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Review of composite materials and applications

Mahesh Bhong [a], Tasneem K.H. Khan [b], Kiran Devade [a], B. Vijay Krishna [c], Sreekanth Sura [d], H.K. Eftikhaar [e], H. Pal Thethi [f], Nakul Gupta [g,*]

[a] *Indira College of Engineering and Management, Pune, India*
[b] *Department of Chemistry, (Science & Humanities Department) Anjuman College of Engineering and Technology, Nagpur, Maharashtra, India*
[c] *Department of Mechanical Engineering, Institute of Aeronautical Engineering, Hyderabad, Telangana, India*
[d] *Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad, Telangana, India*
[e] *College of Engineering Technology, National University of Science and Technology, Dhi Qar, Iraq*
[f] *Lovely Professional University, Phagwara, India*
[g] *Department of Civil Engineering, GLA University, Mathura, UP, India*

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ABSTRACT

This research seeks to discover and analyze the characteristics of composites that contribute to their performance improvement. Molding techniques are employed in a variety of industries to create composite products. Apart from their light weight and their high relative stiffness and strength, they have other advantages as well. Fundamental concepts comprise the material and physical properties, in addition to their design, tooling repair, inspection, and design. High-strength, lightweight materials helped to make helicopters, aircrafts, and rockets that were used for military purposes. It was evident that the components made of metal until that point were superior in terms of mechanical performance however, their weight rendered their usage ineffective. Numerous companies working in the polymer sector were expanding into new markets and expanding. The improved mechanical properties of polymers could solve a number of problems, and this was the case when researchers created a new light polymer in the laboratory. Composites are engineered materials made from two or more parts that have a wide range of physical, chemical, as well as mechanical characteristics. The distinct features of the individual parts and the arrangement of these components inside the structure lead to a myriad of distinct characteristics in composites. Composites can be altered to meet a variety of mechanical, geometrical, structural and chemical demands. Synthetic materials are utilized in various areas, such as construction (such as bridges and structures) as well as the automotive industry (such as bodywork for automobiles) as well as aviation, military (such as boats and ships) and even biology. Composites are fast becoming popular in the field of medicine, despite the fact that polymeric, metallic, and ceramic biomaterials were used for a long time in processes like tissue repair and replacement.

1. Introduction

Composite materials are used in many different fields, including construction (for things like buildings and bridges), the automotive industry (for things like car bodies), aeronautics (which requires materials with the properties of high strength and low density), the production of housing and industrial parts (for things like storage tanks, bathtubs, washing sinks, and shower stalls), and the medical field [1]. Materials scientists and engineers collaborate with biomedical engineers to better people's health, who apply engineering principles to medical biology. Understanding human anatomy and physiology is essential for both fields because it allows the development of biomaterials that, once created and implanted in humans, can carry out their intended functions without causing injury to the surrounding tissues or the body as a whole [2]. The effectiveness with which biomaterials carry out their designated tasks categorizes them into several groups. Due to their various benefits, composite biomaterials have found widespread application in both in vitro and in vivo environments. These multiphase materials are easy to produce and can take on multiple forms and characteristics. By manipulating essential factors such as constituent volume ratios, fibre particle size, shape, orientation, distribution, matrix type, etc., desirable material qualities can be accurately crafted. Compared to metals,

* Corresponding author.
E-mail address: nakul030588@gmail.com (N. Gupta).

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polymers, and ceramics, composite biomaterials provide more leeway in design and may be tailored to have almost any desired combination of properties. This study aims to introduce the concept of composite biomaterials, explore their potential as replacement and repair components, and present an overview of recent developments in this area. The benefits of metal, polymer, and ceramic biomaterials are compared [3]. The need is the starting point for most inventions because it motivates so much of what we do. Initially, he was limited to using the rich natural resources surrounding him. Tools are wood and stone, while clothing is made from animal skins. Next, he discovered he could weave natural fibres like cotton and silk to create cloth. The technological revolution of the previous two centuries has been primarily responsible for the exponential growth in human knowledge. Wattle and daub, used for wall construction for almost 6,000 years, is the first example of a composite material made and used by humans. This construction material has been mainly superseded by concrete, a composite material made of cement and reinforcements like gravel (aggregates), sometimes known as loose stones. Many millions of metric tonnes of concrete are produced worldwide each year. Concrete has a muscular compression strength but a relatively weak tensile strength due to its mechanical characteristics [4].

Natural fibre composites are originated from the environment itself. From the Egyptian and Indus Valley civilizations, clay reinforcement was first utilized as a building material. They are biodegradable, easily available, low in cost and possess moderate strength in engineering, making artefacts etc [5]. Steel reinforcements are frequently added to concrete during casting to increase strength and prevent it from failing under tensile stress. Fibre-reinforced composites are another popular type (FRP). Carbon fibre-reinforced composites are very popular because of their lightweight and easy variation in mechanical properties. Because of the intensive bond between Hydrogen and Vander Waal forces, the carbon and reinforcement agent coalition become unbreakable [6].

Most FRPs are either glass-reinforced plastic or carbon fiber-reinforced composite (CFRC). Carbon and glass are utilized to make CFRC and GRP, respectively, in the form of fibers or inclusions. Epoxy resin, a thermoplastic, is frequently employed as a binding or matrix material. Composite wood, mainly constructed of thin layers of hardwood boards bound together, is one of the many composites [5]. Others include ceramic matrix composites (CMC), metal matrix composites (MMC), polymer matrix composites (PMC), and composites (ACM). Traditional composites include those made with ceramic, metallic, and polymeric matrices (ceramic matrix composites (CMC), metal matrix composites (MMC), and polymer matrix composites (PMC). Due to the utilization of high-strength, low-density fibers, conventional composites have superior strengths, stiffness, and elastic modulus to ACMs [6]. These materials stand out because of their ease of production and their resistance to chemicals, heat, and creep. Synthetic materials, such as plastics, have significantly advanced thanks to research in their creation. Plastic can be made from various sources, including inorganic chemicals, biological matter, or synthetic chemicals. Synthetic organic plastics, essentially polymers, are often referred to by this word. Polymers cannot be made without their constituent monomers. Most of each monomer is composed of carbon and hydrogen atoms. Trace amounts of other elements, such as oxygen, nitrogen, chlorine, and silicon, may also be present. Polymers often take the shape of extremely long chains, which may be linear or branched at numerous locations. Carbon atoms mix easily with other elements and with one another [7]. They create a solid anchor that can carry loads over considerable distances when strung together. This review provides an overview of advanced fiber-reinforced polymer (FRP) composite materials, including their manufacturing techniques, properties, and applications. The authors discuss various types of fibers, matrices, and reinforcement architectures, and highlight the key advancements in composite materials.

Composites are "two essentially different elements that, when mixed, generate a substance having properties that exceed the constituent materials," as the Oxford English Dictionary defines it. Composites are materials in which the matrix and reinforcement have been combined to produce improved qualities over the material used alone [8]. The final composite can have varying properties depending on the method used to cut, align, and place the reinforcement fibers. The addition of this protects the reinforcement from chemical and environmental hazards.

Metal matrix composites, or MMCs, have drawn a lot of interest lately because of their special qualities and extensive variety of uses. MMCs have been the subject of intense research to better understand their synthesis, methods of processing, and mechanical characteristics [9]. Choosing the right kind, size, and quantity of reinforcement is essential for customizing the characteristics of metallic matrices. The tribological characteristics of hybrid composites made of magnesium and reinforced with graphite nanofiber (GNF) and alumina short fiber (Al2O3sf) were the subject of one investigation [10–13]. The synthesis, characterization, healing evaluation, and mechanics of self-healing metal matrix composites (SHMMCs) reinforced with shape memory alloy (SMA) were examined in a different study. Additionally, studies have looked into the application of laser additive manufacturing on several MMC kinds. The design of the material, the interaction between the metal matrix and reinforcement, the techniques of synthesis used in the manufacturing process, and the resulting microstructures and properties were the main topics of this study. The production and use of MMCs have advanced, as demonstrated by recent studies [14]. These composites are appropriate for a range of product-based manufacturing processes due to their distinct mechanical, electrical, chemical, and thermal characteristics.

Construction (for example, buildings and bridges), the automobile industry (for example, car bodies), aeronautics (which requires materials with the properties of high strength and low density), the manufacturing of household and industrial components (for example, storage tanks, bathtubs, washing sinks, and shower stalls), and the medical field are all areas where composites find practical applications (for instance, as biomaterials for tissue engineering). The goal of the multidisciplinary discipline of biomaterials engineering is to improve medical diagnosis and treatment using engineered materials [10]. Biomedical engineering uses engineering principles in medical biology, and materials science and engineering collaborate to improve human health. Understanding human anatomy and physiology is essential for both fields since this knowledge is used to create biomaterials that, once completed and implanted in humans, can carry out their intended functions without causing any harm to the host organism. Different biomaterials are classified based on how efficiently they fulfill their designated tasks [11]. Composite biomaterials fall under this category and are increasingly used in both in vitro and in vivo applications. These multiphase materials are simple to produce while allowing for novel shapes and properties. Changes in the volume ratios of ingredients, the size, shape, orientation, and distribution of fiber particles, the kind of matrix, etc., can readily be made to get the desired material qualities. Composites, unlike metals, polymers, and ceramics, can have nearly any combination of properties by simply changing the constituent parts. This study aims to introduce readers to composite biomaterials, explain their possible applications in replacement and repair components, and analyze the most recent developments in this study area. The benefits and drawbacks of metal, polymer, and ceramic biomaterials are discussed [12]. The reason for writing this review about composites and their applications is to provide a complete review of the factors that drive the research and use of these fascinating materials. From their high-strength and lightweight characteristics to their pliable designs with durability, versatility, and the ability to sustain themselves, composites continue attract engineers and researchers across the globe. Knowing this is a way to understand the constantly changing world of composite materials and their numerous applications, which contribute to technological advances that define our contemporary world. Providing a thorough understanding of composite materials and their uses is the aim of this paper. Its goal is to investigate the characteristics, benefits, and drawbacks of composite materials in a range of industries, including construction, automotive, aerospace, and more. This review will also look at the most recent developments in composite materials and talk about how they might affect next technologies. Researchers will have a better knowledge of composite materials' use in contemporary engineering and how they have shaped our world by the end of this review.

2. Need for composites & benefits

Several advantages of composites can be seen when using metals and wood. Composites' real benefits are their lightweight, relative stiffness, and strength. Lighter cars have quicker acceleration but get worse gas mileage. Shots in golf, tennis, and archery benefit from lightweight composites, increasing their accuracy [13]. A wind turbine's efficiency increases as its blades become smaller and lighter. Rubber wheels have primarily replaced their wooden counterparts, and colorful nylon and polyester have largely replaced cotton in women's fashion. Lightweight aluminum tennis rackets have replaced mainly their heavier wooden predecessors, to name just a few instances. Despite their higher initial cost due to their numerous desired qualities, composites are increasingly being adopted in favor of more conventional materials [14]. Composite materials are important because they can address challenges in industries around the world. These materials are an effective and affordable way to protect metal components against corrosive chemicals like acid rain and salt spray. Their lightweight and high strength properties also contribute to fuel economy and reduce operational costs during transportation. They are therefore an environmentally friendly alternative to traditional materials. It offers new opportunities in the biomedical industry for developing biomaterials which can replace or repair damaged tissues. They are adaptable, allowing for new design possibilities that don't compromise performance or strength. This leads to an increase in efficiency and productivity across industries.

For instance, carbon-fiber reinforced composites can be five times as strong as 1020-grade steel but weigh just one-fifth as much [15]. Carbon-fiber composites can be up to seven times as strong as 6061-grade aluminum and have a modulus that is twice as high. Metals, polymers, ceramics, inorganic glasses, composites, and so on are all examples of materials. Metals have a shorter lifespan when subjected to high temperatures. In general, polymer-rich materials have the potential to function at much chillier temperatures. Despite their strength and thermal expansion capacity, ceramics and polymers are not very practical as structural materials since they become brittle at high temperatures as shown in Fig. 1. In a general sense, composites can be categorized as one of the following:

Fiber Composites: The fibers support the stability of the straight shape.

Particle Composites: Put differently, particles that serve to strengthen matrices. When particles are randomly distributed in a matrix, they support in a manner that is consistent in all directions. Construction materials and synthetics must be excluded.

Flake Composites: Flakes can only be strengthened in two dimensions due to their shape. It is common to find glass or mica in a flake's makeup.

Laminar Composites (layered): Two or more layers of the same or different materials make up a laminar composite.

Combined Composites: Composites are made by blending different substances. In addition, many composites can be fused to create a single product.

Composites play an unexpectedly significant role in driving innovation in the electronics industry. These materials offer several advantages over others (metals, alloys, ceramics, and polymers), including the ability to be produced with precisely controlled chemical, mechanical, thermal, and physical properties. High mechanical strength and stiffness, abrasion, and wear resistance, and so on are typically associated with heavy materials, but the aerospace industry is always looking for lighter alternatives [17]. Besides being aerodynamic, these materials must be simple to manufacture, stable even at high temperatures, and corrosion-proof. Until a more sustainable option is created or discovered, composite materials have been used, are being used, and will continue to be utilized to fulfill the material needs of such sectors. The final qualities of a manufactured composite material are determined by the attributes of each of its constituents, as well as the quantity, shape, and distribution of those attributes [18]. However, material engineers frequently engage in the latter. Mass fractions and volume fractions are two ways to describe the proportions of the various stages or components. Most composites consist of a matrix and an additional element, the inclusion or dispersion phase. The matrix is often a material with relatively high flexibility and moderate fracture strength. The shape and distribution of the latter stage significantly impact the ultimate characteristics of composite materials. The scattered phase's geometry refers to the particles' sizes and shapes, whereas the distribution includes their positions and orientations within the matrix [19].

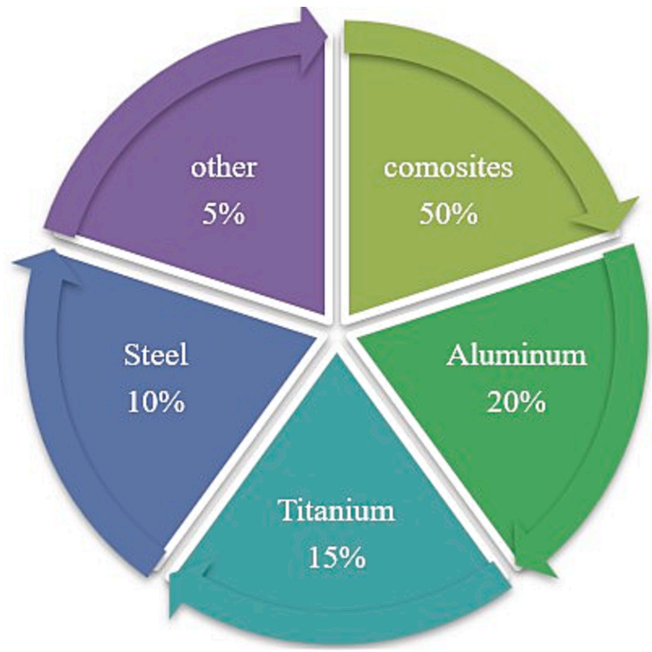

Fig. 1. Materials used in boing787 Body [16].

Composite materials can be broken down into several categories thanks to their evolution over time and the work of many writers. There are three main groups to which they can be assigned: There are two types of composites that use reinforcements: fiber-reinforced composites, which use inclusions with fiber-like properties, and particle-reinforced composites, which use inclusions with uniform axes [20]. Construction composites are a hybrid of modern composites and more conventional materials. Therefore, the primary distinction between the first two categories is the particle geometry in the dispersed phase. Fiber-type particles, like natural fibers, have an irregular geometry but a more excellent length-to-diameter ratio than particle-type particles, which tend to be spherical. Particle- and fiber-reinforced composites can be separated into several groups depending on the matrix used. There are three major categories of composites: those with a metal matrix, those with a polymer matrix, and those with a ceramic matrix. Particle-reinforced composites are strengthened by adding short particulates; these composites can be categorized as large particles or dispersion-strengthened based on the average size of the reinforcements [21]. Large particles (those with a diameter of at least a millimeter) in the former kind bear the brunt of the stress and help keep the matrix from deforming where the two surfaces meet. These limitations are the primary means by which large particle composites are strengthened. When it comes to mechanical stress, the matrix bears the brunt of the weight in dispersion-strengthening composites despite including nanometer-sized particles. This strengthening mechanism occurs at the atomic level, where scattered particles stop dislocation lines from spreading along the matrix. When it comes to composite materials, this approach is by far the most popular option [22]. The system consists of fibers made from mechanically superior materials, such as those with high strength and elasticity, embedded in a matrix made from a material like metal, polymer, or ceramic. The power and stiffness of a composite are determined not only by its individual components' characteristics but also by the length-to-diameter ratio of the fibrous phase, which is an arbitrary but essential parameter [23].

Fiber-reinforced composites can be divided into three primary groups: continuous or long and aligned; discontinuous or short and aligned; and intermittent and randomly oriented. How composites react to tensile loads in terms of stress–strain relationships depends on the orientation of the load concerning the fiber's longitudinal axis [24]. Only composites with threads that run in a straight direction are affected by this. Fibers that are randomly orientated and continually oriented display contrasting qualities. Stress and strain illustration, including threads, matrices, and composites. Failure strength (stiffness) in fiber materials is typically much higher than in the matrix. The failure strain is more significant even if the fiber is more brittle than the matrix. As a result, the failure strength and harmony of fiber-reinforced composites midway between the individual fibers and the matrix [25].

A structural composite is a collection of adequately made composites held together by a uniform adhesive solution. A structural composite's final qualities, such as mechanical and structural integrity, are defined by the compositions of its component ingredients and the geometry of its designs, including the size and shapes of its more substantial building parts [26]. Sandwich panels and laminar composites are the two most common structural composites. Stalking and gluing together two-dimensional sheets with carefully chosen high-strength orientations yields laminar composites. The individual sheets have such a large ratio of surface area to a thickness that the term "two-dimensional" is invented to describe the result. These sheets are typically composite materials with aligned fiber reinforcement. Sandwich panels have a soft inside surrounded by a tough outside, making them different from laminar composites [27]. There is a laminating agent that holds the two parts together. The outside skins are fabricated from metals, laminar composites (like plywood), and fiber-reinforced polymers that are all extremely strong and rigid. On the other hand, core materials are often made from wood, honeycomb, or thermosets.

As was previously indicated, the extensive range of composites with diverse combinations of attributes is made possible by their distinctive design and production freedom. So, unlike conventional materials like steel, the values of composite characteristics are not fixed in advance [28]. However, the strength-to-weight ratio of most composites is relatively poor. Their versatility has led to their incorporation into numerous fields, including medicine, transportation, and even space travel. Composites are typically designed to surpass the performance of alternative materials and fulfill a specific load requirement. This type of composite has several applications in the medical field. They are widely applied in the medical field, where they are used for everything from diagnosing and treating injuries to working with biological materials. When properly fabricated, composite biomaterials can be used to replace or supplement organs that have been damaged due to traumatic or pathological events [29]. The ability to design composite biomaterials with tailored physical, chemical, and mechanical properties for specialized applications is a significant factor in their widespread adoption in modern medical practice. Although biomedical engineering has historically used both natural and synthetic biomaterials, the advent of composites has profoundly altered the field. Constant improvements in these materials and the groundbreaking design of further enhanced medical devices have increased survival rates for accidents and diseases, as well as the quality of life and life expectancy [30]. Like the composite materials used in construction and manufacturing, the three leading composite biomaterials are particle-reinforced, fiber-reinforced, and structural. As before, the performance characteristics of a composite biomaterial are not always the same as those of its constituent pieces (matrix and inclusions) (matrix and inclusions). Evaluating the quality of composites made from polymers (PMCs) is crucial, and non-destructive (NDE) methods play a key role in this evaluation. Ultrasonic testing is a valuable tool as it can measure ultrasonic wave frequency and attenuation. This allows for the detection of imperfections and damages in PMCs with varying fiber orientations. Monitoring the hits to AE and the energy generated helps detect and classify various emission signals during mechanical testing. This process, known as AE testing, allows for the assessment of the subsurface of PMCs and measures heat loss during cooling or curing using infrared thermography and thermographic testing.

The cardiovascular system, also known as the circulatory system, plays a crucial role in maintaining internal body temperature and other vital functions [31]. The heart, the vascular system, and the blood make up the circulatory system, and it's the blood's job to carry oxygen and nutrients around the body. With each heartbeat and blood flow through the veins and capillaries, metabolic wastes are flushed away. Heart conditions, both congenital and acquired, such as coronary artery disease (CAD) and arrhythmias, may necessitate surgery for therapy. In extreme situations of cardiovascular trauma, surgical intervention was required to replace or repair damaged parts of the system. Cardiovascular biomaterials include pacemakers and stents, two of the most well-known devices. Angioplasty is a surgical treatment that uses biomaterial stents to repair and prevent blockages in blood vessels and other bodily passages caused by disease or damage. These passages include the heart's arteries, veins, pharynx, and digestive tract [32].

Additionally, these polymers are used momentarily to maintain open channels during medical procedures. Traditional stent materials include stainless steel and other iron alloys, titanium and its alloys, magnesium and cobalt alloys, and plastics [33]. However, composite biomaterials, including metal and polymer matrix composites, are emerging to function as superior alternatives. Due to their versatility in stent design, low cost, biodegradability, and ease of production, composites are gaining popularity. After providing temporary vascular assistance, the body can absorb newer composite stents. Because of their biocompatibility, achieved by a design that considers how the stent material's surface interacts with the surrounding biological tissues, these materials cause less irritation to the vascular tissue [34].

One of the most crucial life-sustaining devices for the heart is the pacemaker, which biomedical engineers developed. When functioning correctly, this tiny electrochemical mechanism regulates the heart's rhythms to guarantee enough blood pumping and circulation throughout the body [35]. The four essential components of the pacemaker are the lithium-ion battery, the lead, the connector block, and the enclosure. A case containing the pulse generator, battery, and connecting block is surgically implanted just beneath the skin of the head. After the lead's conductive tip has been surgically inserted in the desired heart chamber, the information is connected to the connecting block via the subclavian vein. While traditionally, metals like platinum alloy were utilized for most of a pacemaker's construction, in recent years, composites have been used due to their lower toxicity and lower environmental impact. Composites, being lighter, have taken the place of metal shells in devices like pacemakers. A decrease in pacemaker-related skin reactions has been observed in the former because of the more excellent corrosion resistance of the former [36].

Our incisors, canines, premolars, and molars work together to break down food into smaller pieces that are easier to swallow. The four canine teeth adjacent to the incisors tear food apart, while the premolars and molars accomplish the crushing. Use the eight front teeth, or incisors, for cutting. The human dental system is crucial for speech and other sound production. The dental plan is susceptible to abnormalities and damage from sickness, trauma, and congenital conditions, much like any other body part. Genetic defects can also explain tooth loss or other dental abnormalities. The two most common dental illnesses are plaque and caries (commonly known as tooth decay). In the former, a biofilm is built by bacteria. Due to a lack of oxygen, these bacteria make lactic acid, which dissolves phosphate and calcium from enamel, making it weak and susceptible to infection. Microorganisms like this love the food scraps that get stuck between and around people's teeth after a meal. Depletion of bone-building minerals like calcium and phosphorus can lead to tooth decay and eventual loss. In contrast, the prevalence of cavities in youngsters may be traced back to the food consumed [37].

Traumatic tooth damage might compromise the tooth's structural integrity or make it more susceptible to infection. Since the turn of the century, head traumas have become increasingly common due to accidents and acts of violence, which can devastate a person's oral health. It has become common practice to employ composite biomaterials such as polymer matrix composites for dental implants to restore lost teeth for both functional and aesthetic purposes. These alternatives are more biocompatible than conventional metallic dental biomaterials like silver amalgam. While aluminized silver-mercury fillings are incredibly harmful, acrylic resins lack the stiffness and mechanical strength necessary to serve as prosthetic posterior teeth. Lifting the flap and exposing the bone can replace a missing or broken tooth. First, a pilot hole is drilled into the bone to secure the screw, holding the bone piece in place. As a last step, the prosthetic tooth's abutment is screwed into place.

The most common options are permanent (such as bridges) and removable dental prostheses. Denture wearers should limit their use of removable dental prostheses because they can cause discomfort after prolonged use. These items are often fabricated using corrosion-resistant polycarbonates reinforced with glass fibers. Ultra-high molecular weight polyethylene is commonly used in the construction of fixed bridges. Methacrylic matrix composites reinforced with fiber and inorganic particles have been discovered to possess improved mechanical and aesthetic qualities compared to the typical polymer matrix composites used in dentistry. Dental materials containing titanium-hydroxyapatite are also gaining attention. Because of its bioactive compatibility with the surrounding tissues, hydroxyapatite is chosen for the lower part of the implant, and titanium is used for the upper section due to its incredible mechanical strength.

Cartilage is a flexible and elastic kind of bone that can be found in the ears, nose, ribs, and joints. As an adult, it helps keep the skeleton in place. This material makes up the majority of the structure in newborns, giving place to the more rigid bone formations later on. Polymeric composites such as poly [2–hydroxyethylmethacrylate] (PHEMA) combined with polyethylene terephthalate (PET) synthetic fibers can be utilized to replace cartilage that is either absent at birth or destroyed during development, trauma, or other causes. It is possible to mimic the properties of natural cartilage by modifying the volumes of the two components of this biomaterial. Composite biomaterials, including ultra-high molecular weight polyethylene and hyaluronic acid, are also used as cartilage substitutes. High durability makes this a common choice for replacing damaged joint cartilage, spinal fibrocartilage, or menisci. Wear and exhaustion from repeated stress are significant causes of artificial cartilage failure. We have made steady progress toward finding answers to these problems. Injectable hydrogels, a polymeric biomaterial, are occasionally used with composite biomaterials to reduce wear and expedite healing.

Ligaments are the fibrous fibers that connect bones and cartilage. Many athletes have injuries to the anterior cruciate ligament (ACL). Repairing or replacing this tissue with polymeric and composite biomaterials helps arthritic or damaged joints usually function. Similarly, to artificial cartilage, artificial ligaments wear out and eventually break down due to repeated tension and wear. The inclusions are not durable since they are easily worn down, have poor flexural and torsional strength, and can cause synovial membrane inflammation. For use as a ligament tissue substitute, researchers have created a biodegradable composite biomaterial of polylactic acid and hyaluronic acid ester. Damaged ligaments can mend on their own because of the reduced wear of this prosthesis. The behavior of ethylene-butene copolymer composites with ultra-high molecular weight polyethylene (UHMWPE) reinforcement under cyclic loading was investigated, and it was discovered that, with the right copolymer type and angle combination, these composites could be made into exceptionally fatigue-resistant biomedical applications. As time went on, researchers found that this fatigue-resistant material could be used to create a ligament prosthetic. Despite evidence from animal studies suggesting that PET-reinforced PHEMA cartilage prostheses cause synovitis, they are being used. A high-strength composite material, made by fusing terephthalate polyester fiber with a collagen matrix, has been created to combat this issue. After six months of in vivo testing, this material did not negatively interact with the host tissue. Still, it did not promote the growth and penetration of fibrous tissues between the prosthesis and the host bones.

A joint is the meeting place of two or more bones in the body. These connective tissues allow for mobility and support the entire body. The human body has about 300 joints, most of which see regular use. Unfortunately, dislocations, fractures, and other forms of joint injury are typical results. Extreme cases of arthritis or trauma may necessitate joint replacement surgery, but in many cases, the joint can be brought back to health using therapeutic methods. After surgically exposing the heads of the prosthetic femur and tibia, the stems are drilled into the patient's natural femur and tibia. Together, these components provide movement that is analogous to that of a natural knee.

There are a lot of similarities between the functions of the knee and the hip joint. Hip replacement surgery is an option for patients who have experienced severe damage to their hip joints. Metals, polymers, ceramics, and composites are frequently used in constructing these biomedical instruments [38]. An acetabular cup or shell is implanted into the pelvis using a fixation agent, and a stem leading to the ball is placed into the femur. Alloyed metals or metallic composites are typically utilized for the branch because of the material's excellent strength in tension and compression. Compared to ceramic biomaterials, composite metals have significantly higher resilience to wear. Consequently, they are now employed to construct the ball.

Treatment of bone fractures with composites is successful. Again, this is because bones have a unique makeup that is tailored to their specific function. The superior performance of these materials dramatically aids bone growth and healing. Thus, compatibility is just the beginning. The composites utilized as a framework are biodegradable, so they remain even after their intended purpose has been fulfilled. Composites may also be used for internal fastening mechanisms. In the past, they were made of metal. Metal mechanical aids are incredibly long-lasting but can deteriorate quickly and are stiffer than bone, which can be painful [39]. One practical answer to these problems is polymer composites. Carbon fiber-based polymers could be used to make a device to support the healing bone because of their high strength and elastic qualities, similar to those of natural bone. Due to the nature of the material, there is no risk of corrosion. The biodegradable matrices used to construct the implant can break down while the bone heals, releasing any necessary drugs.

Bone cement helps repair broken bones, and prosthetic joints are easily implanted. When used, it achieves the same results as regular cement. It is a thick, moist material used to seal the area where natural bone meets metal or plastic implants. After the adhesive cures, it fills any spaces between the parts and binds them together securely. The polymerization process creates a bond between the two substances that is very stable. Long-lasting casts can be made using fiberglass, polyester fabrics, and a polyurethane matrix rather than traditional cotton and plaster [40]. Models made from composite materials are more robust, weatherproof, and amenable to creating high-quality X-ray scans. Despite being more challenging to eliminate, their benefits outweigh the drawbacks. In recent years, a new method that can be used as an alternative to the conventional one has emerged: 3-D printed composite castings. Their web-like shape increases ventilation while delivering all the benefits of a regular mixed cast. They also allow the development of patient-specific ergonomic solutions that boost health and well-being. If 3-D printing's speed and quality improvements continue, it may replace conventional manufacturing methods. Composite materials have been the basis of cutting-edge designs for external prostheses. Composites have supplanted wood, metal, and leather. Composites are preferred since they keep the best features of the materials they're made of while also adding their benefits.

In contemporary engineering and manufacturing, the effect of composite materials on sophisticated production processes is a crucial subject. Because of their special qualities, composite materials—which are made up of a variety of components with specific properties—have transformed a number of industries. With the use of pertinent data and references, we will discuss the important influence that composite materials have on advanced manufacturing processes in this section. Because of their excellent strength-to-weight ratio, composites are a great choice for industries like aerospace and automotive where reducing weight is crucial. Composite materials have great strength and durability, which makes them ideal for longer-lasting and more dependable products in a variety of industries, such as construction and maritime. Because composites are naturally resistant to corrosion, they can be used in severe settings and applications where traditional materials might eventually degrade. The mechanical properties of composites can be precisely tailored by engineers using advanced manufacturing processes, enabling the design of materials with specified qualities for a wide range of applications. Composites can be combined with other materials to create unique patterns and multipurpose components by molding them into intricate shapes. Composite production has become more economical and effective thanks to advanced manufacturing techniques including 3D printing and automated layup procedures. By making transportation vehicles lighter and improving the efficiency of renewable energy sources, composite materials help to reduce energy consumption. Composites are useful for applications in electronics, telecommunications, and radar systems because they may be manufactured to have particular electromagnetic properties.

3. Fabrication methods

With such rapid development in such a short period, it's hard to believe composites are only a few decades old. While ceramics show promise for structural applications, there are still challenges to be overcome. Price competition causes significant shifts in the composites market [41]. Molding procedures are used to create many different composite goods. The many techniques of shaping include as shown in Fig. 2.

Some manufacturing processes include casting, centrifugal casting, continuous casting, slip forming, press molding, transfer molding, pultrusion molding, and filament winding. In addition to the methods already mentioned, other methods include thermoplastic molding, vacuum infusion, wet lay-up, compression molding, and computer numerical control (CNC) filament winding.

A "formulator" can be any business that combines raw materials, semi-finished products, or finished goods to create a new product. It is necessary to blend, mix, or otherwise shape elements of natural or synthetic origin that are usually incompatible. The word "formulation" is used to characterize this method. There can be no therapeutic benefit from a drug without the presence of its active components. Paints, cosmetic creams, mayonnaise, and composite materials are made using a light dispersion of numerous immiscible phases that seem homogeneous

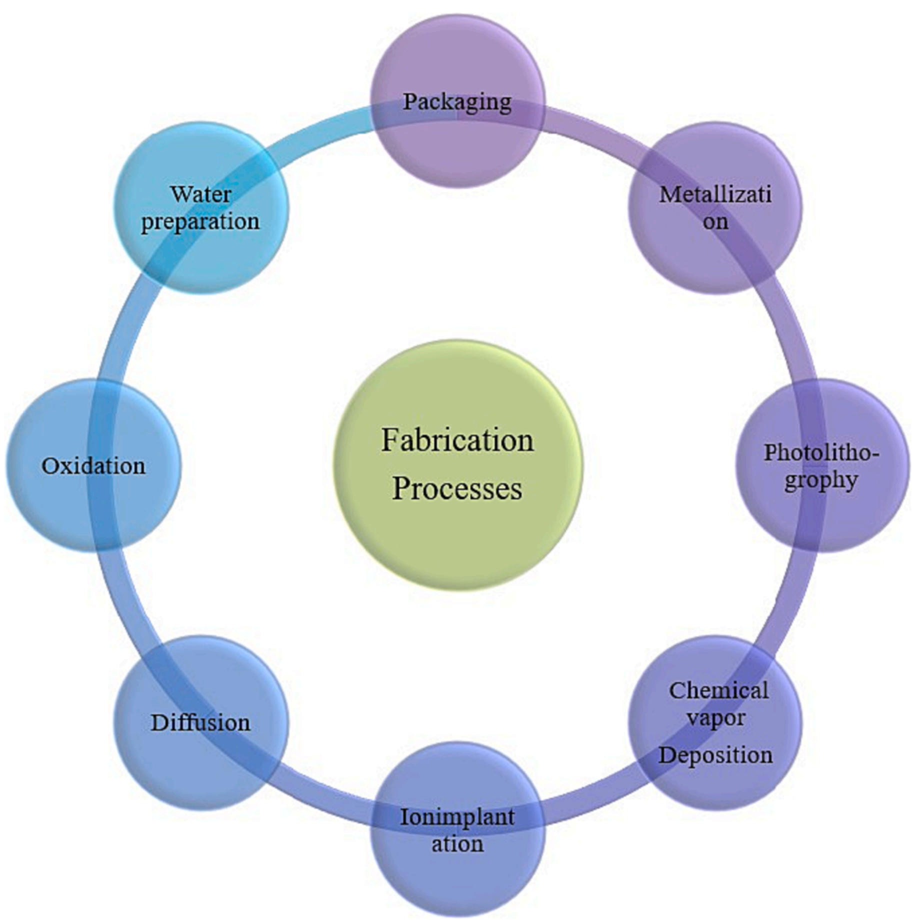

Fig. 2. Fabrication Method [42].

on the macroscopic size but are heterogeneous on the microscopic scale [42]. The success of the entire section hinges on the method of mixing and the durability of the resulting mixture. Some composite materials take the most outstanding qualities of different substances and combine them into one. Matrix-embedded composites are now often classified based on the configurations of their reinforcements (also known as fillers). The matrix helps to maintain order and consistency in loads. The composite may transfer some of the load's stresses to itself. Substances having a history of inconsistency and even anisotropy are the result. Many variables, such as matrix and charge type, charge shape and amount, charge concentration, interface quality, and manufacturing process, can impact the final product quality of a composite.

The permutations are nearly endless, with a wide variety of reinforcement and matrix materials (metal, ceramic, or plastic). As a rule, a composite material will have both a continuous phase and one or more discontinuous phases. Many distinct intermittent phases can be found in hybrid composites. Matrix = constant, reinforcement = supplementary change. The most outstanding qualities of many materials are synthesized into one composite synthetic. A polymer matrix's mechanical and thermal properties can be enhanced using highly modular reinforcements and extreme tension. The production of composites using a polymer matrix provides greater design freedom than that of metals. Benefits include decreased fuel consumption (in airplanes and cars), increased range and payload for missiles, and faster timing in sports (in transport). Reinforced plastics, rubber, steel, organic resins, glass fibers, carbon, and boron are all examples of inorganic composites (resins and short fibers). Materials such as ceramic composites, carbon–carbon composites (made from carbon and carbon fibers), and concrete (made from cement, sand, and additives) are all examples of mineral composites (ceramics and ceramic fibers). Another by-product is composite metals (formed, for example, from aluminum and carbon fibers or boron and aluminum fibers). Packaging, automobiles, light structures, civil engineering, aviation, sports, biomedicine, thermomechanical components, and aerospace are just a few fields that have benefited from composites.

MMC machining is always unique; it is typically done apart from more popular and traditional metal and alloy types. MMCs are made of a soft matrix (e.g., Mg, Al, Ni, C, Ti, etc.) and reinforced hard particles (e.g., SiC, Al2O3) to emphasize the natural progression of the material removal process and impact manufacturing productivity. When machining MMCs, common occurrences include tool damage, abrupt breaking, excessive wear mechanism, a bad surface, and workpiece quality degradation. The excessive rate of plastic deformation that occurs during the material removal process is what causes the significant heat generation. Owing to the MMCs' ambiguous structural integrity, a variety of variables and procedures can be adjusted for a seamless material removal process. Therefore, the distribution of reinforcement for the MMCs portion during the fabrication process plays a crucial role in the produced structure and properties of the composite material. The selection of the cooling/lubrication procedure must be taken into account based on the cutting parameters. A number of writers have embraced the sustainable machining method for handling materials that are difficult to cut. During the milling process on high-density composite materials, one can view an experimental example of the machining procedure. During the material removal process, the dense reinforcement in the workpiece has the potential to fracture, harm the cutting tool, and create surface fissures. The dynamics of the cutting process are altered when soft matrix materials and abrasive hard additives are combined in composite materials. As a result, various machining techniques, such as dry, MQL, cryogenic, flood, or high-pressure flood machining processes, must be used to counteract these obstacles.

4. Application of composites

It is because composites have properties that set them apart from other materials. The capacity to be transported easily or a high strength-to-weight ratio [43]. Reduced stiffness and fatigue; increased toughness. Superior resistance to corrosion and excellent utility. Protection from electricity, fire, and the elements. Ease of fabrication or familiarity with a range of fabrication procedures. Longer longevity and lower expenditures. For many industries, composites are invaluable, as shown in Fig. 3.

4.1. Use of composites in aerospace structure

Composites are frequently used to construct various aircraft accessories, including doors, ring tips, ducts, fairings, random, and dielectric panels. In mechanical and electrical applications, epoxy resin and E-glass roving are used for their high strength and durability [44]. Polar winding is the term used to describe the technique used. Exceptionally robust, robust, and able to make incredibly complicated patterns while also being resistant to rust and rust. Alignment and dimensional stability are two features that can be preserved. The probability of dielectric breakdown is minimal. The maximum possible level of efficiency is reached.

However, it's essential to consider the potential downsides as well. Delamination is the separation of laminate layers at the layer interface due to mechanical stress, such as a blow or a drop in temperature. One or more fibers may get detached from the matrix. A material must have the characteristics to be included in the first table. Due to their versatile nature and array of valuable features, composites find use in various fields. Composite materials are currently actively integrated into most aerospace programs, and the image below shows how the benefits greatly exceed any potential downsides. While experiencing a flurry of hydraulic action. Subtle Disturbance to the Discrete Arrangement of Parts. Problems with production are to be expected. The bearing strength of composites is lower than that of metals. Fig. 4 displays carbon fiber potential in 2017 [45–49].

The aerospace industry relied heavily on autoclaves since composites were a primary raw material. Glass-fibre reinforced plastic (composites) are commonly used in low-speed aircraft. On the other hand, traditional metal tooling is the way to go when mass-producing an identical item. Injection molding using resign works particularly well for producing complex shapes, such as randoms. A random act as a shield for electromagnetic transmission, allowing it to travel farther with less attenuation [51]. A random two most crucial characteristics are a constant electrical thickness and a wavelength compatible with the radar equipment it will use. Titanium and aluminum-based alloys are the first materials used to make aircraft. As we know, Carbon fiber reinforced composites (CFRC) were introduced to the aerospace industry to address various issues such as lack of mechanical strength, complex shapes, fatigue, and fracture resistance. They also addressed static and dynamic resistance, corrosion resistance, engine vibration reduction, higher rate of fuel consumption, and more. After extensive research in this field, the relative strength of aluminum alloy (7075-T6) with CF-reinforced polyester composite and Ti-6Al-4 V were the most validated composite materials used in aerospace. All three components have excellent static, fatigue, and stress management efficiency [52–55].

4.2. Automobile and transportation industry

Composite materials have garnered a lot of attention in the automotive and transportation industries due to the possibility of improved MPG through decreased vehicle weight [56]. In industrialized countries like Japan, graphite-dispersed aluminum composites are commonly used to make frictional auto parts. Composites are used extensively in the automobile and railroad industries. Three-wheeled vehicles for the disabled, taxis, delivery trucks, sports cars, ambulances, caravans, mobile shops, and more are all made with glass fiber-polyester epoxy composites outside the United States. GRP is also used in the motorcycle and scooter industries because of the need for lightweight, weather-resistant, aerodynamic fairings. Several industries, such as maritime,

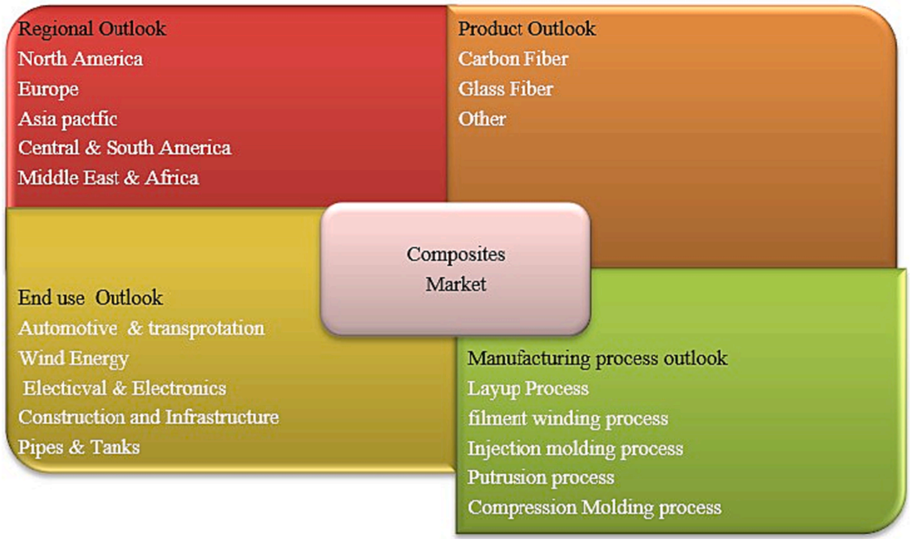

Fig. 3. Sector-wise Composite Materials [44].

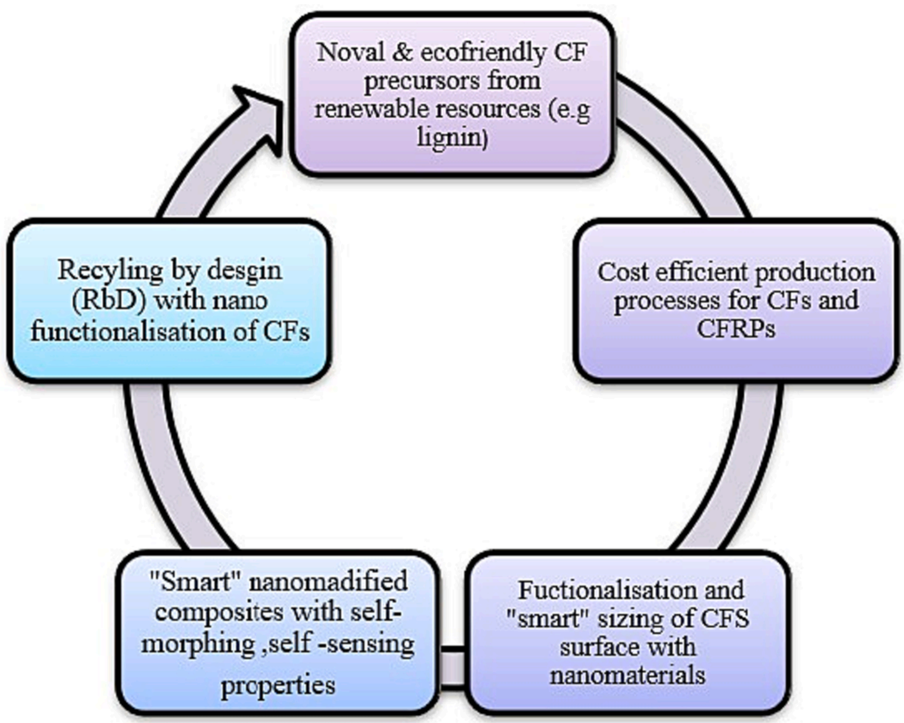

Fig. 4. Carbon Fiber Potential in 2017 [50].

chemical, mechanical, civil, electrical, and electronic, play essential roles in the economy [57–60]. The future studies on composite materials ought to concentrate on a number of important topics. Automation and additive manufacturing are two examples of advanced production systems that present chances for accuracy and efficiency. Investigation of nanocomposites with characteristics enhanced by nanoparticles is warranted. Attention needs to be paid to raw material recycling and sustainability. Studies on durability, biocomposites, and multifunctional composites show promise. For progress, better characterization methods, simulation tools, and manufacturing process optimization are essential. It is essential to evaluate environmental implications through life cycle assessments. Collaborations across disciplines can tackle intricate problems in this developing sector. Within these paths, researchers can focus on particular regions to make significant contributions to the field of composite materials.

5. Conclusions

Composites protect metal components in corrosive chemical conditions like salt spray and acid rain, reducing maintenance costs. Composites possess shape memory and impact tolerance, making them highly useful in transportation. Aluminum-based composites in vehicles are more economical, fuel-efficient, and lightweight than steel or iron counterparts. Combining two metal components into a composite further saves weight and resources during setup. Composites and adhesives/coatings are mutually compatible, offering additional benefits due to their shared polymer composition. Composites excel as insulators, maintaining form and performance even in low temperatures.

- Composites open up a wide range of new design options without compromising performance or strength.
- Fiber-reinforced composites are ideal for electronics due to their high resistance to heat and flame.
- Innovative surface generation methods provide post-mold paint finishes without extensive time and resource investment.
- Biomaterials using composites can heal damaged tissues and serve as replacements for organs, revolutionizing the biomedical industry.
- Aluminum-based composites offer affordability, fuel efficiency, and lightweight properties for vehicles and automobile parts.
- Composites reduce resource consumption, are compatible with adhesives/coatings, and perform well at low temperatures.
- Effective ways to create composites have led to indispensable advancements in the biomedical field for wound healing and tissue engineering.

CRediT authorship contribution statement

Mahesh Bhong: Conceptualization. **Tasneem K.H. Khan:** Methodology. **Kiran Devade:** Supervision. **B. Vijay Krishna:** . **Sreekanth Sura:** Writing – original draft. **H.K. Eftikhaar:** . **H. Pal Thethi:** . **Nakul Gupta:** .

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.

Data availability

No data was used for the research described in the article.

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