CHAPTER – 1

INTRODUCTION

1.1 Need for the composite material

In the 21st century, high strength, lightweight and energy efficient materials have received extensive attention, since the problems of environment and energy are major threshold areas. In order to fulfill this requirement, engineers and researchers are striving to develop new and better engineering materials. The modern engineering material finds wide application in the aerospace, defense field, engineering industry, automobile and leisure industry. The performance and efficiency for these applications can be increased largely by the application of modern engineering materials: composites. Metal matrix composite (MMC) is one such material developed for several applications. Hence, it is clear that technological developments in various fields depend on the advances made in the field of materials and in a way, it is one of the key factors that ultimately decide the extent of perfection and sophistication achieved by modern technology [1].

1.2 Natural Composite

A composite is a material that is formed by combining two or more materials to achieve some superior properties. Almost all the materials which we see around us are composites. Some of them like woods, bones, stones, etc. are natural composites, as they are either grown in nature or developed by natural processes. Wood is a fibrous material consisting of threadlike hollow elongated organic cellulose that normally constitutes about 60-70% of wood of which approximately 30-40% is crystalline, insoluble in water, and the rest is amorphous and soluble in water. Cellulose fibers are
flexible but possess high strength. The more closely packed cellulose provides higher density and higher strength. The walls of these hollow elongated cells are the primary load-bearing components of trees and plants. When the trees and plants are alive, the load acting on a particular portion (e.g. a branch) directly influences the growth of cellulose in the cell walls located there and thereby reinforces that part of the branch, which experiences more forces. This self-strengthening mechanism is something unique that can also be observed in the case of live bones. Bones contain short and soft collagen fibers i.e. inorganic calcium carbonate fibers dispersed in a mineral matrix called apatite. The fibers usually grow and get oriented in the direction of load. Human and animal skeletons are the basic structural frameworks that support various types of static and dynamic loads [2].

1.3 History of composites

Materials science has developed rapidly during the last century to meet the needs for better materials which has tailored properties, enhanced performance and reliability in defense, aerospace, engineering, structures and automobile application [3]. But its main support has come from the newer technologies associated with aircraft, automobile, missiles, space research and in the engineering industry. The increasing demand for lightweight, a stiff and strong material to withstand conditions not previously experienced by man-made components and to perform functions have not been previously envisaged. Some of these requirements were able to be met by improvements in existing methods of manufacture and treatment of well-tried materials.

The first major structural metal matrix composite material system was Boron/Aluminum (B/Al), which was developed in the late 1960s. To date, the only production applications are the tubular struts used in NASA’s Space Shuttle Orbiter mid fuselage. However many airframe, engine component and other items of B/Al have
demonstrated the weight savings of 20 to 65 percent. There is also considerable research in Boron/Titanium, Graphite/Aluminum and Graphite/Magnesium systems which were developed show significant potential in structural applications. New fibers such as SiC were developed in the mid 1970s and coatings for carbon, boron fibers were made as viable additives for metallic matrices. The addition of a ceramic reinforcing phase such as SiC-fibers in a metal matrix such as aluminum produces a composite with a coefficient of thermal expansion (CTE) below that of the matrix metal itself. In addition, long, continuous fibers of SiC, carbon or boron can dramatically increase the modulus of the component over that of the unreinforced matrix. Adding 30% continuous carbon fiber to aluminum matrix will increase the modulus of the metal.

By the mid 1990s, a variety of MMCs was found in spacecraft applications: Carbon-reinforced copper was used in the combustion chamber of rockets, SiC-reinforced copper was used in rocket nozzles, Al₂O₃-reinforced aluminum composites were used in the fuselage and SiC-reinforced aluminum composites were used for wings and blades. The antenna boom on the Hubble Space Telescope was made of a graphite-aluminum composite. The cost of producing MMCs has prevented them from entering into other marketplaces. A notable exception is again in the area of sports equipment, where MMCs such as Duralcan (Al reinforced with 10% Al₂O₃ particulates) and Al reinforced with 20% SiC particulates were used in bicycle frames for lightweight, high strength, very expensive mountain bikes. Honda has used aluminum metal matrix composite for the cylinder liners in some of their engines; B21A1, H22A, H23A and C32B. Toyota has used metal matrix composites in the Yamaha designed 2ZZ-GE engine which is used in Toyota car. All major automotive components like space frames, exterior and interior body panels, instrument panel assemblies, power plants, power trains, drive trains, brake
and steering systems etc. are now being fabricated with a wide variety of composites that include polymer, metal and ceramic matrix composites [4-5].

Every industry is now vying with each other to make the best use of composites. The present trend is to use composites in many disciplines starting from sports goods to space vehicles. This worldwide interest during the last four decades has led to the prolific advancement in the field of composite materials and structures.

1.4 Definitions of composite

A man made composite material is a material consisting of two or more physically and/or chemically distinct phases. The composite generally has superior characteristics than those of each of the individual components. Usually the reinforcing component is distributed in the continuous or discontinuous in matrix component. The word composite and compound came from Latin and referred to fixed or joined products. The following are the important definitions of a composite.

Van Suchetclan [6] explains composite material as heterogeneous material consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

Berghezan [7] defines as “The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their shortcomings” in order to obtain an improved material.

The main constituents of composites are the reinforcements and the matrix. The reinforcements, which are stronger and stiffer, are dispersed in a comparatively less
strong and stiff matrix material. The reinforcements share the major load and in some cases, especially when a composite consists of fiber reinforcements dispersed in a weak matrix (e.g. carbon/epoxy composite), the fibers carry almost all the load [8]. The strength and stiffness of such composites are therefore controlled by the strength and stiffness of constituent fibers. The matrix also shares the load when there is not much difference between the strength and stiffness properties of reinforcements and matrices (e.g. SiC/Titanium composite). However, the primary task of a matrix is to act as a medium of load transfer between reinforcing particulates and also holds the reinforcements together in the matrix material. In this regard, the matrix plays a very vital role. Besides, the matrix may considerably influence the thermal, electrical, magnetic and several other properties of the composite. For example, to obtain a high thermal conductivity composite with SiC-fibers, one may choose an aluminum matrix or copper alloy for the application of sink materials [9].

Metal matrix composites consist of metal matrix and a ceramic reinforcement in various forms such as whiskers, particulates or fibers. They can be tailored to have superior properties such as high specific strength & stiffness, increased wear resistance, enhanced high temperature performance, better thermal & mechanical fatigue and creep resistance than those of monolithic alloys. Currently researchers are focusing on development of aluminum, copper, magnesium and titanium based metal matrix composites and has been exploring their possible applications in several high-tech areas [10-12]. The most common ceramic materials used as reinforcements in metal matrix composites are alumina, boron, tungsten, graphite, fly ash, silicon carbide, titanium carbide, Zr, SiO₂, TiO₂. Some of the researchers developed the metal matrix composites using natural minerals like, Hematite, Garnet and Beryl as reinforcing materials [13-15].
The composites are classified as two phase system, based on the types of reinforcement. They are classified as continuous and discontinuous composites. Based on the matrix materials used, they are classified as,

1. Organic Matrix Composites
2. Polymer Matrix Composites
3. Carbon Matrix Composites
4. Metal Matrix Composites
5. Ceramic Matrix composites

1.5 Metal matrix composites

Metals are extremely versatile engineering materials. A metallic material can exhibit a wide range of readily controllable properties through appropriate selection of alloy composition and thermo mechanical processing method. The extensive use of metallic alloys in engineering reflects not only their strength and toughness but also the relative ease and low cost of fabrication of engineering components by a wide range of manufacturing processes. The development of MMCs has reflected the need to achieve property combinations beyond those attainable in monolithic metals alone. Thus, tailored composites resulting from the addition of reinforcements to a metal may provide enhanced specific stiffness, wear resistance and thermal characteristics.

Metal matrix composites are engineering materials that refer to a metal based materials reinforced with particulates, whisker or fiber which can produce a considerable alteration in the physical and mechanical properties of the base alloy. According to Pradeep Rhotagi, metal matrix composites have proved to be an important class of materials with the potential to replace a number of conventional materials being used in
automotive, aerospace, defense and leisure industries where the demand for lightweight and higher strength components is increasing [1].

The choice of a matrix alloy for an MMC is dictated by several considerations. Of particular importance is whether the composite is to be continuously or discontinuously reinforced. The use of continuous fibers as reinforcements may result in transfer of most of the load to the reinforcing filaments and hence composite strength will be governed primarily by the fiber strength. The primary roles of the matrix alloy are to provide efficient transfer of load to the fibers and to blunt cracks in the event of fiber failure and so the matrix alloy for a continuously reinforced MMC may be chosen more for toughness than for strength. On this basis, lower strength, more ductile and tougher matrix alloys may be utilized in continuously reinforced MMCs [16]. For discontinuously reinforced MMCs, the matrix may govern composite strength. Then, the choice of matrix will be influenced by the consideration of the required composite strength and higher strength matrix alloys may be required [17-19].

1.6 Aluminum alloy

A wide range of aluminum alloys in various forms has been incorporated in MMCs. The density of aluminum alloys is nearer to that of pure aluminum. Pure aluminum melts at 660°C which is relatively low melting temperature in comparison to most other potential matrix metals. This property facilitates processing of Al-based MMCs by solid state routes, such as powder metallurgy and by casting methods. Aluminum alloys are broadly classified as either wrought or cast materials.

The designation schemes for both wrought and cast alloys are based on the major alloying additions.
Wrought alloys are designated by four digits while cast compositions are designated by three digits. Both wrought and cast alloy compositions may be further classified according to the method of increasing mechanical properties: heat treatable or non-heat treatable. Heat treatable refers to alloys that can be strengthened by thermal treatment. Wrought alloys of the 2XXX, 6XXX and 7XXX series are generally heat treatable. Further details of wrought alloys designation and list are shown in table number 1.1.

**Table 1.1: The designation of wrought Al alloys**

<table>
<thead>
<tr>
<th>Series</th>
<th>Description</th>
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<tbody>
<tr>
<td>1xxx</td>
<td>Controlled unalloyed (pure) composition.</td>
</tr>
<tr>
<td>2xxx</td>
<td>Alloys in which copper is the principal alloying element, through other elements, notably magnesium, may be specified.</td>
</tr>
<tr>
<td>3xxx</td>
<td>Alloys in which manganese is the principal alloying element.</td>
</tr>
<tr>
<td>4xxx</td>
<td>Alloys in which silicon is the principal alloying element.</td>
</tr>
<tr>
<td>5xxx</td>
<td>Alloy in which magnesium is the principal element.</td>
</tr>
<tr>
<td>6xxx</td>
<td>Alloys in which magnesium and silicon are a principal alloying element.</td>
</tr>
<tr>
<td>7xxx</td>
<td>Alloys in which zinc is the principal alloying element, but other elements such as copper, magnesium, chromium and zirconium may be specified.</td>
</tr>
<tr>
<td>8xxx</td>
<td>Alloys including tin and some lithium compositions characterizing miscellaneous compositions.</td>
</tr>
<tr>
<td>9xxx</td>
<td>Reserved for future use.</td>
</tr>
</tbody>
</table>
A four-digit numerical designation system is used to identify wrought aluminum alloys. The first digit of the four digit designation indicates the group it belongs like Cu, Mn, Mg, Si, Tin or Mg-Si.

In aluminum alloys from 2xxx to 8xxx alloy groups, the second digit in the designation indicates alloy modification. If the second digit is zero, it indicates the original alloy; integers from 1 through 9 assigned consequently, indicates modifications of the original alloy. Explicit rule has been established for determining whether a proposed composition is merely a modification of a previously registered alloy or it is an entirely new alloy. The last two digits of the four digits in the 2xxx through 8xxx groups have no special significance, but serve only to identify the different aluminum alloys into the group.

1.7 Temper designation system for aluminum alloys

The following lists the temper designations for aluminum alloys:

F. As fabricated. Applies to products shaped by cold working, hot working, or casting processes in which no special control over thermal conditions or strain hardening is employed.

O. Annealed. Applies to wrought products that are annealed to obtain lowest-strength temper, and to cast products that are annealed to improve ductility and dimensional stability. The O may be followed by a digit other than zero. Such a digit indicates special characteristics. For example, for heat-treatable alloys, O1 indicates a product that has been heat treated at approximately the same time and temperature required for solution heat treatment and then air cooled to room temperature.
H. Strain hardened (wrought products only). H applies to products that have been strengthened by strain hardening with or without supplementary heat treatment to produce some reduction in strength. The H is always followed by two or more digits. The digit following the designation H1, H2, and H3, which indicates the degree of strain hardening, is a numeral from 1 through 8. 8 indicate tempers with ultimate tensile strength equivalent to that achieved by about 75 percent cold reductions (temperature during reduction not to exceed 50°C) following a full annealing.

H1. Strain hardened only. H1 applies to products that are strain hardened to obtain the desired strength without supplementary thermal treatment. The digit following the H1 indicates the degree of strain hardening.

H2. Strain hardened and partially annealed. H2 applies to products that are strain hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing. The digit following the H2 indicates the degree of strain hardening remaining after the product has been partially annealed.

H3. Strain hardened and stabilized. H3 applies to products that are strain hardened and whose mechanical properties are stabilized by a low-temperature thermal treatment that slightly decreases tensile strength and improves ductility. This designation is applied only to those alloys that, unless stabilized, gradually age soften at room temperature. The digit following the H3 indicates the degree of strain hardening after stabilization.

W. Solution heat treated an unstable temper applicable only to alloys that naturally age after solution heat treatment. This designation is specific only when the period of natural ageing is indicated.
T. Heat treated to produce stable tempers other than F, O, or H. Applies to products that are thermally treated, with or without supplementary strain hardening, to produce stable tempers. The T is always followed by one or more digits:

T1. Cooled from an elevated temperature-shaping process and naturally aged to a substantially stable condition. Applies to products that are not cold worked after an elevated temperature-shaping process such as casting or extrusion and for which mechanical properties have been stabilized by room-temperature ageing.

T2. Cooled from an elevated temperature-shaping process, cold worked, and naturally aged to a substantially stable condition. Applies to products that are cold worked specifically to improve strength after cooling from a hot working process such as rolling or extrusion and for which mechanical properties have been stabilized by room temperature ageing.

T3. Solution heat treated, cold worked, and naturally aged to a substantially stable condition. Applies to products that are cold worked specifically to improve strength after solution heat treatment and for which mechanical properties have been stabilized by room-temperature ageing.

T4. Solution heat treated and naturally aged to a substantially stable condition. Applies to products that are not cold worked after solution heat treatment and for which mechanical properties have been stabilized by room-temperature ageing.

T5. Cooled from an elevated temperature-shaping process and artificially aged. Applies to products that are not cold worked after an elevated temperature-shaping process such as casting or extrusion and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.
T6. Solution heat treated and artificially aged. Applies to products that are not cold worked after solution heat treatment and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.

T7. Solution heat treated and stabilized, applies to products that have been precipitation heat treated to the extent that they are over aged. The stabilization heat treatment carries the mechanical properties beyond the point of maximum strength to provide some special characteristic, such as enhanced resistance to stress corrosion cracking.

T8. Solution heat treated, cold worked, and artificially aged. Applies to products that are cold worked specifically to improve strength after solution heat treatment and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment.

T9. Solution heat treated, artificially aged, and cold worked. Applies to products that are cold worked specifically to improve strength after they have been precipitation heat treated.

T10. Cooled from an elevated temperature-shaping process, cold worked, and artificially aged. Applies to products that are cold worked specifically to improve strength after cooling from a hot working process such as rolling or extrusion and for which mechanical properties, dimensional stability, or both have been substantially improved by precipitation heat treatment. [20].
1.8 Aluminum cast alloys

Casting compositions are described by a three digit system followed by a decimal value. The decimal 0.0 in all cases pertaining to casting alloy limits. Decimals 1 and 2 concerns ingot compositions, which after melting processing should result in chemistry contributing to casting specification requirement.

1.9 Aluminum metal matrix composites

Aluminum alloy composites are becoming potential engineering materials offering an excellent combination of properties such as high specific strength, high specific stiffness, electrical and thermal considerations, low coefficient of thermal expansion and wear resistance [21].

Nowadays, research all over the globe is focusing mainly on an Aluminum because of its unique combination of good corrosion resistance, low density and excellent mechanical properties. The unique thermal properties of aluminum composites such as metallic conductivity with a coefficient of expansion that can be tailored down to zero, add to their prospects in aerospace and avionics [22-25]. Discontinuously reinforced aluminum composites (DRAC) composed of high strength aluminum and its alloys reinforced with ceramic particulates or whiskers are subclasses of MMCs. The combination of properties and fabricability of aluminum metal matrix composites makes them attractive candidates for many structural components requiring high-stiffness, high strength and low weight.
1.10 Application of Aluminum metal matrix composite

M.K. Surappa reported that, Aluminum matrix composites (AMMCs) are the promising materials in high technology fields. Aluminum matrix composites are becoming potential engineering materials offering an excellent combination of properties such as high specific strength, high specific stiffness, electrical and thermal conductivities, low coefficient of thermal expansion and wear resistance [26]. Because of their excellent combination of properties, AMMCs are being used in a variety of applications in automotive, mining and mineral, aerospace, defense and other related sectors. In the automobile sector, Al composites are used for making various components such as brake drum, cylinder liners, cylinder blocks, drive shaft etc. [27]. In aerospace industries, Al composites are used essentially in structural applications such as helicopter parts (parts of the body, support for rotor plates, drive shafts), rotor vanes in compressors and in aero-engines. The key benefits of Aluminum matrix composites in the transportation sector are lower fuel consumption, less noise and lower airborne emissions. Few important automobile applications are, Saffil reinforced aluminum metal matrix composite in diesel engine piston by Toyota, integrally cast aluminum MMCs engine blocks by Honda and Nissan’s Al-SiC connecting rod [28].

1.11 Al 2000-series metallic matrices

The 2000-series alloys have been used in several aerospace automotive and MMC applications due to their higher strengths compared to the 6000-series alloys. This series of alloys contain copper and magnesium to provide precipitation strengthening through formation of metastable precipitate of S’ (Al\textsubscript{2}CuMg) for higher-magnesium-containing alloys and precipitates of 0’ (Al\textsubscript{3}Cu) for higher copper-to-magnesium ratio alloys upon
heat treatment. They also contain some other elements, such as chromium, zirconium, manganese or titanium to control the grain size. Commonly used 2000-series alloys are 2024, 2124, 2219 and 2618. Al 2014, 2219 and 2219 have been used for slightly higher-temperature application. The higher copper-to-magnesium ratio provides improved properties at elevated temperatures, due to formation of $\theta'$ ($\text{Al}_2\text{Cu}$) precipitate [29].