The present chapter gives a detailed overview of composite materials, types of composites and their processing techniques. It gives information about the fundamental properties and importance of magnesium, aluminum and their alloys as matrix phases for synthesizing metal matrix composites (MMCs). It also includes the previous studies reported on ceramic-reinforced MMCs for high-strength applications. It also discusses various corrosion/degradation mechanisms in a composite material.

1.1 Composites

A composite is a material made up of two or more physically and chemically distinct materials known as matrix and reinforcement. The combination of two or more materials produces a set of properties, which may or may not be there with the parent materials. A matrix is a continuous phase that holds the reinforcement in composite, whereas, reinforcement is a well-distributed phase in the matrix having higher strength than the matrix phase. The purpose of embedding reinforcement in the matrix is to improve the mechanical, electrical or electrochemical behavior of the composite. The properties of a composite material depend upon the individual properties of matrix and reinforcement, their interface and the mechanical/chemical bonding between them (R. Bowen and H. Mark, 1989, G. Lubin, 2013). The conventional materials have certain limitations in achieving strength, stiffness, toughness, and density. To overcome these limitations and to meet the demand of modern-day technology, composites are promising materials of recent interest. There are numerous other factors that influence the final properties of any composite material. These include the nature of matrix as well as reinforcement phase, amount and type of reinforcement, compatibility between the phases, processing conditions and techniques and morphology of the reinforced particles (R. Bowen and H. Mark, 1989; K. K. Chawla, 1997).

1.2 Classification of Composites

The composite materials can broadly classify in two types (W. D. Callister Jr and D. G. Rethwisch, 2012):

1. On the basis of reinforcement phase.
2. On the basis of matrix phase.

Fig. 1.1 shows the classification of composites based on their reinforcement phase. On the basis of reinforcement phase, these may be particles reinforced composites; fibers reinforced composites (continuous or discontinuous) and structural reinforced composites etc. Particles reinforced composites may have the particles of ceramic, metal, glass or glass ceramic. Composites have higher compressive, shear and tensile strength as compared to others. In the fiber-reinforced composites, strong interfacial bond along the fiber length increases the modulus of a composite. The properties of these composites depend on the length and orientation of fibers. The reinforcement material may be metal, ceramic or polymer whereas the matrix phase may be some metal, metal alloy, polymer, glass, glass ceramic or any ceramic material (W. D. Callister Jr and D. G. Rethwisch, 2012; S. Sapuan et al. 2006)

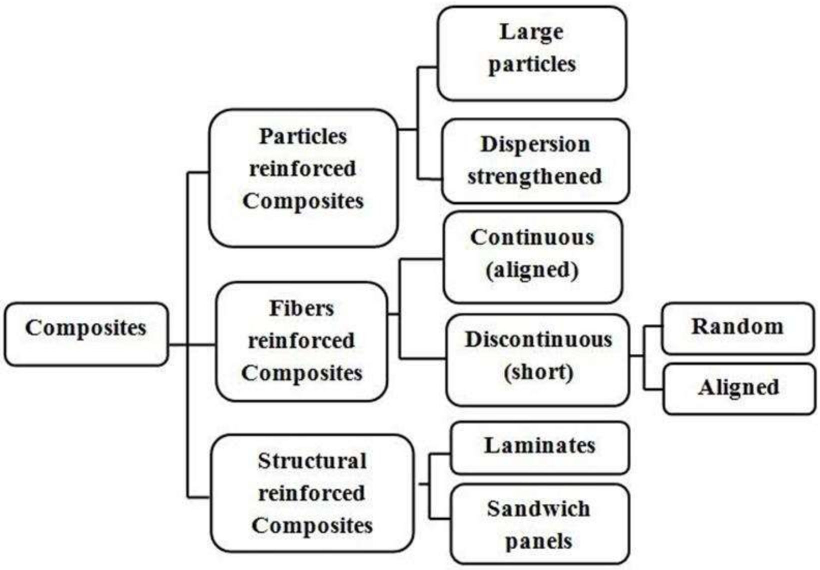

FIGURE 1.1: Classification of composites based on the reinforcement phase (W. D. Callister Jr and D. G. Rethwisch, 2012)

On the basis of matrix phase, composites can be further classified into three parts:

a) Metal Matrix Composites (MMCs)

b) Ceramic Matrix Composites (CMCs)

c) Polymer Matrix Composites (PMCs)

Fig. 1.2 Shows the types of composites based matrix phase.

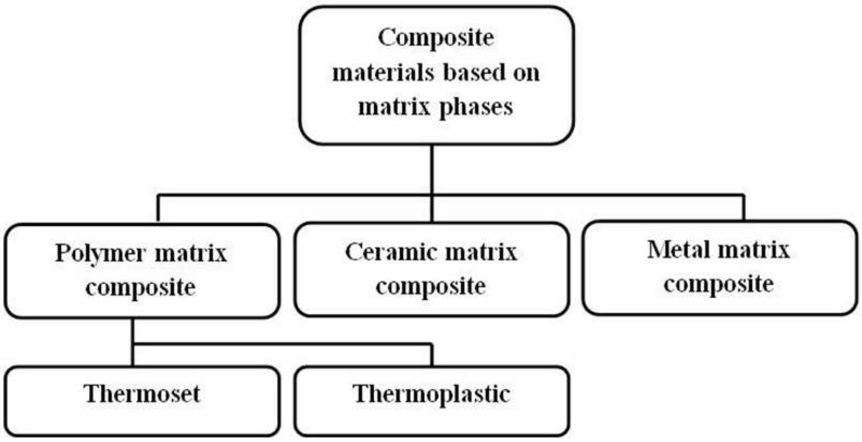

FIGURE 1.2: Classification of composites based on matrix phase

a) Metal Matrix Composites

Metal matrix composites (MMCs) are materials containing at least two constituents, one being metal and the metal is used as a matrix phase. The MMCs have the advantages of having higher modulus, higher strength, and better properties at elevated temperatures, good corrosion resistance, and lower coefficient of thermal expansion. Because of these merits, metal matrix composites are widely used for a wide range of applications viz. aerospace, packaging, transportation and defense areas (W. D. Callister Jr and D. G. Rethwisch, 2012). The composite materials have also be used in applications of heavy-duty and high strength applications, Fe, Ni, and their alloys are used combustion chamber nozzle in a rocket, space shuttle, housings, tubing, cables, heat exchangers, structural members, etc.

b) Ceramic Matrix composites

In this type of composite, the matrix phase is a ceramic material such as silicon carbide, alumina, etc. One of the main objectives in producing ceramic matrix composites is to increase the toughness, high corrosion and wear resistance (W. D. Callister Jr and D. G. Rethwisch, 2012). These are used to make components for high-temperature gas turbines such as combustion chambers, stator vanes and turbine blades.

c) Polymer Matrix Composites

A polymer matrix composite (PMC) is a composite material composed of a variety of short or continuous fibers bound together by an organic polymer matrix. The most commonly used matrix materials are polymeric. The processing of polymer matrix composites need not involve high pressure and does not require high temperature. Also, the equipment required for manufacturing polymer matrix composites is simpler. For this reason polymer composites were developed rapidly and soon became popular for structural applications. Polymer composites are used because the overall properties of the composites are superior to those of the individual polymers. They have a greater elastic modulus than the neat polymer but are not as brittle as ceramics. Polymer matrix composites may contain either thermoplastic or thermoset polymers as a matrix phase. Generally, epoxy, polyester, phenolic, etc. are used as thermoset polymers, whereas, polyethylene, nylon, poly vinyl chloride, etc. are used as thermoplastic matrix. To improve the strength and stiffness of polymer composites, these matrices are generally reinforced with glass fibers (P. Istomin, et al. 2013; E. George and I. Baker, 2001).

1.3 Processing routes for metal matrix composites

A composite material can be processed in different ways. Various processing routes have their merits and demerits. Fig.1.3 shows the different processing routes available to synthesize a composite material.

A metal matrix composite can be synthesized in three ways (D. Zhang, 1993):

1. Solid-state processing
2. Liquid-phase processing
3. In-situ processing
4. Two-Phase processing

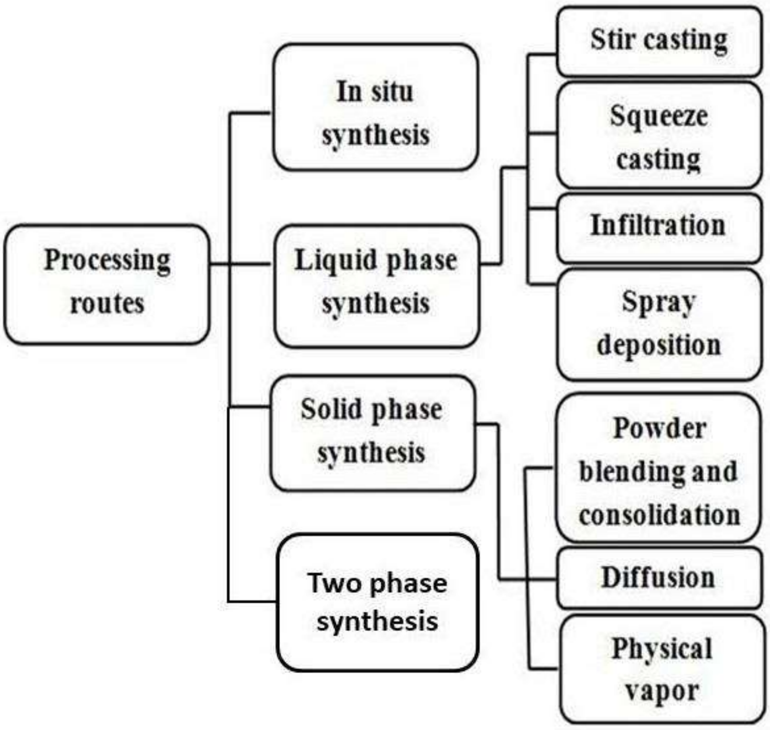

FIGURE 1.3: Different routes for synthesis of metal matrix composites

1.3.1 Solid-state processing

Solid-state synthesis includes different processing techniques such as powder blending followed by consolidation and physical vapor deposition.

(a) Powder blending route: In this method, the metal powder and reinforcement phase are homogeneously mixed either in a dry or wet medium. This mixture is then compacted and consolidated at a high temperature. Compaction is done at room temperature at an optimized load to achieve high green density. Sintering is generally done at a temperature, below the melting point of the matrix phase. It includes neck growth and elemental diffusion at a higher temperature which, results in pore removal and densification.

Optional secondary processes such as extrusion can also be used for better results (A. Hassani, et al. 2014).

(b) Diffusion bonding: Diffusion bonding occurs between the metal surface and continuous/discontinuous fibers under pressure. Continuous or discontinuous fiber reinforced Al or Mg-based metal matrix composites are generally fabricated using this route (B. C. Kandpal, et al. 2015).

(c) Physical vapor diffusion: In this method, the metal vapor is deposited on the surface of the fibers. Fibers are passed through a high partial pressure chamber of metals. The fiber coating occurs after the condensation of the deposit. Usually, the deposition rate varies from 5 to 10 nm /min. These coated fibers finally are compacted using the cold isostatic or hot pressing technique (B. C. Kandpal, et al. 2015).

1.3.2 Liquid-phase synthesis

It involves synthesis routes such as stir casting, squeeze casting, infiltration, etc. (Y. H. Seo and C. G. Kang, 1995).

(a) Squeeze casting: In squeeze casting, molten metal is solidified under pressure within a die. Molten metal is poured into an open die, due to which heat rapidly transfers from the melt to the die under high pressure. It results in a pore-free and fine-grained body. Heat treatment is given to the fabricated parts as per the requirement. Squeeze casting is classified in two forms. The first is direct and the second is the indirect squeeze casting. In the direct method, the die is the part of the mold itself and pressure is directly applied to the melt, whereas, indirect squeeze casting is a two-step process, where pressing is done at low pressure followed by solidification at higher pressure.

(b) Stir casting: This route involves the addition of reinforcement particulates in molten metal followed by solidification. Pre-treated particulates are specifically used for better bonding and strengthening with matrix phases. But the problem is the sedimentation of particulates, which, occurs during synthesis and results in the non-uniformity of the reinforcement phase. 5-100 nm size particles up to 30% content can be added in metal alloy using this route. For example, Al-B4C composite, where the B4C content is 10-15%. In a few studies, the reinforcement particles are added in the semi-solid metal alloy phase to overcome this problem (M. Surappa, 2003).

(c) Spray deposition: In this process, a stream of molten melt is atomized by an inert gas, such as argon or nitrogen, and ceramic particles are added simultaneously. This process is used for manufacturing semi-finished products, which can be later extruded or forged. (J. d. Torralba, et al. 2003).

(d) Infiltration: It is a process to infiltrate the molten metal in the porous reinforcement (whiskers/ fibers). To retain the shape of fiber/ whiskers, metal mixture or silica is added to the melt. 10-70% volume fraction of reinforcement can be added to this route, depending upon the porosity level (D. Zhang, et al. 1993).

1.3.3 In situ synthesis

It involves the chemical reaction within the matrix for the formation of a reinforcement phase. Thermodynamic compatibility at the matrix-reinforcement interface can be achieved using this synthesis route. The other advantages of this route are the high purity reinforcement phase, a strong bond between matrix and the reinforcement phase (B. C. Kandpal, et al. 2015).

1.3.4 Two-phase process

Two-phase process is like a spray deposition method but it involves the mixing of both matrix and reinforcement. In this process, a stream of molten metal is converted into a particulate spray by gas atomization, which then produces a preformed shape by impingement directly onto a collector.

Some of the two-phase processes suitable for fabricating metal matrix composites are **rhea-casting** and **Osprey.**

1.4 Corrosion in materials

Most of the metals (except noble metals like Au, Pt, and Ag) occur in nature in the combined form of their oxides, hydroxides, sulfides, chlorides, carbonates and silicates. All these metals have a natural tendency to revert to a combined state for stability. The natural combined form of metal is more stable than the other metals. That is why metal after extraction from its ore tends to revert to the stable natural combined form. In other words, the process of gradual decay or deterioration / eating of metal from its surface by unwanted chemical /electro-chemical attack by its surrounding environment are called corrosion (I. Singh, et al. 2009). The corrosion process is a reversible and is measured in units such as mils per year or millimeter/year.

Disadvantages of corrosion:

1. Poor in appearance.

2. The plant may be shut down due to failure.

3. Decrease in production rate and replacement of equipment is time-consuming.

4. Contamination of product.

5. Decreased safety from a fire hazard or explosion or release of toxic product.

6. Health hazards from pollution due to corrosion product or due to escaping of chemical from a corroded environment.

1.4.1 Types of corrosion: On the basis of method of occurrence, corrosion is classified in to two types.

1. Chemical/Dry corrosion

2. Electrochemical/Wet corrosion

1.4.1.1 Chemical/Dry corrosion: It occurs mainly due to the direct action of the environment or atmospheric gases like O_2, SO_2, H_2S, halogens, Anhydrous in-organic liquids with a metal surface that is present in its immediate proximity.

Pilling-Bedworth Rule: It **s**tates that 'an oxide is likely to be protective or non-porous if the volume of the oxide is at least as great as the volume of the metal from which it is formed.

- This is expressed in terms of a specific ratio.

Specific ratio= Volume of metal oxide/Volume of metal

- The smaller the specific ratio, the greater the oxide corrosion since the formed oxide film will be porous. So oxygen can diffuse and further corrosion takes place.

1.4.1.2 Electrochemical / wet corrosion: This type of corrosion takes place when a conducting liquid is in contact with a metal or two dissimilar metals are either dipped or immersed partially in a solution (N. M. Kumar, et al. 2015).

- Usually, it takes place in a liquid medium.

- The electrochemical corrosion involves the following-

1. Existence of separate anodic or cathodic parts between which current flows through conducting medium.

2. **At anode:** Oxidation takes place at the anodic part and releases electrons, forming metallic ions. Hence corrosion always occurs at the anode.

$$M \longrightarrow M^{n+} + ne^{-} \qquad (1.1)$$

3. **At cathode:** Reduction reaction takes place at anode, so the released electrons from anode are accepted by non-metals and forms non –metallic ions such as OH^{-} & O^{2-}

4. The metallic & non-metallic ions diffuse towards each other through conducting medium & form corrosion product.

1.5 Applications of Metal Matrix Composites

There are a large number of applications of metal matrix composites. A few of these are as follows:

Aluminum matrix composites are known for their light weight and are highly used in automobile industries. They have their uses in pistons in diesel engines, cylinder bores in engine blocks, propeller shafts, intake and exhaust valves, drive shafts and different brake components (B. C. Kandpal, et al. 2015). MMCs are also used in the aircraft coverings, rotor blades and ventral fins. These components are generally fabricated by powder metallurgy route. Various other aeronautical components such as fan exit guide vanes used in the engines are made of SiC reinforced Ti matrix composites (C. Leyens, M. Peter, 2003). Iron matrix composites were developed to satisfy the requirements for structural parts working at high temperature, high speed and high wear resistance conditions, such as the roll collars and guide wheel of a high-speed wire rod mill. Zinc based metal composites have turned up as a material that can have broad applications when there is a requirement of mechanical loading such as higher tensile strength, fatigue and wear resistance (S.S. Owoeye, 2018).

Magnesium composites are a new class of metal matrix composites widely used in aerospace and automobile industries due to their low density, good mechanical properties, good wear resistance, low thermal coefficient of expansion as compared to conventional metals and alloys (V. Sannakaisa, 2011). The recent advanced research has shown that the magnesium based alloys are used for biodegradable implant in human body. Magnesium based load bearing implants is emerged as a substitute for permanent implants of titanium and stainless steel. The main advantage of using Mg in place of Ti and stainless steel is that magnesium being biodegradable, excrete out of human body through metabolic processes and does not have any harmful effect on surrounding tissues (L. Sennerby, 1992). Mg alloys also exhibits good biocompatibility in the body. Therefore, the in vitro and in vivo biological performance of biodegradable Mg alloys is examined for many years (S. Zhang, 2009). Also, the biological compatibility of magnesium had made it a potential candidate for being used as a load bearing orthopaedic implant in the form of screw, plates and rods.

Thesis Outline

It is expected that the present chapter will be helpful in understanding the composite materials and their types. Different processing parameters in different synthesis routes and type, and content of reinforcement phase affect the properties and applications of metal matrix composites. It will explain the different mechanism of corrosions.

On the basis of previous studies it was decided to develop magnesium based composite reinforced with different materials and which can be used as a load bearing temporary orthopedic implant. The thesis is organized as follows:

Chapter 2 provides a literature review designed to provide a summary of previous works done by the researchers in the field associated with the desired area of interest.

Chapter 3 presents the objectives of the present work, materials selected for the preparation of composites and the method adopted to synthesize the composites.

Chapter 4 explains the various characterizations techniques adopted to estimate the physical, mechanical and biological characteristics of the composites.

Chapter 5 addresses the synthesis and characterization of MgZn20Mn2 based composite reinforced with HAp and 45S5P7 BAG.

Chapter 6 explains the synthesis and characterization of the Mg3Al2Zn0.6Ca.x1393BAG composite.

Chapter 7 explains the biological properties and testing of Mg3Al2Zn0.6Ca.x1393BAG composite

Chapter 8 provides the summary of the findings of this research work, outlines specific conclusions drawn from both the experimental and analytical efforts and suggests ideas and directions for future research.