A Comprehensive Review of the History, Advantages, Applications and Fabrication Techniques of Composite Materials

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Abstract – Composites are materials made from at least two different materials. Composites were initially employed by ancient Egyptians and Mesopotamians in the 1600s B.C. to construct long-lasting houses out of a combination of mud and straw. As late as the Middle Ages, composite items like ceramics and boats relied on reinforcing materials made from straw. When these materials, which have very different chemical or physical characteristics, are combined, a new substance is produced that is unlike any of its component parts. Many people are drawn to novel material because it offers advantages over the status quo, such as greater strength, lower weight, or lower cost. Recent years have seen an uptick in the study of Robotic Materials, composites with built-in capabilities for sensing, actuation, computing, and communication. Because of their superior qualities, composites are increasingly being used in place of more traditional materials; this calls for further study of these materials. This article provides a review of composite materials before going through their history, fabrication methods, benefits, and uses.

Keywords – Fiber-Reinforced Polymer, Resin Transfer Molding, Automated Tape Laying, Automated Fiber Placement, Reaction Injection Molding.

I. INTRODUCTION

Composites are materials made from at least two different materials, and combine elements with noticeably different chemical or physical characteristics to produce a compound with qualities not found in either of the parent components. Composites are unique from mixes and solid solutions in that the constituent parts retain their respective identities inside the final structure. Reinforced concrete and masonry are two common examples of engineered composites, in addition to plywood. Fiber-Reinforced Polymer (FRP), ceramic and fiberglass matrix composite (metal matrices and ceramic composites) are examples of reinforced plastics [1]. For a number of factors, it may be preferable to use brand-new material. Composite materials based on ideas from animals and natural sources that have a small carbon impact are a good example of this kind of material.

Recent years have seen an uptick in the study of robotic materials, which are composites with added functionality for sensing, actuation, computing, and communication. Race car bodywork, boat hulls, pool panels, storage tanks, shower stalls, bathtubs, cultured marble basins, imitation granite and countertops, and bathtubs, and shower stalls are all examples of composite materials used in construction. Composite materials also finding more and more uses in cars and trucks. The most cutting-edge ones are used regularly aboard spaceships and airplanes in harsh conditions. Concrete, the most widely used artificial composite material, is made by combining aggregate (small stones) with a binding substance (usually cement). Concrete is low-priced and strong enough to withstand significant compression without cracking or breaking. Concrete, however, fails under tensile stress (i.e., if it is stretched, it might break with ease). Thus, steel bars that are resistant to high tensile (stretching) pressure, are typically integrated to concrete to compose reinforced concrete, which gives concrete the capacity to withstand being overextended.

Carbon-fiber polymer and glass-plastic polymer are two of the examples of polymers reinforced with fibre. The thermoplastic composites, long-fibre thermoplastics, short-fibre, and long-fiber reinforced thermoplastics are the different types of thermoplastics that may be broken down according to their matrix. In the category of thermoset composites, paper composite panels are only one example. Aramid fiber, an epoxy resin matrix, and carbon fiber make up a large part of many cutting-edge thermoset polymer matrix systems. High-performance composites, shape memory polymer composites are made by combining a shape-memory polymer resins matrix with a fiber or fabric reinforcement. Due to the use of a shape-memory polymer resins matrix as the matrices, the composites may be readily reshaped by applying heat above their temperatures of activation while still retaining high rigorousness and strength at room temperature. They retain their original qualities even after being repeatedly molded and heated. Rigid, lightweight, applicable structure; dynamic reinforcement; and quick manufacturing are some of the various applications of these composite materials. Another category of composites that are high-performing and strenuous are optimized for performance in a highly deformed environment; this makes them a common choice for deployable systems in where structural bending is beneficial.

Nevertheless, unlike shape memory polymers, the performance of high strain composites is often determined by the orientation of the fibers inside the matrix rather than the resin used to create the matrix. Materials like bone (hydroxyapatite based on the collagen fiber), concrete, and cermet (metal and ceramic) are all examples of composites that employ metal fibers to strengthen other metals. A primary design goal for ceramic matrix composites is to increase fracture toughness rather than increase strength. Interwoven fabric composite materials that integrate both the transverse and longitudinal laced thread are another type of composite materials. The fabric-generated composites, such as those made from woven materials, are adaptable. Asphalt concrete, polymer concrete, mastic asphalt, syntactic form, mastic roller hybrid, dental composite, and the mother of pearl are the various examples of ceramic aggregate or organic matrix composites. Chobham armor is considered a sophisticated type of composite with a wide-variety of military uses.

Moreover, some metal powders may be used into the formulation of thermoplastic composite materials to generate products composed of a wide-range density from 2 g/cm^3 to 11 g/cm^3 (just like lead). While "lead replacement" is sometimes used, "High Gravity Compound" (HGC) [2] is the more usual term. Applications include weighing, balancing (for instance, altering the centering of tennis racquet’s density), radiation shielding, and vibrations dampening; conventional composite materials such as stainless steel, aluminum, brass, copper, bronze, lead and tungsten may be replaced with these. When some bio-materials are considered as restricted and toxic (for instance, lead), or whenever secondary costs of operation (for instance, coating, finishing, or machinery) are a factor for consideration, then high composite density become a financially feasible choice.

It has been shown in a number of studies that combining flexible thermoplastic laminates with stiff epoxy-generated carbon fiber-based polymer tends to laminate results in substantially toughened composites with increased impact resistance. Balsa plies intermingled with hotter glue, aluminum plies intermingled with PVC or acrylic polymer, and carbon fiber-based polymer covers intermingled with polystyrene are all examples of interleaved composites having shape memory behavior that do not need the use of polymer-based composites or shape memory metals. Sandwich-produced composites are a segment of composites structured by joining lightweights but somewhat stiff cores between two flexible and thin shells. Whereas the core materials are normally featured to have reduced strength materials, the increased thickness of the sandwich composite allows for greater bending stiffness while maintaining a relatively low overall density.

Timber is a composite material made up of cellulose fiber integrated in hemicellulose and lignin matrix. Oriented strand-board plywood, wood fibre board, wood plastic composites (wood fibres recycled in polyethylene matrices). Laminated paper, plastic-impregnated, or textiles, Pykrete (sawdust within rce matrix), Formica (plastic), Arborite, and Micarta are some of the various items that fall under the umbrella term "engineered wood." Mallite is an example of an engineered laminate composite that has a balsa wood end grain core encased in a lightweight metal and glass fiber reinforced plastic. Materials with great stiffness and low weight are produced. Particulate composites have a filler material consisting of particles that are spread across a matrix that is typically nonmetallic but may also contain materials like glass or epoxy.

This article provides a review of composite materials, discussing their history, production procedures, benefits, and applications. Composites are materials that are made up of two or more distinct materials, each of which has unique features on its own, but which, when combined, create a new material with properties that are not present in either of the original materials. Nothing in the completed structure obscures the novelty of its parts. Many people are drawn to the novel material because it offers advantages over the status quo, such as greater strength, lower weight, or lower cost. Robotic Materials are the result of recent efforts to integrate sensing, computing, communication and actuation into composites. Because of their superior qualities, composites are increasingly being used in place of more traditional materials; this calls for further study of these materials. This is how this paper has been structured: Section II provides a detailed historical background of composite materials. Section III focuses on discussion the different types of composite materials. Section IV, V, and VI provides a discussion of fabrication techniques, advantages and applications of composite materials, respectively. Lastly, Section VII draws a conclusion to the research.

II. HISTORY

The Mongols structured the first known composite material (bow) in 1200 AD [3]. During that time, bows were structured by pressing different pieces of wood together with animal glue and bone, then wrapping the resultant bundle in birch barks. The bows were formidable in both force and accuracy. Genghis Khan's military success may be attributed in large part to the advent of composite Mongolian bows, which were the most potent weapon in the world up until the development of gunpowder. Composites entered its modern age after polymers were created by scientists. In the past, glues and binders were made only from physical resins removed from different animals and plants.

The materials such as phenolic, vinyl, polyester, and polystyrene were launched in the early 1900s. They were more effective than natural resins, but these new synthetic materials were much better. Plastics in and of themselves, however, lacked the necessary strength for use in structural applications. This required the use of reinforcements to provide strength and stiffness. Glass fiber was first produced commercially by Owens Corning in 1935. When fiberglass is mixed with a plastic polymer, the resulting structure is both lightweight and very durable. The modern Fiber Reinforced Polymers (FRP) sector has its roots in this era.

WWII – Driving Early Composites Innovation

Wars have been responsible for the development of several important composites. Similar to how the Mongols invented the composite bow, the FRP industry went from the lab to mass manufacturing during World War Two. Lightweight alternatives were required for use in military aircraft. As time went on, engineers found that these composites had additional advantages besides their low weight and high strength. Because of their permeability to radio waves, fiberglass composites found immediate use in protecting electronic radar systems (Radomes).

Adapting Composites: "Space Age" to "Everyday"

A specialized composites industry was well established by war's conclusion. When the market for military goods slowed, the few pioneers in the field of composites set their sights on expanding into other fields. The use of composites in boat construction was a natural progression, and the first industrial boat hull debuted in 1946. Brandt Goldsworthy, the "grandfather of composites," created cutting-edge production techniques and materials during this period. Several innovations bear his name, but perhaps the most significant is the introduction of the fiberglass surfboard, which completely altered the nature of the sport. Goldsworthy also developed pultrusion, a novel method of production. Ladder rails, instrument handles, pipelines, arrow shafts, armour, train flooring, medical gadgets, and more are just few of the modern examples of things made using this method.

Continued Advancement in Composites

The composites industry reached a critical mass in the 1970s. There have been advancements in the plastic resins and reinforcing fibers used in construction. Kevlar, an aramid fiber invented by DuPont, has replaced traditional textiles as the gold standard for body armor [4]. During the same time, carbon fibers were discovered and quickly began to displace metal as the dominant industrial material. The composites market is still developing, although renewable energy is where much of the expansion is happening at the moment. The blades of wind turbines are becoming larger and larger, therefore engineers and manufacturers need to become creative with their approaches to materials, design, and production. In contrary to metal alloys, the chemical, mechanical, and physical characteristics of the individual components are preserved. A reinforcing element and a matrix make up the two parts.

III. TYPES OF COMPOSITE MATERIALS

Composite materials are typically categorized into two levels as shown in **Table 1**.

Table 1. Types of composites

Matrix-constituent	These include CMCs (Ceramic Matrix Composites), MMCs (Metal Matrix Composites), and OMCs (Organic Matrix Composites) (e.g., carbon matrix composite, and polymer matrix composite).
Reinforcement form	These include laminar composites, particular composites, and fibre reinforcement composites e.g., continuous and discontinuous fibres.

In fibre reinforcement composites, fibres are incorporated into a matrix to form a composite. If the composite's characteristics change when the fibres are lengthened or shortened, we refer to it as a short- or discontinuous-fibre composite. Nonetheless, the fibre length must be optimal for the composite's elastic modulus to be deemed continuous fibre reinforced. Due to their tiny diameter, fibers are readily bent when subjected to an axial force. Yet, they exhibit excellent tensile qualities. These fibers need to be stabilized so that they don't buckle or bend under their own weight.

In the laminar composites, layers of materials are kept together in a laminar composite by a matrix. This class includes sandwich architectures. Dispersed or embedded particles make up the constituent parts of a matrix body to create a Particulate Composite. Flakes or powder might make up the particles. Examples include concrete and particle boards made from wood. The most often seen composite materials may be broken down into the following groups according to their reinforcing type: (1) "Fibrous Composites," which use fibers as reinforcement. a. "Random Fiber" reinforced composites use short fibers; b. Composites reinforced with continuous fibers (sometimes called long fibers) (2) Particles, which are used as reinforcement in these composites (Particulate materials). (3) Flake composites, in which flat flakes are used as reinforcement: and (4) reinforcing fillers (Filler composites).

IV. FABRICATION TECHNIQUES

Composites may be made in different ways. Even though some of the ways have been adopted from other fields (injection molding), many have been created in response to unique problems in product design or production. The materials, the part's design, and the part's final use are all crucial considerations when deciding which technique to utilize. Molding is used in composite manufacturing to modify reinforcements and resin. An effectual model instrument is required to effectively shape unstructured fiber or resin mixture before and during the curing process. Hand layup is the most fundamental technique for producing thermoset composites, and it involves manually affixing layers of dry fabric (called "plies") or prepreg plies to an instrument to establish laminate stacks. When layups are complete, resins are applied to dried-up plies (using resins infusion). In this, there are a number of treatments that may help.

The simplest method is to wait for cure to occur at normal temperature. Nevertheless, cure may be sped up by subjecting the material to heat (typically in ovens) and pressure (in a vacuum). The use of an autoclave is necessary for the curing of many high-performance thermoset components since this kind of part requires both high heat and high consolidation pressure. The upfront and ongoing costs of an autoclave may be rather high. Autoclaves allow manufacturers to cure several components at once. Autoclaves with computer-monitored and –controlled vacuum, pressure, temperature, and inert atmosphere environments allow for remote and unattended monitoring of the process of curing and optimize the technique's efficiency.

To effectively cure lightweight laminates, E-beam (electronic beam) curing has been investigated. For radiation-sensitive resins to undergo polymerization and crosslinking, E-beam curing reveals the composite lay-ups to E-stream, which generates ionizing radiations. The processes of X-ray curing and microwave curing are functionally equivalent. Ultraviolet (UV) curing is a fourth option that uses UV light to initiate a crosslinking reaction after a photoinitiator has been introduced to a thermoset resin. For ultraviolet curing, the resin and reinforcements must be transparent to light.

Open Molding

Open molding represents one-dimensional molds, which are a popular and cost-effective approach to producing fiberglass composite products. Boat decks, and hulls, recreational vehicle components, fenders and car cabs, bathtubs, spas, and shower stalls, as well as other moderately sized, non-complex designs are often molded using open molding, which may be semi-automatic or hand lay-up alternative spray-ups. Before sprayup may commence in an open mold, a mold release must be applied to the molds. Once these molds' release has been employed, gel coats, if used, are usually sprayed into the mold. The mold may be utilized to produce the final product after the gel coat has cured. Using a chopper gun to break the glass fiber into smaller pieces before blowing it directly into the sprayed resin stream, catalyzed resins (with a 500 cps to 1000 cps viscosity) is scattered into the molds.

Applying resins and gel coatings in large droplet at a reduced pressure, as achieved using fluid bombardment spray heads and non-atomizing spray guns driven by piston pumps, reduces emissions of volatile organic compounds. Another possibility is the breaker impregnators, which resemble a paint roller but is filled with resin instead of paint. After the sprayup process is almost complete, the laminate is manually condensed using rolls. The laminate skins, which may be made of wood, foam, or any other material, are then sprayed with a sprayup layer to firmly embed the core between the skins. The part is taken out of the mold after curing and chilling. Sprayup and hand layup are typically employed in tandem in order to save production time.

Resin Infusion Processes

With the constant need for higher output, fabricators have been pushed to find more efficient alternatives to hand layup and to automate those procedures whenever feasible. Resin Transfer Molding (RTM) [5], sometimes identified as liquid molding is a frequent substitute. We can attest to the fact that RTM's advantages are significant. Resins and dry pre-forms employed in RTM are typically less expensive compared to the prepreg materials and could be stored at normal (room) temperatures. The method is able to create thick, near-net shaped components, which means less finishing is required. In addition to producing smooth finishes on all visible surfaces, it also produces complicated pieces that are true to size and have high levels of surface detail. The RTM technique allows for the incorporation of molded fittings and core materials and different hardware into the component structure by inserting them into the preform before closing the mold. Cycle times, which may take days with hand layup, can be reduced to hours or minutes with RTM, and the method can be integrated into a repeatable, and automated manufacturing process for even greater efficiencies.

In Reaction Injection Molding (RIM) [6], a rapid-cure catalyst and resin are incorporated into molds into two distinct streams, whereas in RTM they are premixed before the injection under pressure. Because of this, there is no need for a dispensing head since the mixing and subsequent chemical reaction take place inside the mold itself. Suppliers in the automotive sector often use a combination of quick preforming techniques and structural RIM (SRIM) to create structural components that do not necessitate an "A" class finish. Over the past few decades, computable robots have become a standard method for spraying a mixture of chopped binder and fiberglass onto mold or preform screen that is fitted with a vacuum. Fiber orientation may be manipulated by directing robotic sprayup. Dry fiber insertion integrates stitched preforms with RTM, another similar process. Automated controls guarantee minimal voids and reliable preform reproduction, even with fiber quantities as high as 68%, and all without the requirement for trimming.

The most rapidly developing kind of recent molding technology is called VARTM (Vacuum-Assisted Resin Transfer Molding) [7], which encompasses a family of procedures with a number of commonalities. One major distinction between RTM and VARTM is that in the latter, resins are injected into pre-forms only using vacuums, as opposed to being pushed in under pressure. To perform VARTM, it is not necessary to apply intense heat or pressure. As a result, VARTM utilizes affordable tooling, allowing for the low-priced, single-shot production of massive, complicated components. The VARTM method involves packing fiber reinforcements into a mold with just one side exposed, and then sealing the mold with a cover (usually a plastic bagging film) to create a vacuum. In most cases, a "manifold" (a collection of ports and feed lines) is used to introduce the resin to the building. It is sucked up by suction and pumped through the reinforcements, where it flows via a network of channels made specifically for that purpose. The final product may include as much as 70% fiber. Marine, land-based, and infrastructural components are all current uses for this technology. The Boeing Co. (Chicago, IL), NASA, and even some smaller fabricators have used this technique to make autoclave-free laminates of aircraft grade.

High-volume Molding Technique

Compression Molding

Compression molding, a technique for mass-producing thermosets, requires high-quality yet pricey metal dies. When the expected quantity of finished goods is more than 10,000 units, this option becomes viable. Using SMC (Sheet Molding Compound), hybrid sheet materials created by sandwiching the shredded fiberglass between different sheets of thicker resin paste, a single set of forged steel dies may produce as many as 200,000 individual pieces. The newly available low-pressure SMC formulations provide open molders with a low-capital investment entries into closed mold production with the possibility for extremely low VOC emissions and a very high-quality surface finish. As a result of carbon's superior stiffness and strength compared to its weight, SMC reinforced with carbon fiber is being considered by the automotive industry for use in external body panels and other components. Microcracking, a conditioning that traditionally stimulated paints to "pop" during the process of painting may now be avoided using newer, tougher SMC formulations (outgassing, the escape of gases from the micro-cracks during ovens cure, causes surface craters). In order to address the demands of specialized applications that call for UV, impact, and moisture resistance as well as high standards in surface quality, composites producers in commercialized market are establishing their resin and composing SMC in-house.

Injection Molding

Most typically, filled thermoplastics are used in injection molding, and examples include nylon with sliced glass fibres. The process is high-volume, closed, low-pressure, and rapid. Although thermoplastic and metal casting producers formerly dominated certain sectors, automated injection molding of BMC has shifted the balance of power in recent decades. Some multi-cavity molds may create as many as 2,000 of a given tiny component per hour, and injection rates generally range from one to five seconds. Using BMC, you may use either compression molding or transfer molding to create components with substantial wall thicknesses. To do transfer molding, a calibrated BMC charge is added into a pot with a runner, which goes to the molds' cavity. The materials are inserted into the cavity by a plunger and cured by applying heat and pressure.

Filament Winding

In terms of automation, repeatability, and material costs, filament winding is a continual production/fabrication approach that can achieve all three with reasonable ease. The circumferential or "hoop" strength of filament-wound components is unparalleled. When it comes to filament winding, golf club shafts are by far the most popular use. The remainder of the market is dominated by cylindrical products such fishing rods, pipes, compressed gases, and other fishing gear.

Pultrusion

Similarly to RTM, pultrusion has been utilized with polyester resins and glass fiber for decades, but only in the past decade has it found utility in sophisticated composites. The reinforcing fibers (often tow, continuous, or tow mat) are drawn via pre-heated resin bath, and therefore molded into certain types as it goes through a single or multiple formation bushings or guides in this straightforward, low-cost, continuous process. After being heated in a die, the material is then able to adopt its final form. The resultant profile is then cooled and trimmed to size further down the line. Pultrusion results in flawless, post-processing-free components. The method of pultrusion may be modified to produce a variety of solid and hollowed profiles that are continuous and uniform.

Tube Rolling

The production of tubes and rods of certain length is possible using the time-honored method of tube rolling, which is used in the composites industry. It is ideal for cylindrical or conical tubes with a small diameter and a length of up to 20 feet (6.2 meters). Tubing with a diameter of up to 152 mm (6 inches) could be rolled with ease. Prepreg fabrics with a sticky surface or unidirectional tape are often used for this purpose. Materials are precut in patterns optimized for the desired ply scheduling and fiber architecture. A mandrel is wrapped over each pattern piece while pressure is applied to compress and debulk the material, which is put out on a flat surface. The first row of transverse fibers is the only one that aligns with the real 0° axis whenever rolling tapered mandrels e.g., for golf shafts or fishing rods. Therefore, the fibers should be continuously re-oriented by re-identifying the pattern components at different intervals on a regular basis to provide flexural capacity to the tube.

Automated Fiber Placement (AFP)

Automated Fiber Placement (AFP) [8] is accomplished by numerically controlling an articulated robot placement head, which are capable of dispensing, clamping, cutting and restarting about 32 prepreg tows concurrently, allowing for rapid, automated insertion into a mandrel. Ply form is mostly determined by the minimal cut length (small row length machinery could lie down). Integrated to a five-axis gantry or fitted with filament winders, or issued as a full, bespoke model, the fiber placement heads have several potential applications. Dual mandrel stations are a feature of certain machines that may boost output. Faster processing, less waste and cheaper labor, fewer components, and more consistency amongst them are only some of the benefits of fiber insertion. Large, intricate thermoset items are often manufactured using this method.

Automated Tape Laying (ATL)

As an even faster automated technique, Automated Tape Laying (ATL) [9] involves the continuous laying down of prepreg tape to construct components rather than the use of individual tows. It is often utilized for components with very intricate angles and curves. Tape layup is flexible since it can be modified for use with either thermoset or thermoplastic materials, and it also allows for process breaks and straightforward direction changes. The tape spool(s), winder(s), winder(s) guides, position sensors, tape slitters/cutters, and compaction shoe are all segments of the heads. Heads could be mounted onto gantry, which is placed above an instrument, or they could be placed on the end of multi-axial articulated robots, which rotate around a mandrel or instrument. It is true that ATL is often quicker and more capable of placing more material over greater distances, but AFP is more adept at placing material over curved surfaces and is thus more suited to shorter courses. These techniques, which originated in the machine tool sector, have been widely used in the production of several parts of the next Airbus A350 XWB and Boeing 787 Dreamliner, including the fuselage, wings skinning panels, wingbox, and tail. Several aircraft, including the F-35 Lightning-II fighter jets, the V22 Osprey tiltrotors troop’s transportation, and others, rely heavily on components made with ATL and AFP.

Centrifugal Casting

For high-performing, corrosive-resistant services, centrifugal casting of tubing with a diameter ranging from 25 mm (1 inch) to 356 mm (14 inches) provide alternative filament windings. Although multiaxial fiberglass wrapped pipe offers better strength at the same wall thickness, 0°/90° woven fiberglass in cast pipe offers both transverse and hoop tensile strength across pipe walls. The casting procedure entails injecting an epoxy or polyvinyl chloride resin into 150G radially spinning molds, where it gets into the woven fabric lining the inner-most surface of molds. The resin is forced through the fabric layers by centrifugal force, resulting in a smooth exterior, and the surplus resin is poured into molds, amounting to resin-rich, and abrasion- or corrosion-resistant inner liners. Now, extrusion may also be used to make thermoplastic parts with fiber reinforcement. Extruded composites made from thermoplastics and wood flour (or additions such as fly ashes or bast fibers) has gained significant traction in recent years. WPCs are utilized in places where wood decking, paneling, door and window frames, and fence would normally be installed.

V. ADVANTAGES

Table 2. provides a discussion of the advantages of composite materials.

Table 2. Composite materials advantages	
Light Weight	Composites are lightweight alternatives to traditional materials like wood and metal. Lighter vehicles and planes have a greater fuel economy because of their low weight (more miles to the gallon). Aircraft designers give careful consideration to weight since it directly impacts the plane's performance, including its fuel efficiency and top speed. The new Boeing 787 Dreamliner is one such airliner that uses more composites than metal in its construction.
High Strength	The strength of composites may be engineered to exceed that of metals like aluminum and steel. Metals maintain their strength in any orientation. On the other hand, composites may be made to be very robust in a particular orientation by careful engineering and design.
Strength Related to Weight	When comparing two materials, the strength-to-weight ratio measures how powerful one is in comparison to the other. Steel, for example, is both robust and heavy. Bamboo poles are a good example of a sturdy and lightweight material. Strong and lightweight composites may be created. Composites are employed in aircraft construction because of its excellent strength-to-weight ratio. For instance, a composite might be designed to be bent in just one way. When more strength is required in one direction, the metal used in the construction must often be thicker, which increases the overall weight. Composites have the potential to be both robust and lightweight. Composites now have the greatest strength-to-weight ratios in constructions.
Corrosion Resistance	Composites may be used outside without worrying about deterioration from the elements, and they can even withstand chemical attacks that would destroy other materials. Composites are a reliable material for chemical storage and transport. If left outside, they will withstand the elements and temperature swings.

High-Impact Strength	When exposed to a strong impact, such as the abrupt force of bullets or blasts from explosions, composites may be designed to absorb the energy and return it to its original shape. For this reason, composites are often utilized as blast barriers in aircraft, buildings, and military vehicles, as well as in bulletproof jackets and panels.
Design Flexibility	Composites are more malleable than most other materials, making it possible to form them into intricate designs. Because of this, designers now have almost limitless potential in terms of form and shape. As an example, fiberglass composites are widely used in today's boat construction because of their cheap cost and high flexibility in mold design. This allows for more innovative boat forms and designs at a lower overall cost. Composites may have any desired surface finishing, or texture molds into them, from pebbly to smooth.
Part Consolidation	A whole metal mechanism may be replaced by a single composite component. Time and money are saved throughout the machine's or building's lifetime if the number of moving components is reduced.
Dimensional Stability	Composites do not shrink or expand when exposed to heat or moisture. In contrast, wood expands and contracts in response to variations in humidity. Use composites where a snug, consistent fit is essential. For instance, they are installed in airplane wings to keep the wings from expanding or contracting when the plane changes altitude.
Nonconductive	The composite material does not allow the flow of electricity. They are well-suited for use in electrical utility poles and electronic circuit boards because to this feature. Certain composites can be made electrically conductive if that property is required.
Nonmagnetic	Since they lack metals, composites cannot be magnetized. They are safe to use near delicate electronics. The big magnets utilized in MRI (magnetic resonance imaging) equipment function more efficiently due to the absence of magnetic interference. The table and the equipment housing are both made of composite materials. The hospital's concrete walls and floors are strengthened with composite rebar during construction.
Radar Transparent	Since radar signals are not attenuated by composites, they are well-suited for usage in any environment where radar systems is in operation, whether on the land or in the air. Stealth aircraft, like the B-2 bomber flown by the United States Air Force and designed to evade radar detection, rely heavily on composites.
Low Thermal Conductivity	Materials made from composites have excellent insulating properties. In structures, they are employed on doors, paneling, and windows to provide added defense against the elements.

VI. APPLICATION OF COMPOSITES

Aircraft Sector

Due to its high durability, strength, corrosion resistance, damage tolerance, and fatigue resistance, fiber reinforced composites have emerged as a viable alternative to traditional metals for numerous aviation components. Moreover, composites provide considerable weight benefits and better adaptability due to the material's ability to be shaped to fit the design requirements. To date, well-crafted individual composite components are around 20-30% lighter than their typical metal counterparts. While all-composite aircraft are already on the market, improvements in the practical application of composites could allow for much more reduction in structural weights of aeroplanes. Filaments or fibers are integrated into the resin matrices to form the composite materials utilized in the aerospace industry. Carbon, aramid, glass, and their hybrids are the most often used fibers. Typically, the epoxy-based system used to make up the resin matrix has a curing temperature range of 120 to 180 degrees Celsius (250 to 350 degrees Fahrenheit). In the 1950s and 1960s, glass fiber reinforced polymers were used to create the first functional composite airplane components. The rudder and fin of a Grumman E-2A, as well as helicopter transparencies, frames, radomes, fender flares, propellers, etc.

Composites such as BFRP (Boron Fibre Reinforced Plastics) and (CFRP) Carbon Fibre Reinforced Plastics) were preferred to aluminium due to their considerably high-performance airplane constructions because of their highstrength and stiffness in conjunction with their low density. Aramid FibreReinforced Plastics (AFRP) have been used for light loaded constructions due to its low density. While AFRP fibers have excellent tensile stress, they have relatively low compressive strength, limiting its applicability to lightly loaded constructions. Glass Fibre Reinforced Plastics (GFRP) has emerged as a go-to material for lightweight aircraft and structural components with low loads. Composites have gone from being used for a few minor access panels and canvas frames to practically all of the airframe's surfaces, reducing weight and resulting in better performance, less drag, and higher resistance to corrosion.

Hence, composite materials such as GFRP, CFRP, and AFRP are now often used for aviation applications such as engine cowlings, landing gear doors, floor panels, flight control surfaces, firings, radomes, fan ducts, etc. The weight reduction amount that may be achieved using composites varies greatly depending on the kind of plane and the component in question. **Fig 1** displays the percentage of weight saved due to the use of composites. When the percentage of composite material in a system rises, these tend to decrease.

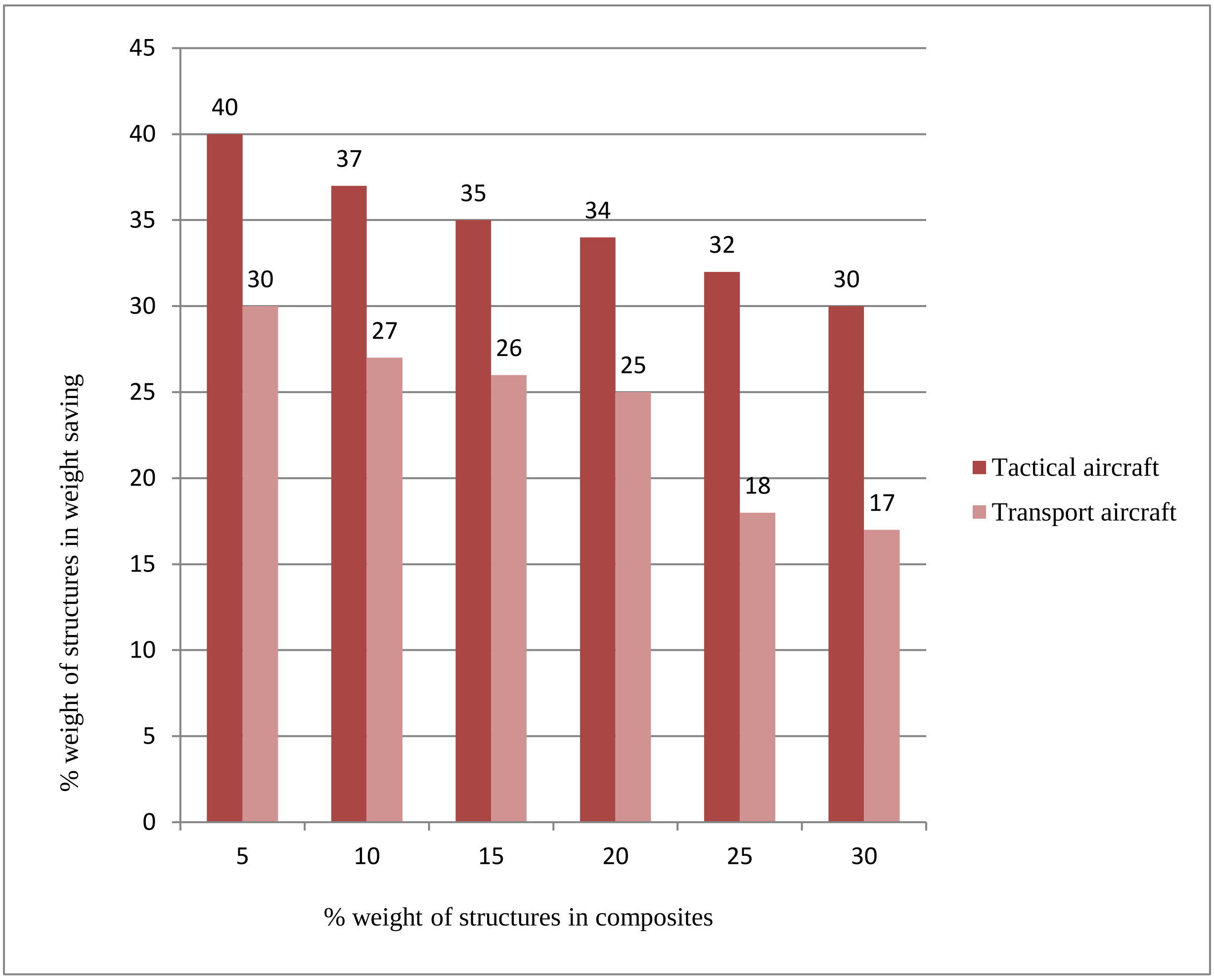

Fig 1. Comparisons for weight savings against the aircraft type

Components of composite aircraft utilized for structural purposes are often made using a sandwich construction method, with the face sheets made of carbon fiber or carbon fiber coupled with aramidor glass fibers, and the honeycomb core made of glass fibers. Composite components are necessary for interior aircraft applications due to their mechanical qualities and processability. Furthermore, the materials used within the pressurized cabin of an airplane must be fireproof. Composite materials, often fiber-reinforced epoxy or phenolic resin, are used for a variety of interior sections, including overhead bins, sidewall panels, ceilings, floor boards, galleys, cargo floor-board liners, partitions, etc.

The low smoke, low flammability, low hazardous gaseous emission of the phenolic resin system make it a popular choice for use in interior applications. Inside the interior, impact resistance, rigidity, and surface smoothness are prioritized throughout the design process. Glass fibers are the standard fiber choice for usage in airplane cabins. These days, modern composite materials are used for a wide range of aircraft parts, both non-structural, and structural depending on a host of parameters including in-service loads, weather conditions, etc. [10]. In this section, we will discuss about how composites have been used in various aircraft, the most common issues that have arisen in service, and what can be done to fix them.

Structural Applications

For quite some time, composites have been employed in building. Uses for these products vary from decorative claddings and gratings to structural components and whole bridge systems in industries such as manufacturing and construction. Its corrosion resistance and light weight make them a good choice for many stress-free environments. Despite extensive research and development, widespread application of high-performing FRP for major structural application has lagged behind. Composites provide enormous potential to replace traditional construction materials like wood, metal, and concrete.

Construction

Doors, windows, panels, non-structural gratings, furniture, tanks, long-lasting roof construction, structural elements, and whole bridge models are all examples of places where composites are being increasingly employed in construction. With benefits including corrosion resistance, long lifespan, minimal maintenance, and convenience in workability, fire resistance, etc., components constructed of composite materials find a wide-range application in dis-banding support, wide-range architectural buildings imparting smart looks, massive signages, etc. **Table 3** lists a few common composite structural uses.

Table 3. Composite application in construction and building

Quartz sand and acrylic resin composite	Kitchen sink
Red-mud plastic (polyster, PVC) reinforcement with sisal fibres	Roofing, door panels, roofing, paneling
Glass fiber reinforcement nylon/PP	Door hinge
Fiber polysters reinforced with glass	Partitions, sanitary ware, ceilings, pipes, storage tanks, and roofing sheets
Coir fibers with lime and fly ashes or cements	Blocks and bricks for walls
PF//UF resin and bagasse	Blocks and panels
Epoxy with red muds/jute fiber polyester	Sheets, and panels, partitiions, wall cladding, and door shutter
Red mud, vegetable fiber and polyester	Corrugated and flat roofing sheet, tiles and shutters
Poplar woods and polymer	Doors, window frames and door shutter
Sisal/jute/coconut fibers and plass fiber with the gypsum plasters	Perforated and solid construction blocks
Sisal/jute/coconut fibers and plass fiber with the gypsum plasters	Ceiling, wall panels and partition boards

In addition to being regarded as a cost-effective choice for brand-new bridge construction, the use of composites in seismic retrofitting, repair, and upgrading of present concrete bridges is on the rise. Reinforcement of concrete in tunnels might benefit greatly from the use of composite-based 2D and 3D grid-type reinforcements because to its weathering and chemical-resistance simplicity, and lightweight of shaping to match curvature. Reinforcement grids used in concrete are often made from high-performance fibers like carbon, glass, hybrids, and aramid, which have been integrated with resin models ranging from thermoplastic resin models to viny esters to thermoplastics. Major cost reductions at the system level were realized as a result of a combination of variables including but not limited to:

Road Bridges

Using high performance FRP in bridges has garnered a lot of attention since bridges are such a significant part of the construction industry. Repair, seismic retrofitting, and upgrades using FRP have shown to be effective in extending the useful life of concrete bridges. To save costs without sacrificing quality, FRP is being evaluated for use in bridge replacements. For places that depend on the usage of salt de-icing to preserve accessibility of roads, polymer composite materials are considered to provide potential benefits, which are absent in the traditional bio-materials, notably for their pliability to corrosive assaults. The road bridge industry has benefited greatly from the development of design methods and production efficiencies that may be applied to other areas of civil construction. Commercially available composites are currently being used in the construction of decks for pedestrian and vehicle bridges spanning streams, railroads, and roads. For canal bridges having a lift-up part to allow boats to pass, and for easy transportation and assembly in distant regions without access to large lifting equipment, the lightweight of composites is very useful. Composite decks are very lightweight and strong, having a load capacity six to seven times that of reinforced concrete decks. The composite's long lifespan of at least 50 years means that only occasional superficial cleaning will be necessary.

Because of its resistance to moisture and corrosion, the composite will not rust like metal and crack like concrete during freeze-thaw cycles. When the superstructure of an older bridge is in good condition, composite bridgedecks are a great option for a replacement. This replacement can be done quickly and with little impact on traffic. Using composites to create a lightweight, prefabricated module immediately reduces expenses by keeping commerce running as smoothly as possible throughout construction. Instead of the weeks or days it takes to fully initiate an upgrade of the deck with the traditional one, the light weight composite modules could be integrated in a matter of minutes. Heavy equipment expenses may be cut because of the composite deck's excellent strength-to-weight ratio. The possibility for a greater load rating is also increased by a lighter deck.

With their superior resilience to corrosion and fatigue, composites may greatly cut down on the frequency of maintenance and replacement. Life-cycle expenses are reduced and service life is increased due to the resilience of composites. High-strength glue is used to join the double-trapezoid profile, and bridge deck's hexagon sections in a carefully monitored process. The pieces are built off-site at a factory and then sent to the construction site. Composite bridge decks are a lightweight, durable alternative to traditional concrete or wood bridge decking. Fibreglass Reinforced Plastic (FRP) [11] composite bridge decks are assembled from bonded and interlocking pultruded parts. Placed perpendicular to the flow of traffic and supported by huge spans of beams.

Mechanical interlock and a large bonding surface are provided by the FRP decks' interlocking double trapezoid composite pieces and full depth hexagon connections. When building highway bridges with modular FRP decks, it is important to know how the deck will hold up to the weight of vehicles. Bridge decks experience cyclical loads from traffic during their service life. The pultrusion technology used to create the composite bridge decks makes it possible to construct the decks in continuous lengths that can then be trimmed to the desired dimensions. Thus, it allows for more versatility in fabricating composite bridge decks to accommodate a wide range of product dimensions. West Virginia is home to the first modular FRP Bridge decking in the United States. Even after being subjected to 2 million load cycles, composite bridge decking showed no signs of significant fatigue. The Laurel Lick structure is comprised of composite, piling, short-column abutments, and stringers in addition to the deck. The decks failed in a controlled manner, absorbing a lot of energy but remaining stable thereafter. It is clear from these West Virginia installations that FRP (Fiber-Reinforced Polymer) composites are a greater selection for highway bridges because to their excellent performance and low maintenance requirements.

Power Transmission

It is currently common practice to assemble high voltage electrical transmission towers using pultruded composite parts with a "snap and build" construction process that does not need the use of fasteners or adhesives. The composites tower components weigh around a third less than typical steel similar structures, making it easy to transport them into inaccessible regions and erect them with minimal crews. Due to its insulating properties, composite also allows associated insulators to be placed closer together, resulting in a smaller overall tower and less impact on the surrounding environment. Towers made of composite materials have a significant advantage in saltwater conditions because to their resistance to corrosion. During the course of three years of operation, test towers on the Pacific coast of California have endured high salt contamination without developing arcing, which causes insulator and subsequent system failure. But, galvanized steel towers need regular washings to get rid of corrosive, conductive salt deposits that build up over time.

Power Distribution and Lighting

Increasingly, people are opting for composite power and lighting poles due to their superior performance and lower environmental impact. The use of traditional wooden poles leads to tree cutting. They need to be treated with very toxic chemicals to prevent decay and termite infestation, and those chemicals have been shown to seep into the groundwater and other nearby water sources. Lightweight composite poles are simple to carry and construct; they are resistant to corrosion, rot, and insect attack; they have great insulating characteristics; and they may be built to drastically lessen the likelihood of accident deaths when placed in close proximity to roadways.

Repair, Retrofit and Rebars

Composite plates may be easily bonded in place by hands without the necessity for heavy-lifting tools, making them an ideal choice for repairing masonry beams, structures, skyscrapers, and other structures that have been damaged or compromised by impact, earthquakes, or subsidence. Much quicker than using conventional methods, these fixes may be made. Composite reinforcement bars could be employed in steel lieu in traditional reinforcing concrete to eliminate the "concrete cancer" issues caused by the reinforcement's internal corrosion. The use of composites rebars, however more expensive up front, is warranted in situations where the complexity or location of the building makes future repairs impossible or prohibitively expensive.

Door Frames and FRP Doors

As there is a limited supply of wood for construction, it is important to encourage the production of low-cost FRP construction materials in order to satisfy the requirements of construction and housing industries. FRP doors with cores of expanded polystyrene, rigid polyurethane foam, coir/jute felt, paper honeycomb, etc., have probable applications in school, office, home, labs, hospitals, and other commercial and institutional settings. Due to the widespread adoption and use of structural sandwich construction for principal load-bearing models, the FRP doors may be fabricated in a wide range of sizes and configurations. Contact moulding or hand lay-up approach is used for the majority of the production process. Each door's front and back sheets are made independently. Several kinds of inserts made of wood are sandwiched between two sheets. After the in-situ-foaming procedure, the sheets are painted and polished to fulfill the aesthetic requirements. The sheets then encase the PU foam.

The doors acquire fire resistance through the correct use of chemicals. And since they're made out of composite material, the doors are impervious to both moisture and insects. As opposed to wooden doors, FRP ones are far more affordable. Contact moulding may also be used to create the FRP doorframes. In order to use this technology, the RV-TIFAC CDC (Composite Design Centre) within Bangalore has been working on developing FRP doors and doorframes as part of the Advanced Composites Mission initiative of the Government of India. The CDC's FRP doors are built to meet all BIS requirements (IS: 4020). The FRP door technology has been transferred to over thirty businesses after successful field testing and customer feedback. Increased precision in our understanding of how to design, test, and produce cost-effective composite goods has resulted from the widespread use of sandwich construction across numerous sectors. The structural performance is maximized while the weight is minimized by using cores built with low-density form materials or honeycomb. The specific choice of material utilized as core material is determined by other factors like heat resistance, vibration damping, and sound insulation.

VII. CONCLUSION

On a macroscopic scale, composite materials refer to systems of materials integrated of multiple components (either mixed or bound). Concrete, for instance, is a composite material comprised of cement, sand, stones, and water. In the case of metals, the resulting alloy is known as a polymer, and in the case of plastics, it is known as a polymer. Reinforcement (fibers, flakes, particles, and/or fillers) is often incorporated in a matrix to form a composite material (polymers, ceramics, or metals). Both the matrix and reinforcement work together to generate the desired shape, with its reinforcement aspect enhancing its mechanical capabilities. It has been shown that when two materials are mixed in the right way, the resulting substance is stronger than each one alone. Composites are the perfect material for many uses because they combine the beneficial qualities of many different materials. Because of their superior qualities, composites have largely supplanted traditional building materials. Thus, there has to be a massive increase in study of composite materials. Automotive and aerospace industries are pushing new breakthroughs in composite materials, which bodes well for their future. Because of the rise in popularity of electric cars and the introduction of electric urban taxis, composites are increasingly being used for complex structural applications. By refining processes in this way, costs may be lowered, and the resulting technological advancements can be shared with other sectors.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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Competing Interests

There are no competing interests.

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