COMPOSITE MATERIALS - HISTORY, TYPES, FABRICATION TECHNIQUES, ADVANTAGES, AND APPLICATIONS

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Abstract— This paper presents a brief introduction of composite materials followed by history, fabrication techniques, advantages and applications.A **composite material** (also called a **composition material** or shortened to **composite** which is the common name) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials. More recently, researchers have also begun to actively include sensing, actuation, computation and communication into composites,[1] which are known as Robotic Materials. As the composite materials possess great properties they are substituting various other conventional materials therefore, the research on composite materials must be developed further.

Index Terms— Fibrous Composites, Filament winding, History, Resin infusion processes.

I. INTRODUCTION

A typical composite material is a system of materials composing of two or more materials (mixed and bonded) on a macroscopic scale. For example, concrete is made up of cement, sand, stones, and water. If the composition occurs on a microscopic scale (molecular level), the new material is then called an alloy for metals or a polymer for plastics.

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material.

II. HISTORY

The first uses of composites date back to the 1500s B.C. when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Straw continued to provide reinforcement to ancient composite products including pottery and boats.Later, in 1200 AD, the Mongols invented the first composite bow. Using a combination of wood, bone, and “animal glue,” bows were pressed and wrapped with birch bark. These bows were extremely powerful and extremely accurate. Composite Mongolian bows provided Genghis Khan with military dominance, and because of the composite technology, this weapon was the most powerful weapon on earth until the invention of gunpowder.

The modern era of composites did not begin until scientists developed plastics. Until then, natural resins derived from plants and animals were the only source of glues and binders.In the early 1900s, plastics such as vinyl, polystyrene, phenolic and polyester were developed. These new synthetic materials outperformed resins that were derived from nature.However, plastics alone could not provide enough strength for structural applications. Reinforcement was needed to provide the strength, and rigidity. In 1935, Owens Corning introduced the first glass fiber, fiberglass.Fiberglass, when combined with a plastic polymer creates an incredibly strong structure that is also lightweight. This is the beginning of the Fiber Reinforced Polymers (FRP) industry as we know it today.

WWII – Driving Early Composites Innovation

Many of the greatest advancements in composites were incubated by war. Just as the Mongols developed the composite bow, World War II brought the FRP industry from the laboratory into actual production. Alternative materials were needed for lightweight applications in military aircraft. Engineers soon realized other benefits of composites beyond being lightweight and strong. It was discovered that fiberglass composites were transparent to radio frequencies, and the material was soon adapted for use in sheltering electronic radar equipment (Radomes).

Adapting Composites: “Space Age” to “Everyday”

By the end of the WWII, a small niche composites industry was in full swing. With lower demand for military products, the few composites innovators were now ambitiously trying to introduce composites into other markets. Boats were an obvious fit for composites, and the first commercial boat hull was introduced in 1946.At this time Brandt Goldsworthy, often referred to as the “grandfather of composites,” developed new manufacturing processes and products. He is credited with numerous advancements including being the first to fiberglass a surfboard, which revolutionized the sport.Goldsworthy also invented a manufacturing process known as pultrusion. Today, products manufactured from this process include ladder rails, tool handles, pipes, arrow shafts, armor, train floors, medical devices, and more.

Continued Advancement in Composites

In the 1970s the composites industry began to mature. Better plastic resins and improved reinforcing fibers were developed. DuPont developed an aramid fiber known as Kevlar, this fiber has become the standard in armor due to its high tenacity. Carbon fibers was also developed around this time; it has since been replacing metal as the new material of choice.The composite industry is still evolving, with much of the growth is now focused around Renewable energy Wind turbine blades are constantly pushing the limits on size and are requiring advanced materials, designs, and manufacturing.In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are a reinforcement and a matrix.

III. TYPES OF COMPOSITE MATERIALS

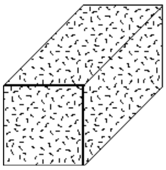
Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

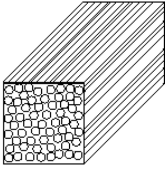
- The second level of classification refers to the reinforcement form - fibre reinforced composites, laminar composites and particulate composites. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.
- Fibre Reinforced Composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.
- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

Based on the form of reinforcement, common composite materials can be classified as follows:

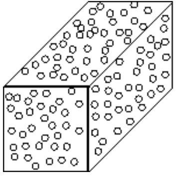
1. Fibers as the reinforcement (Fibrous Composites):
   a. Random fiber (short fiber) reinforced composites



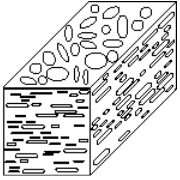
   b. Continuous fiber (long fiber) reinforced composites



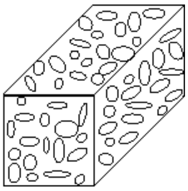
2. Particles as the reinforcement (Particulate composites):



3. Flat flakes as the reinforcement (Flake composites):



4. Fillers as the reinforcement (Filler composites):



IV. FABRICATION TECHNIQUES

There are numerous methods for fabricating composite components. Some methods have been borrowed (injection molding, for example), but many were developed to meet specific design or manufacturing challenges. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or application. Composite fabrication processes involve some form of molding, to shape the resin and reinforcement. A mold tool is required to give the unformed resin /fiber combination its shape prior to and during cure.

The most basic fabrication method for thermoset composites is ***hand layup***, which typically consists of laying dry fabric layers, or "plies," or prepreg plies, by hand onto a tool to form a laminate stack. Resin is applied to the dry plies after layup is complete (e.g., by means of resin infusion).

Several curing methods are available. The most basic is simply to allow cure to occur at room temperature. Cure can be accelerated, however, by applying heat, typically with an oven, and pressure, by means of a vacuum.Many high-performance thermoset parts require heat and high consolidation pressure to cure — conditions that require the use of an autoclave. Autoclaves, generally, are expensive to buy and operate. Manufacturers that are equipped with autoclaves usually cure a number of parts simultaneously. Computer systems monitor and control autoclave temperature, pressure, vacuum and inert atmosphere, which allows unattended and/or remote supervision of the cure process and maximizes efficient use of the technique.

Electron-beam (E-beam) curing has been explored as an efficient curing method for thin laminates. In E-beam curing, the composite layup is exposed to a stream of electrons that provide ionizing radiation, causing polymerization and crosslinking in radiation-sensitive resins. X-ray and microwave curing technologies work in a similar manner. A fourth alternative, ultraviolet (UV) curing, involves the use of UV radiation to activate a photoinitiator added to a thermoset resin, which, when activated, sets off a crosslinking reaction. UV curing requires light-permeable resin and reinforcements.

Open molding

Open contact molding in one-sided molds is a low-cost, common process for making fiberglass composite products. Typically used for boat hulls and decks, RV components, truck cabs and fenders, spas, bathtubs, shower stalls and other relatively large, noncomplex shapes, open molding involves either hand layup or a semi-automated alternative, sprayup.

In an open-mold sprayup application, the mold is first treated with mold release. If a gel coat is used, it is typically sprayed into the mold after the mold release has been applied. The gel coat then is cured and the mold is ready for fabrication to begin. In the sprayup process, catalyzed resin (viscosity from 500 to 1,000 cps) and glass fiber are sprayed into the mold using a chopper gun, which chops continuous fiber into short lengths, then blows the short fibers directly into the sprayed resin stream so that both materials are applied simultaneously. To reduce VOCs, piston pump-activated, non-atomizing spray guns and fluid impingement spray heads dispense gel coats and resins in larger droplets at low pressure. Another option is a roller impregnator, which pumps resin into a roller similar to a paint roller.

In the final steps of the sprayup process, workers compact the laminate by hand with rollers. Wood, foam or other core material may then be added, and a second sprayup layer imbeds the core between the laminate skins. The part is then cured, cooled and removed from the reusable mold.

Hand layup and sprayup methods are often used in tandem to reduce labor.

Resin infusion processes

Ever-increasing demand for faster production rates has pressed the industry to replace hand layup with alternative fabrication processes and has encouraged fabricators to automate those processes wherever possible.

A common alternative is resin transfer molding (RTM), sometimes referred to as liquid molding. The benefits of RTM are impressive. Generally, the dry preforms and resins used in RTM are less expensive than prepreg material and can be stored at room temperature. The process can produce thick, near-net shape parts, eliminating most post-fabrication work. It also yields dimensionally accurate complex parts with good surface detail and delivers a smooth finish on all exposed surfaces. It is possible to place inserts inside the preform before the mold is closed, allowing the RTM process to accommodate core materials and integrate "molded in" fittings and other hardware into the part structure. Finally, RTM significantly cuts cycle times and can be adapted for use as one stage in an automated, repeatable manufacturing process for even greater efficiency, reducing cycle time from what can be several days, typical of hand layup, to just hours — or even minutes.

In contrast to RTM, where resin and catalyst are premixed prior to injection under pressure into the mold, reaction injection molding (RIM) injects a rapid-cure resin and a catalyst into the mold in two separate streams. Mixing and the resulting chemical reaction occur in the mold instead of in a dispensing head. Automotive industry suppliers combine structural RIM (SRIM) with rapid preforming methods to fabricate structural parts that don't require a Class A finish. Programmable robots have become a common means to spray a chopped fiberglass/binder combination onto a vacuum-equipped preform screen or mold. Robotic sprayup can be directed to control fiber orientation. A related technology, dry fiber placement, combines stitched preforms and RTM. Fiber volumes of up to 68 percent are possible, and automated controls ensure low voids and consistent preform reproduction, without the need for trimming.

Vacuum-assisted resin transfer molding (VARTM) refers to a variety of related processes that represent the fastest-growing new molding technology. The salient difference between VARTM-type processes and RTM is that in VARTM, resin is drawn into a preform through use of a vacuum only, rather than pumped in under pressure. VARTM does not require high heat or pressure. For that reason, VARTM operates with low-cost tooling, making it possible to inexpensively produce large, complex parts in one shot.

In the VARTM process, fiber reinforcements are placed in a one-sided mold, and a cover (typically a plastic bagging film) is placed over the top to form a vacuum-tight seal. The resin typically enters the structure through strategically placed ports and feed lines, termed a “manifold.” It is drawn by vacuum through the reinforcements by means of a series of designed-in channels that facilitate wetout of the fibers. Fiber content in the finished part can run as high as 70 percent. Current applications include marine, ground transportation and infrastructure parts. This method has been employed by The Boeing Co. (Chicago, Ill.) and NASA, as well as small fabricating firms, to produce aerospace-quality laminates without an autoclave.

High-volume molding methods

Compression molding is a high-volume thermoset molding process that employs expensive but very durable metal dies. It is an appropriate choice when production quantities exceed 10,000 parts. As many as 200,000 parts can be turned out on a set of forged steel dies, using sheet molding compound (SMC), a composite sheet material made by sandwiching chopped fiberglass between two layers of thick resin paste. Low-pressure SMC formulations that are now on the market offer open molders low-capital-investment entry into closed-mold processing with near-zero VOC emissions and the potential for very high-quality surface finish.

Automakers are exploring carbon fiber-reinforced SMC, hoping to take advantage of carbon’s high strength- and stiffness-to-weight ratios in exterior body panels and other parts. Newer, toughened SMC formulations help prevent microcracking, a phenomenon that previously caused paint “pops” during the painting process (surface craters caused by outgassing, the release of gasses trapped in the microcracks during oven cure).

Composites manufacturers in industrial markets are formulating their own resins and compounding SMC in-house to meet needs in specific applications that require UV, impact and moisture resistance and have surface-quality demands that drive the need for customized material development.

Injection molding is a fast, high-volume, low-pressure, closed process using, most commonly, filled thermoplastics, such as nylon with chopped glass fiber. In the past 20 years, however, automated injection molding of BMC has taken over some markets previously held by thermoplastic and metal casting manufacturers. For example, the first-ever BMC-based electronic throttle control (ETC) valves (previously molded only from die-cast aluminum) debuted on engines in the BMW *Mini* and the Peugeot *207*, taking advantage of dimensional stability offered by a specially-formulated BMC supplied by TetraDUR GmbH (Hamburg, Germany), a subsidiary of Bulk Molding Compounds Inc. (BMCI, West Chicago, Ill.,).Injection speeds are typically one to five seconds, and as many as 2,000 small parts can be produced per hour in some multiple-cavity molds.

Parts with thick cross-sections can be compression molded or transfer molded with BMC. Transfer molding is a closed-mold process wherein a measured charge of BMC is placed in a pot with runners that lead to the mold cavities. A plunger forces the material into the cavities, where the product cures under heat and pressure.

Filament winding is a continuous fabrication method that can be highly automated and repeatable, with relatively low material costs. Filament winding yields parts with exceptional circumferential or “hoop” strength. The highest-volume single application of filament winding is golf club shafts. Fishing rods, pipe, pressure vessels and other cylindrical parts comprise most of the remaining business.

Pultrusion, like RTM, has been used for decades with glass fiber and polyester resins, but in the last 10 years the process also has found application in advanced composites applications. In this relatively simple, low-cost, continuous process, the reinforcing fiber (usually roving, tow or continuous mat) is typically pulled through a heated resin bath and then formed into specific shapes as it passes through one or more forming guides or bushings. The material then moves through a heated die, where it takes its net shape and cures. Further downstream, after cooling, the resulting profile is cut to desired length. Pultrusion yields smooth finished parts that typically do not require postprocessing. A wide range of continuous, consistent, solid and hollow profiles are pultruded, and the process can be custom-tailored to fit specific applications.

Tube rolling is a longstanding composites manufacturing process that can produce finite-length tubes and rods. It is particularly applicable to small-diameter cylindrical or tapered tubes in lengths as great as 20 ft/6.2m. Tubing diameters up to 6 inches/152 mm can be rolled efficiently. Typically, a tacky prepreg fabric or unidirectional tape is used, depending on the part. The material is precut in patterns that have been designed to achieve the requisite ply schedule and fiber architecture for the application. The pattern pieces are laid out on a flat surface and a mandrel is rolled over each one under applied pressure, which compacts and debulks the material. When rolling a tapered mandrel — e.g., for a fishing rod or golf shaft — only the first row of longitudinal fibers falls on the true 0° axis. To impart bending strength to the tube, therefore, the fibers must be continuously reoriented by repositioning the pattern pieces at regular intervals.

Automated fiber placement (AFP) The fiber placement process automatically places multiple individual prepreg tows onto a mandrel at high speed, using a numerically controlled, articulating robotic placement head to dispense, clamp, cut and restart as many as 32 tows simultaneously. Minimum cut length (the shortest tow length a machine can lay down) is the essential ply-shape determinant. The fiber placement heads can be attached to a 5-axis gantry, retrofitted to a filament winder or delivered as a turnkey custom system. Machines are available with dual mandrel stations to increase productivity. Advantages of fiber placement include processing speed, reduced material scrap and labor costs, parts consolidation and improved part-to-part uniformity. Often, the process is used to produce large thermoset parts with complex shapes.

Automated tape laying (ATL) is an even speedier automated process in which prepreg tape, rather than single tows, is laid down continuously to form parts. It is often used for parts with highly complex contours or angles. Tape layup is versatile, allowing breaks in the process and easy direction changes, and it can be adapted for both thermoset and thermoplastic materials. The head includes a spool or spools of tape, a winder, winder guides, a compaction shoe, a position sensor and a tape cutter or slitter. In either case, the head may be located on the end of a multi axis articulating robot that moves around the tool or mandrel to which material is being applied, or the head may be located on a gantry suspended above the tool.

Although ATL generally is faster than AFP and can place more material over longer distances, AFP is better suited to shorter courses and can place material more effectively over contoured surfaces. These technologies grew out of the machine tool industry and have seen extensive use in the manufacture of the fuselage, wing skin panels, wingbox, tail and other structures on the forthcoming Boeing 787 *Dreamliner* and the Airbus A350 XWB. ATL and AFP also are used extensively to produce parts for the F-35 *Lightning II* fighter jet the V-22 *Osprey* tiltrotor troop transport and a variety of other aircraft.

Centrifugal casting of pipe from 1 inch/25 mm to 14 inches/356 mm in diameter is an alternative to filament winding for high-performance, corrosion-resistant service. In cast pipe, 0°/90° woven fiberglass provides both longitudinal and hoop strength throughout the pipe wall and brings greater strength at equal wall thickness compared to multiaxial fiberglass wound pipe. In the casting process, epoxy or vinyl ester resin is injected into a 150G centrifugally spinning mold, permeating the woven fabric wrapped around the mold's interior surface. The centrifugal force pushes the resin through the layers of fabric, creating a smooth finish on the outside of the pipe, and excess resin pumped into the mold creates a resin-rich, corrosion- and abrasion-resistant interior liner. Fiber-reinforced thermoplastic components now can be produced by extrusion, as well. A huge market has emerged in the past decade for extruded thermoplastic/wood flour (or other additives, such as bast fibers or fly ash) composites. These wood plastic composites, or WPCs, used to simulate wood decking, siding, window and door frames, and fencing.

V. ADVANTAGES

Light Weight - Composites are light in weight, compared to most woods and metals. Their lightness is important in automobiles and aircraft, for example, where less weight means better fuel efficiency (more miles to the gallon). People who design airplanes are greatly concerned with weight, since reducing a craft's weight reduces the amount of fuel it needs and increases the speeds it can reach. Some modern airplanes are built with more composites than metal including the new Boeing 787, Dreamliner.

High Strength - Composites can be designed to be far stronger than aluminum or steel. Metals are equally strong in all directions. But composites can be engineered and designed to be strong in a specific direction.

Strength Related to Weight - Strength-to-weight ratio is a material's strength in relation to how much it weighs. Some materials are very strong and heavy, such as steel. Other materials can be strong and light, such as bamboo poles. Composite materials can be designed to be both strong and light. This property is why composites are used to build airplanes—which need a very high strength material at the lowest possible weight. A composite can be made to resist bending in one direction, for example. When something is built with metal, and greater strength is needed in one direction, the material usually must be made thicker, which adds weight. Composites can be strong without being heavy. Composites have the highest strength-to-weight ratios in structures today.

Corrosion Resistance - Composites resist damage from the weather and from harsh chemicals that can eat away at other materials. Composites are good choices where chemicals are handled or stored. Outdoors, they stand up to severe weather and wide changes in temperature.

High-Impact Strength - Composites can be made to absorb impacts—the sudden force of a bullet, for instance, or the blast from an explosion. Because of this property, composites are used in bulletproof vests and panels, and to shield airplanes, buildings, and military vehicles from explosions.

Design Flexibility - Composites can be molded into complicated shapes more easily than most other materials. This gives designers the freedom to create almost any shape or form. Most recreational boats today, for example, are built from fiberglass composites because these materials can easily be molded into complex shapes, which improve boat design while lowering costs. The surface of composites can also be molded to mimic any surface finish or texture, from smooth to pebbly.

Part Consolidation - A single piece made of composite materials can replace an entire assembly of metal parts. Reducing the number of parts in a machine or a structure saves time and cuts down on the maintenance needed over the life of the item.

Dimensional Stability - Composites retain their shape and size when they are hot or cool, wet or dry. Wood, on the other hand, swells and shrinks as the humidity changes. Composites can be a better choice in situations demanding tight fits that do not vary. They are used in aircraft wings, for example, so that the wing shape and size do not change as the plane gains or loses altitude.

Nonconductive - Composites are nonconductive, meaning they do not conduct electricity. This property makes them suitable for such items as electrical utility poles and the circuit boards in electronics. If electrical conductivity is needed, it is possible to make some composites conductive.

Nonmagnetic - Composites contain no metals; therefore, they are not magnetic. They can be used around sensitive electronic equipment. The lack of magnetic interference allows large magnets used in MRI (magnetic resonance imaging) equipment to perform better. Composites are used in both the equipment housing and table. In addition, the construction of the room uses composites rebar to reinforced the concrete walls and floors in the hospital.

Radar Transparent - Radar signals pass right through composites, a property that makes composites ideal materials for use anywhere radar equipment is operating, whether on the ground or in the air. Composites play a key role in stealth aircraft, such as the U.S. Air Force’s B-2 stealth bomber, which is nearly invisible to radar.

Low Thermal Conductivity - Composites are good insulators—they do not easily conduct heat or cold. They are used in buildings for doors, panels, and windows where extra protection is needed from severe weather.

Durable - Structures made of composites have a long life and need little maintenance. We do not know how long composites last, because we have not come to the end of the life of many original composites. Many composites have been in service for half a century.

V. APPLICATIONS

Appliance
Cooking, Dishwasher, Refrigerator, Small Appliances, Laundry, Ice Machines
Construction
Entry Doors, Garage Doors, Architecture, Countertops, Wastewater Treatment
Electrical Distribution
Circuit Breakers, Motor Control, Centers, Generators, Switchgear, Busway, Control Cabinets, Cross Arms
Energy
Wind Turbine, Fuel Cells, Solar Panels,Pumps
Forward Lighting
Headlamps, Reflections
HVAC
Drain Pans, Blower Housing, Wall Sleeves, Control Panels, Recreational Vehicles
Lighting
Class 1/ DV2, Light Housing, In ground, Explosion Proof, Reflectors
Marine
Engine Covers, Personal Watercraft, Boat Access Covers, Electrical Buyer's, Motor Housing
Sanitary/Plumbing
Faucets, Sinks, Drains, Showers, Bathtubs
Transportation Resisters
Drive Motors, Controls, Valve Covers, Oil Pans, Air Suspensions

CONCLUSION

In a nutshell the composites are the materials which have many desirable properties and makes them the best material that can be used in many applications. These properties make the composite materials replace the already existing materials which are used in the present days. Therefore the research on the composite materials must expand through leaps and bounds.

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