

Synthetic Composite Materials: A Review of Manufacturing Processes and Applications

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Review Article

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ABSTRACT

This review paper provides an overview of synthetic composite materials and their manufacturing processes, as well as their various applications in different industries. The manufacturing processes discussed in this paper include resin transfer molding, vacuum infusion, filament winding, pultrusion, compression molding, and additive manufacturing. The various reinforcement materials used in synthetic composites, such as glass fibers, carbon fibers, aramid fibers, natural fibers, and nanofillers, are also discussed. The review paper provides a comprehensive understanding of synthetic composite materials and their manufacturing processes, along with their various applications and emerging research areas. The paper concludes that synthetic composite materials have the potential to revolutionize various industries and contribute to sustainable and environmentally friendly manufacturing processes.

Keywords: Synthetic composite; Reinforcement materials; Manufacturing; Processes

INTRODUCTION

The development of composite materials dates back to ancient times, where natural materials such as straw, mud and animal skins were used to make composite materials for various purposes. However, the modern development of synthetic composite materials began in the mid-twentieth century when researchers started to explore the use of polymer matrix composites in various applications. Synthetic composite materials are a class of materials that are made by combining two or more constituent materials to form a composite with enhanced properties. This class of materials has gained significant attention in various industries due to their unique combination of properties such as high strength, stiffness and low weight. Synthetic composites are typically composed of a matrix material and a reinforcement material, where the matrix material provides the bulk of the material properties and the reinforcement material enhances specific mechanical, thermal, or electrical properties.

In recent years, the demand for synthetic composite materials has increased, and the manufacturing processes for producing these materials have become more advanced. The manufacturing process used for synthetic composites depends on the desired properties and end-use application. The development of fiber-reinforced polymer composites has been a focus of extensive research, aiming to enhance mechanical properties, wear resistance, and thermal stability for various applications. Mishra et al., demonstrated that adding glass fibers to biofiber-reinforced polyester composites significantly improved mechanical properties, with chemically modified sisal fibers further enhancing properties ^[1]. Abenojar et al., used analytical techniques to show that boron carbide improved the mechanical properties and wear resistance of epoxy adhesive. Asi found that adding Al₂O₃ particles to glass fiber-reinforced composites enhanced bearing strength. Jawaid et al. highlighted the potential of hybrid composites in balancing cost and performance, addressing environmental concerns. Agarwal et al., noted improved properties of glass fiber-reinforced epoxy composites with Silicon Carbide (SiC) filler. Sudheer et al., showed that ceramic whisker and solid lubricant fillers improved the mechanical and tribological properties of epoxy/glass composites. Gull et al., demonstrated significant improvements in mechanical and thermal properties of polyester composites with increased Zinc Oxide (ZnO) loading. Masghouni et al., enhanced the fiber/matrix interface in carbon Fiber Reinforced Polymers (FRPs) using ZnO nanowires, improving mechanical properties and damping capabilities. Ganesha et al., showed improved mechanical properties of glass fiber-reinforced epoxy composites with cerium oxide filler. Hu et al., developed high-strength, high-thermal-conductivity Al₂O₃/epoxy composites for electronic packaging. Erklig et al., enhanced the impact response of fiber-reinforced polymer composites by adding graphene nanoparticles to the epoxy matrix. Arpitha et al., developed sustainable polymer composites using natural and synthetic fibers, improving properties with E-glass fibers and filler ^[2]. Das et al., investigated coir fiber-reinforced epoxy composites filled with Al₂O₃ filler, showing promising erosion wear performance. Rallini et al., used nano-boron carbide as a nanomodifier in phenolic matrix composites, improving thermal stability and oxidation resistance. Ramadan et al., enhanced the mechanical and physical properties of jute fabric-reinforced epoxy composites through hybridization with silicon carbide particles. Bulut et al., investigated the effects of borax, perlite, and sewage sludge ash particles on S-glass/epoxy composite laminates, finding significant increases in properties up to a critical particle loading. Mutalikdesai et al., improved the mechanical behavior of glass fiber reinforced epoxy hybrid composites with various fillers ^[3]. Sarkar et al., demonstrated that aluminum filler reduced wear loss in glass epoxy composites. Yazman et al., showed significant improvements in mechanical properties of epoxy composites with Al₂O₃ nanoparticles. Shahinur and Hasan discussed natural and synthetic fiber-reinforced composites, highlighting their properties, performance, cost, and environmental benefits. Alsayed et al., enhanced the thermal stability and mechanical properties of HDPE composites with ZnO nanoparticles. Vaggar et al., increased the thermal conductivity of glass fiber reinforced polymer composites with silicon carbide filler. Navaneethan et al., reviewed the

mechanical properties of synthetic fibers for retrofitting damaged structures [4]. Rajak et al., discussed the use of synthetic fibers in polymer matrix composites to create lightweight materials with improved properties. Singh et al., explored the effect of fiber orientation on the mechanical properties of hybrid composites. Jani et al., investigated the use of natural fillers in natural fiber reinforced polymer composites for manufacturing applications, showing promising machinability results. Navaratnam et al., highlighted the benefits of using FRP composites in engineering infrastructures. Maithil et al., underscored the importance of enhancing the mechanical properties of natural fiber-reinforced polymer composites. Kanagaraj et al., assessed the viability of using synthetic fiber-reinforced polymer stirrups in reinforced concrete beams, showing satisfactory structural performance and lower environmental impacts compared to steel stirrups. These studies demonstrate the diverse approaches and significant advancements in the development and application of fiber-reinforced polymer composites, with potential for further improvements and applications in various fields [5].

Synthetic composites represent a revolutionary frontier in manufacturing, offering a diverse array of processes to suit various needs. These composites are at the forefront of innovation, offering unparalleled strength, durability, and versatility. Let's delve into the intricate world of synthetic composites and explore the vast landscape of manufacturing processes that define their creation. One of the oldest and most widely used manufacturing processes for synthetic composites is hand lay-up. This process involves the manual placement of fibers and resin on a mold, making it ideal for small production runs and custom parts. On the other end of the spectrum, Resin Transfer Molding (RTM) is a closed-mold manufacturing process that uses a vacuum to draw resin into a preform placed in a mold. This process is perfect for producing complex shapes with high accuracy and repeatability [6]. Winding is another fascinating process that involves the winding of fibers around a rotating mandrel. This method is ideal for producing hollow structures with high strength-to-weight ratios. Pultrusion, on the other hand, is a continuous manufacturing process that involves the pulling of fibers through a resin bath and a heated die, making it perfect for high-volume parts with consistent properties. Compression molding is a widely used process that involves the compression of a preform in a mold, ideal for producing large, flat parts with uniform thickness. Resin infusion, on the other hand, involves the vacuum-assisted infusion of resin into a preform, making it ideal for large, complex parts with high strength-to-weight ratios. SMC (Sheet Molding Compound) is another compression molding process ideal for large, flat parts with uniform thickness and high surface quality. The autoclave process involves the use of an autoclave to apply heat and pressure to a preform, ideal for producing parts with complex shapes and high quality. Vacuum bagging applies pressure to a preform using a vacuum bag, ideal for parts with good surface quality and low void content. CFRTF (Carbon Fiber Reinforced Thermoplastic) involves impregnating continuous fibers with a thermoplastic resin and consolidating them into a preform, perfect for parts requiring high strength and stiffness at high processing rates. Tape laying and Automated Fiber Placement (AFP) are processes that involve the automated placement of fibers onto a mold, each offering unique advantages for parts with high fiber volume fractions and complex shapes.

The applications of synthetic composites are vast and varied, spanning industries such as aerospace, automotive, construction, marine, sports, recreation, and medicine. These materials have revolutionized the aerospace industry, offering high strength, stiffness, and low weight for structural components, engine parts, and interior fittings. In the automotive sector, synthetic composites are used for body panels, chassis components, and interior parts, contributing to weight reduction and improved fuel efficiency. The versatility and performance of synthetic composites continue to drive innovation across industries, shaping the future of manufacturing and engineering. Synthetic composites have been used in the construction industry for various applications, including bridges, buildings, and pipelines [7]. Tunali suggested that composites offer unique properties, crucial in modern construction and product design. Examples include bathroom fixtures and ceramic coatings with advanced surface functionalities achieved through nanomaterials and composites. These

materials have been used to replace traditional materials such as steel and concrete, offering improved performance and durability. Synthetic composites have been used in the marine industry for various applications, including boat hulls, decks, and masts. Karrupaswamy et al., highlighted the importance of green hybrid composite materials in sustainable development. They emphasize the environmental impact and health hazards of non-biodegradable composites, promoting the use of green alternatives for marine applications. Synthetic composites have been used in the sports and recreation industry for various applications, including golf clubs, tennis rackets, and bicycles. Zhang discussed the increasing use of composite materials in sporting goods, highlighting advancements in developed countries and notable achievements in China. They emphasize the growing market and predict composites as the mainstream in the sports goods industry. Synthetic composites have been used in the medical industry for various applications, including orthopedic implants and prosthetics. Biswal et al., discussed composite materials, particularly polymer composites, highlighting their unique properties and applications in biomedical fields. They focused on classifications, synthesis methods, and the potential for use in artificial organs and medical devices. Synthetic composites have been used in the energy industry for various applications, including wind turbine blades and solar panels. Trzepieciński et al., addressed the rising global demand for electricity and the imperative for renewable energy sources. They specifically examine how composite materials are utilized in power generation technologies such as photovoltaic panels, wind turbines, fuel cells, and biogas generators. Synthetic composites have been used in the electronics industry for various applications, including printed circuit boards and antennas. Researchers have emphasized the importance of filler-reinforced composites in microelectronics, discussing the use of different materials like glass fibre cloths, paper, and fillers in printed circuit boards. The article also touched on the advancements in polymer-based materials, including thermoplastics and thermosets, for electronic packaging materials, highlighting their efficiency and ability to meet stringent requirements. Synthetic composites have been used in the packaging industry for various applications, including food packaging and medical packaging. Zhang et al., discussed the increasing demand for food due to population growth, urbanization, and globalization, leading to challenges in food safety. They highlighted the importance of food packaging in maintaining food quality and safety and explored the use of polymeric materials and polymer composites in food packaging. The review summarized recent advances in polymer-based packaging, focusing on biodegradable polymers and polymer composites, and discussed their applications in improved, active, and intelligent packaging. Synthetic composites have been used in the defense industry for various applications, including armor and missile components. Siengchin review highlighted the potential of polymer, metal, and ceramic composites for lightweight defense systems, suggesting future research could lead to advancements in defense applications. Leading countries prioritize cutting-edge technologies, and defense R and D is advancing to meet new threats with sophisticated lightweight equipment.

Puttegowda et al., discussed the significance of natural and synthetic fibers, their production, and various applications. They emphasized the importance of hybrid composites, combining these fibers with polymer matrices, for green engineering solutions. The chapter highlighted the benefits of composite materials, particularly in aerospace and other industries, due to their superior properties compared to traditional metallic materials. Kasirajan et al., discussed the significant increase in the use of plastic mulch in agriculture worldwide, highlighting its benefits such as soil temperature increase, weed suppression, moisture retention, pest reduction, and improved crop yields [8]. They also addressed the environmental concerns related to the disposal of plastic mulch and the development of biodegradable alternatives. Synthetic composites have been used in the textile industry for various applications. Sulochani et al., provided an overview of using textile materials as reinforcement in polymer composites, discussing research studies, types of textiles and polymer matrices, fabrication techniques, properties, testing methods, standards, and applications in industries like automotive, aeronautical, defense, and

construction. Synthetic composites have been used in the transportation industry for various applications, including trains and buses. Dmitruk et al., highlighted the crucial role of polymer-based composite materials in various industries, including transportation, sports, leisure, and military. They emphasized the adaptability, cost-effectiveness, and competitive performance of these materials compared to metal alloys.

With advancements in materials science, the use of synthetic composites is expected to expand further in the future.

This review paper aims to provide an overview of synthetic composite materials, their manufacturing processes, and applications. The paper will also highlight the challenges associated with manufacturing synthetic composites and their potential future directions. This paper will be of interest to researchers and engineers working in the field of materials science and engineering, as well as individuals interested in the development and applications of synthetic composites.

LITERATURE REVIEW

Synthetic composite materials

Synthetic composite materials are engineered materials made by combining two or more constituent materials with different physical or chemical properties to create a new material with superior properties. The constituent materials may include fibers, particles, or polymers, which are combined using various manufacturing processes. These materials have a wide range of applications due to their unique properties, including high strength-to-weight ratio, corrosion resistance, thermal stability, and low thermal expansion.

The use of synthetic composites has grown significantly over the years, with applications in aerospace, automotive, construction, sports equipment, and medical devices, among others. These materials have the potential to reduce weight, increase fuel efficiency, and enhance performance, making them increasingly important in modern manufacturing.

The manufacturing processes used to produce synthetic composites are diverse and include hand lay-up, resin transfer molding, filament winding, pultrusion, compression molding, resin infusion, sheet molding compound, and autoclave, among others. The selection of the appropriate manufacturing process depends on the desired properties of the composite material and the required production volume ^[9].

Despite their numerous advantages, synthetic composites also have some limitations, such as high material cost, complex manufacturing processes, and difficulty in recycling. Nevertheless, research continues to improve these materials and overcome their limitations, with the ultimate goal of developing sustainable and cost-effective composite materials.

Manufacturing processes of synthetic composite materials

Manufacturing processes for synthetic composite materials vary depending on the type of composite material being produced, the properties required, and the production volume.

Resin Transfer Molding (RTM): Resin Transfer Molding (RTM) is a composite manufacturing process that involves injecting resin into a mold containing dry fibers or preforms. The resin is injected under pressure, impregnating the fibers and forming a solid composite part. RTM produces high-quality composite parts with consistent properties. Since the mold is sealed, the risk of voids and air pockets in the final part is minimized ^[10]. By varying the fiber orientation and resin selection, the mechanical properties of the part can be tailored to meet specific requirements. The RTM process can be used to produce parts with complex geometries, making it suitable for a wide range of applications. RTM is a largely automated process, which reduces labor costs and increases production efficiency. RTM is a relatively expensive process due to the cost of the equipment and the complex tooling required. The RTM process typically has longer cycle times compared to other processes, which may affect production efficiency. Despite of limitations, the RTM process is widely used in the production of high-

performance composite parts for aerospace, automotive, and marine applications.

Vacuum infusion: Vacuum infusion, also known as resin infusion, is a composite manufacturing process that involves using vacuum pressure to infuse resin into a dry fiber reinforcement. The process starts by placing a dry fiber reinforcement into a mold, which is then sealed using a flexible bagging material ^[11]. The bagging material is then attached to a vacuum pump, which draws out the air from the cavity, creating a vacuum. Next, the resin is introduced into the mold either manually or by using a resin infusion system. The vacuum pressure helps to draw the resin into the fibers, ensuring that the entire mold is filled with resin. Once the mold is completely filled, the resin is cured at a specific temperature and pressure to form a solid composite part. The process is highly efficient and generates less waste than traditional methods, as the resin is only used where it is needed. The properties of the composite can be tailored to meet specific requirements by varying the resin system and fiber reinforcement. The process produces high-quality parts with consistent properties ^[12]. The vacuum pressure helps to minimize voids and defects in the final part. The process can be used to produce parts with complex geometries, as the flexible bagging material can conform to the shape of the mold. The process can take longer than other manufacturing methods due to the time required to evacuate the air from the mold. The process requires specialized equipment, which can be expensive. The process requires skilled operators who understand the nuances of the vacuum infusion process to achieve high-quality parts

Filament winding: Filament winding is a composite manufacturing process that involves winding continuous fibers, usually in the form of rovings or yarns, onto a mandrel or mold in a precise pattern. The fibers are impregnated with resin as they are wound onto the mandrel, forming a composite part. The mandrel is prepared by applying a release agent and a layer of mold release wax. The fibers are coated with a resin or a sizing material to improve their handling and adhesion properties. The fibers are wound onto the mandrel in a precise pattern, typically in a 0-90 degree orientation. Fibers are impregnated with resin as they are wound onto the mandrel. The part is cured at a specific temperature and pressure, ensuring the resin hardens and forms a solid composite part. The continuous fiber reinforcement results in a high strength-to-weight ratio, making it suitable for high-performance applications. By varying the fiber orientation and resin selection, the mechanical properties of the part can be tailored to meet specific requirements. The process can be highly automated, resulting in high production rates. Process is highly efficient, with minimal waste generated during the manufacturing process ^[13]. The filament winding process can be used to produce parts with complex geometries, such as conical or cylindrical shapes. The process can be expensive due to the cost of the equipment and the complexity of the tooling required. The filament winding process typically has longer cycle times compared to other processes, which may affect production efficiency. The size of the parts that can be produced is limited by the size of the mandrel.

Pultrusion: Pultrusion is a continuous manufacturing process used to produce Fiber-Reinforced Polymer (FRP) composite materials with constant cross-sectional profiles. The process involves pulling reinforcing fibers, typically in the form of rovings, through a resin bath and into a heated die. The fibers are then cured by heat, forming a solid composite part. The continuous fiber reinforcement results in a high strength-to-weight ratio, making it suitable for high-performance applications. By varying the fiber orientation and resin selection, the mechanical properties of the part can be tailored to meet specific requirements. The process can be highly automated, resulting in high production rates. The process is highly efficient, with minimal waste generated during the manufacturing process ^[14]. The pultrusion process can be used to produce parts with complex geometries, such as beams, tubes, and channels. The process is not suitable for producing parts with thicknesses greater than approximately 10 mm. The process can be expensive due to the cost of the equipment and tooling required. The process can generate high scrap rates due to the difficulty in controlling the resin impregnation process. Despite these limitations, the pultrusion process is widely used in the production of composite materials for

construction, transportation, and infrastructure applications

Compression molding: Compression molding is a manufacturing process used to produce thermosetting plastic parts and composite materials. The process involves placing a pre-measured amount of material into a heated mold cavity, closing the mold, and applying pressure and heat to cure the material into its final shape. The process can be highly automated, resulting in high production rates. The molds used in the process are relatively inexpensive, making the process cost-effective for high-volume production. The process is highly efficient, with minimal waste generated during the manufacturing process. By varying the fiber orientation and resin selection, the mechanical properties of the part can be tailored to meet specific requirements. The process is suitable for producing large parts with low to medium complexity. The process is not suitable for producing parts with high complexity or tight tolerances. The process is limited to the use of thermosetting resins and reinforcing fibers. The process can have long cycle times, depending on the part size and complexity.

Additive manufacturing: Additive manufacturing, also known as 3D printing, is a manufacturing process that creates three-dimensional objects by adding layers of material, usually plastic or metal, one layer at a time. This is in contrast to traditional manufacturing processes, which typically involve removing material from a larger piece of material to create the final product. Additive manufacturing allows for highly customized objects to be produced quickly and at a relatively low cost. Manufacturing can produce highly complex shapes and geometries that may be difficult or impossible to create using traditional manufacturing methods. Manufacturing can reduce material waste, as only the required amount of material is used to create the object. Additive manufacturing can produce objects quickly, which can be advantageous in some industries, such as aerospace and medical. Additive manufacturing is limited by the types of materials that can be used for printing, which may be a concern for some applications. Additive manufacturing can produce objects with a rough surface finish, which may require additional finishing processes. While additive manufacturing can be cost-effective for small production runs or highly customized objects, it may not be cost-effective for large-scale production.

Reinforcement materials for synthetic composites

Reinforcement materials play a critical role in the development of synthetic composites, which are widely used in a variety of industries due to their unique properties and advantages over traditional materials. The primary function of reinforcement materials is to enhance the strength, stiffness, and durability of the composite material, while also reducing its weight. Reinforcement materials used in synthetic composites can be classified into two categories: Fibers and particles. Fiber reinforcements are typically long and thin, with high aspect ratios, while particle reinforcements are usually smaller and more spherical. Fiber reinforcements include materials such as carbon fibers, glass fibers, aramid fibers, and natural fibers like flax, hemp, and bamboo

Glass fibers: Glass fibers are a common type of reinforcement material used in the manufacturing of synthetic composites. They are made by drawing out molten glass into thin fibers, which are then woven into a fabric or mat. The resulting material is lightweight, strong, and durable, making it suitable for a wide range of applications. Glass fibers are particularly useful in composite materials due to their high strength and stiffness-to-weight ratio. They are also resistant to heat, moisture, and chemicals, which makes them ideal for use in harsh environments. Glass fibers can be used in a variety of composites, including thermoset composites and thermoplastic composites. In the manufacturing process, glass fibers are typically combined with a resin matrix to form a composite material. The matrix material can be a thermoset resin such as epoxy, or a thermoplastic resin such as nylon or polypropylene. The glass fibers are laid out in a specific orientation and impregnated with the resin, and then cured to form a solid composite. Glass fibers can be woven into different types of fabrics or mats, depending on the application. For example, a plain weave fabric is a simple over-under pattern that is easy to manufacture,

while a twill weave fabric has a more complex pattern that provides higher strength and stiffness. The orientation of the fibers can also be tailored to meet specific design requirements, such as increasing strength in a particular direction ^[15].

Carbon fibers: Carbon fibers are a type of reinforcement material used in the manufacturing of synthetic composites. They are made from precursor materials such as Polyacrylonitrile (PAN), rayon, or pitch, which are heated to high temperatures in the absence of oxygen to produce a carbon-rich material. The resulting carbon fibers are lightweight, strong, and stiff, with excellent fatigue resistance and thermal conductivity. Carbon fibers are particularly useful in composite materials due to their high strength-to-weight ratio, making them ideal for use in applications where weight reduction is important. They are commonly used in aerospace, automotive, and sporting goods applications, where high performance is critical. In the manufacturing process, carbon fibers are typically combined with a matrix material, such as an epoxy resin, to form a composite material. The carbon fibers are laid out in a specific orientation and impregnated with the resin, and then cured to form a solid composite. Carbon fibers can be woven into different types of fabrics or mats, depending on the application. The orientation of the fibers can also be tailored to meet specific design requirements, such as increasing strength in a particular direction ^[16]. The resulting carbon fiber composite materials are strong, stiff, and lightweight, making them ideal for high-performance applications. One drawback of carbon fibers is their cost, which can be significantly higher than other reinforcement materials such as glass fibers. However, advances in manufacturing technology and increased demand for high-performance materials have led to a reduction in the cost of carbon fibers over the years.

Aramid fibers: Aramid fibers, also known as aromatic polyamide fibers, are a type of synthetic fiber commonly used as a reinforcement material in composite manufacturing. They are composed of long chains of repeating units containing aramid groups, which provide high strength and stiffness. Aramid fibers have a unique combination of properties, including high tensile strength, excellent abrasion resistance, and low density. They are particularly useful in applications where weight reduction is important, such as in aerospace, defense, and sporting goods. In the manufacturing process, aramid fibers are typically combined with a matrix material, such as an epoxy resin, to form a composite material. The fibers are laid out in a specific orientation and impregnated with the resin, and then cured to form a solid composite. Aramid fibers can be woven into different types of fabrics or mats, depending on the application. The orientation of the fibers can also be tailored to meet specific design requirements, such as increasing strength in a particular direction. The resulting aramid fiber composite materials are strong, stiff, and lightweight, making them ideal for high-performance applications. One of the most well-known brands of aramid fibers is Kevlar, which is commonly used in body armor, helmets, and other protective equipment. Aramid fibers are also used in a variety of other applications, including structural components, racing sails, and reinforced hoses.

Natural fibers: Natural fibers are a type of reinforcement material used in the manufacturing of synthetic composites. They are derived from renewable resources such as plants, animals, and minerals. Examples of natural fibers include wood fibers, flax, jute, hemp, sisal, bamboo, and kenaf. Natural fibers offer several advantages in composite manufacturing, such as being lightweight, cost-effective, biodegradable, and having low energy consumption during production. They also have good mechanical properties, such as high strength, stiffness, and toughness. Additionally, natural fibers are environmentally friendly, making them a popular choice in sustainable manufacturing. In the manufacturing process, natural fibers are typically combined with a matrix material, such as a thermoplastic or thermoset resin, to form a composite material. The fibers can be woven or aligned in different orientations to meet specific design requirements. Natural fibers can also be used in hybrid composites, which combine two or more types of fibers to achieve specific properties. Natural fiber composites have a wide range of applications, such as in the automotive industry for interior and exterior components, in construction for building materials, and in packaging for food and consumer goods. They are also used in sports equipment,

such as surfboards, skateboards, and snowboards. One of the challenges with using natural fibers is their variability in properties, which can depend on factors such as the species, growth conditions, and processing methods. However, research efforts have focused on improving the consistency and performance of natural fibers in composite manufacturing.

Nanofillers: Nanofillers are small particles with at least one dimension in the nanometer range (typically less than 100 nm). They are used as reinforcement materials in the manufacturing of synthetic composites to improve their mechanical, thermal, electrical, and other properties. Nanofillers can be composed of a variety of materials, such as metals, ceramics, polymers, and carbon-based materials, and can be incorporated into a range of matrix materials, including thermoplastics, thermosets, and elastomers. In the manufacturing process, nanofillers are typically added to the matrix material in small quantities (less than 5% by weight) and dispersed uniformly throughout the composite. The small size of the nanofillers allows them to create a larger interfacial area with the matrix, resulting in improved bonding and increased reinforcement. Nanofillers can provide several benefits to synthetic composites, such as increasing strength, stiffness, toughness, and thermal stability. They can also improve other properties, such as electrical conductivity, fire resistance, and UV resistance. Additionally, nanofillers can enhance the barrier properties of composites, such as gas permeability and moisture resistance [17]. Nanofiller-reinforced composites have a range of applications, such as in electronics, aerospace, automotive, and biomedical fields. For example, nanofillers can be used to reinforce the matrix material in electrical and thermal insulation materials, structural materials for aircraft and spacecraft, and biomedical implants. One of the challenges with using nanofillers is achieving a uniform dispersion throughout the composite, as they tend to agglomerate due to their small size and high surface area. However, various methods have been developed to overcome this challenge, such as sonication, mixing, and surface modification.

DISCUSSION

Applications of synthetic composites

Synthetic composites have a wide range of applications in various industries due to their unique properties and advantages over traditional materials. Some of the applications of synthetic composites are:

Aerospace and aviation: Synthetic composites have revolutionized the aerospace and aviation industry by offering lightweight and high-strength materials that enhance the performance of aircraft. Some of the key applications of synthetic composites in aerospace and aviation include: Composite materials are used in the manufacturing of aircraft fuselage and wings. These materials offer high strength, stiffness, and lightweight properties, which make them ideal for aircraft components that are subjected to high loads and stresses. Synthetic composites are used in the manufacturing of engine components, such as fan blades, casing, and vanes. These materials offer high-temperature resistance and lightweight properties, which are critical for aircraft engines. Composite materials are also used in the manufacturing of interior components, such as cabin floors, seats, and overhead compartments. These materials offer weight reduction and durability, as well as the ability to withstand fire and smoke. Synthetic composites are used in the manufacturing of helicopter rotor blades. These materials offer high strength, stiffness, and lightweight properties, which are critical for helicopter performance. Composite materials are used in the manufacturing of satellite structures, such as antennas, solar panels, and support structures. These materials offer lightweight properties, which are critical for satellite launch and orbit.

Automotive: Synthetic composites have various applications in the automotive industry due to their lightweight, high strength, and durability properties. Some of the key applications of synthetic composites in the automotive industry include: Composite materials are used in the manufacturing of body panels, such as hoods, fenders, and roofs. These materials offer high strength and stiffness, which helps in improving the crashworthiness of the vehicle and reducing its weight. Synthetic

composites are used in the manufacturing of chassis components, such as suspension arms, subframes, and cross members. These materials offer high stiffness and strength, which improves the handling and performance of the vehicle. Composite materials are also used in the manufacturing of interior components, such as dashboards, door panels, and seats. These materials offer weight reduction, durability, and improved aesthetics. Synthetic composites are used in the manufacturing of engine components, such as intake manifolds, valve covers, and oil pans. These materials offer weight reduction and improved thermal management properties. Composite materials are used in the manufacturing of wheels, which offer weight reduction and improved performance. These wheels are often used in high-end sports cars and racing vehicles. With the rise of electric vehicles, composite materials are being used in the manufacturing of battery enclosures. These materials offer high strength, lightweight, and improved safety for the battery system ^[18].

Construction: Synthetic composites have various applications in the construction industry due to their high strength, lightweight, and durability properties. Some of the key applications of synthetic composites in construction include: Composite materials are used in the manufacturing of building panels, such as cladding, roofing, and flooring. These materials offer high strength and stiffness, which helps in improving the overall durability and energy efficiency of the building. Synthetic composites are used in the construction of bridges due to their high strength and lightweight properties. These materials are often used in the construction of bridge decks, which offer improved corrosion resistance and durability. Composite materials are used as reinforcement in concrete structures, such as beams, columns, and slabs. These materials offer improved strength and durability, which helps in reducing the amount of concrete needed and improving the overall structural integrity of the building. Synthetic composites are used in the manufacturing of pipes for water and sewage systems. These materials offer improved corrosion resistance and durability, which helps in reducing maintenance and replacement costs. Composite materials are used in the manufacturing of wind turbine blades, which offer high strength, stiffness, and lightweight properties. These materials help in improving the overall efficiency and reliability of the wind turbine system. Composite materials are used in the manufacturing of sports facilities, such as stadium roofs, stands, and athletic tracks. These materials offer improved strength, durability, and aesthetics, which helps in creating a safe and comfortable environment for athletes and spectators.

Marine: Synthetic composites have various applications in the marine industry due to their high strength, lightweight, and corrosion-resistant properties. Some of the key applications of synthetic composites in marine includes: Composite materials are used in the manufacturing of boat hulls, which offer high strength, stiffness, and lightweight properties. These materials help in improving the overall performance, fuel efficiency, and durability of the boat. Synthetic composites are used in the construction of various marine structures, such as piers, docks, and buoys. These materials offer improved corrosion resistance and durability, which helps in reducing maintenance and replacement costs. Composite materials are used in the manufacturing of various parts of submarines, such as pressure hulls and sonar domes. These materials offer high strength, stiffness, and acoustic properties, which helps in improving the overall performance and safety of the submarine. Synthetic composites are used in the construction of offshore structures, such as oil and gas platforms and wind turbines. These materials offer improved corrosion resistance, durability, and fatigue resistance, which helps in reducing maintenance and replacement costs and improving the overall performance and safety of the structure. Composite materials are used in the manufacturing of various water sports equipment, such as surfboards, paddleboards, and kayaks. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall performance and durability of the equipment.

Sports and recreation: Synthetic composites have various applications in sports and recreation due to their high strength, lightweight, and durable properties. Some of the key applications of synthetic composites in sports and recreation include:

Composite materials are used in the manufacturing of various sporting goods, such as tennis rackets, golf clubs, hockey sticks, and ski poles. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall performance and durability of the equipment. Composite materials are used in the manufacturing of bicycle frames, which offer high strength, stiffness, and lightweight properties. These materials help in improving the overall performance, speed, and durability of the bicycle. Synthetic composites are used in the manufacturing of various protective gear, such as helmets, body armor, and shin guards. These materials offer high impact resistance and lightweight properties, which helps in improving the overall safety and comfort of the gear. Composite materials are used in the manufacturing of various recreational equipment, such as kayaks, canoes, and paddleboards. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall performance and durability of the equipment. Synthetic composites are used in the manufacturing of various exercise equipment, such as weight lifting equipment, treadmills, and ellipticals. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall performance and durability of the equipment.

Medical: Synthetic composites have several applications in the medical field due to their biocompatible, lightweight, and durable properties. Some of the key applications of synthetic composites in medicine include: Composite materials are used in the manufacturing of prosthetics and implants, such as artificial joints, dental implants, and bone grafts. These materials offer high strength, stiffness, and biocompatibility, which helps in improving the overall performance and durability of the implants. Synthetic composites are used in the manufacturing of various surgical instruments, such as forceps, scissors, and retractors. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall functionality and ease of use of the instruments. Composite materials are used in the manufacturing of various diagnostic equipment, such as X-ray machines and CT scanners. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall performance and durability of the equipment. Synthetic composites are used in the manufacturing of various rehabilitation equipment, such as braces, supports, and crutches. These materials offer high strength, stiffness, and lightweight properties, which helps in improving the overall comfort and functionality of the equipment. Composite materials are used in the manufacturing of drug delivery systems, such as nanocarriers and implants. These materials offer high biocompatibility and drug loading capacity, which helps in improving the overall efficiency and effectiveness of the drug delivery system ^[19].

Challenges and future directions

The selection of the right combination of matrix and reinforcement material is crucial for the performance of synthetic composites. The materials should be compatible with each other and should offer the desired mechanical and physical properties. The manufacturing process for synthetic composites involves several stages, such as mixing, molding, curing, and finishing. The process parameters, such as temperature, pressure, and time, need to be controlled carefully to ensure that the materials are produced with the desired properties and quality. The quality of synthetic composites depends on several factors, such as the quality of raw materials, process parameters, and post-processing. Quality control measures, such as inspection, testing, and certification, need to be implemented to ensure that the materials meet the desired quality standards. The cost of manufacturing synthetic composites is higher compared to traditional materials, such as steel and aluminum. The high cost of raw materials, equipment, and specialized labor can make it challenging to produce synthetic composites at a competitive price. The manufacturing of synthetic composites involves the use of chemicals and materials that can be harmful to the environment. Proper disposal of waste materials and adherence to environmental regulations are essential to minimize the environmental impact of synthetic composite manufacturing.

Future directions in synthetic composites offer enhancement in mechanical properties and expansion in various industries. Research is being conducted on developing synthetic composites that can withstand high-temperature environments for applications in the aerospace and energy industries. Research is being conducted on developing lightweight and strong synthetic composites for structural applications, such as bridges, buildings, and other infrastructure. Research is being conducted on the development of smart composites that can sense and respond to changes in their environment, making them useful for applications in aerospace, defense, and biomedical industries. Research is being conducted on developing sustainable and environmentally friendly methods for the manufacturing and recycling of synthetic composites to reduce waste and pollution [20].

CONCLUSION

Synthetic composite materials are becoming increasingly popular due to their unique properties and advantages over traditional materials. In this review, we have discussed the various manufacturing processes used to produce synthetic composites, including resin transfer molding, vacuum infusion, filament winding, pultrusion, compression molding, and additive manufacturing. We have also explored the various reinforcement materials used in synthetic composites, such as glass fibers, carbon fibers, aramid fibers, natural fibers, and nanofillers. Furthermore, we have highlighted the various applications of synthetic composites in aerospace, automotive, construction, marine, sports and recreation, and medical industries. We have also discussed the manufacturing challenges associated with synthetic composites and the emerging applications and research areas.

In conclusion, synthetic composite materials are a promising class of materials that offer unique advantages in terms of weight reduction, strength, durability, and design flexibility. With continued research and development, synthetic composites have the potential to revolutionize various industries and contribute to sustainable and environmentally friendly manufacturing processes.

REFERENCES

1. Mishra S, et al. Studies on mechanical performance of biofibre/glass reinforced polyester hybrid composites. *Compos Sci Technol*. 2003;63:1377-1385.
2. Abenojar J, et al. Effect of boron carbide filler on the curing and mechanical properties of an epoxy resin. *J Adhes*. 2009;85:216-238.
3. Asi O. An experimental study on the bearing strength behaviour of Al₂O₃ particle filled glass fiber reinforced epoxy composites pinned joints. *Compos Struct*. 2010;92:354-363.
4. Jawaid MH, et al. Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review. *Carbohydr Polym*. 2011;86(1):1-8.
5. Agarwal G, et al. Thermo-mechanical properties of silicon carbide filled chopped glass fiber reinforced epoxy composites. *Int J Adv Struct Eng*. 2013;5:21.
6. Sudheer M, et al. Enhanced mechanical and wear performance of epoxy/glass composites with PTW/graphite hybrid fillers. *Procedia Mater Sci*. 2014;6:975-987.
7. Gull N, et al. Synthesis and characterization of zinc oxide (ZnO) filled glass fiber reinforced polyester composites. *Mater Des*. 2015;67, 313-317.
8. Masghouni N, et al. Quasistatic and dynamic mechanical characterization of a woven carbon fiber-zinc oxide nanowires-epoxy composite. *Polym Compos*. 2015;36:2184-2192.

9. Ganesha B, et al. Effect of cerium oxide as filler material on e-glass fiber/epoxy reinforced polymer composites. *Int J Dev Res.* 2016;6:7425–7428.
10. Hu Y, et al. A novel approach for Al_2O_3 /epoxy composites with high strength and thermal conductivity. *Compos Sci Technol.* 2016;124:36–43.
11. Erklig A, et al. Charpy impact response of glass fiber reinforced composite with nano graphene enhanced epoxy. *Period Eng Nat Sci.* 2017;5.
12. Arpitha GR, et al. Hybridization effect of sisal/glass/epoxy/filler based woven fabric reinforced composites. *Exp Tech.* 2017;41:577–584.
13. Das G, et al. Erosion wear behavior of coir fiber-reinforced epoxy composites filled with Al_2O_3 filler. *J Ind Text.* 2017;47:472–488.
14. Rallini M. et al. Effect of boron carbide nanoparticles on the thermal stability of carbon/phenolic composites. *Polym Compos.* 2017;38:1819–1827.
15. Ramadan N, et al. Behavior of hybrid SiC /Jute epoxy composites manufactured by vacuum assisted resin infusion. *Polym Polym Compos.* 2017;25:333–344.
16. Bulut M, et al. Tensile and impact characterization of S-glass/epoxy composite laminates containing microscale borax, perlite, and sewage sludge ash particles. *J Braz Soc Mech Sci Eng.* 2018;40:199.
17. Trzepieciński T, et al. Application of composite materials for energy generation devices. *J Compos Sci.* 2023;7:55.
18. Sarkar P, et al. Effect of aluminum filler on friction and wear characteristics of glass epoxy composites. *Silicon.* 2018;10:715–723.
19. Yazman S, et al. A comparative study on the effect of CNT or alumina nanoparticles on the tensile properties of epoxy nanocomposites. *Arab J Sci Eng.* 2019;44:1353–1363.
20. Alsayed Z, et al. Thermo-mechanical properties of high density polyethylene with zinc oxide as a filler. *Iran Polym J.* 2020;29:309-320.