METAL MATRIX COMPOSITES: A MODERN APPROACH TO MANUFACTURING

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PREFACE

Metal matrix composites (MMCs) are a class of advanced materials that have gained significant attention in recent years due to their unique properties and superior performance characteristics. They are composed of a metal matrix, typically aluminium, titanium, or magnesium, reinforced with a high-strength ceramic or metallic material such as silicon carbide, carbon fibers, or aluminium oxide. This combination results in a material that exhibits exceptional mechanical properties, including high strength, stiffness, and wear resistance, making them suitable for a wide range of applications in modern industry.

The relevance of metal matrix composites to modern industry can be traced back to their ability to provide high-performance solutions to some of the most challenging problems faced by engineers and designers. In aerospace, MMCs are used for structural components in aircraft engines, landing gear, and airframe structures, as well as space applications such as rocket nozzles and thermal protection systems. These components need to withstand extreme conditions, such as high temperatures, pressure, and high-impact loads, making MMCs an ideal choice. In the automotive industry, MMCs are used in brake rotors, engine components, and suspension systems, where high wear resistance, low friction, and improved fuel efficiency are key requirements. MMCs have been shown to offer significant weight savings and improved performance over traditional materials, such as cast iron or steel, which can improve fuel efficiency and reduce greenhouse gas emissions. MMCs' unique properties have also found applications in the electronics and microelectronics industry, where they are used in heat sinks, packaging materials, and electronic substrates. These components need to dissipate heat efficiently and reliably, and MMCs have been shown to exhibit superior thermal conductivity and excellent dimensional stability under high temperatures, making them ideal for these applications. In addition, MMCs have shown potential in the defence and military industry for their superior properties. They are used in ballistic armour and vehicle protection systems, where they provide excellent protection against high-velocity projectiles, mines, and improvised explosive devices. MMCs have also been used in cutting tools and moulds, where they provide high-wear resistance and dimensional stability. The development of MMCs has been facilitated by advancements in materials science and manufacturing technologies. Advanced fabrication techniques, such as powder metallurgy, casting, and additive manufacturing, have enabled the production of complex shapes and sizes, as well as the incorporation of multiple reinforcement materials, allowing for tailored properties and performance characteristics.

In short, the use of metal matrix composites in modern industry has been instrumental in the development of high-performance materials and products that meet the demanding requirements of various applications. The unique properties of MMCs, such as high strength, stiffness, and wear resistance, combined with advancements in manufacturing technologies, have enabled their use in critical applications, such as aerospace, automotive, electronics, and defense. As technology continues to evolve, it is expected that MMCs will play an increasingly important role in the development of innovative products and solutions in various industries.

The motivation to prepare an edited book on this topic was to provide a comprehensive resource for students and professionals in the field of materials science and engineering. The book covers a broad range of topics related to metal matrix composite manufacturing, including the various fabrication methods, characterization techniques, and applications. The intended audience for this book includes students and professionals in the field of materials science and engineering, as well as researchers and engineers working in the field of metal matrix composite manufacturing. The book provides a comprehensive resource for those seeking to gain an in-depth understanding of metal matrix composite manufacturing, including the fundamental principles, latest developments, and future trends in the field.

In conclusion, this book provides a comprehensive overview of metal matrix composite manufacturing, covering the fundamental principles, latest developments, and future trends in the field. It is designed to be an essential resource for students and professionals in the field of materials science and engineering, as well as researchers and engineers working in the field of metal matrix composite manufacturing. We hope that this book will be a valuable resource for those seeking to gain an in-depth understanding of metal matrix composites with its relevance to the modern industry

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CHAPTER 1

Metal Matrix Composites: An Introduction and Relevance to Modern Sustainable Industry

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Abstract: Metal matrix composites (MMCs) are a family of strong yet lightweight materials that have many industrial uses, particularly in the automotive, aerospace, and thermal management industries. By choosing the best combinations of matrix, reinforcement, and manufacturing techniques, the structural and functional features of MMCs may be adjusted to meet the requirements of diverse industrial applications. The matrix, the interaction between them, and the reinforcement all affect how MMCs behave. Yet, there is still a significant problem in developing a large-scale, cost-effective MMC production method with the necessary geometrical and operational flexibility. This chapter provides an overview of Metal Matrix Composites (MMCs), their historical development, properties of MMCs, classification of MMCs, diverse applications, and the relevance of MMCs to sustainable industries.

Keywords: Artificial intelligence, Composite materials, Industry 4.0, MMC, Machine learning, Sustainability.

COMPOSITE MATERIALS

Composites, also known as composite materials, are materials made up of two or more distinct materials that are combined to form a new material with enhanced characteristics [1]. The use of composite materials can be traced back to ancient times, with examples including mud bricks reinforced with straw, and boats made from reeds and papyrus [2, 3]. In the 20th century, composites began to be used more widely in various industries owing to their desirable characteristics such as high resistance against corrosion, high strength-to-weight ratio, and stability.

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During World War II, composites were used in the construction of aircraft, such as the De Havilland Mosquito, which was made with a plywood composite [4].

After the war, the aerospace industry continued to be a major user of composites, with materials such as fiberglass and carbon fiber being used in the construction of aircraft and spacecraft. In the 1960s and 1970s, composites began to be used in the construction of sports equipment, such as tennis rackets and golf clubs [5, 6]. This trend continued into the 1980s, with composites being used in the construction of high-performance racing yachts and Formula One cars. Composites are employed in a variety of sectors today, including sports equipment, construction, automotive, marine, and aerospace. New materials and manufacturing processes continue to be developed, expanding the range of applications for composites and making them increasingly important in modern industry.

Composite materials are constructed of two or more different types of constituent materials that are combined in a way that produces a new material with superior properties compared to individual materials [7, 8]. The constituent materials can be organic or inorganic and can include fibers, resins, metals, ceramics, and polymers. There are several types of composite materials, each with unique properties and applications [9 - 11].

Polymer Matrix Composites (PMCs)

Fiber-reinforced polymers, sometimes referred to as polymer matrix composites (FRPs), are made up of a polymer matrix and a reinforcing fiber, such as carbon or glass fibers. The fibers are embedded in the polymer matrix to create a material with high strength and stiffness, making PMCs ideal for use in aerospace, automotive, and sports equipment applications.

Metal Matrix Composites (MMCs)

A metal matrix and a reinforcing substance make up MMCs, such as ceramic or carbon fibers. MMCs are known for their high strength and stiffness, as well as their resistance to high temperatures and wear. These properties make them ideal for use in aerospace, automotive, and military applications.

Ceramic Matrix Composites (CMCs)

A ceramic matrix is made up of ceramic matrix composites and a reinforcing material, such as carbon or silicon carbide fibers. CMCs are known for their high strength and stiffness at high temperatures, making them ideal for use in high-temperature applications, such as in gas turbines and heat exchangers.

Carbon Fiber Reinforced Polymer (CFRP)

One example of a carbon fibre reinforced polymer is carbon fibre reinforced plastic. PMC uses carbon fibers as the reinforcing material. CFRP is known for its stiffness, making it ideal for use in aerospace, automotive, and sports equipment applications.

Glass Fiber Reinforced Polymer (GFRP)

It is a type of PMC that uses glass fibers as the reinforcing material. GFRP is known for its high strength and stiffness, as well as its resistance to corrosion, making it ideal for use in marine and construction applications.

Natural Fiber Composites (NFCs)

Natural fiber composites are made up of a natural fiber, such as bamboo or wood, and a matrix material, such as a polymer or resin. NFCs are known for their low cost, biodegradability, and renewable nature, making them ideal for use in sustainable applications.

Hybrid Composites

Hybrid composites are made up of two or more different types of reinforcing materials, such as fibers or particles, in a single matrix material. Hybrid composites can have a range of properties, depending on the combination of materials used, and are often used in aerospace, automotive, and military applications.

Fig. (**1**) shows various types of composites along with various types of MMCs based on their matrix material. In conclusion, composite materials have revolutionized the world of engineering and technology by providing materials with superior properties than traditional materials. The different types of composite materials allow engineers and designers to choose the appropriate material for a given application based on the required properties, cost, and environmental impact. As technology advances, new composite materials and manufacturing techniques will continue to be developed, expanding the range of applications for composites and making them increasingly important in modern industry.

METAL MATRIX COMPOSITES

One kind of composite material is metal matrix composites (MMCs), consisting of a metal matrix, usually a light metal such as aluminium, magnesium, or titanium, reinforced with a secondary phase, which can be a ceramic, metal, or

CHAPTER 2

Structure-Property Correlations in Metal Matrix Composites

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Abstract: Metal matrix composites (MMCs) having particulate or laminate structure are extensively used in a wide range of applications including cutting tools, automotive vehicles, aircraft, and consumer electronics. In a composite material, two or more dissimilar materials are combined to form another material having superior properties. The matrix is a continuous phase in a composite material and is usually more ductile and less hard phase. In the matrix phase, aluminum, magnesium, titanium and copper are some of the metals widely used matrix materials. Compared with unreinforced metals, MMCs offer much better mechanical and thermal properties as well as the opportunity to tailor these properties for a particular application. In order to fabricate MMCs, various processing techniques have been evolved which can be categorized as liquid state method: Stir Casting, Infiltration, Gas Pressure Infiltration, Squeeze Casting Infiltration, Pressure Die Infiltration, solid state method: Diffusion bonding, Sintering and vapor state method: Electrolytic co-deposition, Spray co-deposition and Vapor co-deposition. The microstructure of MMCs such as orientation, distribution and aspect ratio of reinforced phase can effectively influence the properties of composite materials. The effective properties of MMCs can be predicted using the analytical or numerical methods. Analytical methods such as: Turner Model, Kerner Model, Schapery bonds, Hashin's bond and Rule-of-Mixtures are used widely for effective properties computation. However, analytical methods cannot take into account the material microstructure, and therefore, the finite element method has been used extensively to model the real microstructure of composites and to predict the deformation response and effective properties of composites.

Keywords: Hashin bound, Metal matrix composites, Shtrikman bound, Structural properties.

COMPOSITE MATERIALS

The ever-increasing demands from technology due to rapid advancements in the fields of aerospace, automotive, marine, sporting goods and aircraft have led to

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the development of high-performance composite materials [1]. Various processing techniques and advanced technologies have been developed to fabricate composite materials and this has made composites an attractive candidate and superior alternative to traditional materials. It is difficult for conventional metals and alloys to keep up with technological advancements.

Two or more materials, having considerably different properties, are combined to form the composite material. Therefore, a composite material can be defined as a material that consists of two or more materials having chemically distinct phases, microscopically heterogeneous but homogeneous macroscopically. Different constituents of a composite material do not dissolve or blend into each other and work together to yield much superior properties [1 - 5].

The matrix phase is the continuous phase of a composite material. In general, the matrix phase is a ductile material that helps to hold the dispersed phase. But this definition is not always applicable, for example, in the case of ceramic matrix composites, the matrix phase is harder and brittle. The phases embedded in the matrix in a discontinuous form are known as reinforcement. The reinforced phase should be uniformly dispersed in the matrix phase for better properties. The reinforced phase is usually stronger than the matrix. The properties of composites depend on the properties of their constituents, the bonding between constituents, and the size of reinforced particles. The distribution of particles: uniform or clustered also influences the effective material behavior. A strong bonding between the matrix and the reinforcement helps the matrix to transfer the load to the reinforcement phase [6 - 8].

CLASSIFICATION OF COMPOSITE MATERIALS

The classification of composites is based on: the type of matrix, type of reinforced, and fabrication techniques used [1]. The matrix phase could be metal, ceramic, and polymer (Fig. **1**).

METAL MATRIX COMPOSITES

Metal matrix composites are an important class of composites relevant to a wide variety of applications. Low-density metals, such as aluminum or magnesium are widely used as the matrix materials in these composites [6, 7]. The metal phase is usually reinforced with particulate or fibers of a ceramic material, such as silicon carbide or graphite. A much better combination of mechanical, thermal, and thermo-mechanical properties as well as the opportunity to tailor these properties for a particular application are offered by MMCs [8 - 15].

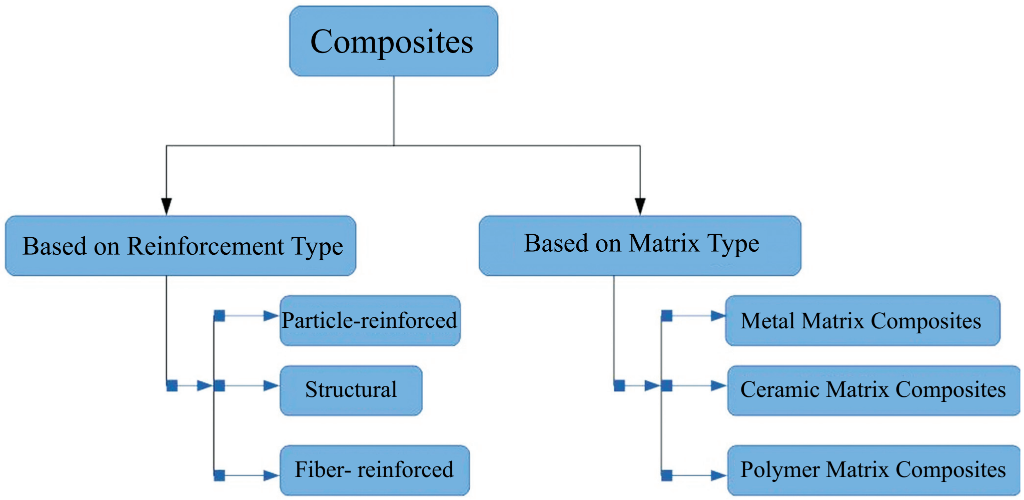

Fig. (1). Classification of composite materials.

Based on matrix material

a. Metal Matrix Composites (MMCs)

b. Ceramic Matrix Composites (CMCs)

c. Polymer Matrix Composites (PMCs)

Based on reinforcing material structure

a. Particle Reinforced Composites

b. Fibre Reinforced Composites

c. Laminated Composites

ANALYSIS OF COMPOSITE'S BEHAVIOR

The composite materials are fabricated by combining constituent materials having significantly different properties, and therefore computation of the effective properties of composites is a field of vital interest. Different types of analytical and numerical methods have been used by researchers to predict the effective properties of composites. Virtual simulation of deformation behavior using numerical methods such as finite element method (FEM), finite difference method (FDM) or atomistic simulations can be applied to understand the new materials behavior and their effective properties, and this reduces the expense on laboratory

CHAPTER 3

A Critical Review of Fabrication Techniques and Possible Interfacial Reactions of Silicon Carbide Reinforced Aluminium Metal Matrix Composites

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Abstract: In this review article, the current status of and recent developments in fabrication techniques for all types of Silicon Carbide reinforced Aluminium Metal Matrix Composites (SiC-AMMCs) have been elaborately discussed. The comparative studies on fabrication methods have also been reported in this article. Furthermore, the possible interfacial reactions between aluminium and silicon carbide that have been presented by researchers were also explored and their causes and remedies have been discussed. The entire discussion in this review article reveals that liquid fabrication processes (especially stir casting) are used effectively for mass production, intricate shapes, a variety of products, nano-composites, *etc*. The solid-state processes are performed below the melting temperature of matrices, resulting in the least possible interfacial reactions leading to unwanted compounds' formation. The literature on interfacial reactions reveals that the Al_4C_3 compound is mostly formed as a result of the reactions between aluminium and silicon carbide and exhibits a deleterious effect on the composite properties.

Keywords: Aluminium, Fabrication, Interfacial reactions, Metal matrix composite, Review, Silicon carbide.

INTRODUCTION

A few decades ago, conventional materials were used to produce aerospace, automotive, marines, defence, sports equipment, *etc*. but these materials have high density, low corrosion and wear resistance, low strength to weight ratio and high

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cost. At present, researchers are focusing their attention on overcoming these shortcomings by replacing conventional materials with composite materials [1]. The superior qualities of the composite, which replace conventional monolithic materials and their alloys, extend their applications in automobile, defense, marine, sports and recreation industries [2, 3].

Composite is a combination of matrix and reinforcements. The matrix is a base or mother metal/alloy, in which reinforcement particles are embedded. The matrix is always a light metal, which supports the reinforced particles within the grain structure and the newly developed strong grain structure can hold more external loads. So, it is desirable to have strong interfacial bonding and wettability between the matrix and reinforced particles to get the material with improved properties [4].

Matrix Materials

Light metals, such as aluminium, titanium, magnesium, and zinc and their alloys are used as a matrix in MMCs. Other materials like copper, nickel, lead, iron, and tungsten are also used in some particular applications. Moreover, cobalt and Co-Ni alloys are used as a base matrix in particular applications, where the materials are subjected to high temperature [5 - 9]. In the last one-two decades, the use of Aluminium Matrix Composites (AMCs) has increased rapidly, particularly in automotive, recreation and aerospace applications due to their lower density, lower coefficient of thermal expansion, higher wear resistance, lower costs, availability, higher strength/weight ratio, and higher resistance to corrosion and lower processing temperature requirement than competitive materials [10].

Reinforcement Materials

Reinforcements in composite materials are second-phase materials, which are added in the matrix. A reinforcement prevents deformation and improves desirable properties such as strength, hardness, stiffness, wear resistance, *etc*. of the base metal/alloy.

Before 1970, mono-filaments of tungsten (W), Be, Al_2O_3, *etc*. were used as reinforcements. At the beginning of 1970, the interest was directed towards the use of SiC, Al_2O_3 and C multi-filaments and whiskers [11]. In the last decade, the use of particulate reinforcements has attracted the interest of researchers due to their availability at low cost, well-established fabrication processes, *etc*. Also, the discontinuous particulate reinforcements-based composite exhibits the least interfacial reactions, superior properties, high strength-to-weight ratio, relative ductility, *etc* [12, 13].

Particulate-reinforced materials can generally be classified as, (1) ceramics/metallic materials, (2) agro waste materials, and (3) industrial waste materials. The ceramics mostly used as reinforcement are borides, carbides, nitrides, and oxides of the metallic materials *e.g.* SiC, B_4C, Al_2O_3, Ni_3Al, Al_4N_3, TiB_2, and $ZrSiO_4$ [14, 15]. Apart from these, other reinforcements are MWCNT, WC, diamond, AlO, Si_3N_4, *etc*. Among these materials, SiC particulate ceramic is widely used in different composites. The addition of SiC in the aluminium matrix enhances wear resistance, hardness value and tensile strength, but with the loss of machinability and toughness resistance [16]. Industrial waste materials are the second category of reinforcements, which are used in AMCs. These materials include fly ash (FA) and red mud. Several authors have reported their extensive work regarding the utilization of fly ash as reinforcement in mono as well as hybrid MMCs [17 - 19]. However, limited research work is reported on the use of red mud as reinforcement in the AMCs. The third category of reinforcement is related to agro waste materials. These materials include BLA (bamboos leaf-ash), eggshell waste, RHA (rice husk-ash), sugarcane bagasse-ash, maize stalks waste-ash, CCA (corn cob-ash), *etc*. No doubt, the single agro waste reinforced AMCs have improved properties than the unreinforced ones, but exhibit inferior properties than synthetic reinforced composites. The main motive of using such materials is to reduce materials cost by maintaining the desired level of essential properties [20 - 24].

Of these, the Silicon Carbide reinforced Aluminium Metal Matrix Composites (SiC-AMMCs) are ones being the most popular composite materials used these days. Such lightweight composites are widely used in automotive and aircraft where the weight is the main concern. With the addition of SiC (in different ratios) in the aluminium matrix, the properties like hardness, tensile strength, wear resistance, density, *etc*. are increased, but with the loss of ductility and toughness [16]. Moreover, these composites exhibit heterogeneous and anisotropic properties [25, 26], which are not desirable because of internal voids, irregular grain structure, variable density, and porosity that occur in such composites. However, the machinability of SiC-AMCs can be improved by using secondary reinforcements (like Graphite) with SiC in aluminium matrices [27]. Also, the secondary processing of novel composites (like extrusion, rolling, forging, and heat treatment processes) can remove these defects. A small amount of Mg may be added to improve the interfacial bonding between the constituents [28]. Also, the coating of copper and CNT on SiC improves the wettability of particles and strengthens metallurgical bonding [29]. So the basic awareness of Al-SiC composite materials and their properties can provide a solid foundation for widespread industrial applications.

CHAPTER 4

Synthesis Approaches and Traits of Carbon Fibers-Reinforced Metal Matrix-Based Composites

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Abstract: In this chapter, an overview of the advancement and research efforts that have been undertaken on CFR-MMC (carbon-fiber reinforced metal matrix-based composites) during the last several decades is presented. Carbon fiber is widely implemented in the construction sector for rehabilitation and structural repair projects. Although, studies show that carbon fiber-reinforced metal-matrix (CFR-MMC) has a bright future, the use of carbon fibre as a reinforcement in metal matrix is still in its development. The uses, and traits of carbon fiber are discussed in general terms in this study. The various traits such as mechanical, and structural properties of the resultant CFR-MMC, are significantly influenced by the structure and content of the carbon fibre as well as its bonding to the MM (Metal matrix). The effect on the various traits of MMCs by CFs (Carbon fibers) was investigated. In addition, a detailed study on the various synthesis approaches for the preparation of CFR-MMC has been taken into practice in this book chapter.

Keywords: Composite, Carbon fibers, Cellicious precursor, Diffusion bonding, Fiber reinforcement, Ion platting, Mechanical properties, Melt stirring, Metal matrix composite precursors, Powder metallurgy, PAN precursor, Pitch precursor, Plasma spraying, Reinforcement, Synthesis approaches, Squeeze casting, Structural properties, Scanning electron microscopy, Tow.

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INTRODUCTION

The progress of technology has led to the increasing demand for innovative materials to handle day-to-day difficulties for a variety of uses. MMCs (Metal Matrix Composites), which is the combination of two or more elements to create a new composite, have emerged as one of the most significant material systems in recent decades. The demand for lightweight structural materials for aerospace and automotive applications is quite high. Conventional materials, including titanium and aluminium, are unable to handle most of the modern-day obstacles [1]. The properties of these materials decrease rapidly at extreme temperatures, limiting their use in essential components. Combining inherent matrix toughness and ductility with high specific strength and high stiffness materials, such as CFs (carbon fibers) or ceramic filaments, allows for the production of materials that can be used in advanced applications and overcome performance difficulties. The introduction of such reinforcements into metal matrix enhances elastic modulus, tensile strength, hardness, as well as additional mechanical characteristics substantially [2]. Other characteristics of metal matrix composites, such as corrosion resistance, CTE, wear resistance, coefficient of friction, and thermal conductivity (TC) can be tuned to meet application necessities. At the same time, the material's CTE must be small so that it creates a lesser amount of thermal stress during the heat process. Copper and aluminium have comparatively high values of coefficient of thermal expansion, resulting in significant thermal stresses [3]. According to research, SiC (Silicon carbide) reinforced metal matrix composite with low CTE can give maximum heat absorption rates as well as minimum thermal stresses. As an alternative to bulk metal heat sinks, diamond particle-reinforced copper metal matrix composite has also been researched. Even though, it has been demonstrated that these MMCs have improved thermo-mechanical properties, up to 60% more volume of reinforcement may still be necessary. In an effort to reconcile, thermo-mechanical and machinability characteristics of CFR-MMCs have been studied for heat sink applications. The aeroplane, aerospace, vehicle, and electronics sectors have all expressed interest in CF-MMCs [4]. Simply said, conventional metallic alloys and pure metals are usually unable to bring effective characteristics in challenging applications. This resulted in the creation of composites with certain traits that are highly suitable for a specific purpose. MMCs are already being used in a variety of real-world applications. Multi-chip modules, power electronics modules, disc brakes, drive shafts, and, automobile engine cylinders, are a few prominent applications of MMCs.

CARBON FIBER

Carbon fibers (CFs) are the fibers that have at least 92 wt% of carbon and construct a fibre shape. The early background of the carbon fibers is shown in Fig. (**1**). Carbon fibers are fibers with a diameter of 5 to 10 µm and are mostly made of carbon atoms. Commercially, bundles of carbon fibers are described as tow, which basically means a bundle of thousands of numbers of carbon fibers (1 tow stands for 1000 fibers in a bundle). CFs are appropriate for applications requiring high young's modulus, strong tensile strength, high chemical resistance, low density, moderate thermal expansion, and outstanding electrical and thermal conductivity. Commercial production and usage of carbon fibers as a reinforcing material occurred more than a half-century later [5]. A CF is composed of layers of carbon atoms (graphene sheets) organised in a regular hexagonal pattern and with an atomic structure similar to graphite [6]. CF layer planes can either have a hybrid structure, a turbostratic structure, or a graphitic structure depending on the precursors used and the production methods. Layer planes are consistently arranged parallel to one another in graphitic crystalline regions. The atoms on a plane are covalently joined by sp^2 bonding, while the sheets are bonded by van der waals forces, which are rather weak [1]. The d-spacing between two the graphene layers in a single graphitic crystal is approximately 0.335 nm. In mostly carbon fibers, the basic units of structures are stacked in turbostratic layers. The parallel graphene sheets in a turbostratic structure are folded, slanted, or divided randomly or haphazardly. Uneven stacking and the presence of sp^3 bonding have been seen to increase d-spacing [7, 8]. The microstructure of carbon fibre is defined by the precursors and the processing conditions [9]. Carbon fibers were synthesized by pyrolyzing a precursor material in an inert atmosphere at high temperatures. Different precursors (PAN, Pitch, and cellulosic-based precursors) can create carbon fiber using various processing methods, but the basic thermal conversion mechanisms are the same for all methods. The initial stage in the production of carbon fibre is the stabilisation of precursor fibres between (200 and 400 °C) in air. Stabilization increases the thermal stability and reduces fiber collapse at higher temperatures. The stabilised precursor fibers are next carbonization, which involves placing oxidised fibres in non-reactive environment at high temperatures (1900 °C) to eliminate the non-carbonaceous components like hydrogen, nitrogen and oxygen. Carbon fibers are generated at this stage, but to raise carbon concentration and young's modulus, graphitization is used, in which the fibres are heated (at maximum temperature).

CHAPTER 5

Fabrication and Interfacial Bonding of CNT-reinforced Metal Matrix Composites

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Abstract: Recent advances in various engineering applications demand new materials that have multi-functionality along with suitable structural properties. Metal matrix composites are the class of materials that satisfy this purpose due to their lightweight, increased strength, and other improved mechanical properties. These composite materials can be prepared by various conventional techniques which aim reducing the cost of production and meeting the demand of the industries efficiently. The properties and functionality of these materials are greatly influenced by the type of reinforced particulates and their composition in the metal matrix. Many reinforcement particles or fibers can be used in MMC depending upon the applications. Commonly used reinforced materials are graphene, polymers, carbon fibers, ceramic materials, *etc*. Among the carbon family, carbon nanotubes (CNT) exhibit enhanced performance as an ideal reinforcement material for MMCs. With outstanding intrinsic physical properties, CNTs are considered a promising candidate for reinforcement. CNT owes its properties due to its small diameter, high tensile strength, stiffness, high Young's modulus, and good chemical stability. They exhibit thermal stability even at high temperatures and exhibit good electrical conductivity. They also show improved fatigue resistance and plasticity and thus broaden the performance of the MMC. In this chapter, various fabrication techniques along with blending and processing methods of CNT-reinforced MMC have been discussed. The main methods have been explained with their schematic representations. The advantages and limitations of these methods have also been discussed. A strong interfacial bonding between the reinforced particulate and the metal matrix affects the performance of the material. This chapter also deals with a deep understanding of the various interfacial bonds that can exist between CNT and the metal matrix.

Keywords: Bonding interface, Carbon nanotubes, Mechanical properties, Metal matrix composite, Reinforcement effect, Solid state processing.

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INTRODUCTION

Rapid industrialization demands the development of high-performance materials for varied engineering applications. With technological advancements, automobile, aircraft, and aerospace industries especially expect the fabrication of next-generation materials that are high in strength and hardness besides being ultra-light, environmentally friendly [1], and comparatively economical. In this context, the spotlight is focused on composite materials. These materials maintain the original characteristics of the host material and can also be tailored for additional properties by doping or reinforcement with other mono-lithic compounds. The reinforcement particle is added to attain improved properties like strength, toughness, stiffness, electrical and thermal conductivity, electromagnetic shielding, coefficient of thermal expansion, damping and wear resistance [2 - 4]. These technologically improved materials then exhibit enhanced and unique properties that might not be exhibited by the base material and hence show multifunctional applications. Composite materials can be categorized into different types: polymer, metal, and ceramic [5, 6] depending upon the host matrix and the reinforcement particle. The reinforcement particle can be incorporated in the form of homogenous or discontinuous dispersion in the host matrix at the microstructural level. Another way of reinforcement of particles can be in the form of a continuous layer surrounding or within the matrix. The reinforced particles can be oxides, nitrides, and carbides of metals and metalloids. Depending upon the large volume fraction of the host matrix, the composite material is termed a Polymer matrix composite (PMC), Metal matrix composite (MMC), and Ceramic matrix composite (CMC). For lightweight and low-temperature applications, polymer matrix composites are used. On the other hand, for high-temperature, inert atmosphere applications ceramic matrix composites are used. These CMCs exhibit high mechanical properties. The metal matrix composites are lightweight, work under high temperatures, and exhibit outstanding mechanical properties as well. MMCs can be easily tailored for microstructure and other physical properties' modifications. Since the host matrix is a metal or an alloy of metal, it can undergo a wide range of thermo-mechanical processing. Technological interest in MMCs arose due to their profound stiffness even at low density MMCs, which offer the advantage of high strength to weight ratio, high elastic modulus, good thermal and electrical conductivity, lower coefficient of thermal expansion, superior elevated temperature properties like rupture strength and improved creep resistance, better fatigue performance and ability to resist moisture and radiations. Due to these advantages, MMCs find wide applications in the automotive and aerospace industries [7 - 11]. Fig. (**1**) shows the various classification of matrix & reinforcement types in MMC.

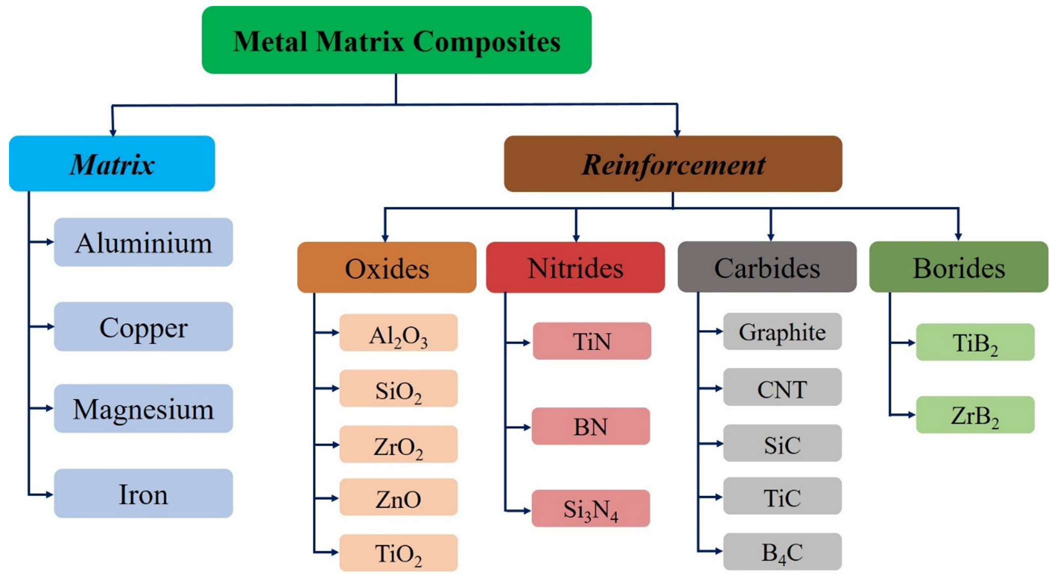

Fig. (1). Classification of matrix & reinforcement types in MMC.

Various reinforcement particles or fibers can be used in MMC depending upon the applications. Depending on the type of reinforcement material used, MMCs can be particle-reinforced composites or whisker-type short-fiber composites or sheets of continuous fiber composite. In particle-reinforced MMCs, ceramics, metals, amorphous material or glasses can be used as reinforcement material. These types of MMCs have high modulus than the host matrix but have low permeability and ductility. Thus they can sustain high tensile strength and shear and compressive stress. The fiber-reinforced MMCs also have high modulus and are bonded with the matrix along the fiber length with strong covalent bonds. The fibers are relatively oriented and thereby make a strong impact on the mechanical properties of the MMC. Commonly reinforced materials used are graphene, polymers, carbon fibers, ceramic materials [12], *etc*. Though ceramic-reinforced MMCs exhibit good mechanical properties but they exhibit poor electrical and thermal properties [13]. Carbon fiber-reinforced MMCs (CF-MMC) exhibit a good balance between thermo-mechanical properties and machinability and can be effectively utilized for heat sink applications [14, 15]. Due to their capability of high wear resistance, CF-MMCs can be used as bearings and wear parts with improved friction coefficients. Owing to their self-lubricating effect and high-temperature strength, CF-MMCs have superior, strength, modulus, and electrical conductivity. Hence they find important applications in aerospace, automobile, and electronic industries [16 - 19]. In the recent era, carbon materials like graphene find wide applications as reinforced materials in MMC for the synthesis

CHAPTER 6

Biotribology: Recent advancements, Applications, Challenges and Future Directions

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Abstract: Tribology deals with basic principles and understanding of three concepts: friction, wear, and lubrication. Now, bio tribology is one of the most exhilarating fields of tribological study. In this book chapter, the authors made efforts to review and provide brief thoughts about the various sections of the biotribology such as orthopedics, artificial implants, biomimetics, bio-lubricants, biomaterials, ocular tribology, skin tribology, haptics, dental tribology, sports tribology. Apart from these, biotribology deals with a few more exciting areas *i.e.*, in personal care like skin creams, cosmetics, *etc*., and oral processing studies such as mouthfeel and taste perception.

This comprehensive review comes to a close with four studies, *i.e.*, bio-friction of the biological systems, tribology of medical and surgical devices, biocompatibility issues related to biomaterials, and critical aspects of bio-tribocorrosion. A critical review of bio-friction studies for the various biological systems is presented, and significant underlying tribological-lubrication mechanisms are also discussed.

The present emphasis and forthcoming advancements of the various medical and surgical instruments in context with the fundamental tribology principles and pertaining mechanisms for an efficient, versatile, and multi-functional bio-system will be discussed in this book chapter. Furthermore, major challenges faced by R&D officials and medical teams are discussed.

Biocompatibility and bio-tribo-corrosion of biomaterials are serious concerns in bio tribology. In-depth discussions of current trends, implementations, and their guidelines for the future are also included. In a nutshell, bio tribology studies can contribute noteworthy scientific, social, engineering, and healthcare benefits; the openings and possibilities are significant.

Keywords: Artificial implants, Biotribology, Bio-tribocorrosion, Bio-friction, Biomimetic, Bio-lubricants, Biomaterials, Challenges, Composites, Dentistry, Ocular tribology, Skin tribology, Sports tribology, Tribology.

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INTRODUCTION

Bio-tribology is the study of tribological aspects (friction, wear & lubrication) of biological systems or natural phenomena. Apart from this, it belongs to multidisciplinary fields Table **1** such as biomedical engineering, medical technology, nanotechnology, material engineering, *etc*. These things collectively diversify the impact on our daily life and research aspects. In general, it is not limited to implant replacement (Fig. **1**), but significantly affects sports equipment design and personal care products [1, 2].

Table 1. Brief about key subjects or areas that are included in the biotribology [1 - 40].

Major Application Sectors in the Biotribology	Area of Study
Joints (Synovial and cartilaginous) and ligaments	Basic types; applications; impairment and failure; replacement methods; risks and complications.
Tissue substitutes	Biological tissues; Biodegradable scaffolds; hydrogels; tissue-engineered skin substitutes; dental tissues; synthetic bone tissues, meniscus, and tendons.
Prostheses implant or Artificial implant	*Prostheses implant:* Craniofacial prostheses, extra/intra-oral prostheses, dental prostheses, neck Prostheses, breast prostheses, nipple prostheses, penile prostheses; Artificial *implant:* Neurosensory implantation, Cardiac replacements, Orthopedic inserts, Electric inserts, Contraception implants; Cosmetic implants, *etc*. Other applications: Articular joints, catheters, heart pumps, stents.
Biomimicry	Self-healing and bio-inspired materials; Development of surface based on surface tension Biomimetics; Bio-inspired technologies.
Locomotion	Microbial & bacterial motility; mechanics; slip mechanisms; locomotor effects; movement of microorganisms; study of motor skills.
Drug delivery	Controlled-release formulations; nanomedicine; biologic drug carriers; Oral dispersive medicines; injections; Modulated drug release; Targeted drug delivery; Bioavailability.
Ocular tribology	Anatomy; Targeting of the ocular surface and diseases; contact lenses; tear film; Disorders; wetting; Hydrogels; Micro-scale friction measurements (surface friction) and mechanisms; Diffusion phenomenon; various syndromes; Reverse engineering.
Skin tribology	Skin friction modeling; Damage and blistering mechanisms, bedsores, sweat lubrication; product-skin interactions; surface texturing and polymer coatings.
Haptics	Touch perception; Haptic Texture; surface texturing techniques; ergonomics; Haptic sensation; Surface haptic technology and Somatosensory system.
Tribology of personal care	Kinetic friction; Adhesion and wear phenomenon; Rheology; Multiple regression modeling; Skin and hair solutions; cosmetic treatments; Exfoliators.
Oral processing	Foodstuffs and beverages; mouth feel and texture perception; biomechanical functions; study of multiple physicochemical properties; sensory texture perception.

(Table 1) cont.....

Major Application Sectors in the Biotribology	Area of Study
Dental tribology	Wear of dental replacements; anchoring of biomechanical inserts; tribe-corrosion; restorative materials and implant design; biocompatibility; oral lubrication and the underlying mechanism; oral hygiene practice on dental tissues; Properties of dental tissues.
Tribology in Industry	Testing methodologies; Understanding of customer experience and ultimate guide to significant strategies; technological solutions; Energy saving technologies; Advanced manufacturing systems; Highly sophisticated diagnosis arrangements; Micro technologies for MEMS and Nanotechnologies for NEMS; Tribology networks; Mechanization; mass production; Automated production; Cyber physical systems; Friction studies on gears; bearings and lubricating oils; Additive technology; Computational and experimental tribology; EHD lubrication regime; contact mechanics and surface topographic investigations; condition monitoring, rheology; superlubricity; Tribotronics; Human machine interaction and concept of wearables.
Sports tribology	Reliable surfacing solutions; grip improving agents; low-friction characteristics; surface topography/texture tailoring; protruded scales and pattern on contacting surfaces; absorbing materials; study of adhesion properties; better tribological understanding of material-surface interaction; skin friction; ergonomics; material behavior.
Biolubricants	Renewable; Plant-derived or environmentally acceptable lubricants; Bio-corrosion and bio-fouling; Study of biodegradability; non-toxic and oxidative stability; tribo-reactive materials for automotive applications.
Tribology involved in natural phenomena	Geotribology; Fractures and discontinuities in rocks; Geo-mechanical modeling; microphysical models to map the underlying frictional phenomenon; Earthquakes; avalanches; landslip or other subsurface phenomena.

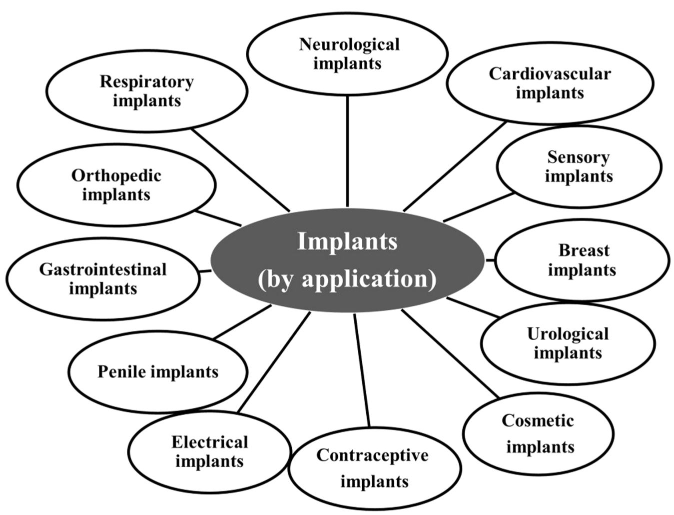

Fig. (1). Various type of implants (by application) [27, 80, 81, 87, 88].

CHAPTER 7

A Review on Reinforcement and Its Effect on Aluminium-Based Composites

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Abstract: In today's world, there are different materials that are already used in certain applications and have been performing well. As the need and the complications in certain areas have been progressively discovered, there is a wide requirement for materials' research that has a combined effect of more than one property which is a limitation of monolithic materials. To have such an effect, the fabrication of certain materials having a well-tailored blend of properties as per the reinforcement is used to form a composite. A review has been carried out for the various research works and the effort is being made to summarize the effect of mono and hybrid reinforcements on the materialistic properties as compared to the base material.

Keywords: Aluminium, Composites, Hardness, MMC, Tribological test.

INTRODUCTION

As material science has advanced in many ways, there is a need for advancement in material research as the application areas have become very competitive in nature. This thus requires a lot of research on metals and non-metals thus leading to different analytical studies to find the optimum use of the material in a certain field of application. During the research, it has been found that various Metal Matrix Composites (MMCs) combine the properties of two different materials which lead to the production of a new material which is basically an alloy. This alloy has a higher percentage of the base material and a much lower percentage of the alloying materials that are combined with it. The main idea behind this type of material production is to majorly have the properties of the base metal but due to the application areas in certain fields, these properties somewhat need an alteration. These small changes in properties can be made with the help of alloying elements being used to increase the tensile strength, and compressive strength and alter wear properties to a great extent. As we see, the introduction of

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an alloying element leads to a composite, similarly the formation of a metal composite sometimes also called MMC in the case of a metal alloy. Thus an MMC is created when another alloying element is added to a base metal to positively alter its properties. This alteration makes it useful in various fields like aerospace, marine and automotive areas (Fig. **1**). The term ‘composite' is usually referred to describe a material in which distinct phases can be seen easily under a microscope, rather than at the atomic level. These distinct phases contribute to the formulation of a well-tailored material in which the properties of a composite differ from those of the individual element constituting it. In other words, the strength of one element rectifies the weakness of the alloying element. It is observed that the combination of these materials should be carefully calculated to exhibit distinctive mechanical and thermal properties. In recent years, the use of bio-reinforced composites has also gained some interest in research. The utilization of bio-waste material such as groundnut shell ash, fly ash, sugarcane bagasse ash, *etc*. has been explored which could be also be an additional reinforcement beyond the elemental reinforcement (Fig. **2**). This approach leads to the reuse of industrial waste and concurrently reduces the cost of the composite production.

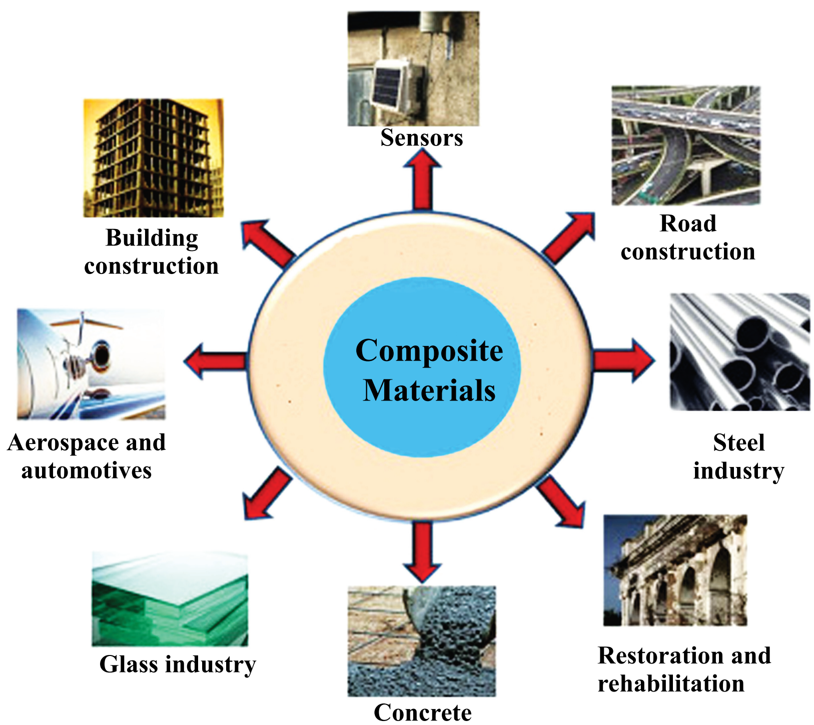

Fig (1). Use of composite materials in various fields.

It is observed that various types of reinforcements are used in the development of the MMCs. These can be present in the form of fibers referred to as fiber-reinforced composites, laminar sheets, known as laminar composites or in particle form called particulate composites. The MMCs thus developed in the various categories have shown various positive results. The density of the material reduces by 20-40%. Despite achieving lower density, higher strength is obtained which can be up to four times the material strength to density ratio. Higher directional mechanical property is observed, particularly in terms of the tensile properties of the material. Thus, the developed MMCs have greater strength than the pure steel or aluminium with greater fatigue endurance. The toughness of the material is also not compromised; in fact, it surpasses that of ceramics and glasses. Machining these MMCs is also easy with the various methods, making them applicable in various fields. The corrosive properties of these composites are found to be superior as compared to the regular metals.

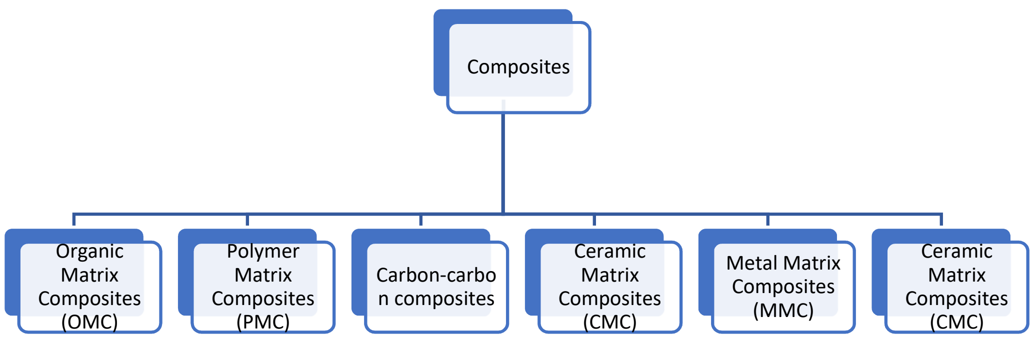

Fig (2). Classification of composites.

Metal matrix composites combine the properties of two different metals. Aluminium matrix composites (AMCs) are also types of composites that find their application with various available alloying elements available, usually ceramic materials (TiC, SiC, B_4C, Gr, Al_2O_3, WC, TiO_2*etc*.). The process of making these AMCs can be executed with the help of powder metallurgy or liquid metallurgy. Additionally, due to the lightweight nature of aluminium, it is used in various moving parts such as automobile components like engine heads, pistons, piston rings, shafts, drives *etc*. Considering this, the addition of a self-lubricating material needs to be studied to overcome the wear properties of aluminium, and materials like graphite can be considered. Due to the above-mentioned points, research on composite appears very promising, leading to the discovery of better AMCs having much superior properties.

CHAPTER 8

Hybrid Glass Fiber Reinforced Composites: Classification, Fabrication and Applications

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Abstract: The need to develop and use materials that are both much lighter and stronger than current materials but are also more energy-efficient has been felt due to the ongoing depletion of resources and the rising demand for component efficiency. Composites are the best available suitable materials due to their excellent ultra-light weight and outstanding strength characteristics. They have great energy absorption capacity, high stiffness, high fracture toughness, and low thermal expansionin addition to being highly strong in effect and light in weight. Today, composites are being used in an increasing number of technical fields, from the automotive to aviation.

Keywords: Applications, Composites, Fabrication Techniques, Fiber reinforced polymer, Mechanical Properties.

INTRODUCTION

Materials with high strength, stiffness, hardness, and other properties are needed to meet the constantly growing need of new advanced technologies. Composites are becoming increasingly popular because of their reduced weight, increased durability and outstanding wear resistance. Composites are resilient to a variety of environmental stresses. On a macro scale, these materials often have multiple chemically or physiologically distinct component constituents. They are divided by a distinct interface based on their respective compositions. Composites are formed up with one or more constant phases and one or more discontinuous phases [1].

Classification of Composites

As indicated in Fig. (**1**), composites can be split into two groups: those composed of natural fibres, such as wood, palm, and bamboo, and those made of artificial

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fibres, such as glass and carbon. Products made from synthetic composites can be distinctive, flexible, and of high quality, which is not possible with materials from other traditional sources. High-durability artificial composites are utilised gradually for a variety of applications in demanding operating environments. Materials with special mechanical qualities, a lower specific weight, and greater resistance to external influences are needed to meet fundamental industrial needs. Moreover [2 - 9], enhanced mechanical characteristics in composites are necessary to reach and maintain certain safety standards and cost-effectiveness.

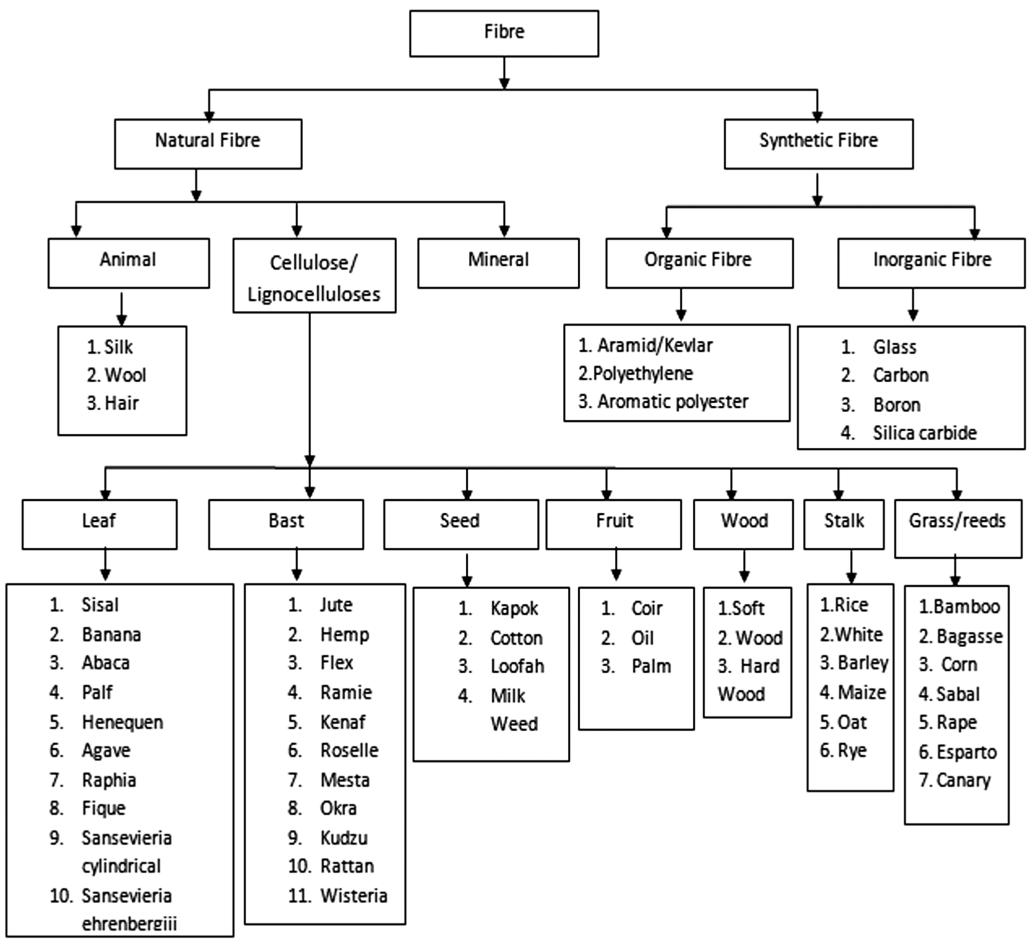

Fig. (1). Classification of various fibre materials [12].

Various synthetic composites used in polymers are either thermoplastics or thermosetting plastic polymers. In these composites, the cross-linked polymeric chain is used which ensures that the structure should be strong and rigid. Due to this rigidity, it makes the polymer almost impossible to melt or dissolve, whereas thermosetting plastics start melting when exposed to various solvents. They also own the characteristic of moulding under thermal conditions [10 - 12].

Moreover, an epoxy resin is used to connect these polymers together. Epoxy resin typically consists of linear epoxy resins and a curing agent such as poly [13 - 22] bisphenol-A diglycidylether) DGEBA and triethylenetetramine (TETA), as shown in Fig. (**2**), which reflects the repeated number of units, often between two and 25.

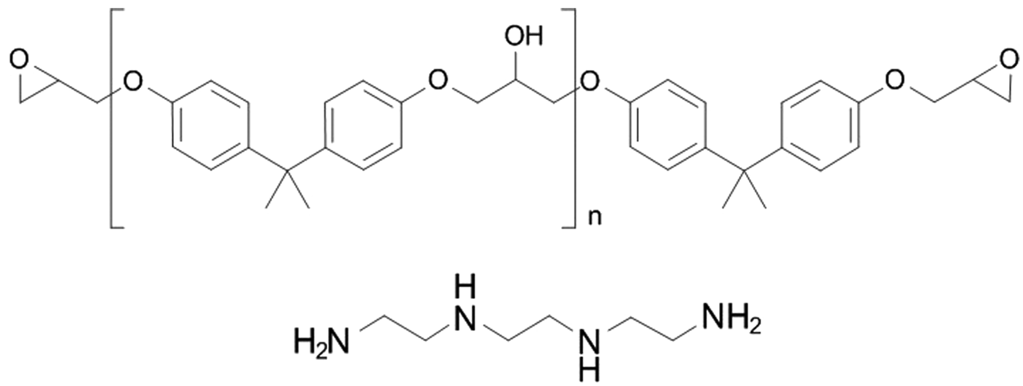

Fig. (2). Structure of DGEBA and TETA polymers with an as the repititive unit.

These groups interact with one another to cure the matrix and create a hard, stiff structural unit. A cross-linked structure made of DGEBA and TETA is shown in Fig. (**3**).

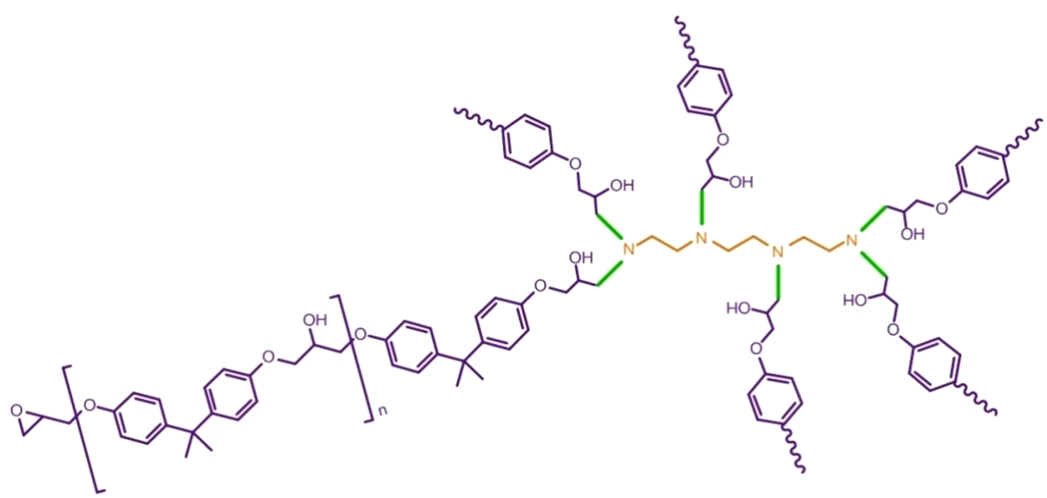

Fig. (3). An example of cross linked chemical structure of DGEBA and TETA.

CHAPTER 9

Corrosion and Wear Behaviour of Metal Matrix Composites

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Abstract: Metal matrix composite (MMC) has several attractive characteristics (low coefficient of thermal expansion, lightweight, better abrasion, high strength-to-weight ratio, superior stiffness, thermal stability, *etc*.), when compared with monolithic materials. Due to these charming characteristics, MMC materials have received wide scope in distinct industries (marine, aerospace, defence, mineral processing industry, automotive, electronic, and recreation industries, *etc*.). But, owing to the requirement of higher ductility and brittleness in the form of reinforcement and matrix, there is a need to improve the properties of composite (MMC) that will fulfil the requirement of the engineers. In addition, MMCs are typically more prone to corrosion and wear as compared to their monolithic matrix alloys. Thus, the study of corrosion and wear behaviour of distinct composites such as Al/SiC *etc*. are highly important for better corrosion resistance for distinct applications. This chapter provides an overview of the corrosion and wear behaviour of MMCs and applications.

Keywords: Applications of MMCs, Classification, Corrosion, Historical development, Metal matrix composite, Material properties.

INTRODUCTION

Metal-matrix composites (MMCs) are metals that have had continuous or discontinuous reinforcement added to them, often in the form of fibres, mono-filaments, whiskers, short fibres, particles, *etc*. Metals (such as stainless steel, and tungsten), nonmetals (such as silicon, and carbon), or ceramics (SiC, Al_2O_3) can

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all be used as reinforcements. The choice of the reinforcing ingredient and matrix metal is often made based on how effectively the two work together to provide the desired qualities. MMCs are typically strong, rigid, and light, although they are sometimes designed for other characteristics. Also, reducing weight, thermal expansion, friction, and wear, reinforcements have been utilized in MMCs to enhance their properties. Even while MMCs have characteristics that are more advantageous than those of their separate components, corrosion resistance is frequently compromised. Due to the inclusion of reinforcements that change the micro-structure, electro-chemical characteristics, and corrosion morphology, the corrosion behaviour of MMCs frequently differs dramatically from that of their mono-lithic matrix alloys [1, 2].

What are MMCs

Metals are strengthened with fibres or other particles to create metal-matrix composites (MMCs), which may be used to increase or customise qualities including tribological and mechanical properties. In general, MMCs are additionally prone to corrosion than their mono-lithic matrix alloy counterparts. Various degradation issues may result from the interactions between reinforcement particles or fibres and the matrix, such as electrochemical, chemical, or physical interactions. Processing issues might potentially cause corrosion issues [3]. MMCs have improved mechanical properties over traditional materials. The materials are made up of reinforcement and metal materials, which are added to metal matrices to enhance their toughness, stiffness, strength, and wear and tear resistance. Ceramics, carbon fibres, and various metals are examples of reinforcing materials. MMCs are being employed more frequently in various sectors *i.e*. defence, sports, automotive and aerospace, for their unique qualities. They outperform traditional materials such as steel and aluminium alloys due to their higher wear resistance, strength, and remarkable thermal stability. In addition, MMCs are widely used in high-performance, lightweight, and long-lasting items such as engine parts, braking systems, drive shafts *etc*. Casting, infiltration, and powder metallurgy are all processes for producing MMCs. Some of the disadvantages of MMCs are their high cost, difficult production, and proclivity for interfacial interactions b/w the MMCs and the reinforcing material. Thus, current research focuses on developing new materials, improving existing properties such as corrosion resistance, fracture toughness, and fatigue life, and fixing their flaws. In conclusion, MMCs offer unique properties that make them appropriate for a diversity of applications [4 - 6].

HISTORICAL GROWTH OF MMCs

Early 1900s' research on the idea of strengthening metals with additional materials to enhance their mechanical properties led to the invention of MMCs. The availability of new processing methods and the stipulation for materials with enhanced mechanical qualities have, in general, driven historical growth in MMCs. To create materials with even superior qualities, researchers are at present working with new matrix material and reinforcement type combinations. The historical improvement of MMCs is represented in Fig. (**1**). In addition, the examples of distinct models as well as theories that have been developed to find out the characteristics as well as behaviour of MMCs are given in Table **1** [7].

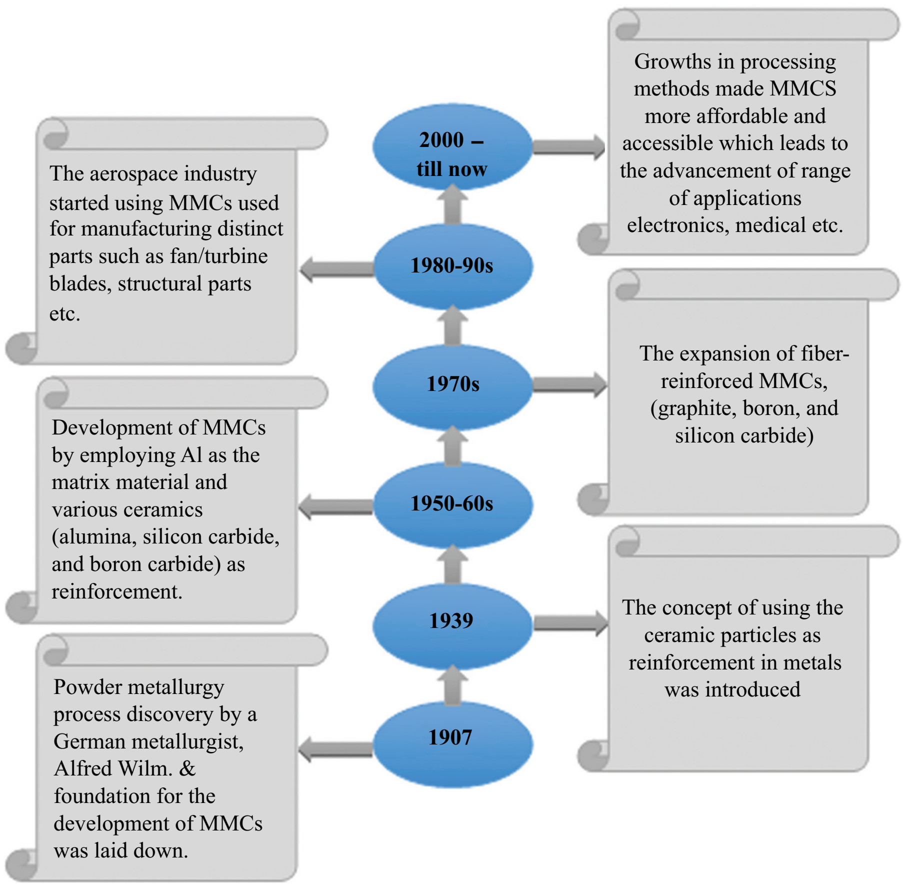

Fig. (1). Growth of MMCs [8, 9].

CHAPTER 10

An Experimental Investigation of Process Optimization of EDM for Newly Developed Aluminium Metal Matrix Composites

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Abstract: The aim of this investigation is to investigate the contribution of controllable input parameters (*viz*. pulse on times, peak currents) on the performance of two newly developed MMCs (Al-8.5%SiC-1.5%Mo and Al-7%SiC-3%Mo). Both the metal matrix composites were fabricated using the stir-casting method. Thereafter, various tests such as microhardness test, tensile test, and porosity analysis of the newly developed composite were performed. To carry out the machining trials, an L_{18} orthogonal array (OA) was chosen. Optimization of the machining process was performed according to Taguchi analysis followed by grey relational analysis (GRA). The results showed that with increasing weight fraction of the molybdenum particulates, microhardness and density of the composites increase with a small reduction in the tensile strength. In addition, pulse on time is the most contributing parameter among others to obtain optimal process performance. The optimum setting of input variables suggested by GRA to obtain optimal responses is a molybdenum composition of 3%, Pulse on time of 70 µs, and a peak current of 9A. Based on the interaction plot, it is evident that process performance measures of EDM depend on controllable input parameters.

Keywords: AMMC, EDM, GRA, Molybdenum, Optimization, Silicon Carbide.

INTRODUCTION

Today's materialistic world has become very advanced in terms of research and developing almost new kinds of infrastructural elements and manufacturing them

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based on unique scientific requirements. To fulfill the need and specific requirements, scientists and engineers are upfront to find out new materials for specific use [1, 2]. This phenomenon encouraged them to invent and make new materials by combining two or more materials. During combination, both materials exchange their chemical, physical, and mechanical properties with each other thus possessing new materials with new properties. Recently, composite materials are becoming too popular in the industrialized world to satisfy and fulfill the desired needs as per requested requirements.

Composite materials are fabricated with two or more distinguishable materials defining totally dissimilar mechanical, physical and chemical properties which are combined together in an orderly manner to create an almost new material. This newly developed material is specialized for specific use. Based on matrix materials, these are classified as a polymer matrix, metal matrix, ceramic matrix and natural composites such as wood, which is composed of cellulose (a polymer – C6H10O5) and lignin [3]. However, in the manufacturing methodology of composite material, which material's property is to be changed is taken as a matrix material and the material which is added into matrix material to change its properties is called the reinforcement material [4]. When the matrix material is polymer, then the fabricated material will be PMCs; if the base material is metal, then the manufactured one will be MMCs and CMCs, if ceramic is taken as the matrix material. Matrix material is considered a monolithic material in which the fiber system of other materials is to be embedded. Both matrix materials and reinforcement materials are identical at macroscopic and microscopic levels.

When the base or matrix material is an alloy or a metal, then the composite material is known as MMCs. When two or more reinforcement materials are added to the matrix material, then the resulting material is called "Hybrid MMCs (HMMC's). These advanced HMMCs are developed for lightweight and heavy-duty applications [5]. The changes in the properties are relied upon by both materials-matrix and reinforcement. Constituent materials can be added into the matrix material in the following forms – continuous fibre and discontinuous fibre form, particulate form and monocrystalline whiskers form.

Among the family of metal matrix composites, AMMCs are one of them. This type of composite material is well-renowned for its low weight and heavy load work abilities. By combining the strength of reinforcement with the ductility of matrix material, composite defines the properties of both materials – the matrix and the reinforcement. For compositions, usually silicon carbide (SiC) or Aluminium Oxide (Al_2O_3) is taken as a reinforcement material. However, the reinforcements are still distinguishable at macroscopic or microscopic levels after composing. AMMCs have significant importance in the manufacturing of long-lasting applications where higher specific stiffness and strength are required. Usually, high-speed and continuous-running components of machines and robots are manufactured from this composite material. After being composed of silicon carbide, it can withstand higher elevated temperatures with excellent thermal conductivity thus highly useful for making automotive engines.

Aluminium 6061 alloy has low specific gravity and possesses a good strength-to-weight ratio. It possesses significant engineering applications in the field of aerospace and automotive industries. The combination of good strength at low weight and its high weldability properties, allows the use of Al 6061 alloy for making the fuselage structure of aeroplanes, helicopter rotor skins, structural towers, bridges, frame making of vehicles, and rail coaches. It is highly weldable by two different fusion welding methods (TIG and MIG welding). Throughout the time of welding, there is a loss of strength magnitudes to 40% of the main strength of the material that occurs at joints made by welding. Thanks to its heat treatment ability by which, 30% of its strength loss can be recovered by 2-phase T6 heat treatment. The Al 6061 grade composite material has higher thermal conductivity than 7075 Al and possesses low resistivity in the electric current flow thus having higher electrical conductivity. Therefore, it has indicative importance in the manufacturing of conductive materials. The Al 6061 alloy has predominant engineering importance in the manufacturing processes of extrusion, forging, and casting.

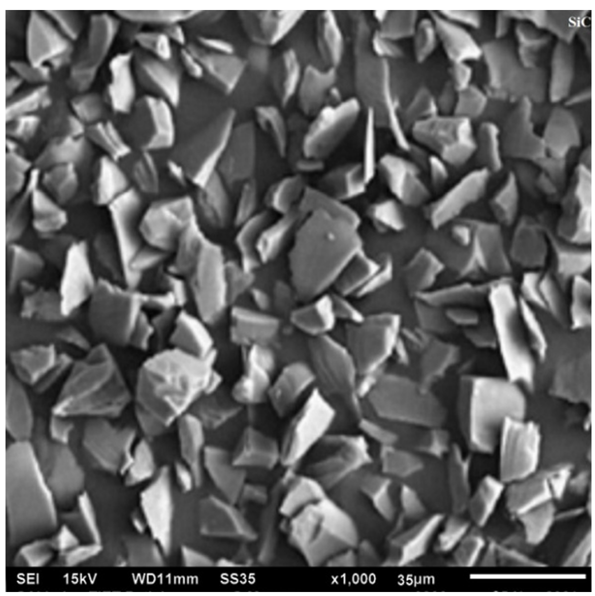

Fig. (1). SEM Images of Silicon Carbide (SiC).

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Prof. Virat Khanna is an associate professor and head of the Department of Mechanical Engineering at Maharaja Agrasen University, HP, India with 12 years of teaching experience. He did Ph.D. in mechanical engineering from Maharaja Agrasen University, HP, India. He completed M Tech in mechanical engineering in 2013. His research areas are aluminium metal matrix nanocomposite (graphene, CNT, processing technique, optimisation and mathematical modelling techniques). He has published and presented more than 35 papers in journals and conferences of national and international reputation. He is also the editor of several books and conference proceedings with various international publishers like Elsevier, CRC Press, IGI Global, Bentham Books, etc.

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Santosh Kumar

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