good foundry practice, but overcoming thermodynamic barriers is more difficult Generally ceramic reinforcements used in MMCs are non-wettable by the metallic melt, requiring an external driving force to overcome the surface energy barriers This force is provided by stirring the melt with a mechanical stirrer or using electromagnetic stirring It has been shown that alloy chemistry, temperature of particle addition and stirring rate are some of the parameters controlling wettingof the reinforcement by the melt [158] Once the particles are transferred into the liquid and the energy barrier is overcome, the surface energy or surface forces will not change with position inside the melt The dynamics of particles in the melt will be governed by other forces including gravity, buoyancy or by stirring action However, twoproblems complicate the incorporation process (i) particle agglomerates must be broken up before complete dispersion and wetting can occur, and (11) it is energetically conducive for the particles to become attached to gas bubbles.

During particle addition, there is some local solidification o f the melt induced byparticles, and the entire matrix melt temperature can fall below the solidus, depending on the temperature of the particles It was also found that the perturbation in the solute field due to the presence of particles can change the dendrite tip radius, and the dendrite tip temperature [159]. As the density of particles increases, these actions cause a dendritic-to-cell transition. The length of the dendritic also decreases in the presence of particles.

The method of particle introduction to the matrix melt is a very important aspect of the casting process. There are a number of techniques [160] for introducing and mixing the particles However, some of these methods have several disadvantages Gas injection of particles for example will introduce a quantity of gas into the melt, some methods are not very effective dispersing the particles and some, such as the ultrasonic technique are very expensive, and are difficult to scale to production level Whereas, by using centrifugal action, the distribution o f the particles vanes from the inner to outer part of a billet because of the differences in centrifugal force [161].

## 4.9 Particle Characteristics

One major processing problem is that particles either sink or float, depending on the particle,liquid density ratio In foundry operations, segregation of the particles may occur between the time stirring has stopped, and the melt has solidified Clustering of the particles is a contributory problem, making the particles settle more quickly. Therefore the particles may be unevenly distributed macroscopically (denude region due to settling) and microscopically (clusters of particles) [162]. Particle enriched zones may form either as a consequence of gravity segregation of particles in melts during holding, or during slow solidification or as a consequence of selective segregation under the action of centrifugal acceleration in centrifugal casting [163] In foundry operations, where composite ingots are remelted for product casting, there may be problems of clustering if the melt is not intensively stirred At sufficiently long holding times, top partsof the casting are completely denuded of particle which settle to the lower parts the casting, as a function of time [164] Therefore the melt must be restirred prior to casting if long holding times m the molten state are used According to Geiger et al [165] the settling rate will also be a function of the particle density and size, with particle shape and size possibly playing a role [166] At high volume fractions, particles interact with each other and settling is hindered [167] Hindered settling for spherical particles has been modelled by Richardson and Zaki [168] with the particle velocity, Vc is given by Vc = V0(lf)n where, V0 is the Stokes's velocity,/ is the volume fraction of particles, and n is a factor dependent on the Reynolds number, the particle diameter and the container diameter, and which increases with increasing particle diameter The study on the settling indicate that the finer the dispersions and the higher their volume fraction, the slower the rate of settling Hanumanth et al [169] using an average particles size of 90|im found a slurry of 02 volume fraction of SiC particles settled completely in about 300 seconds resulting in loosely packed particles at the bottom of an aluminium alloy matrix At lower volume fraction of particles the settling time is less So, it is apparent that slurry with large size particles will have to be stirred all the time until casting In practice the situation is complicated by the fact that there is a range of particle shapes and sizes As large, irregular particles sink, the liquid they displace can influence the settling rate of other particle [170] settling is not a concern during initial mixing because of the turbulence in the mixer, but it is important in any subsequent molten metal transfer Thomas [171] studied the state of dispersion of particles in slurry under dynamic conditions of flow, and in this context it was found that the particle shape and size are the most important parameters. The flow behaviour of the slurries has been summarised as follows:

1. Particles below 10 nm size are almost always carried fully suspended in the liquid, and gravitational effects are negligible
2. Gravitational effect is not negligible for particles in the size range of 10 p.m to 100 im, and a particle concentration gradient will develop.
3. Particles ranging from 100 to 1000 |im in size, are fully suspended at high velocities and often deposit at the bottom of the channel at lower flow velocities

According to Ray [172], when the flow velocity is above a critical value for a given size of particle, the suspension will remain homogeneous during flow If the flow velocity is reduced below the critical value, the suspension becomes homogeneous If the flow velocity is further reduced, the particles will sediment at the bottom of the channel and move by tumbling over each other.

## 4.10 Mixing

It is essential to produce as uniform a distribution as possible without any gas entrapment, since any gas bubbles will attach to reinforcement particles leading to poor bonding with the matrix Excessive gases content can result from over agitated melts, which lead to unacceptable porosity content in the ingot Even in inert gas or vacuum operated processes, top melt surface agitation is known to cause problems.

Stirring is a complex phenomenon, and it can be a problem to control the process such that a uniform distribution of particles is achieved Mechanical stirring being usually used during melt preparation or holding, the stirring condition, melt temperature, and the type, amount and nature of the particles are some of the mam factors to consider when investigating this phenomenon [173, 174,175,176] Settling and segregation are both to be avoided.

In creating a homogeneous distribution of particles in a molten alloy, the high shear rate caused by stirring the slurry should result in a fairly uniform particle distribution in the radial direction, and also prevent particles from settling secondary flow in the axial direction results m transfer of momentum from high to low momentum regions and causes lifting of particles.

## 4.11 Solidification

There are essentially three mechanisms, which will affect particle redistribution during solidification processing These are agglomeration, sedimentation and particle engulfment or rejection (pushing) ahead of the solidification front The prevalence of one or more of these mechanisms is dependent upon elements of the processing technique as well as the physical and chemical properties of the particle and the matrix [177,178,179].

The distribution of particles in the resulting solid may or may not follow the distribution in the liquid The actual distribution of particles that one obtains in the solidified material will largely depend upon the morphology of the interface that is present under given experimental conditions When the particles are trapped by a plane front or cells, the distribution remains similar to that present in the liquid prior to solidification On the other hand, when a dendritic structure is present during solidification, then the solidification of particles in the solid can be significantly different from that in the liquid The trapping of particles between dendrites usually occurs just behind the tip, within the first ten secondary branches These secondary branches close to the dendrite tip have smaller branches The particles which are trapped between these branches, as close to the tip will remain between these branches as the dendrites grows The particles that have been trapped a few branches behind the tip may appear to be trapped at the base of the dendrite in metallic systems

Excessive particle redistribution during processing can result in vast particle-free zones in a casting, substantial particle agglomeration and clustering, and an mterdendntic reinforcing distribution. A homogeneous distribution of the reinforcement phase is desirable in order to generate uniform stress distributions during service, and it is suggested that this can be achieved by reducing holding and casting times, thus avoiding extensive settling, and by stimulating particle engulfment into the primary matrix gramme or dendrites during freezing.

During solidification of liquid containing dispersed second phase particles, the particles in the liquid melt can migrate towards, or away from the freezing front. It has been found that those small particles are entrapped between the secondary arms, while comparatively large particles are entrapped between primary dendritic arms [180,181] When the composite slurry is poured into a cold mould, the temperature of the melt drops rapidly at the mould boundary Thus dendrites appear on the mould boundaries first and push the particles in a direction opposite to heat transfer as the temperature in the mould decreases According to Xiao et al [182], in MMC castings there is a boundary layer over which (due to friction at the boundaries and the growing mechanism of dendrites), only few particles are entrapped This results in a lower volume fraction of particles near the boundaries.

It is now well established that depending on the interfacial energies, a growing crystal can either engulf or reject particles [183,184,185] Engulfment of the reinforcement means that not only the particles unlikely to be associated with brittle intermetallic phases and other particles in the mtordendritic and intergranular regions,but the fact that engulfment occurs suggests that reinforcement wetting has taken place, and that the interfacial bonding between the particles and the matrix must be good Two mechanisms have been suggested for particle pushing from fluid flow [186,187] In the firstmechanism, the particle is in contact with the solid and it is moved over the surface by the fluid flow as the solid grows Whereas in the second mechanism, the particle which is i located near the solidification front becomes trapped because of the roughness of the solidification front When the particle is rejected by the growing crystals and pushed ahead of the advancing interface, a viscous force is generated and this tends to prevent the pushing of the particle Hence, it is the balance of these counteracting forces which decides the rejection or engulfment of the particle It is parameters such as relative density difference, relative difference in thermal conductivity and heat diffusivity between the particle and the metallic melt, and alloy composition will affect the shape of the solidification front anddetermine the magnitude of these forces [188,189] particle pushing suggests that the solid metal has no affinity for the reinforcement and that the interfacial bonding is weak Strong interfacial bonding is essential for effective load transfer from the matrix to the particle and for delaying the onset of matrix decohesion, both of which have a profound effect on the strength and stiffness of the composite.

Solidification rate will influence the size of dendrite arm spacing At high cooling rates where the dendrite arm spacing is smaller than the particle size, particles become virtually immobile and no solidification induced segregation results.Therefore finer DASs either close to, or even greater than, the average particle size will produce a more uniform distribution of the particles in the matrix Increasing the dendrite arm spacing leads to particle clustering, and clustering increases with increases m particle content However according to Lloyd [190], the reinforcement does not normally nucleate A1 dendrites,and does not affect the cast grain size. Engulfment and nucléation both require that a low solid interfacial energy be present, just as particle incorporation requires a low particles-liquid interfacial energy.

This is usually achieved through the solid and particles sharing the same crystal structure and lattice parameter Ceramic material known to act as gram refiner such as $T1B_2$ and TiC, are likely to be engulfed within the metal gram rather than be pushed to the boundaries It is also established that a finer gram size will give better mechanical properties In this context Kennedy et al [191] incorporated particles of $TiB_2$, TiC and $B_4C$ into aluminium alloy melt This was done without the use of external mechanical agitation A wetting agent which produce KALF based slag in the melt surfacewas also added A variety of casting techniques have been used to cast molten alloys containing suspended ceramic particles The choice of casting technique and configuration mould are important A sand mould was used [192] to cast aluminiumcontaining particles $AI_2O_3$, SiC and glass, and some settling of coarse particles was observed This is because of the slow cooling rate allowed by the sand mould It was suggested that a metal chips could be introduced in the sand mould to enhanced the solidification and reduce the floating or settling tendency of the particles [193] Aluminium based composites have also been cast by Deonath et al [194], demonstrating good distribution of particles as a result of reasonably rapid freezing While in centrifugally cast aluminium,graphite [195], lighter graphite particles segregated to the inner periphery of the casting , and similar I results have been reported for porous alumina [196], and mica [197], dispersed in aluminium alloys. During centrifugal casting of an aluminium alloy containing zircon particles, however, the heavier zircon particles separate at the hollow casting's outer periphery.

# CHAPTER 5

## RESULTS AND DISCUSSION

### 5.1 Introduction:

The breakthrough in the development of reinforcement matrices, including composite manufacturing, may be attributed to a greater understanding of the lightweight materials that composite materials can produce, resulting in lower costs and improved performance. There has been an increase in demand for newer, heavier, stiffer, and lighter-weight materials in fields such as aerospace and manufacturing [198]. Composite materials are evolving primarily in response to unprecedented technical demands resulting from rapidly advancing activities in the aerospace, aviation, and automotive industries. These materials outperform many traditional engineering materials like metals in terms of strength and modulus due to their low specific gravity. [199]. It is now able to make new composites with improved mechanical and physical properties as a consequence of comprehensive research into the existence of substances and a deeper understanding of their structure-property relationship. Continuous progress has led to the use of composites in a wider range of applications, including high-performance composites such as PMCs, CMCs, and MMCs [200]. With traditional monolithic materials, the ability to achieve a good combination of strength, stiffness, durability, and density is limited. Composites [201] are the most promising materials of recent interest for overcoming these shortcomings and meeting modern technology's ever-increasing demand. Metal matrix composites (MMCs) have significantly improved properties over unreinforced alloys, such as high specific strength, specific modulus, damping power, and high wear resistance. AMCs have a wide range of applications in our daily lives [202]. The advantages of using particles strengthened AMCs materials over unreinforced materials include increased strength and specific modulus, improved stiffness, light weight, low thermal expansion coefficient, high thermal conductivity, optimised electrical properties, increased wear resistance, and improved damping capabilities [203]. Within the matrix, particles, short fibres, continuous fibres, and mono filaments can all be used as reinforcing constituents. Aerospace, temperature control, industrial materials, and automotive applications such as engine pistons and brake discs now use it [204]. Some of the key properties of composite materials are high stiffness and strength, low density, high temperature stability, high electrical and thermal conductivity, adjustable coefficient of thermal expansion, corrosion resistance, increased wear resistance, and so on [205]. The reinforcement holds the matrix in place and enhances the matrix's total material properties, enabling it to form the required shape. The latest combined material outperforms each of the individual materials when correctly crafted [206]. Composites are multifunctional material structures with properties that are unmatched by discrete materials. Coherent structures are created by mechanically merging multiple or more similar materials of different compositions, features, including shapes [207].When compared to their wrought alloy counterparts, metal matrix composites (MMCs) have received a lot of attention in recent years because of their superior strength and stiffness, as well as their high wear and creep resistance [208]. Another of the primary goals of matrix composites is to create a composite with a fine balance of hardness and strength which reduces crack and defect vulnerability while simultaneously enhancing static and dynamic properties[209]. Complex fabrication paths, minimal fabric capacities, and a tiny change in property enhancement among whiskers as well as fine particle enhancement are all things to keep in mind. Because of the health risks associated with handling SiC whiskers, the emphasis has recently shifted to particulate fibres rather than aluminium whisker reinforcement, which is lighter and more wettable with silicon carbide [210]. MMCs are a form of DRA composite made out of high strength aluminium alloys including silicon carbide particulate matter or whiskers. Aluminium metal matrix composites provide excellent targets for several building elements requiring high stiffness, high strength, and low weight owing to the combination of properties and fabricability. [211].SiC as a reinforcing in Aluminum Composites is generally designed toward replace some beryllium components in missile guidance systems since structural performance is high without any need for special fabrication management necessitated by that of the latter's toxicity. Weight-saving applications commonly use aluminum-based alloys [212]. Stir Casting [213] is a liquid state method of fabricating composite materials in which a dispersed phase (ceramic particles, short fibres) is mechanically mixed with a molten matrix metal. Traditional casting methods are used to cast the liquid composite material, and it can also be processed using traditional metal forming techniques. The primary aim of this paper is to use stir casting to prepare an Al-SiC composite material for mechanical and metallurgical testing.

## 5.2 Materials and method:

### 5.2.1 Material Selection:

To make AlMMC, commercially pure Aluminum was used as the matrix and 5% Silicon Carbide was used as reinforcement. Figure 10 displays a pure SiC powder with a scale of 50 microns.

**Fig.10. Silicon Carbide powder**

### 5.2.3 Experimental Method:

To extract moisture, the SiC elements were preheated at 200°C for 2 hours. By raising the temperature of commercially pure Al to 770°C, it was melted. A mild steel stirrer was then used to stir the melt. When a vortex formed in the melt as a result of stirring, SiC particles were added to it. For the duration of the accumulation of the particles, the melting temperature was held at 700-720°C. The molten metal was then poured into a clay graphite crucible. The schematic view of a stir casting setup with a stirrer is shown in Figure 11.

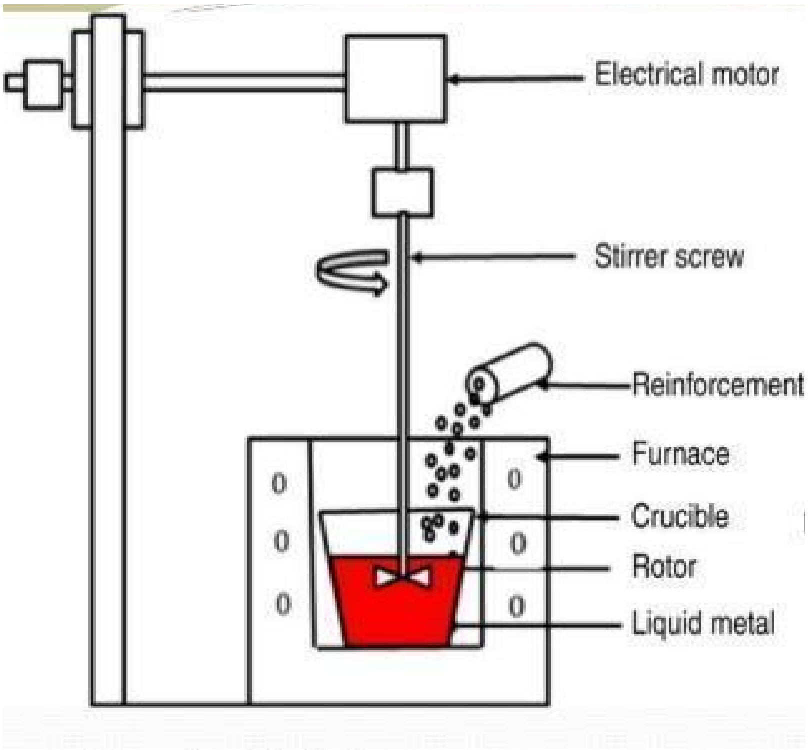

**Fig.11. Stir Casting**

## 5.3 RESULT AND DISCUSSION

### 5.3.1 BRINELL HARDNESS TEST:

The addition of silicon carbide particles to an aluminium matrix increases the stiffness of the material. Dispersion strengthening and particle reinforcement may also contribute to the composite's power. As a result, using Silicon carbide as a filler in Aluminum casting reduces density while increasing hardness, which are both important in industries like automotive. Table 4 and Figure 12 show the hardness value of pure Al and 5 wt% SiC with Al matrix.

**Table.4.Hardness value of pure Al with 0wt% SiCand Al wit 5wt% SiC:**

| S.NO | 0 wt% SiC | 5 wt% SiC |
|---|---|---|
| 1 | 26.5 | 38.9 |
| 2 | 27.0 | 39.2 |
| 3 | 26.8 | 39.6 |
| Average | **26.8** | **39.2** |

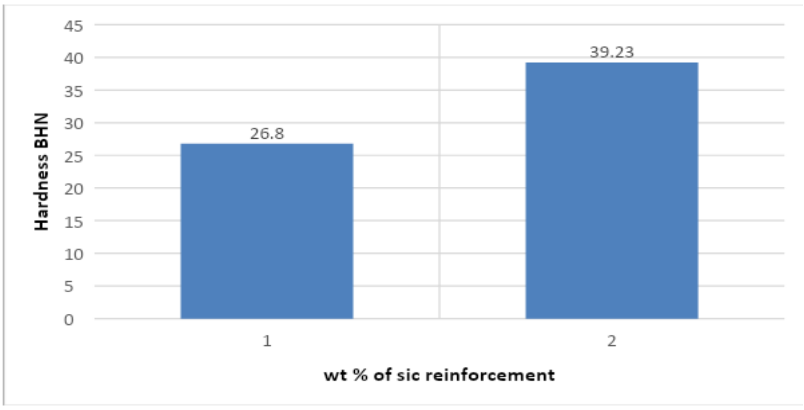

**Fig.12. Hardness value of Al with 0wt% and 5wt% SiC Composite**

### 5.3.2 MICROSCOPIC ANALYSIS:

The properties of particulate composites are heavily influenced by the morphology, density, form, and distribution of reinforcing particles. Solidification and particle distribution are the variables that influence particle distribution.

The particle distribution was studied by looking at the microstructures of the samples cut from the plate casting at various locations. Figures 13.a and 13.b display optical micrographs of MMC's. In the case of Aluminum /Aluminum, particles were found to be uniformly distributed (5 percent SiC), The particles were isolated at specific positions on the plates. Few particles were found on the casting's outer surface. This is due to particle segregation that is governed by gravity. In the presence of SiC mixture at different concentrations, however, micrographs of Al revealed uniform particle distributions.

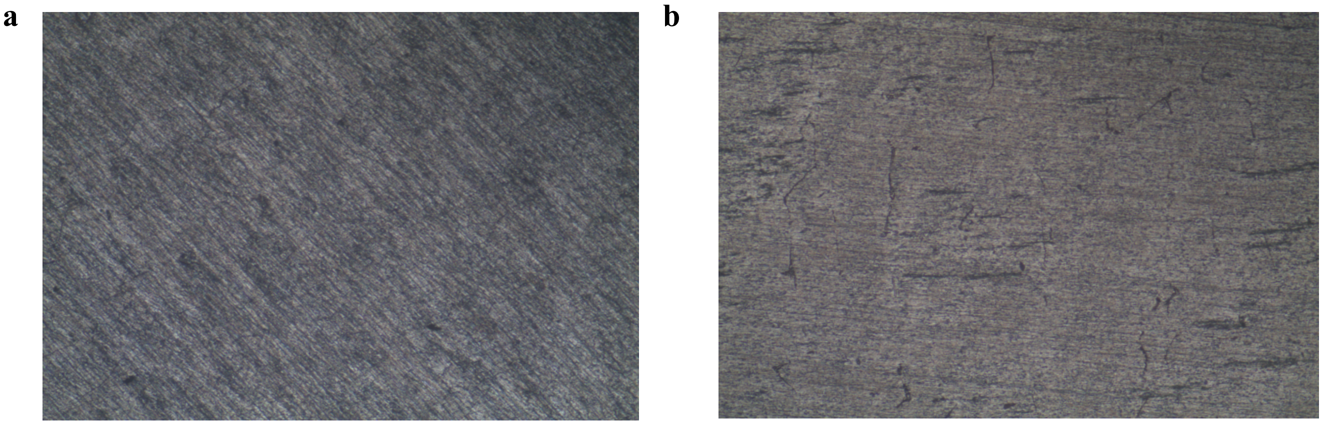

**Fig.13. (a) Microstructures of Pure Al; (b) Microstructures of Al with 5wt% SiC.**

### 5.3.3 SEM ANALYSIS

The casted Al with SiC was analysed by SEM with a moderate size of 10 microns, as shown in fig. In the Al matrix, the SEM picture indicates a uniform distribution of reinforcement particles. It also reveals that during the stirring process, grain boundaries and dendritic structures of Al were created. The SEM Micrograph of Al-5 percent wt SiC is shown in Figure 14.

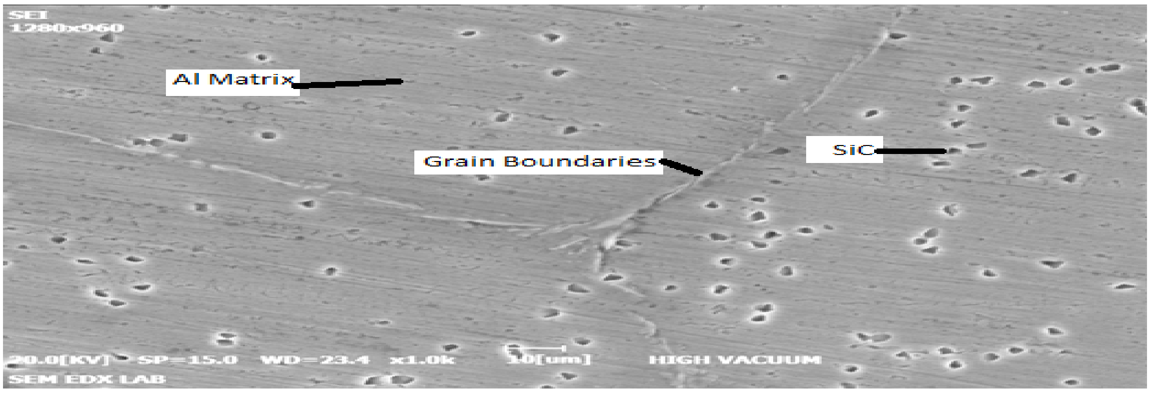

**Fig. 14. SEM Image For 95:5 Al and SiC**

## 5.4 Conclusion:

According to the findings of the analysis, Silicon carbide can be used to make composites. By stir casting, silicon carbide up to 5% by weight can be successfully applied to Al to create composites. With the addition of Silicon carbide, the stiffness and toughness of Al composites have improved. The dispersion of particle reinforcement improves the composite. SEM test revealed the uniform distribution of silicon carbide particles in Al matrix. Also found few grain boundaries through SEM test.

## List of Publications:

1. Lavepreet Singh , Sandeep Kumar, Shivam Raj, Shivam and Piyush Badhani. "*Development and characterization of aluminium silicon carbide composite materials with improved properties*." Materials Today: Proceedings (2021).

2. Lavepreet Singh, Sandeep Kumar, Shivam Raj, Shivam and Piyush Badhani. "*Aluminium Metal Matrix Composites: Manufacturing and Applications* " 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* 1149 012025.

3. Accepted and presented at ICAPIE-2021 (6th International Conference on Advanced Production and Industrial Engineering (ICAPIE) - 2021):

   Authors : Sandeep Kumar, Lavepreet Singh, Shrikant Vidya, Shiavm Raj, Shivam and Piyush Badhani
   Title : *REVIEW ON ALUMINIUM METAL MATRIX COMPOSITES AS AN ALTERNATIVES TO CONVENTIONAL MATERIALS*
   Number : 275

## REFERENCES

1. A.K.Dhingra, “metal replacement by composite”, JOM 1986, Vol 38 (03), p. 17.
2 .K.Upadhya, “composite materials for aerospace applications, developments in ceramic and metal matrix composites”, Kamaleshwar Upadhya, ed.., warrendale, PA: TMS publications, 1992, pp. 3-24.
3. Greg Fisher, “Composite: Engineering the ultimate material”, Am. Ceram. Soc, Bull. Vol. 63 (2), pp. 360-364.
4.T.G.Nieh, K.R. Forbes, T.C. Chou and J. Wadsworth, “Microstructure and deformation properties of an Al2O3-Ni3Al composite from room temp to 14000 C”, High performance Composites for the 1990’s Eds. S. K. Das, C. P. Ballard and F. Marikar, TMS-New Jersey, 1990, pp 85-96.
5. T. W. Clyne, An Introductory Overview of MMC System, Types and Developments, in Comprehensive Composite Materials, Vol-3; Metal Matrix Composites, T. W. Clyne (ed), Elsevier, 2000, pp.1-26.
6. L.M.Manocha & A.R. Bunsell “Advances in composite materials”, Pergamon Press, Oxford, 1980, Vol.2, p 1233-1240.
7. Jartiz, A.E., Design 1965, pp. 18
8.Kelly, A. (1967) Sci. American 217, (B), 161.
9. Berghezan, A. Nucleus, 8(5), 1966, (Nucleus A. Editeur, 1, rhe, Chalgrin, Paris, 16(e)
10. Van suchetclan, Philips Res. Repts. Vol. 27. 1972, pp. 28.
11. B.D.Agarwal and L.J.Broutman, “Analysis and performance of fiber composites” John Wiley & Sons, New York, 1980, pp.3-12.
12. J.O.Outwater, The Mechanics of Plastics Reinforcement Tension, Mod. Plast: March 1956.
13. R.Wetter, Kunststoffe in der Luft-und Raumfahrt, Kunststoffe, 60, Heft 10 (1970).
14. P.H.Selden, ‘ Glasfaserverstarkte Kunststoffe’, SpringerVerlag, 1967.
15. Pradeep Rohatgi, IUNIDO’s State-of-the-art series: “Advances in Materials Technology: MONITOR”, Compiled by the Industrial Technology Development Division Department of Industrial Promotion, Vienna, Austria, No.17, Feb. 1990.
16. N.J. Parrat, “Reinforcement effects of Silicon Nitride in Silver and Resin Matrices”, Powder Metallurgy, Vol. 7(14), 1964, pp 152-167.
17. R. R. Irving, “Composites Go After Commercial Markets”, Iron Age, Sept.5th, 1986, pp 35-38.
18. A. Mortensen, J.A. Cornie and M. C. Flemings, “Solidification processing of Metal Matrix Composites”, JOM, Vol. 40(2), 1988, pp 12-19.
19. D.L. McDanels and C.A. Hoffman, “Microstructure and orientation effects on properties of discontinuous Silicon Carbide/ Aluminum Composites” NASA Tech. Pap. 2303, Cleveland, OH, 1984, pp 1-29.
20. J.L. Cook and Walter R. Mohan, “Whisker-reinforced MMCs’ Metal, Carbon / Graphite and Ceramic Matrix Composites”, 1987, pp 896-902.
21. Milton W. Toaz, “Discontinuous Ceramic Fiber MMCs” International Encyclopedia of Composites, Vol. 3. ed. Stuart M. Lee, VCH Publishers, NY, p. 903-910.
22. D. L. McDanels and A. R. Signorelli, “Evaluation of low cost Aluminum Composites for Aircraft engine Structural Applications”, NASA Tech. Memo. No. 83357, Washington, DC, 1983.
23. William J. Baxter, “The strength of MMCs Reinforced with Randomly oriented Discontinuous Fibers”, Mett. Tran. Vol. 23A, Nov. 1992, pp 3045-3053.
24. David M. Schuster, Michael D. Skibo and Williams R. Hoover, “Production and Semi-Fabrication of an Aluminum Composite Material”, Light Metal Age, Feb. 1989, pp 15-19.

25.H. J. Rack, “P/M Aluminium MMCs’ Dispersion Strengthened Al Alloys”, eds. Y.M. Kim and W. M.Griffith, TMS, Warrandale, PA, The Metallurgical Soc., 1988, pp 15-19.
26. Alan L, Geiger and J.Andrew walker, “The processing and properties of discontinuously reinforced Aluminium Composite”, JOM, August 1991, pp 8-15.
27. R.L. Trumper, Met. Mater, Vol. 3, 1987, p p. 662.
28. R. A. Higgins, “Properties of Engg. Materials”, Holder & Stoughton , 1986.
29. Margaret Hunt, “Aerospace Composites”, Mater. Engg., Cleveland, Vol. 108(6), 1991, pp 27-30.
30. J. Lock; Prof. Engg. , April 1990, Vol. (21).
31. K. U. Kainer. Prasad. “Composite material Technology”, Vol. 37, 1991, pp.191.
32. W. Wei, “High Temp. MMCs for Aero Engines; Challenges and potential”, Metals and Materials Journal, Aug 1992, pp 430-435.
33. Richards Demeis, “New life for Aluminium”, Aerospace America, March1989, pp. 26-29.
34. M. Taya & R.J.Arsenault, “Metal Matrix Composite thermo mechanical behavior”, Pergamon press, 1989.
35. J. Doychak, “Metal and Intermetallic Matrix Composites for Aerospace Propulsion and Power Systems”, JOM, Vol. 44(6), 1992, pp. 46-51.
36. D.J. Lioyd, “Particle Reinforced Al and Mg Matrix Composites”, Int. Mat. Rev., Vol. 39(1), 1994, pp. 1-23.
37. A.Wang & H.J.Rack, “Transition wear behaviour of SiC-particulate and SiCwhisker reinforced 7091 Al metal matrix composites”, Journal of Material Science and Engineering A, Vol. 147, 1991, pp 211-224.
38. T.Alpas, J.Zhang, “Effect of microstructure (particulate size and volume fraction) and counter face material on the sliding wear resistance of particulate-reinforced aluminum matrix composites”, Metall. Mater.Trans. A, Vol. 25, 1994, pp 969-983.
39. Rohatgi. P.K., Guo. R.Q., Huang. P., Ray .S., “Friction and Abrasion Resistance of Cast Aluminum Alloy- Flyash Composites”, Metal. Mater. Trans. A, Vol. 28A, 1997, pp. 245-250.
41. A.P. Sannino, H.J.Rack, “Dry sliding wear of discontinuously reinforced aluminum composite: review and discussion”, Wear, Vol.189, 1995, pp 1-19.
42. M.K.Surappa, S.V.Prasad, P.K.Rohatgi, “Wear and abrasion of cast Al-alumina particle composites”, Wear Vol. 77, 1982, pp 295-302.
43. A.Wang, H.J.Rack,“Dry sliding wear in 2124 Al-SiCw/17-4 PH stainless steel systems”, Wear Vol. 147, 1991, pp 355-374.
44. Mechmet Acilar, Ferhat Gul “Effect of applied load, sliding distance and oxidation on the dry sliding wear behaviour of Al-10 Si/Cp composites produced by vacuum infilatration techniques. Journal of Materials & Design Vol.25, (2004) pp 209-217.
45. Liu Yao-hui, Du Jun et.al. “High temperature friction and Wear behaviour of Al2O3 and /or Carbon short fibre reinforced Al-12 Si alloy Composites” Wear 256, 2004, pp 275-285.
46. M.Bai, Q.Xue, X.Wang, Y.Wan, W.Liu, “Wear mechanism of SiC whiskerreinforced 2024aluminum alloy matrix composites in oscillating sliding wear tests”, Wear Vol. 185 ,1995, pp 197-202.
47. A.Alahelisten, F.Bergman, M.Olsson, S.Hogmark, “on the wear of aluminum and magnesium metal matrix composites”, Wear Vol.165, 1993, pp221-226.
48. J.Q.Jiang, R.S.Tan, A.B.Ma, “Dry sliding wear behaviour of Al2O3-Al composite produced by centrifugal force infiltration”, Material Science and Technology, Vol. 12, 1996, pp 483-488.
39. P.N.Bindhumadhan, H.K.Wah, O.Prabhakar, “Dual particle size (DPS) composites: effect on wear and mechanical properties of particulate matrix composites” Wear, Vol. 248, 2001, pp 112-120.
40. S.C. Tjong, S.Q. Wu, and H. Liao:“Wear behavior of an Al–12% Si alloy reinforced with a low volume fraction of SiC particles.” Journal of composite science and technology, Vol–57, Issue–12, Dec 1997, pp 1551-1558.
41. S.C.Tjong, H.Z.Wang and S.Q.Wu “Wear Behavior of Aluminum based Metal Matrix Composites Reinforced with a Perform of Aluminosilicate Fiber” Metallurgical and Materials Transactions A, Vol 27A, (1996) 2385-2389.
42. M.Singh, D.P.Mondal et.al. “Development of light weight aluminum alloy hard particle composite using natural minerals for wear resistance application. National conventions on Emerging materials on wear applications. paper no TS- 4/5, 2003, Bhopal.

43. Dry sliding Wear behaviour of Cast SiC reinforced Al MMCs.Tiejuna Ma, Hideki Yamaura et.al. Material Science Engineering, A, 360 (2003) pp 116-125.
44. R. Mehrabian, R.G. Riek and M. C. Flemings, “preparation and casting of MetalParticulate Non-Metal Composites,” Metall. Trans, Vol. 5A, 1974, pp 1899-1905.
45. J. Eliasson and R. Sandstorm, “Applications of Aluminium Matrix Composites,” Part 1, G. M. Newaz, H. Neber-Aeschbacherand F. H. Wohlbier eds., Trans. Tech. publications, Switzerland, 1995, pp 3-36.
46. John E. Allison, Gerald S. Cole, “Metal Matrix Composites on the automotive Industry: Opportunities and Challenges”, JOM, Vol. 45(1), 1993, pp 19-24.
47. D. J. Lloyd, “Particulate Reinforced Composites Produced by Molten mixing,” High Performance Composites for the 1990’s, eds. S.K.Das, C.P. Ballard and F.Marikar, TMS-New Jersey, 1990, pp 33-46.
48. M.G. McKimpson and T.E.Scott, “Processing and Properties of MMCs Containing Discontinuous Reinforcement”, Mat. Sci. and Engg., Vol. 107A, 1989, pp 93-106. 173
49. H.J. Rack, “Metal Matrix Composites”, Adv. Mater. Processes, Vol. 137 (1), 1990, pp 37-39.
50. A. W. Urquhart, “Molten Metals Sire MMCs, CMCs”, Adv. Mater. Processes, Vol. 140(7), 1991, pp 25-29.
51. V. V. Bhanuprasad, K. S. Prasad, A.K. Kuruvilla, A. B. Pandey, B. V. R. Bhat and Y. R. Mahajan, “Composite Strengthening in 6061 and Al-4Mg Alloys”, . at. Sci. Vol. 26, 1991, pp 460-466.
52. M. S. Zedias, P. S. Gilman and S.K.Das, “High Temperature Discontinuously Reinforced Aluminium”, JOM, Vol. 43(8), 1991, pp 29-31.
53. M. S. Zedias, P. S. Gilman and S.K.Das, “ High Temperature Aluminium-Base Composites”, High performance Composites for the 1990’s eds. S. K. Das, C.P.Ballard and F. Marikar, Tms-Newjersey, 1990, pp 61-82.
54. C.P. You, A.W. Thompson and I. M. Bernstein, “Proposed Failure Mechanism in a Discontinuously Reinforced Aluminium Alloy”, Scr. Metall., Vol. 21, 1987, pp 181-185.
55. T. W. Clyne and J. F. Mason, “ the squeeze Infiltration process for Fabrication of MMCs”, Metall. Trans., Vol. 18A, 1987, pp 1519-1530.
56. M. Gupta, I.A. Ibrahim, F. A. Mohamed, E. J. lavernia, “Wetting and Interfacial Reactions in Al-Li-SiCp MMCs Processed by spray Atomozation and Deposition”, J. Mat. Sci. Vol. 26, 1991, pp 6673-6684. 174
57. D.Z. Yang, S. L. Dong, J. F. Mao and Y. X. Cui, “Fabrication Microstructure and Properties of A SiCw/ Al-Li-Cu-Mg-Zr Composite”, Key Engineering Materials, Vol.s 104-107, Metal Matrix Composites, Part 1, G. M. Newaz, H. NeberAeschbacher and F. H. Wohlber eds., Trans. Tech. Publications, Switzerland, 1995, pp 627-632.
58. D.J. Lloyd, “The Solidification Microstructure of Particulate Reinforced Al/SiC Composites”, Comp. Sci. Tech., Vol. 35, 1989, pp 159-179.
59. D Charles, “Addressing the Challenges of Aircraft Components design and Manufacturing from MMCs”, J. Aerospace Engg (Proc. I. Mech E) pp 1-13, 1992.
60. Michael E. Buck, “Addressing fibers from Advanced Composites”, Advanced Materials and Processes, pp 61-68, Sept 1987.
61. Alan, L.Geigr and Michael Jackson, “Low-Expansion MMCs Boost Avionics”, Advanced Materials and Processes”, pp 23-32, July 1989.
62. J. R. Roos, J. P. Celis, J. Franser and C.Buelens, “the Development of Composite Plating for Advanced Materials”, JOM, Vol. 42(11), 1990, pp 60-63.
63. Herbert Dietrich, “Carbon/Carbon, Protected / Protedted”, Mater. Engg. Vol. 108(8), 1991, pp 34-35.
64. T.S. Chester, “Non-metallic Materials for Gas Turbine Engines: Are They Real?”. Adv. Mater. Processes, Vol. 139(6), 1991, pp 32-39.
65. M.V. Roode, J. R. Price and C. Stala, “Ceramic Oxide Coatings for the Corrosion Protection of SiC”, J. Engg. Gas Turbines Power Trans. ASME, Vol. 115(1), 1993, pp 139-149. 175
66. D. Huda, M.A. El Baradie & M.J.S. Hashmi, “Metal Matrix Composites: Materials aspects. Part II” journal of material processing technology, Vol.37 (1993),528-541.
67. Alok Satapathy & S.C.Mishra “Plasma Spray Coating of Red Mud on Metal” Proceeding of DAE-BRNS, International Symposium on Applications of Power Beams in Advanced Material

Processing, BARC, Mumbai, 2002, pp.709-712.
68. E. Hunt, P.D. Pitcher and P. J. Gregson, “Advanced Al and Mg Alloys”, T. Khan and G. Effenberg eds., ASM.
69. D. H. Kim, E.J. Lavernia and J. C. Earthman, “ Fatigue Crack growth behaviour of a continuous alumina fiber reinforced Magnesium alloy”, High performance Composites for the 1990’s eds. S.K. Das, C. P. Ballard and F. Marikar, TMS-New Jersey, 1990, pp 117-126.
70. P.J. Meachter and J.E. Oneil, “Communication: Rapid Solidification Processing of Magnesium-Lithium Alloys”, Metall. Trans., Vol. 15A, 1984, pp 237-240.
71. J.E. Hack, R. E. Page and G.R. Leverant, “Tensile and Fatigue Behaviour of Aluminium Oxide Fiber Reinforced Magnesium Composites: part I. Fiber Fraction and Orientation” , Metall. Trans., Vol. 15A, 1984, pp 1389-1396.
72. N.Eustathopoulos, D.Chatain and L.Coudurier, “Wetting and Interfacial Chemistry in Liquid Metal Ceramic Systems”, Mat.Sci and Engg. Vol.135A, 1991, pp 83-88.
73. R.J.Arsenault, ‘The Strengthening of Al Alloy 6061 by Fiber and Platelet Silicon Carbide,’ Mat. Sci. Engg., Vol. 64, 1984, pp171-181.
74. I.Adeqoyin, F.A.Mohamed and E.J.Lavernia, ‘Particulate Reinforced MMCs-A Review, J. Mat Sci., Vol.26, 1991, pp1137-1156. 176
75. Von F. Lowshenko, F. Kunter and G.Jangg, “Eigenschaften Von Dispersion geharteten $Al$-$Al_4C_3$ Werkstoffen”, Planseeberichtefur Pulvemattallurgie, Bd. Vol.25, 1997, pp. 205-213.
76. R. Tiwari, H. Herman, K. Kowalsky and D.R. Marantz, “Mechanical behaviour of thermal sprayed Metal-Matrix Composites”, High Performance Composites for the 1990’s, eds. S.K.Das, C.P. Ballard and F. Marikar, TMS-New Jersey, 1990, p 195.
77. A.H. Nakagawa and M.N.Gungor, “Microstructure and Tensile properties of $Al_2O_3$ Particle Reinforced 6061 Al Cast Composites”, eds. P.K.Liaw and M.N.Gungor, “Fundamental Relationship Between Microstructure and Mechanical Properties of MMCs”, The Minerals, Metals & Materials Society, 1990, pp 127-143.
78. A. K. Kuruvilla, V.V. Bhanuprasad, K. S. Prasad and Y.R. Mahajan, “Effect of different reinforcements on Composite-strengthening in aluminium”, Bull. Mater. Sci., Vol. 12(5), 1989, pp 495-505.
79. R.L. Mehan, “Fabrication and Evaluation of Sapphire Reinforced Al Composites”, Metal Matrix Composites, ASTM-STP, Vol. 438, 1968, pp 29-58.
80. J. Zhang, R.J. Perez, M. N. Gungor and E.J.Lavernia, “Damping Characteristics of Graphite Particulate Reinforced Aluminium Composites”, Developments in Ceramics and Metal Matrix Composites. Kamleshwar Upadhya, ed., Warrendale, PA: TMS Publication, 1992, pp 203-217.
81. Thomas D. Nixon and James D.Cawley,“Oxidation Inhibition Mechanisms in coated Carbon-Carbon Composites”, J. Am. Ceram. Soc., Vol. 75(3), 1992, pp 703-708.
82. M.V Ravichandran. R.Krishna Prasad and E.S.Dwarakadasa, J. Mater. Sci. Letts; Vol-11, 1992, p.452. 177
83. P.K.Balasubramanian, P.Srinivasa Rao, et.al. J.Mater.Sci.Letts., Vol-8, 1989, p.799.
84. J.Singh, S.K.Goel, V.N.S.Mathur and M.L.Kapoor; J.Mater. Sci., Vol-26. 1991.
85. Deonath and P.K.Rohatgi, ‘Fluidity of Mica Particle Dispersed Aluminum Alloy: J. Mat. Sci., Vol. 15, 1980. pp 2777-2784. 115 Deonath, R.T.Bhat and P.K.Rohatgi, “Preparation of Cast ALLOY-Mica Particle Composites”: J. Mater. Sci., Vol. 15, 1980, pp.1241-1251.
86. M.K.Surappa and P.K.Rohatgi, ‘Preparation and Properties of Cast Aluminum Ceramic Particle Composites, ‘J.Mat. Sci., Vol.16, 1981, pp.983-993.
87. A.Banerji, M.K.Surappa and P.K.Rohargi, Cast Aluminum Alloys Containing Dispersions of Zircon Particle, ‘Metall. Trans. Vol. 14B, 1983, PP.273-283.
88. M.S.Zedalis, J.D.Bryant, P.S.Gilman and S.K.Das, ‘High-Temperature Discontinuously Reinforced Aluminium. JOM, Vol.43 (8), 1991. pp. 29-31.
89. M.Taya and R.J.Arsenault “Metal Matrix Composites–Thermo mechanical behaviour” (1989) New York, Pergmon Press, p -238-243.
90. K.K.Chawla, Composite materials–Science and Engineering, (1987) New York Springer Verlag, pp. 67-72.
91. D.Huda, M.A.Elbardie& M.S.J.Hashmi, Jour. Mat. Proc. Tech., Vol.37, 1993, pp.529- 530.
92. J.R.Vinson & T.W.Chou, “Composite Materials and their use in Structure”, Applied Science

publisher, 1975, p 44. 178
93. N. Axen, A.Alahelisten and S.Jacobson"Abrasive wear of alumina fibre reinforced aluminum." Journal of wear Vol.173, Issue 1-2, 1994, pp.95–104.
94. Zongyi.Ma, Jing, Yuxiong. Lu, Hongwei.Shu, and Inurn. Gao. "Abrasive wear of discontinuous SiC Reinforced aluminum alloy composites". Journal of wear Vol. 148, Issue-2, Aug 1991.pp. 287 – 293.
95. K.M. Shorowordi, A.S.M.A. Haseeb, J.P.Ceils,"Velocity Effect on Wear, Friction and Tribochemistry of Aluminum MMC sliding against Phenolic Brake Pad ". Journal of wear, 2003.
96. Yoshiro.Iwai, Hidetomo.Yonede, and Tomomi.Honda "Sliding wear behaviour of SiC whisker reinforced aluminum composite". Journal of wear, Vol. 181-183, Issue –2, Mar 1995, pp 594-602.
97. Liang.Y.N, Ma.Z.Y, Li.S, Bi.J "Effect of particle size on wear behaviour of SiC particulate reinforced aluminum alloy composite" Journal of Material science, Vol- 14, Jan 1995, pg 114-116.
98. L.Cao, Y.Wang, C.K.Yao: "The wear properties of an SiC whisker reinforced aluminum composite". Journal of wear, Vol. 140, Issue-2, Nov 1990, pp. 273-277.
99. A. Ravikiran, M.K.Surappa "Effect of sliding speed on wear behaviour of A 356 Al –30 wt% SiCp MMC", wear, Vol 206 ,1997 pp. 33-38.
100. F.A.Girot, J.M.Quenisset & R.Naslain, Composite Science Technology, Vol.30, 1987, p. 155. 131 F.A. Badia and P.K. Rohatgi, AFS Trans. Vol 77, 1969, p. 402.
101. D. Huda, M.A.El Baradie, & M.J.S.Hashmi, "Metal Matrix Composites: Manufacturing aspects. Part I", journal of material processing technology, Vol. 37, 1993, pp. 513-528.
102. M. A. EL Baradie, "Manufacturing aspects of metal matrix composites", Journal of Materials Processing Technology, Vol. 24, 1990, pp 261-272.
103. S.D. Ridder, S.Kou and R.Mehrabian, "Effect of Fluid Flow on Macrosegation in Axi-Symmetric Ingots," Metall. Trans., Vol. 12B, Sept.1981, pp 435-447.
104. R.H. Bricknell, "The Structure and Properties of A Nickel-Base Super alloy Produced by Osprey Atomization-Deposition", Metall. Trans., Vol. 17A, 1986, pp 583-591.
105. S. Kohara, Mater. Manufact. Process., Vol. 5, 1990, p. 51.
106. A.R. Champion, W.H. Krueger, H.S. Hartman and A.K. Dhingra, Proc. Int. Conf. on Composite Materials, AIME, Warrendale, PA 1978, p. 883.
107. Bonollo F , Guemero R , Sentimanti E , Tangenni I and Yang V L , Effect of Quenching on the Mechanical Properties of Powder Metallurgy Produced Al-SiC Particles, Metal Matrix Composites, Material Science and Engineering, A 144, 1991, pp 303-310
108. Skibo M , M oms P L and Lloyd D J , Structure and Properties o f Liquid Metal Processed SiC Reinforced Aluminium, World Materials Congress, Chicago, 1988, pp 257-262
109.Surappa M K and Rohatgi P K , Preparation and Properties o f Cast Aluminium Ceramic Particle Composites, Journal of Materials Science , 16, 1981, p 983
110.Maruyama B and Rabenberg L , Interfaces In Metal Matrix Composites, Proceedings Conforence, Eds Dhingra A K and Fishm an, S G New Orleans, TMS-AMIE, 1986, pp 233-238
111.Quigley B F , Abbaschian G J , Wunderlin R and Mehrabian R , Metallurgical Transaction A, 13A, 1982, p 93
112.Khrishnan B P , Surappa M K and Rohatgi P K , Journal of Material Science, 16, 1981, pp 1209-1216
113.Fleming M C and Mehrabian R , Transaction American Foundrymen's Soc ,81, 1973, p 81
114.Fleming M C Rich R G and Young K P , AFS International Cast Metal, 1, 1976, p 11
115.Ghosh P K Rays S , and Rohatgi P K , Transaction of Japan Institute of Metal, 25, 1984, p 440
116.Miwa K , Fabrication o f SiCp Reinforced Aluminium Matrix Composites by Compocasting Process, Journal o f Japan Foundryman's Society, 62, 1990, pp 423-428
117.Lee H C and Kim M S , A Fabrication Method of Aluminium-Short Fibre Alumina Matrix Composites by Compocasting, Proceedings of the KSME-JSME Joint Conference, 1990, pp 471-475
118.Salvo L Esperance G L , Suery M, and Legoux J G , Interfacial Reaction and Age Hardening in Al-Mg-Si Metal Matrix Composites Reinforced with SiC Particles, ibid, A177, 1994, pp 173-183
119.Yilmaz M and Altintas S , Properties of Al-Mg-SiC Composites Produced by a Modified Compocasting Technique, Proceedings o f the 2nd Bienniel European Joint Conference On Engineering Systems, London, ASME New York, 1994, pp 119-124
120.Labib A , Liu H and Samuel F H , Effect of Solidification Rate (0 l-100C/s) On the

Microstructure, Mechanical Properties and Fractography of Two Al-Si-10 Volume % SiC particles Composite Castings, Materials Science and Engineering, A 160, 1993, pp 81-90
121.Zhong W M , Esperance G L and Suery M , Interfacial Reaction in Al-Mg/SiCp Composites During Fabrication and Remelting, Metallurgical and Materials Transactions A, 26A, 1995, pp 2637-2649
122.Milliere C and Suery M , Fabrication and Properties of Metal Matrix Composite Based On SiC Fibre Reinforced Aluminium Alloys, Materials Science and Technology, 4, 1988, p 41
123.Ghosh P K and Ray S , Fabrication and Properties o f Compocast AlumimumAlumina Particulate Composites, Indian Journal of Technology, 26, 1988, pp 83- 94
124.Miwa K , Takashi I And Ohashi T , Fabrication of SiC Whiskers Reinforced Aluminium Matrix Composites by Compocasting Process, Proceedings of the 2nd 224 International Conference On The Semi Solid Alloys and Composites, Eds Brown S B and Fleming M C , MIT, Massachussets, 1993, p 398-405
125.W angW and Ajerch F , Particle Interaction of Melt-Stirred Al-Si/SiCp Composites, Proceedings of International Symposium in Production & Fabrication o f Light Metal & Metal Matrix Composites, Edmonton Alberta, 1992, pp 629-641
126.Gupta M and Surappa M K , Processing-Microstructure-Mechanical Properties of Aluminium-Based Metal Matrix Composites Synthesis Using Casting Route, Key Engineering Materials, 104-107, 1995, pp 259-274
127.Ghosh P K and Ray S , Effect of Porosity and Alumina Content On the High Temperature Mechanical Properties o f the Compocast Aluminium Alloy-Alumina Particulate Composite, Journal o f Materials Science, 22, 1987, pp 4077-4086
128.McCoy J W , Jones C and Wawner F E , Preparation and Properties of Cast Ceramic/Aluminium Composites, SAMPE Quarterly, Jan 1988, pp 37-50
129.Y am adaK , Sekiguchi S and Matsumiya T , The Optimum Condition of Compocasting Method For Particulate Metal Matrix Composites, 34th International SAMPE Symposium, 1989, pp 2266-2277
130.Young R M K and Clyne Y M , Journal of Materials Science, 21, 1986, pp 1057- 1069
131.Yarrandi F M , Rohatgi P K and Rays S , Two Phase Flow Behaviour and Microstructure in Aluminium Alloy-SiC Particulate Composite, Proceedings of 2nd International Conference On Processing of Semi Solid Alloy & Composites, 1993, pp 447 - 465 225
132.Narciso J , Alonso A , Pamies A , Cordovilla C G and Louis E , Wettability of Binary and Ternary Alloys of the System Al-Si-Mg with SiC Particulate, Scnpta Metallurgical, 31, 1994, pp 1495-1500
133.Wang W and Ajersch A , Silicon Phase Nucleation On SiC Particulate Reinforcement In Hypereutectic Al-Si Alloy Matrix, Materials Science and Engineering, A 187 1994, pp 65-75
134.SurappaM K and Rohatgi P K , Metenals Technology, 5, 1978, pp 358-361
135.Ray S , M Tech Dissertation, ITT Kanpur, India, 1969
136.Gibson P R , Clegg A J and Das A A , Foundry Trade Journal, 152,1982, pp 253-256
137.Ray S , Casting o f Composite Components, Proceeding o f the 1995 Conference On Inorganic Matrix Composites, Banglore, India, 1996, TMS, pp 69-89
138.Hanumanth G S , Iron G A and Lafremer S , Metal Transaction, 23B, 1992, p 753
139.Richardson I F , Casting o f Silicon Carbide Reinforced Aluminium Alloys, Foundryman, 82, 1989, pp 538-542 [91] Ribes S K and SueryM , Effect o f Particle Oxidation On Age Hardening o f AlSi-Mg/SiC Composite, Scnpta Metallurgy, 23, 1989, pp 705-709
140.M onta M , Metal Matrix Composites, Advances Composite Matenals, 4, 1995, pp 237-246
141.Lloyd D J , The Solidification Microstructure o f Particulate Reinforced Alumimum/SiC Composites, Composites Science and Technology, 35, 1989, pp 159-179 226
142.Mortensen A , Comie J A and Fleming M C , Columnar Solidification In a Metal Matrix Composites, Metallurgical Transaction A, 19A, March 1988, pp709- 721
143.Uhlmann D R , Chalmers B and Jackson K A , Journal o f Applied Physic, 35, 1964, p 2986
144.Chernov A and Mehmkova A M , Soviet Physics - Crystallography, 10, 1966
145.Bolling G F and Cisse J , J Crystall Growth, 10,1971
146.Samuel A M , Gotmare A and Samuel F H , The Effect of Solidification Rate and Metal Feedability On Porosity and S1C/AI2O3 Particle Distribution In an Al-SiMg (A356) Alloy, Composite Science and Technology, 53, 1995, pp 301-315

147.Rohatgi P K , Asthana R and Das S , Solidification, Structure and Properties of Cast Metal-Matnx Composites, International Metal Review, 31,1986, p 115- 139
148.Geiger G H and Doiner D R , Transport Phenomena in Metallurgy, Addison Wesley Publication, C o , 1973
149. SekkarJA and Tnvedi R , Materials Science and Engineering, A147, 1991, p 9
150.Hunt W H , Interfaces m Metal Matrix Composites, Eds D hingraA K and Fishman S G , TMS-AIME, 1986, pp 3-25
151.Kang C G , Ray S and Rohatgi P K , Micromechanical Solidification Heat Transfer In One Dimensional AI-AI2O3 Composites and Its Consequences O Microstructure Evolution, Materials Science & Engineering A Structural 227 Materials Properties, Microstructure and Processing, 188, Nov 30 1994, pp 193- 199
152.Fukunaga H , Komatsu S and Kanoh Y , Bulletin of Japan Society Mechanical Engineering, 26, Oct 1983, p 1814
153.Abe Y , Nakatam M , Yamatsuta K , and Homkiri S , Developments In the Science and Technology of Composite Materials, Proceedings of the 1st European Conference On Composite M aterials, ECCM-1, Bordeaux, France, Eds B unsellA R Lam icqP and Massiah A , September, 1985, pp 604-609
154.Jeng S C and Chen S W , The Solidification Characteristic o f A6061 and A3 56 Aluminium Alloys and Their Ceramic Particles Reinforced Composites, Acta M aterials, 45, 1997, pp 4887-4899
155.Backerud L , Chai G and Tammiren J , American Foundrymen’s S o c, Skan Aluminium De Plaines, EL, 2, 1990
156.Kaufmann H , Neuwirth E , Larsher J and Pacyna H , Aluminium Alloys, Eds Arnberg A , Lahne O and Ryum N , NTH and SINTEF Trondhiem, Norway, 1992, p 81
157.Ray S , Cast Metal Matrix Composites - Challenges In Processing and Design, Bulletin Materials Science , 18, 1995, pp 693-709
158.Moon H K , Ito Y , Corme and Flemings M C , Key Engineering Materials, 15, 1993, pp 79-80
159.Carotenuto G , Gallo A andNocolais L , Degradation of SiC Particles In Alummium-Based Composites, Journal Materials Science, 29, 1994, pp 4967- 4974 228
160Mummery P and Derby B , Influence of Microstructure On the Fracture Behaviour of Particulate Metal matrix Composites, Materials Science & Engineering A Structural Materials Properties, Microstructure and Processing Papers on Metal Matrix Composites, A135, 1991, pp 221-224
161.M illiereC and Suery M , Advanced Materials Research and Developments For Transport, Edn Lamicq, Pans, 1985, pp 241-24
162.Mada M and Ajersh F , Tnxotropic Effect in Semi-Solid Al-6%Si Alloy, Metal and Ceramic Matrix Composite, Ed B hagatR B , TMS Publication ,18, 1990, pp 337-350
163.Hoover W R , Recent Advances In Castable Metal Matrix Composite, in Proceedings of International Conference " Fabrication of Particulates Reinforced Metal Matrix Composites", Montreal, Canada, 1990, pp 115-123
164.Hoover W R , Die Casting of Duralcan Composites, Proceedings of the 12th Riso International Symposium on Materials Science Metal Matrix Composites - Processing, Microstructure and Properties, Riso Natl Lab Roskilde Denmark, 1991, p 387
165.Girot F A , Albingre L , Qeumsset J M and Naslain R , Rheocasting AluminiumM atnx Composites, Journal of Metal, 39, 1987, pp 18-21 [118] Fleming M C , Behaviour of Metal Alloys In the Semi-Solid State, Metallurgical Transaction, 22A, 1991, pp 957-981
166.Moon H K , Materials Science & Engineering, 144A, 1991, pp 253-265 229
167.Asthana R , and Tewan S N , Interfacial and Capillary Phenomena In Solidification Processing o f Metal Matrix, Composites Manufacturing, 4, March, 1993, p 3-25
168.Sekkar J A , Material Science & Engineering, 147, 1991, pp 9-21
169.K rishnanB P SurappaM K and Rokatgi P K , Journal of Materials Science, 16, 1981, pp 1209-1216
170.Lajoye L and Suery M , Solidification Processing, Proceedings Conference Sheffield, September, 1987, pp 473-476
171.K rishnanB P and Rohatgi P K , Metal Technology, February, 1984, p 41
172.Yarrandi F , Ph D Thesis, University o f Wisconsin-Milwaukee, 1991
173.Geiger J F and Zaki W N , Chemical Engineering Science, 3, 1954, p 65

174. Laffremere S and Iron G A , Sedimentation During Liquid Processing of Metal Matrix Composites, Proceedings of International Symposium ' Production, Refining, Fabrication and Recycling o f Light Metals’, Eds Boushard M and Tremblay P , Pergamon Press, 1990, pp 177-186
175.Richardson F J and Zaki W N , Transaction International Chemical Engineering, 32, 1954, pp 35-53
176.Hanumanth G S and Iron G A ,Particle Incorporation By Melt Stirring For the Production of Metal Matrix Composites, Journal of Materials Science, 28, 1993, pp 2459-2465
177.Mirza S and Richardson J F , Chemical Engineering Science, 34, 1979, pp 447- 454
178.Thomas D G , AICHE J , 1, 1962, p 373 230
179.Ray S Casting of Metal Matrix Composites, Key Engineering Materials, 104- 107, 1995, pp 417-446
180.Lloyd D J , Particle Reinforced Aluminium and Magnesium Matrix Composites, Journal of International Materials Review, 39, 1994, pp 1-5
181.Mortensen A and Jin I , Solidification Processing o f Metal matrix Composites, International Materials Review, 37, 1992, pp 101-128
182.El-kaddah N E and Chang K E , The Dispersion o f SiC-Al Slurries m Rotating Flows, Materials Science & Engineering A Structural Materials Properties, Microstructure and Processing, A144, Oct 1 1991, p 221-227
183.Stefanesfu D M and Dhindaw B K , Kakkar S A and Moitra Q , Behavior of Ceramic Particles at the Solid-Liquid Metal Interface In Metal Matrix Composite, Casting Handbook (ASM), 15, 9th Edition, 1988, pp 142-147 [137] Xiao K and Lyons J S , On the Distribution of Particulate In Cast MMCs, Journal of Reinforced Plastic and Composites, 15,1996, pp 1131-1148
184.Stefanesfu D M , Moitra A , Kacar A S and Dhindaw B K , The Influence of Buoyancy Force and Volume Fraction o f Particles On the Particles Pushing/Entrapment Transition During Directional Solidification o f Al/SiC and Al/Graphite Composites, Metallurgical Transaction A, 121 A, 1990, p 231-239
185.Rohatgi P K , Yarrandi F M and Liu Y , Influence of Solidification Conditions On Segregation o f Aluminium-Silicon Carbide Particle Composites, ASM International Conference On Cast Reinforced Metal Matrix Composites Eds, Fishman S G , and Dhingra A K , 1988, p 249 231
186.Asthana R and Tewari S N , Engulfment o f Foreign Particles By a Freezing Interface, Journal of Materials Science, v28, 1993, p 5414-5425
187.Han N , Pollard G , stevens R , Interfacial Structure and Fracture of Aluminium Alloy A356-SiC Particles Metal Matrix Composite, Materials Science and Technology, 8,1992, pp 184-187
188.Han Q , and Hunt J D , Redistribution o f Particles During Solidification, ISIJ In t, 35, 1995, pp 693-699
189.Han Q D , M Phil Thesis, Department of Materials , University of Oxford, 1994
190.Jin I And Lloyd D J , Solidification o f SiC Particulate Reinforced Al-Si Alloy Composites, Fabrication of Particulate Reinforced Metal Composites, Eds Massounave J , and Hamel F G , ASM In t, 1990, pp 47-52
191.Kennedy A R McCartney D G and Wood J V , Homogeneous Metal Matrix Composites Produced By a Modified Stir Casting Technique, Synthesis/Processing of Lightweight Metallic Materials, Eds Frose F H , SuryanarayananaC and Ward C M , TMS, 1995, pp 261-174
192.Patton A M , Journal Institute o f Metal, 100, 1972, p 197
193.Biswas P K , PhD Thesis, Indian Institute of Science, Bangalore, 1981
194.Deonath R T and Rohatgi P K , Journal of Materials Science, 15, 1980, p 1241
195.Krishnan B P et a l, Transactions AFS , 84,1976, P 73
196.Surappa M K , PhD Thesis, Indian Institute o f Science, Bangalore, 1979
197.Deonath R T and Rohatgi P K , Journal of Composites, 12, 1981, p 124
198.Rohatgi, Pradeep K. "Metal matrix composites." *Defence science journal* 43.4 (1993): 323.
199.Ramsden, Jeremy. *Applied nanotechnology: the conversion of research results to products*. William Andrew, 2018.
200.Bledzki, A. K., and Jochen Gassan. "Composites reinforced with cellulose based fibres." *Progress in polymer science* 24.2 (1999): 221-274.
201.KUMAR, K. ANIL, et al. "Wear Behavior of AA7075-TiB2 Nano Composites." (2017).
202.Reddy, P. Venkateshwar, et al. "Mechanical and wear performances of aluminium-based metal

matrix composites: a review." *Journal of Bio-and Tribo-Corrosion* 6 (2020): 1-16.

203.Rahman, Md Habibur, and HM Mamun Al Rashed. "Characterization of silicon carbide reinforced aluminum matrix composites." *Procedia Engineering* 90 (2014): 103-109.

204.Eliasson, J., and R. Sandström. "Applications of aluminium matrix composites." *Key engineering materials*. Vol. 104. Trans Tech Publications Ltd, 1995.

205.Nakamura, Yoshinobu, et al. "Mechanical Properties of Metallic Perovskite Mn3Cu0. 5Ge0. 5N: High-Stiffness Isotropic Negative Thermal Expansion Material." *Journal of the American Ceramic Society* 92.12 (2009): 2999-3003.

206.Mallick, Pankar K. *Fiber-reinforced composites: materials, manufacturing, and design*. CRC press, 2007.

207.Banga, Honey, V. K. Singh, and Sushil Kumar Choudhary. "Fabrication and study of mechanical properties of bamboo fibre reinforced bio-composites." *Innovative System Desing and Enginnering* 6.1 (2015): 84-98.

208.Chigal, Gaurav, and Gaurav Saini. "Mechanical testing of Al6061/silicon carbide metal matrix composite." *IJREAS* 2.2 (2012): 221-238.

209.Chigal, Gaurav, and Gaurav Saini. "Mechanical testing of Al6061/silicon carbide metal matrix composite." *IJREAS* 2.2 (2012): 221-238.

210.Lu, Hui, et al. "Design, fabrication, and properties of high damping metal matrix composites—a review." *Materials* 2.3 (2009): 958-977.

211.Asare, Ted. *Fabrication and damping behavior of particulate BaTiO3 ceramic reinforced copper matrix composites*. Diss. Virginia Tech, 2004.

212.Chandel, Vikrant, Onkar Singh Bhatia, and M. S. Sethi. "Fabrication and characterization of Al 7075-cenosphere composite & its comparison with pure Al 7075: a review." *Int J Res Stud Sci, Eng Technol. ISSN* (2015): 2349-4751.

213.Kandpal, Bhaskar Chandra, Jatinder Kumar, and Hari Singh. "Manufacturing and technological challenges in stir casting of metal matrix composites–a review." *Materials Today: Proceedings* 5.1 (2018): 5-10.

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To cite this article: Lavepreet Singh *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1149** 012025

ICFTMM 2020 IOP Publishing
IOP Conf. Series: Materials Science and Engineering 1149 (2021) 012025 doi:10.1088/1757-899X/1149/1/012025

# Aluminium Metal Matrix Composites: Manufacturing and Applications

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**Abstract:** Aluminium metal matrix composites(AMCs) is widely used in the industrial applications right now. Aluminum metal matrix composites have properties that no other monolithic material can match. Due to their superior strength to conventional materials, aluminium matrix composites (AMCs) have a broad variety of industrial applications. The nature of reinforcing, that can take the form of constant or undefined fibres, has a big influence on the properties of aluminum metal matrix composites. Thus it depends on the fabrication methods for aluminium matrix composites, which are influenced by a number of factors including the type of reinforcement and matrix used, its required degree with surface morphology integrity, as well as physical, mechanical, electro-chemical, and thermal properties. This article provides an overview of the manufacturing processes and different reinforcing elements used during the synthesis of Al-MMCs. Generally, the reinforced particles like carbides, nitrides, and compounds of oxides are used. This paper gives a brief overview on various methods that are beung used to manufacture aluminium metal matrix composites. The present study offers a description of the synthesis, mechanical behaviour, and utilisation of aluminium metal matrix composites. The main processing methods for making or production of aluminium metal matrix composites(AMCs) are thoroughly discussed. Finally, questions of commercialization as well as business issues are also discussed.

**Keywords:** AMC; Matrix; Commercialization; Industrial Aspects; Mechanical Behavior

## 1. Introduction:

Aluminium metal matrix composites have a wide variety of applications in the automotive sector. Aluminium matrix composites are a high-demand commodity in the aerospace, vehicle, and other engineering applications. A composite is a matter made up of components formed with the help of physically combining already present monolithic materials for generating a single material with diffrent properties from the proposed prototype. Every composite, in general, has two phases: (a)metal matrix ;(b) reinforcements In particular, the matrix is consistent and accompanies the discrete reinforcement process of the composite material. The composites have been distributed into four categories: 1) matrix (ceramic, metal, and carbon), 2) reinforcements (oxide, carbide, and nitride), 3) structure (continuous fibre, short fibre, whisker, and particulate matter), and 4) processing directions, and 5) orientation [1-2]. The form of matrix and reinforcement, its mechanical and thermal properties, and the degree for micro - structural integrity needed are all factors influencing the processing technique selected. The type of reinforcement, the variance for reinforcement materials, as well as the relationship of both the matrix with the reinforcement are all important factors in deciding the composite's properties of the resulting [3].

Nonmetallic ceramics like Silicon carbide, Carbon, alumunium-di-oxide, Silicon-di-oxide, Boron, are commonly used[4]. Magnesium reinforced composites have received much interest because of their better mechanical and corrosion properties. The majority of Magnese-Aluminium alloys contains

Materials Today: Proceedings xxx (xxxx) xxx

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# Development and characterization of aluminium silicon carbide composite materials with improved properties

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ARTICLE INFO

*Article history:*
Received 25 March 2021
Received in revised form 11 April 2021
Accepted 16 April 2021
Available online xxxx

*Keywords:*
Reinforcement
Silicon Carbide
Aluminium
Micro structural
Stir casting

ABSTRACT

In the recent years Metal Matrix Composites (MMCs) have proved great application potential in the field of aerospace and automotive industries due to their superior strength to weight quantitative relation and resistance to high temperature. Due to high manufacturing cost of the particulate metal matrix composites component and several technical challenges associated with casting technology, its widespread application for engineering purpose is restricted. The main aim of the present study is to cast and evaluate properties of the composite by increasing the stirring time and limiting the weight percentage of reinforcement. In this study, Aluminium (Al) is used as the pure matrix material and Silicon carbide (SiC) is used as the reinforcement material for the stabilization of the matrix. Stir casting is used to make aluminium matrix composites (AMC) by varying SiC content (0 to 5% wt. %) with the help of four blade motor stirrers rotating at a speed of 550 rpm for 20 min. A detailed study of mechanical and micro structural properties of Al-SiC composites is performed using Scanning Electron Microscopy for the characterization of the composite properties. The results indicated that the mechanical properties of the composite have been improved considerably with the addition of SiC in Al matrix. It was also observed that SiC was uniformly distributed over Al matrix due to continuous stirring in the mould and presence of few clustering was revealed in Micro structural observation.

Selection and peer-review under responsibility of the 3rd International Conference on Futuristic Trends in Materials and Manufacturing.

## 1. Introduction

The breakthrough in the development of reinforcement, matrices, including composite manufacturing attributed to a greater understanding of the lightweight materials that composite materials can produce, resulting in lower total cost of final product with improvised performance. There has been an increase in demand for novel light-weight materials with high stiffness in fields such as aerospace and manufacturing [1]. Composite materials are evolving primarily in response to unprecedented technical demands resulting from rapidly advancing activities in the aerospace, aviation, and automotive industries. These materials outperform many traditional engineering materials like metals in terms of strength and modulus due to their low specific gravity. [2]. It is now able to make new composites with improved mechanical and physical properties as a consequence of comprehensive research into the existence of substances and a deeper understanding of their structure–property relationship. Continuous progress has led to the use of composites in a wider range of applications, including high-performance composites such as PMCs, CMCs, and MMCs [3]. With traditional monolithic materials, the ability to achieve a good combination of strength, stiffness, durability, and density is limited. Composites [4] are the most promising materials of recent interest for overcoming these shortcomings and meeting modern technology's ever-increasing demand. Metal matrix composites (MMCs) have significantly improved properties over unreinforced alloys, such as high specific strength, specific modulus, damping power, and high wear resistance. AMCs have a wide range of applications in our daily lives [5]. The advantages of using particles strengthened AMCs materials over unreinforced materials include increased strength and specific modulus, improved stiffness, light weight, low thermal expansion coefficient, high thermal conductivity, optimized electrical properties, increased wear resistance, and improved damping capabilities [6]. Within the matrix, particles, short fibres, continuous fibers, and mono filaments can all be used as reinforcing constituents. Aerospace, temperature con-

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https://doi.org/10.1016/j.matpr.2021.04.220
2214-7853/
Selection and peer-review under responsibility of the 3rd International Conference on Futuristic Trends in Materials and Manufacturing.

Please cite this article as: L. Singh, S. Kumar, S. Raj et al., Development and characterization of aluminium silicon carbide composite materials with improved properties, Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.04.220