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Matrix materials used in composites: A comprehensive study

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ABSTRACT

Composites are very significant materials for a large variety of applications in various engineering areas because of their enhanced mechanical, physical, and machining properties. These materials have been endless of applications because of their behavior, mainly mechanical, compared to other materials since it has demonstrated less density and significantly higher resistance. The composite materials have many benefits and excellent properties in comparison to conventional materials, which make the application of composites in many areas. More research and studies are being carried out to improve the characteristics and manufacturing techniques further, to promote the potential implementation of composites. In recent years, the application and development of MMCs have increased in many engineering fields. With the arrival of innovative technologies, high research activities and the development of different processing techniques, composites with improved properties become attractive materials for engineering applications. A wide array of metals, especially low-density metals or alloys, are generally selected as the matrix material for the composite. This research article provides a brief overview of matrix materials generally used in composites, and types of composites, with their important aspects.

1. Introduction

The advancement and growth of societies have historically been closely related to their member's expertise to develop and use materials to meet their requirements. Historically, old civilizations have built laminated structures composed of metallic and non-metallic materials. The history of modern-day composite perhaps started in the 1930s. In 1960, the introduction of polymer-based composites prompted commercial exploitation by multiple sectors. Composites are since then considered superior materials and are designed and produced for different industrial and non-industrial purposes, including aerospace, automotive and sports equipment. Efforts were made in the late 1970s to develop metal matrix composite (MMC) materials, mainly from aluminum alloys, using SiC whisker reinforcements. The main motive for these attempts was to considerably improve aluminum alloy characteristics by attaining high specific modulus and specific strength. The high cost of whiskers led to the development of particle reinforcements. At the end of the 20th century, the direction of research focused on the use of low-cost reinforcements. Composite materials are widely used in many industries such as automotive, mechanical and aerospace, because of exceptional properties. A composite material is the union of two or more materials, different from each other, to get better properties (mechanical, physical, thermal, electrical). Composites usually comprising one continuous phase known as a matrix together with one or more discontinuous phase are called reinforcements. Composite materials have two phases, the reinforcing and matrix, for the matrix phase, ceramic's metals or polymers utilized, and for reinforcing phase Fibers, Particles utilized. The discontinuous phase is harder or softer, relying on the application. Components which needed excellent wear resistance are manufactured with harder reinforcements and to obtain characteristics like lubrication softer reinforcements such as graphite and molybdenum are used. Characteristics of composite materials depend upon the reinforcements and the matrix. The matrix holds the reinforcement in order to create the desired shape even though the reinforcement improves the overall characteristics of the matrix. The elements of the composite must not react with one another at high temperatures, which result in early failure of the composite. The all-natural composite was found in various forms

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as, bone tissues, hardwood and so on throughout the history of humanity. Several composites utilize nowadays, which developed via innovation together with efficiency at the optimum price and ideal for ultra requiring demands like space industries. The factors that affect composite characteristics comprise the geometry of reinforcement, shape of the discontinuous phase, distribution of concentration, orientation of reinforcement, and volume fraction. Concentration determines the input of the single constituent and influences composite characteristics, while orientation impacts the composite isotropy. Traditional monolithic materials possess constraints to regard possible combinations of different properties [1,2].

Galy et al. [3] studied the preparation of SiC-reinforced Al-MMCs and mechanical properties. If the particle size decreases, the density will decrease and if the size of the particle increases, the hardness will decrease. Rao et al. [4] studied the SiC reinforced Al 7075. If there is an increment in the size of the particle and weight percentage of SiC, improvement in the strength and hardness obtained. Pradhan et al. [5] studied the tribological properties of SiC-reinforced aluminum alloy LM6 MMC under dry, alkaline and aqueous medium. Fabrication method was stir casting. Wear was minimum in dry sliding then aqueous medium and after that in an alkaline environment. Kandpal et al. [6] studied the properties of Al2O3 reinforced Al 6061 composite. The result shows that the ductility decreased with increment in Al2O3 content.

2. Types of composite materials

The classification of composite Based on the matrix materials shown in Fig. 1.

The background of growth of metallic and ceramic matrix composites is considerably even more current than that of the polymer matrix composites. The preliminary research study on metallic as well as ceramic matrix composite could not make perfect high-quality composites as it was focused on continuous carbon or boron fiber, continuous development in the field of fibers accelerated this research. The role of the matrix is to keep the reinforcement particles in place and to support them. In general, reinforcements affect mechanical and physical characteristics or on any other tailored characteristics improved from the matrix material. A wide range of characteristics can be acquired by combining many possible reinforcements and matrix, to alter material characteristics to meet specific requirements. The matrix maintains the reinforcement to create the required shape while the reinforcement increases the entire mechanical characteristics of the matrix. The matrix is monolithic material in which usually the reinforcement is embedded and must be uniformly distributed throughout the matrix. Materials such as aluminum, magnesium, nickel, titanium, cobalt can be used as matrix materials. The reinforcement phase should be well bonded to the matrix material [7].

2.1. Polymer matrix composites (PMCs)

Currently, PMCs are commonly used composite, from available composites. In PMCs, the matrix generally reinforced with ceramic fibers since they have high strength in comparison of the matrix material. The characteristics of PMCs are relying on the matrix, reinforcement, process parameters, microstructure, composition and the interphase. PMCs are well-known for their reasonable price and the easy method of production. The manufacturers of PMC can create cost-effective products with various manufacturing procedures. Each manufacturing process has features defining the sort of product to be manufactured. This expertise enables the manufacturer offers the best option for the consumer. Polymer matrix composites consist of thermoplastic or thermosetting plastic as a matrix with one or more reinforcements, such as carbon, glass, steel and natural fibers. Polymers produce good components as they could be processed conveniently. Lightweight is an important feature of polymers. Polymer composite composites (PMCs) offer a wide variety of properties. Some of them are high strength, excellent impact, compression, fatigue properties; cost-effective processes of production and tooling, outstanding chemical and corrosion resistance, available at low-cost chemical inertness and good mechanical characteristics. The applications of PMCs are generally in rocket, aircraft and sports equipment [8].

2.2. Ceramic matrix composites (CMCs)

Ceramic Matrix Composites are a mixture of ceramic particulates, fibers and whiskers with a matrix of another ceramic and may be defined as solid materials that normally show highly strong bonding generally ionic, but in a few cases, it may be covalent. The ceramic matrix can be reinforced by ceramics, metals, glasses, and polymers. The ceramic-based matrix materials are having exceptional corrosion resistance, high melting points, superior compressive strength, and stability at high temperatures. Ceramic matrices are the common choice for high-temperature applications such as pistons, blades, rotors in gas-turbine parts. They can survive at high temperatures and operate efficiently in corrosive environments. The principal goals in the making of CMCs are to enhance the toughness because monolithic ceramics are brittle but having high stiffness and strength. It is crystal clear that the reinforcement along with particulates and continuous fibers, has led to a rise in

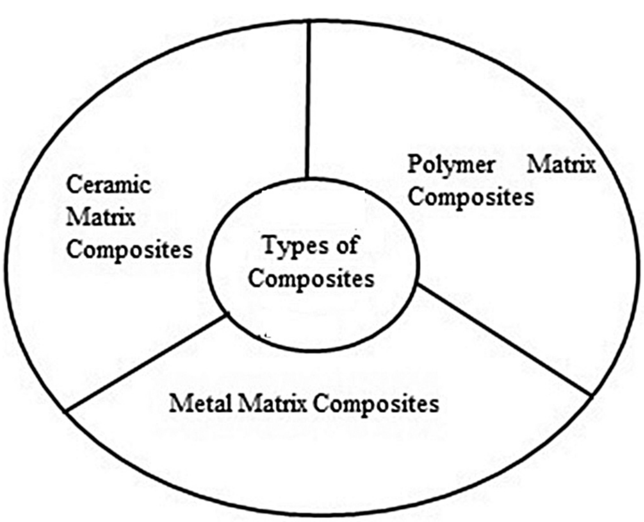

Fig. 1. Classification of Composites according to Matrix Materials.

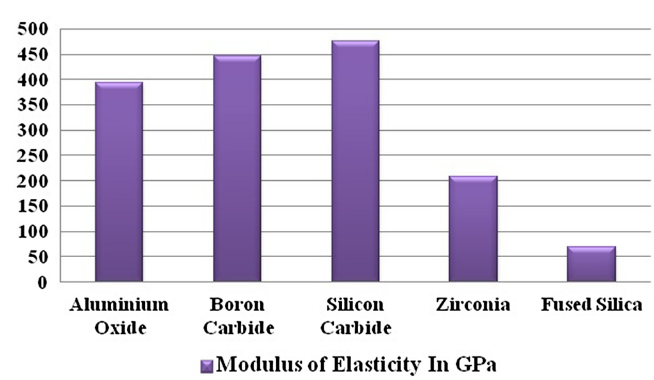

Fig. 2. Modulus of Elasticity of ceramic materials.

toughness, but the rise is even more considerable for the second, CMCs either oxide-based or non-oxide based, a comparison of modulus of elasticity of few ceramics shown in Fig. 2.

The major drawbacks of CMCs are failures at low strain, which restricts the stress in the fiber at lower levels. It has a reasonably high modulus and lower ductility that protect against adjustment of thermal stresses from any sort of variation in thermal expansion [9].

2.3. Metal matrix composites (MMCs)

Metal Matrix Composites are widely recognized as advanced materials. MMCs are better than conventional materials in terms of enhanced mechanical and thermal properties that embrace good wear resistance and exceptional thermal conductivity. Mechanical properties of some metals which generally used as a matrix are shown in Fig. 3, Fig. 4, Fig. 5. Currently, common matrix metals are Aluminum, Copper, Iron, Magnesium, Nickel and Titanium.

Aluminum alloys are mostly used in automobile and aerospace sector in structural applications due to good forming and joining properties, low density, excellent strength, and corrosion resistance. Ceramic particles are incorporated to make a composite material, to enhance the strength of aluminum and its alloys. Composites based on titanium have a vast application, especially as a material for high-temperature structures. Alloys of titanium are typically used in the aerospace components because of superior strength at high temperature and good corrosive resistance. The material, however, is expensive. Magnesium is the lightest out of a range of non-ferrous metals, generally used in electronics equipment, the chain saw housings and gearbox housings for aerospace applications. Copper can be easily cast and formed. Copper-based composite materials having excellent wear resistance and are used in electronics as electrical contacts and elements of the electronics system. Metal Matrix Composites have actually stimulated extreme attention in the current times for potential industrial applications. MMCs have a wide range of prospective applications in many industries. Recent research in a field of MMCs highlighted the right potential to produce composites with outstanding mechanical properties. These MMCs can be a perfect substitute of costly conventional alloys used for both structural and functional applications. Aluminum matrix composite is recommended for advanced structural applications.

In an attempt to acquire more commercially feasible products, more effective fabrication methods are essential. A variety of procedures are used in the manufacturing of MMCs. The primary intention is to introduce additional effective, economical as well as production techniques, to fulfill the requirements of different industries. The considerable amount of research study is going on in the field of manufacturing of MMC, which lowered its expenditure to a reasonable level. Through an appropriate combination of metal matrix and reinforcement, it is feasible to get the intended properties for a specific application. MMCs have metallic characteristics of matrix alloys and ceramic characteristics of reinforcements. The reinforcement particulates generally used to increase strength and modulus of elasticity and commonly used are SiC, Al2O3, TiN, TiC, B4C, TiB2. Among these, the addition of SiC and Al2O3 into the aluminum matrix shows enhanced properties [10,11].

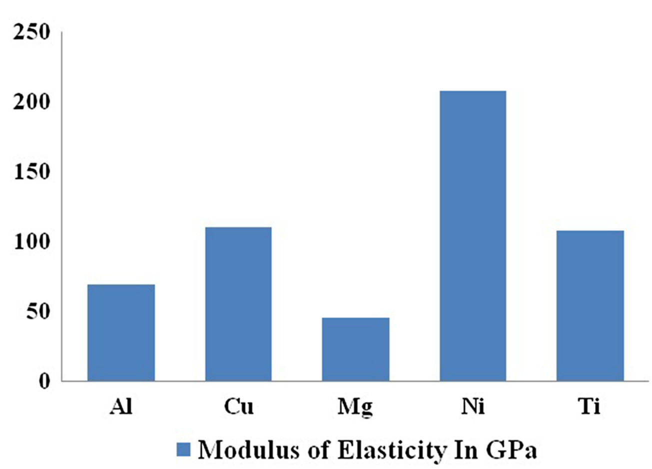

Fig. 3. Modulus of elasticity for different metals normally used as matrix material.

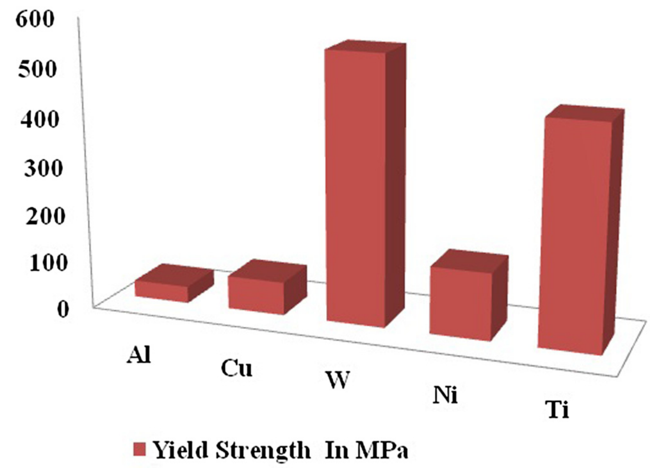

Fig. 4. Yield Strength of metals generally used as matrix material.

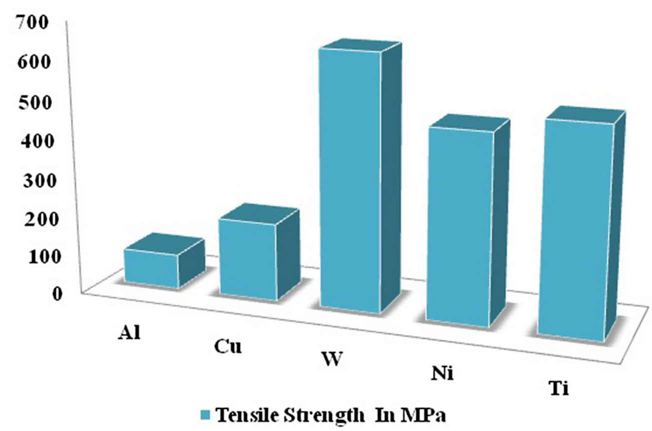

Fig. 5. Comparison of Tensile Strength of metals commonly used as matrix material.

2.3.1. Aluminum metal matrix composites (Al-MMCs)

Al and its alloys are generally used for producing MMC. In most of the engineering applications, Aluminum and its alloys grabbed the attention most as matrix material in MMCs due to their outstanding mechanical properties, excellent ductility, and good corrosion resistance. Aluminum matrix composites are familiar due to their easy availability, low-cost and attractive wear resistance. Al-MMCs are widely used due to the combination of factors such as durability, machinability and accessibility than other competing materials. The additions of nonmetallic material, i.e., fly ash, SiC, Boron carbide, can improve the machining, tribological and mechanical properties of Aluminum alloy matrix. These compos-

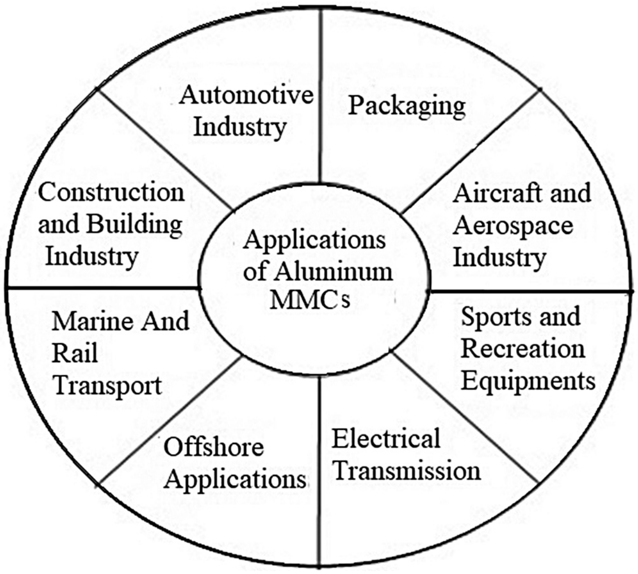

Fig. 6. Different applications of aluminum MMCs in Industries.

ites possess a vast array of application in industries, which are given in Fig. 6.

Aluminum MMCs are very famous for their flexibility in processing and their exceptional mechanical and tribological properties, thus become a highly acceptable material for a broad array of applications. The early research focused on the growth of aluminum matrix composites. Magnesium-based composites drawn less interest primarily because of its intrinsic properties of low deformability at room temperature and poor corrosion resistance, although their characteristics can be comparable or better than aluminum based composites. Among MMCs, particulate reinforced aluminum matrix composite is the most important one. Particulate MMCs have a high property of ductility and offer more excellent wear resistance. Reinforced aluminum alloy MMCs, fabricated by the vortex method [12,13,14].

3. Conclusion

The fast-developing technology has accelerated the advancements in the field of materials, which is actually the principal input of Industry. High-strength, as well as lightness, are the most critical requirements for materials used in advanced industries. For this function, composite materials were made. Research is ongoing to address some of the current obstacles and difficulties identified in the growth of matrix materials used in composites. New technological innovations and evolving trends refer to the enhanced use of MMCs in the present and prospective industrial developments. It is no wonder that we are not yet in the era of MMCs. It is also evident that a significant and long-term dedication to the growth of MMC is needed if their real capacity is to be achieved. In the field of composite materials, constant development and progress continued to achieve the mechanical and physical properties necessary in accordance with the required application. It is evident that the future of composites is exceptionally bright.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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