Chapter I
CHAPTER-1
INTRODUCTION

1.1 Introduction
Conventional materials have the limitations in achieving good combination of strength, stiffness, toughness and density etc. To overcome these limitations and to meet the ever increasing demand of modern day technology, composites are most promising materials of recent days. Metal matrix composites (MMCs) possess high strength, hardness, toughness, and good thermal resistance properties as compared to unreinforced alloys.

Now a day the particulate reinforced aluminum matrix composite are gaining importance because of their low cost with advantages like isotropic properties and the possibility of secondary processing and facilitating fabrication of components. Particle reinforced composites have higher specific strength, specific modulus and good thermal resistance as compared to unreinforced alloys. The particulate composite can be prepared by injecting the reinforcing particles into liquid matrix through liquid metallurgy route by casting. Casting route is preferred as it is less expensive and amenable to mass production. Among the entire liquid state production routes, stir casting is the simplest and cheapest one. Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface.

1.2 Composite materials
A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale. Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than each individual material. Many of common materials (metals, alloys, doped ceramics and polymers mixed with additives) also have a small amount of dispersed phases in their structures, however they are not considered as composite materials since their properties are similar to those of their base constituents. Favorable properties of composites materials are high stiffness and
high strength, low density, high temperature stability, adjustable coefficient of thermal expansion, corrosion resistance, improved wear resistance etc.

1.3 Classification of composites

The composites are classified in two ways. One is on the basis of matrix used and the second is on the basis of the shape and size of the reinforcement. The detailed classification of composites is given in the Fig1.1.

Fig1.1: Classification of composites
1.3.1 Metal matrix composites

The matrix phase for a metal matrix composite (MMC) is a metal and which is ductile. MMCs are manufactured with the aims, to have high strength to weight ratio, high resistance to abrasion and corrosion, resistance to creep, good dimensional stability, and high temperature resistance. The main advantages that MMCs possess over ceramic matrix composites (CMCs) are the usability at high temperatures, high strength to weight ratio, and resistance to corrosion by organic fluids. MMCs are used in industries like automobile, marine, nuclear power plants, and aerospace’s.

Metal Matrix Composites (MMCs), like all composites consist of at least two chemically and physically different phases. Generally, there are two phases, i.e. a fibrous or particulate phase in a metallic matrix. Common types of MMC are

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

Aluminum is the most popular matrix to the metal matrix composites (MMCs). The Al alloys are quite attractive due to their low density, their capability to be strengthened by precipitation, their good corrosion resistance, high thermal and electrical conductivity, and their high damping capacity. Aluminum matrix composites (AMCs) have been widely studied since 1920s and are now used in sporting goods, electronic packaging, and automotive industries. They offer a large variety of mechanical properties depending on the chemical composition of the Al-matrix. They are usually reinforced by Al₄C₃, Al₂O₃, SiC, boron, and carbon.

1.3.2 Ceramic matrix composites

Ceramic Matrix Composites (CMC) is designed to improve toughness of conventional ceramics, the main disadvantage of which is brittleness. Ceramic Matrix Composites are reinforced by either continuous (long) fibers or discontinuous (short) fibers. Short-fiber (discontinuous) composites are produced by conventional ceramic processes from an oxide (alumina) or non-oxide (silicon carbide) ceramic matrix reinforced by whiskers of silicon carbide (SiC), titanium boride (TiB₂), aluminum...
nitride (AlN), zirconium oxide (ZrO₂) and other ceramic fibers. Most of CMCs are reinforced by silicon carbide fibers due to their high strength and stiffness. Long-fiber composites are reinforced either by long monofilament of long multifilament fibers. The best strengthening effect is provided by dispersed phase in form of continuous monofilament fibers, which are fabricated by chemical vapor deposition (CVD) of silicon carbide on a substrate made of tungsten (W) or carbon (C) fibers. Monofilament fibers produce stronger interfacial bonding with the matrix material improving its toughness.

1.3.3 Polymer Matrix Composites

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

1.3.4 Particle reinforced composite

Particle reinforced composites are again divided into large particle composites and dispersion strengthened composites. In large particle composites the size of particles is larger than that of dispersion strengthened composites. If the bonding is good then the matrix movement can be restrained. Concrete and Reinforced Concrete are examples of large particle composites as shown in Fig.1.2.

In dispersion strengthened composites the particle size varies from 10-100 nm. The small particles are dispersed throughout the matrix and prevent plastic deformation by blocking the motion of dislocations.

Particulate-reinforced MMC show the advantage of nearly isotropic properties and cost-effectiveness. Furthermore, an additional advantage of the particulate-reinforced over fiber reinforced MMC is that most existing processing techniques can be used for fabrication and finishing of the composites, including hot rolling, hot forging, and hot extrusion.
1.3.5 Fiber reinforced composites

Fibers are responsible for high strength and stiffness ratio to weight of the composite. These reinforced composites can be further subdivided into continuous and discontinuous fibers. Continuous fibers are those which have lengths normally greater than 15 times the critical length (l > 15 l_c) and discontinuous fibers have lengths shorter than this. The discontinuous fibers can be aligned or randomly oriented as shown in Fig.1.3. It is obvious that for better strength of the composite and better load transfer the fibers should be continuous. Examples of some fibers are carbon fibers, boron fibers, E-glass fibers, SiC fibers, and Al₄C₃ fibers etc.

![Fiber Orientations in Fiber Reinforced Composites](image)

Fig.1.3: Fiber reinforced composite

1.3.6 Laminate Composites

Laminate composite is composed of two-dimensional sheets or panels with different fiber orientations, which is arranged several layers and the layers are stacked and subsequently cemented together such that the orientation of the high strength direction varies with each successive layer. Or when a fiber reinforced composite consists of several layers with different fiber orientations, it is called laminate composite. It is also known as multilayer composite. These are generally designed to
provide high strength and low cost at a lighter weight. A familiar laminate composite is plywood as shown in Fig.1.4.

![Laminated composite](image1.png)

**Fig.1.4: Laminated composite**

### 1.3.7 Sandwich composites

In a sandwich panel, a thicker core separates two thin sheets. The sheets or faces are bonded adhesively to the core. The core is generally low density material, or comb core, such as a polymer foam or expanded metal structure and provides support to the outer faces. It should be able to prevent buckling of the sandwich panel. The sheets present in outward direction should be made from a strong and stiff material like steel, titanium, Al alloys, etc to sustain various stresses due to loading. The popular core consists of a ‘honeycomb’ structure, which finds wide use in industries such as the aircraft industry, where higher strength and lower weight are important factors, and the sandwich composites as shown in Fig.1.5.

![Sandwich composite with honeycomb structure](image2.png)

**Fig.1.5: Sandwich composite with honeycomb structure**

### 1.4 Characteristics of composites

Characteristics of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite material to a great
extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sectioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Composites as engineering materials normally refer to the material with the following characteristics:

- Artificial Materials.
- Consist of at least two different elements with a well defined interface.
- Properties are influenced by the volume percentage of elements.
- Having at least one property not possessed by the individual constituents.

Generally, a composite material is composed of reinforcement and matrix. The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

1.5 Constituents of composite materials

A composite material is a material consisting of two or more physically and chemically distinct parts, suitably arranged, having different properties respect to those of the each constituent parts. In practice, most composites consist of a bulk material (the ‘matrix’), and a reinforcement of some kind, added to increase the strength and stiffness of the matrix.

1.5.1 Matrix

The matrix phase is a primary phase, and it is usually more ductile and less hard phase. It holds the dispersed phase and shares a load with it. Function of matrix is to take the load and transfer it to the reinforcement and it binds or holds the reinforcement and protects the same from mechanical or chemical damage that might occur by abrasion of their surface. Matrix also separates the individual fibers and prevents brittle cracks from completely across the section of the composite.
1.5.2 Reinforcing element

Reinforcing element or secondary phase is embedded in the matrix in a continuous or discontinuous form. This secondary phase is called dispersed phase. Dispersed phase is usually stronger than the matrix, therefore it is sometimes called reinforcing phase. The reinforcement can be either continuous, or discontinuous. Discontinuous MMCs can be isotropic, and can be worked with standard metalworking techniques, such as extrusion, forging or rolling. In addition, they may be machined using conventional techniques, but commonly would need the use of poly crystalline diamond tooling (PCD). Continuous reinforcement uses monofilament wires or fibers such as carbon fiber or silicon carbide. Because the fibers were embedded into the matrix in a certain direction, the result is an anisotropic structure in which the alignment of the material affects its strength.

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. Reinforcements are characterized by their chemical composition, shape, dimensions, and properties as in gradient material.

1.6 Stir casting process for production of AMMC

Stir Casting is a liquid state method of fabrication of composite materials, in which a dispersed phase (ceramic particles, short fibers) is mixed with a molten matrix metal by means of mechanical stirring as shown in Fig.1.6. H. K. Shivanand et. al., [29] compared by studying various methods of producing Metal Matrix Composites and concluded that the stir casting method is the best and low cost method for producing the Metal matrix composite materials. In this process particles are often tend to form agglomerates, which can be only dissolved by intense stirring. However, here gas access into the melt must be absolutely avoided, since this could lead to unwanted porosities or reactions. Careful attention must be paid to the dispersion of the reinforcement components, so that the reactivity of the components used is coordinated with the temperature of the melt and the duration of stirring, since reactions with the melt can lead to the dissolution of the reinforcement components.
Because of the lower surface to volume ratio of spherical particles, reactivity is usually less critical with stirred particle reinforcement than with fibers.

1.7 Applications of AMMCs

Applications of metal matrix composites can be conveniently grouped by market area, since each area requires set of properties and cost that result in particular subsets of metal matrix composite materials being of primary interest. The primary markets for MMCs are divided into aerospace, automotive, commercial and industrial products, and electronics packaging which represents the area of greater interest [93].

1. Aerospace applications are the original driving force for Aluminium metal matrix composite development. This is due to the quest for weight reduction for improved performance and payload capabilities combined with high value placed on weight savings. Examples for aerospace application are aircraft structure, aero engine, space structure and other space applications.

2. In the automotive market, properties of interest to the automotive engineer include increased stiffness, wear resistance, and improved cycle fatigue resistance. Weight saving is also important in automotive applications for achieving performance improvements with much lower cost. Examples for automotive applications are engines, brake system, driveshaft and other automotive applications
3. In commercial and industrial sector, improved performance is highly valued. As a result many of materials that gain favour in aerospace industry market are also applied in this sector also. Examples for commercial and industrial sector are recreational, computer hard disk drives and

Advantage with respect to unreinforced metals:

- Major weight savings due to strength-to weight ratio.
- Exceptional dimensional stability.
- Higher elevated temperature stability, i.e., creep resistance.
- Significantly improved cyclic fatigue characteristics.

With respect to polymer matrix composite, MMCs offers the following advantages:

- Higher strength and stiffness
- Higher service temperatures.
- Higher electrical conductivity (grounding, space charging).
- Higher thermal conductivity.
- Better transverse properties.
- Improved joining characteristics.
- Radiation survivability

1.8 Machining process of AMMCs

The machining process of AMMCs is required where they offer the benefits of part integration. Machining of metals is very common and is easily performed however, the machining of metal matrix composites facing several challenges as high surface roughness, shorter tool life because of the abrasive nature of the composite. Generally machining on AMMCs is carried out by both the conventional and non-conventional method of machining.

1.8.1 Non-conventional method

Non-conventional machining methods are gaining applications in wider engineering areas due to their ability to produce complex shapes on difficult-to-cut especially hard materials without contact of tool and work piece and the difficult-to-cut materials are machined smoothly by the non-conventional machining processes such as electrical discharge machining (EDM), electro-chemical machining (ECM), laser beam machining (LBM) and abrasive water jet machining (AWJM).
1.8.2 Drilling of AMMC

Amongst traditional machining processes, drilling is one of the most important metal-cutting operations, comprising approximately 33% of all metal-cutting operations. Drilling processes are widely used in the aerospace, aircraft and automotive industries. Although Non-conventional machining methods are gaining applications in wider engineering areas due to their ability to produce complex shapes on difficult-to-cut especially hard materials without contact of tool and work piece and the difficult-to-cut materials are machined smoothly by the non-conventional machining processes, conventional drilling method still remains one of the most common machining processes.

The conventional types and methods of application of cutting fluid have been found to become less effective when the cutting fluid cannot properly enter into the chip-tool interface to cool and lubricate the interface due to bulk plastic contact of the chip with the tool rake surface. It requires serious concern on the use of cutting fluid, particularly oil-based type cause pollution of the working environment, water pollution, soil contamination and possible damage of the machine tool slide ways by corrosion. The modern industries are therefore looking for possible means of dry or near dry, clean, neat and pollution free machining. Minimum Quantity Lubrication (MQL) refers to the use of cutting fluids of only a minute amount—typically of a flow rate of 50-500 ml/hour—which is about three to four orders of magnitude lower than the amount commonly used in flood cooling, for example, up to 10 liters of fluid can be dispensed per minute. The concept of Minimum Quantity Lubrication (MQL)

1.9 Design of Experiments

Design of experiments is a series of tests in which purposeful changes are made to the input variables of a system or process and the effects on response variables are measured. Design of experiments is applicable to both physical processes and computer simulation models. Experimental design is an effective tool for maximizing the amount of information gained from a study while minimizing the amount of data to be collected. Factorial experimental designs investigate the effects of many different factors by varying them simultaneously instead of changing only one factor at a time. Factorial designs allow estimation of the sensitivity to each factor and also to the combined effect of two or more factors. Experimental design methods
have been successfully applied to several Ballistic Missile Defense sensitivity studies to maximize the amount of information with a minimum number of computer simulation runs. In a highly competitive world of testing and evaluation, an efficient method for testing many factors is needed. Design of experiments was invented by Ronald A. Fisher in the 1920s and 1930s at Rothamsted Experimental Station, an agricultural research station 25 miles north of London. In Fisher’s first book on design of experiments he showed how valid conclusions could be drawn efficiently from experiments with natural fluctuations such as temperature, soil conditions, and rain fall, that is, in the presence of nuisance variables. The known nuisance variables usually cause systematic biases in groups of results (e.g., batch-to-batch variation). The unknown nuisance variables usually cause random variability in the results and are called inherent variability or noise. Although the experimental design method was first used in an agricultural context, the method has been applied successfully in the military and in industry since the 1940s. Besse Day, working at the U.S. Naval Experimentation Laboratory, used experimental design to solve problems such as finding the cause of bad welds at a naval shipyard during World War II. George Box, employed by Imperial Chemical Industries before coming to the United States, is a leading developer of experimental design procedures for optimizing chemical processes. W. Edwards Deming taught statistical methods, including experimental design; to Japanese scientists and engineers in the early 1950s at a time when “Made in Japan” meant poor quality. Genichi Taguchi, the most well known of this group of Japanese scientists, is famous for his quality improvement methods.

1.10 Optimization

Improving an existing process that meets the given requirements and satisfies all the restrictions/constraints placed on it is called the optimum process. Material parameters such as matrix material, reinforcement material, size of the reinforcement material and percentage of the reinforcement material plays vital role in mechanical and drilling characterization of the composite materials and machining parameters such as speed, feed, point angle, Tool material and cutting fluids play vital role in drilling characterization. These parameters have a major effect on the quality of production, cost of production and production rate; hence their judicious selection assumes significance. The selected parameters should yield desired quality of mechanical and drilling characteristics while utilizing the resources. Traditionally the
selection of parameters is carried out based on the experience of the foremen and referring the available catalogues and handbooks.

1.10.1 Optimization methods

There are different types of optimization methods. Grey theory is one of the important theories and can be used to analyze the uncertainty, multi-input and discrete data. A grey system has a level of information between black and white. The grey relational analysis is a measurement of the absolute value of the data difference between sequences, and is also used to measure an approximate correlation between sequences. It is an effective means of analyzing the relationship between the sequences with less data and can analyze many factors.

One more theory for optimization of multiple responses is desirability function analysis. This method makes use of an objective function, $D(X)$, called the desirability function and transforms an estimated response into a scale free value ($d_i$) called desirability. The desirability ranges are from zero to one (least to most desirability, respectively). The factor settings with maximum total desirability are considered to be the optimal parameter conditions.

Fuzzy logic is logic for approximate reasoning, in such a way, it is a logic whose peculiar characteristics are, truth values expressed in linguistic terms, linguistic variables, which are allowed to take linguistic values, imprecise truth tables, and inference rules with approximate instead of exact validity. Fuzzy logic is quite diverse from standard logic systems, as boolean, multivalent, or modal logic. In particular, this conceptual framework is quite different from the probabilistic framework. In fact, fuzzy logic is aimed at treating problems affected by imprecision due to lack of sharp criteria for deciding set membership, rather than to the presence of random variables and stochastic processes.
1.11 Flow Chart

The entire work of this thesis is represented in the Flow Chart as show in Fig 1.7

Fig 1.7: Flow chart of the present work