Introduction (1)

There are many reasons for the growth in composite applications, but the primary impetus is that the products fabricated by composites are stronger and lighter. Today, it is difficult to find any industry that does not utilize the benefits of composite materials. In the past three to four decades, there have been substantial changes in technology and its requirement. This changing environment created many new needs and opportunities, which are only possible with the advances in new materials and their associated manufacturing technology. In the past decade, several advanced manufacturing technology and material systems have been developed to meet the requirements of the various market segments. Broadly speaking, the composites market can be divided into the following industry categories:

1. aerospace,
2. automotive,
3. construction,
4. marine,
5. corrosion resistant equipment,
6. consumer products, appliance/business equipment, and
7. others.

The range of materials can be classified into the categories: **(2)** Metals, Polymers, Ceramics and inorganic glasses and Composites.

Metals lose their strength at elevated temperatures. High-Polymeric materials in general can withstand still lower temperatures. Ceramics outstrip metals and polymers in their favorable melting points, ability to withstand high temperatures, strength and thermal expansion properties, but due to their brittleness they are often unsatisfactory as structural materials. This lead to the exploration of composites.

Emergence of strong and stiff reinforcements like carbon fibre along with advances in polymer research to produce high performance resins as matrix materials have helped meet the challenges posed by the complex designs of modern aircraft. The large scale use of advanced composites in current programmes of development of military fighter aircraft, small and big civil transport aircraft, helicopters, satellites, launch vehicles and missiles all around the world is perhaps the most glowing example of the utilization of potential of such composite materials.

The Aerospace Industry (1)

The aerospace industry was among the first to realize the benefits of composite materials. Airplanes, rockets, and missiles all fly higher, faster, and farther with the help of composites. Glass, carbon, and Kevlar fiber composites have been routinely designed and manufactured for aerospace parts. The aerospace industry primarily uses carbon fiber composites because of their high-performance characteristics. The hand lay-up technique is a common manufacturing method for the fabrication of aerospace parts; RTM and filament winding are also being used. The below charts shows the estimated growth of composites in aerospace applications.

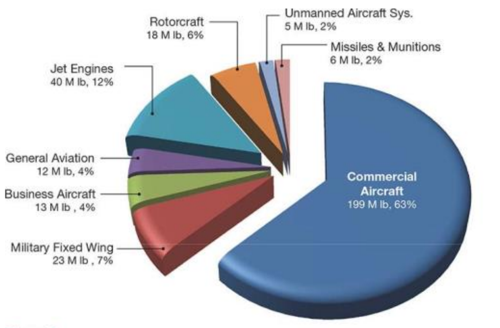


Figure 3

Source: CFC (Jan 2014)

Estimated 2013-2022 market for aerospace composite structures (flyaway weight of 308 million lb).

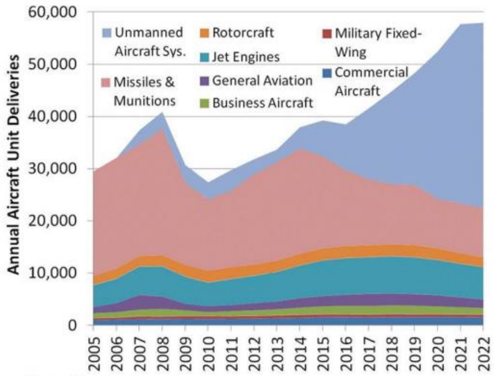


Figure 2

Source: CFC (Jan 2014)

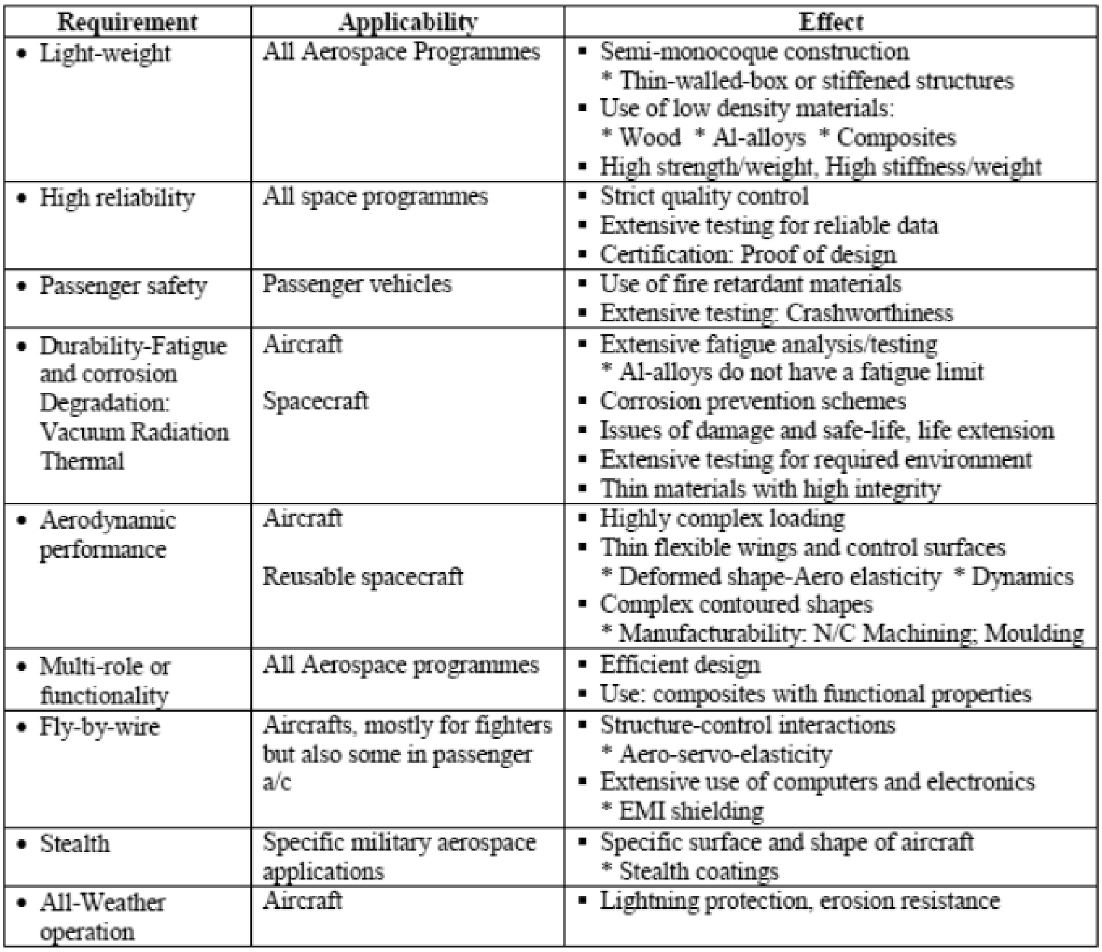
Aerospace systems unit deliveries, 2005-2022

http://www.compositesworld.com/articles/the-outlook-for-thermoplastics-in-aerospace-composites-2014-2023

The aerospace structures and features

Important requirements of an aerospace structure and their effect on the design of the structure are presented in the below table.

Table 1. Features of aircraft structure.



Requirement	Applicability	Effect
• Light-weight	All Aerospace Programmes	▪ Semi-monocoque construction * Thin-walled-box or stiffened structures ▪ Use of low density materials: * Wood * Al-alloys * Composites ▪ High strength/weight, High stiffness/weight
• High reliability	All space programmes	▪ Strict quality control ▪ Extensive testing for reliable data ▪ Certification: Proof of design
• Passenger safety	Passenger vehicles	▪ Use of fire retardant materials ▪ Extensive testing: Crashworthiness
• Durability-Fatigue and corrosion Degradation: Vacuum Radiation Thermal	Aircraft Spacecraft	▪ Extensive fatigue analysis/testing * Al-alloys do not have a fatigue limit ▪ Corrosion prevention schemes ▪ Issues of damage and safe-life, life extension ▪ Extensive testing for required environment ▪ Thin materials with high integrity
• Aerodynamic performance	Aircraft Reusable spacecraft	▪ Highly complex loading ▪ Thin flexible wings and control surfaces * Deformed shape-Aero elasticity * Dynamics ▪ Complex contoured shapes * Manufacturability: N/C Machining; Moulding
• Multi-role or functionality	All Aerospace programmes	▪ Efficient design ▪ Use: composites with functional properties
• Fly-by-wire	Aircrafts, mostly for fighters but also some in passenger a/c	▪ Structure-control interactions * Aero-servo-elasticity ▪ Extensive use of computers and electronics * EMI shielding
• Stealth	Specific military aerospace applications	▪ Specific surface and shape of aircraft * Stealth coatings
• All-Weather operation	Aircraft	▪ Lightning protection, erosion resistance

Applications of composites in aerospace structures

It is to be realized that in order to meet the demands in the above table, it is necessary to have materials with a peculiar property-set. The use of composites has been motivated largely by such considerations.

The composites offer several of these features as given below:

1. Light-weight due to high specific strength and stiffness
2. Fatigue-resistance and corrosion resistance
3. Capability of high degree of optimization: tailoring the directional strength and stiffness
4. Capability to mould large complex shapes in small cycle time reducing part count and assembly times: Good for thin-walled or generously curved construction
5. Capability to maintain dimensional and alignment stability in space environment
6. Possibility of low dielectric loss in radar transparency
7. Possibility of achieving low radar cross-section

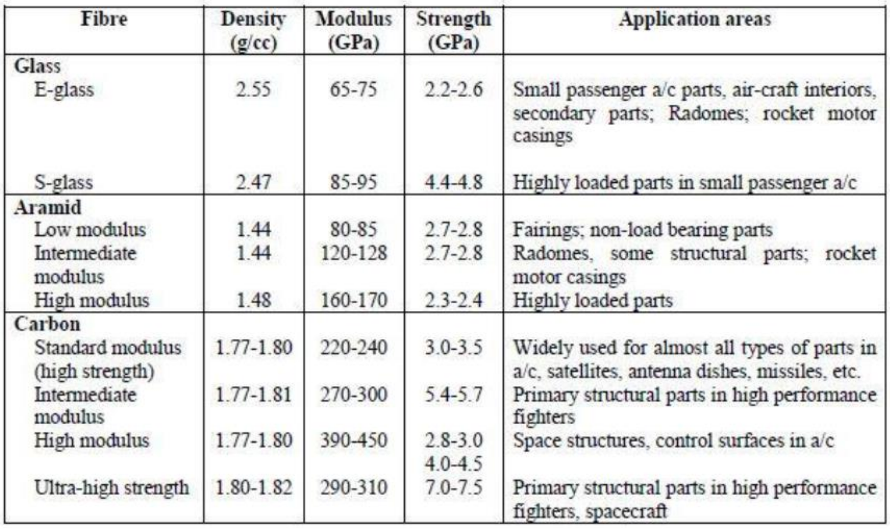
These composites also have some inherent weaknesses:

1. Laminated structure with weak interfaces: poor resistance to out-of-plane tensile loads
2. Susceptibility to impact-damage and strong possibility of internal damage going unnoticed
3. Moisture absorption and consequent degradation of high temperature performance
4. Multiplicity of possible manufacturing defects and variability in material properties.

Materials for aerospace composites

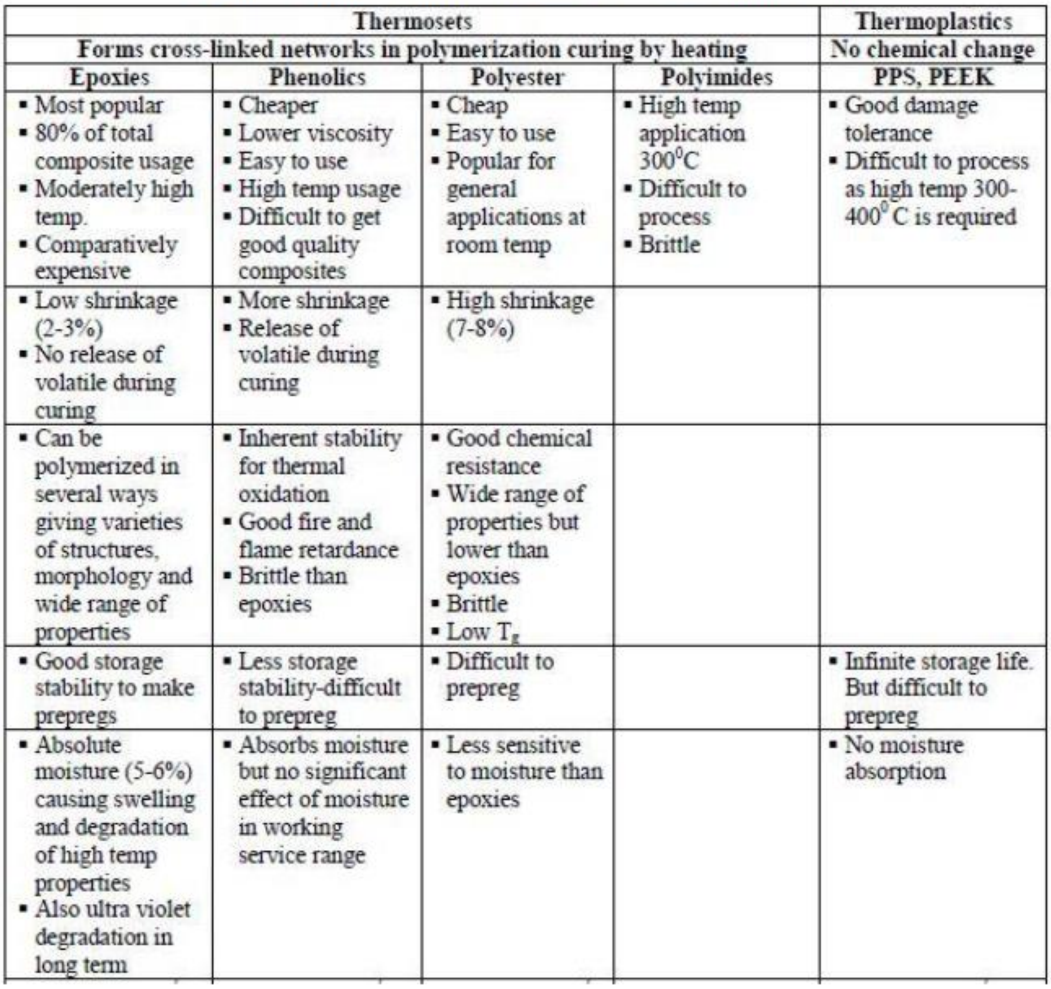
The materials systems which have been considered useful in aerospace sector are based on reinforcing fibers and matrix resins given in table 2 and 3, respectively. Most aerospace composites use prepregs as raw materials with autoclave moulding as a popular fabrication process. Filament winding is popular with shell like components such as rocket motor casings for launch vehicles and missiles. Oven curing or room temperature curing is used mostly with glass fibre composites used in low speed small aircraft. It is common to use composite tooling where production rates are small or moderate; however, where large number of components are required, metallic conventional tooling is preferred. Resin injection moulding also finds use in special components such as radomes. Some of the popular systems are given in table 4 along with the types of components where they are used in a typical high-performance aircraft.

Table 2. Reinforcing fibers commonly use in aerospace applications.



Fibre	Density (g/cc)	Modulus (GPa)	Strength (GPa)	Application areas
Glass				
E-glass	2.55	65-75	2.2-2.6	Small passenger a/c parts, air-craft interiors, secondary parts; Radomes; rocket motor casings
S-glass	2.47	85-95	4.4-4.8	Highly loaded parts in small passenger a/c
Aramid				
Low modulus	1.44	80-85	2.7-2.8	Fairings; non-load bearing parts
Intermediate modulus	1.44	120-128	2.7-2.8	Radomes, some structural parts; rocket motor casings
High modulus	1.48	160-170	2.3-2.4	Highly loaded parts
Carbon				
Standard modulus (high strength)	1.77-1.80	220-240	3.0-3.5	Widely used for almost all types of parts in a/c, satellites, antenna dishes, missiles, etc.
Intermediate modulus	1.77-1.81	270-300	5.4-5.7	Primary structural parts in high performance fighters
High modulus	1.77-1.80	390-450	2.8-3.0 4.0-4.5	Space structures, control surfaces in a/c
Ultra-high strength	1.80-1.82	290-310	7.0-7.5	Primary structural parts in high performance fighters, spacecraft

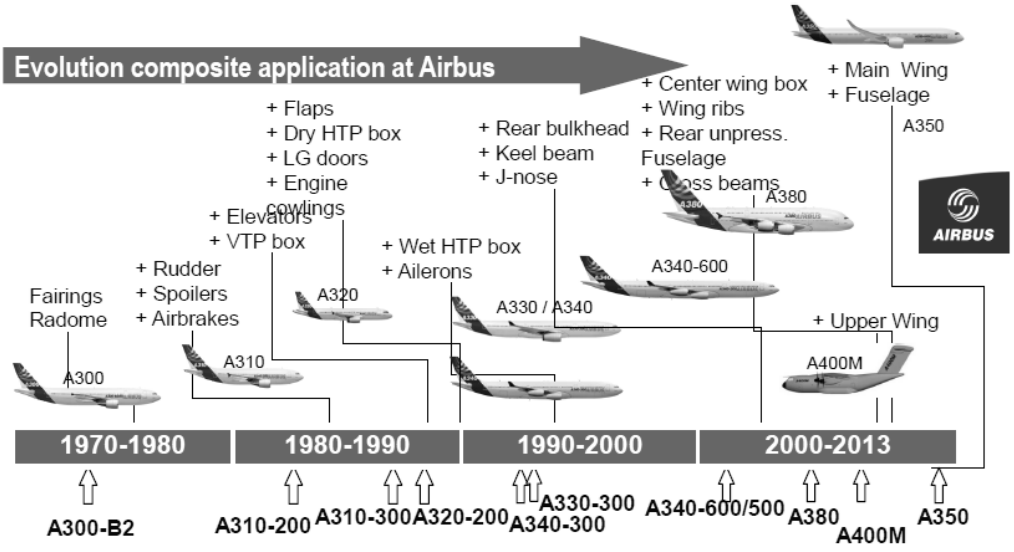
Table 3. Polymeric matrices commonly used in aerospace sector.



Thermosets				Thermoplastics
Forms cross-linked networks in polymerization curing by heating				No chemical change
Epoxies	**Phenolics**	**Polyester**	**Polyimides**	**PPS, PEEK**
▪ Most popular ▪ 80% of total composite usage ▪ Moderately high temp. ▪ Comparatively expensive	▪ Cheaper ▪ Lower viscosity ▪ Easy to use ▪ High temp usage ▪ Difficult to get good quality composites	▪ Cheap ▪ Easy to use ▪ Popular for general applications at room temp	▪ High temp application 300^{0}C ▪ Difficult to process ▪ Brittle	▪ Good damage tolerance ▪ Difficult to process as high temp 300-400^0 C is required
▪ Low shrinkage (2-3%) ▪ No release of volatile during curing	▪ More shrinkage ▪ Release of volatile during curing	▪ High shrinkage (7-8%)		
▪ Can be polymerized in several ways giving varieties of structures, morphology and wide range of properties	▪ Inherent stability for thermal oxidation ▪ Good fire and flame retardance ▪ Brittle than epoxies	▪ Good chemical resistance ▪ Wide range of properties but lower than epoxies ▪ Brittle ▪ Low T_g		
▪ Good storage stability to make prepregs	▪ Less storage stability-difficult to prepreg	▪ Difficult to prepreg		▪ Infinite storage life. But difficult to prepreg
▪ Absolute moisture (5-6%) causing swelling and degradation of high temp properties ▪ Also ultra violet degradation in long term	▪ Absorbs moisture but no significant effect of moisture in working service range	▪ Less sensitive to moisture than epoxies		▪ No moisture absorption

APPLICATIONS (3)

Business and Commercial aircrafts



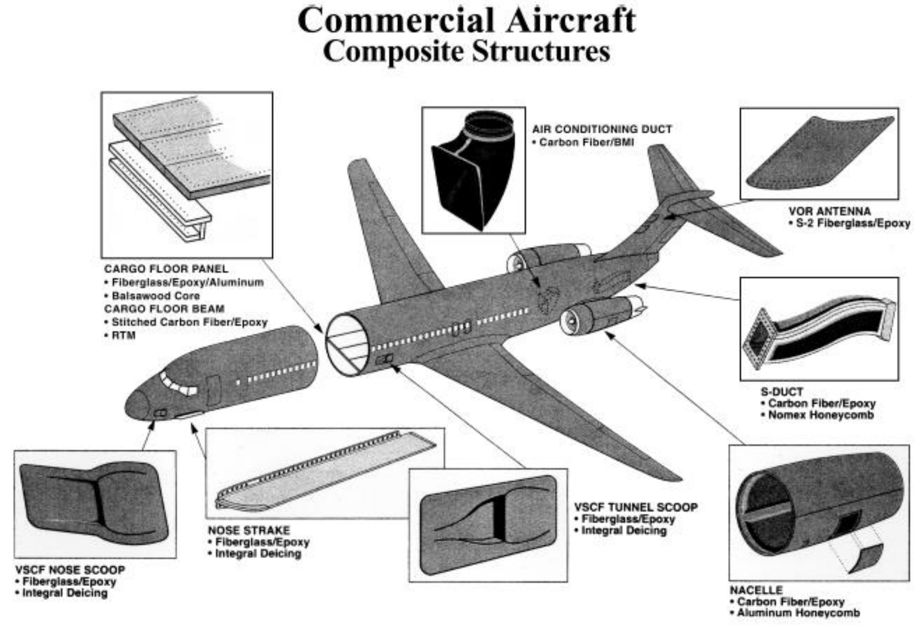


FIGURE 1.7
Typical composite structures used in commercial aircraft. (Courtesy of Composites Horizon, Inc.)

(1) The major reasons for the use of composite materials in spacecraft applications include weight savings as well as dimensional stability. In low Earth orbit (LEO), where temperature variation is from –100 to +100°C, it is important to maintain dimensional stability in support structures as well as in reflecting members. Carbon epoxy composite laminates can be designed to give a zero coefficient of thermal expansion. Typical space structures are tubular truss structures, facesheets for the payload baydoor, antenna reflectors, etc. In space shuttle composite materials provide weight savings of 2688 lb per vehicle.

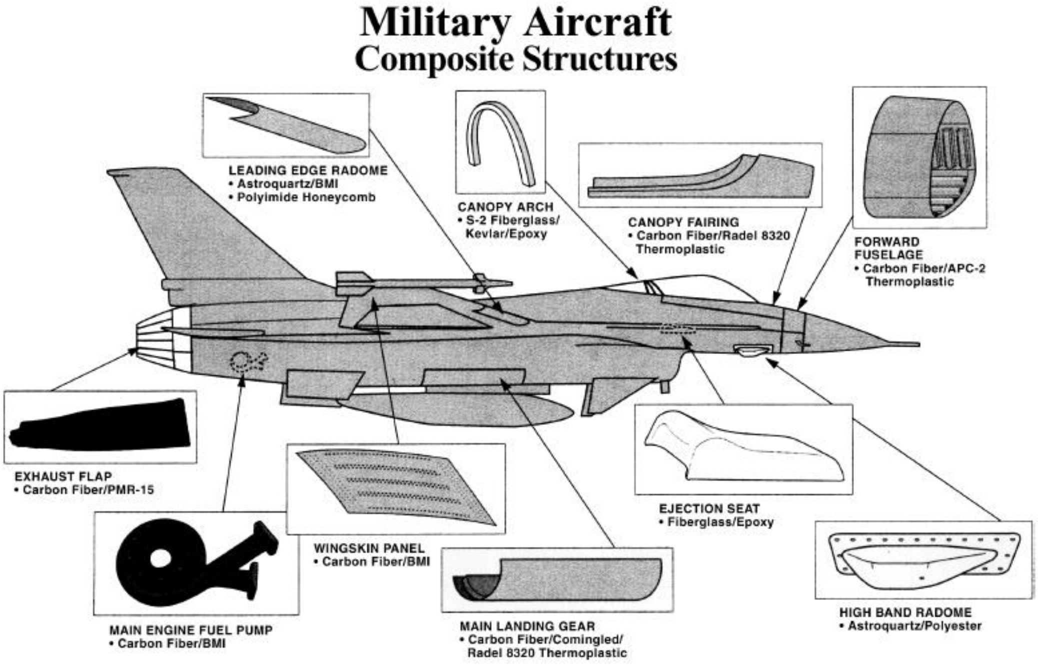


FIGURE 1.8
Typical composite structures used in military aircraft. (Courtesy of Composites Horizon, Inc.)

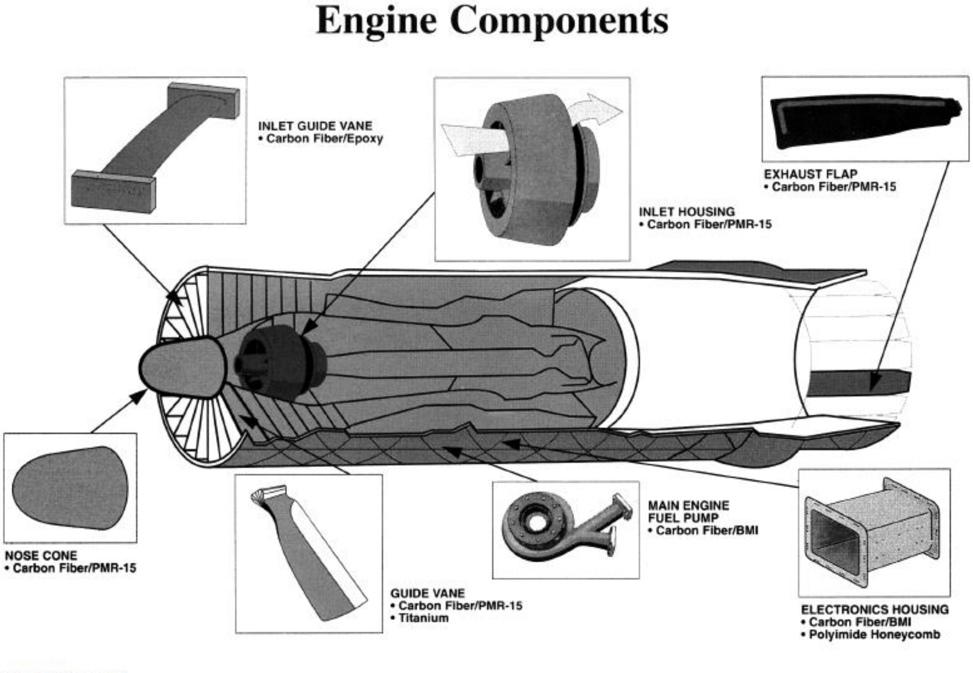


FIGURE 1.9
Composite components used in engine applications. (Courtesy of Composites Horizon, Inc.)

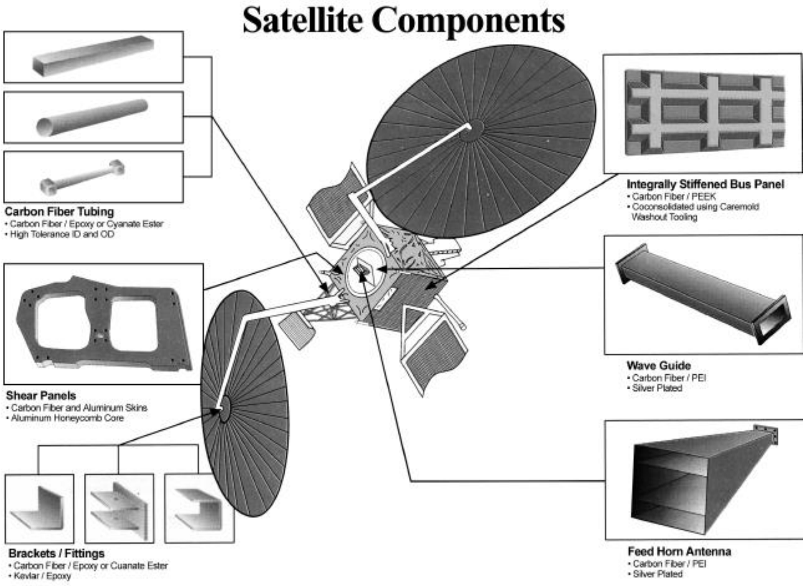


FIGURE 1.10
Composite components used in satellite applications. (Courtesy of Composites Horizon, Inc.)

Passenger aircrafts such as the Boeing 747 and 767 use composite parts to lower the weight, increase the payload, and increase the fuel efficiency. The components made out of composites for such aircrafts are shown in Table 1.3.

Composite Components in Aircraft Applications

	Composite Components
F-14	Doors, horizontal tails, fairings, stabilizer skins
F-15	Fins, rudders, vertical tails, horizontal tails, speed brakes, stabilizer skins
F-16	Vertical and horizontal tails, fin leading edge, skins on vertical fin box
B-1	Doors, vertical and horizontal tails, flaps, slats, inlets
AV-8B	Doors, rudders, vertical and horizontal tails, ailerons, flaps, fin box, fairings
Boeing 737	Spoilers, horizontal stabilizers, wings
Boeing 757	Doors, rudders, elevators, ailerons, spoilers, flaps, fairings
Boeing 767	Doors, rudders, elevators, ailerons, spoilers, fairings

POLYMER MATRIX COMPOSITES IN AUTOMOBILES (4)

The automotive industry is widely viewed as being the industry in which the greatest volume of advanced composite materials, particularly polymer matrix composites (PMCs), is using. Motivations for using PMCs include weight reduction for better fuel efficiency, improved ride quality, and corrosion resistance. Extensive use of composites in automobile body structures would have important impacts on methods of fabrication, satellite industry restructuring, and creation of new industries such as recycling.

The application of advanced materials to automotive structures require:

1. clear evidence of the performance capabilities of the PMC structures, including long-term effects;
2. the development of high-speed, reliable manufacturing and assembly processes with associated quality control; and

3. evidence of economic incentives (which will be sensitively dependent on the manufacturing processes).

The three performance criteria applicable to a new material for use in automotive structural applications are

1. fatigue (durability),
2. energy absorption (in a crash), and
3. ride quality in terms of noise, vibration, and harshness (generally related to material stiffness).

Extensive research and development (R&D) efforts currently underway are aimed at realizing eight potential benefits of PMC structures for the automotive industry:

1. weight reduction, which may be translated into improved fuel economy and performance;
2. improved overall vehicle quality and consistency in manufacturing;
3. part consolidation resulting in lower vehicle and manufacturing costs;
4. improved ride performance (reduced noise, vibration, and harshness);
5. vehicle style differentiation with acceptable or reduced cost;
6. lower investment costs for plants, facilities, and tooling—depends on cost/volume relationships;
7. corrosion resistance; and
8. lower cost of vehicle ownership.

PERFORMANCE CRITERIA (4)

From a structural viewpoint, there are two major categories of material response critical to applying PMCs to automobiles. These are fatigue (durability) and energy absorption. In addition, there is another critical vehicle requirement, ride quality, which is usually defined in terms of noise, vibration, and ride harshness, and is generally perceived as directly related to vehicle stiffness and damping. Material characteristics play a significant role in this category of vehicle response.

POLYMER MATRIX COMPOSITE MATERIALS

The fiber with the greatest potential for automobile structural applications is E-glass fiber–currently. Similarly, the resin systems likely to dominate at least in the near term are polyester and vinyl-ester resins based primarily on a cost/processability trade-off versus epoxy. Higher performance resins will only find specialized applications, even though their ultimate properties may be somewhat superior. The form of the glass fiber used will be very application-specific, and both chopped and continuous glass fibers should find extensive use. Most structural applications involving significant load inputs will probably use a combination of both chopped and continuous glass fibers with the particular proportions of each depending on the component or structure.

CARBON COMPOSITES (5)

A fascinating material with unlimited possibilities

Carbon composites are already used in many branches such as automotive engineering, racing, aerospace technology, wind energy production, mechanical engineering, automation and robotics technology, medical technology and the sports industry.

Carbon composites has a wide range of advantages such as:

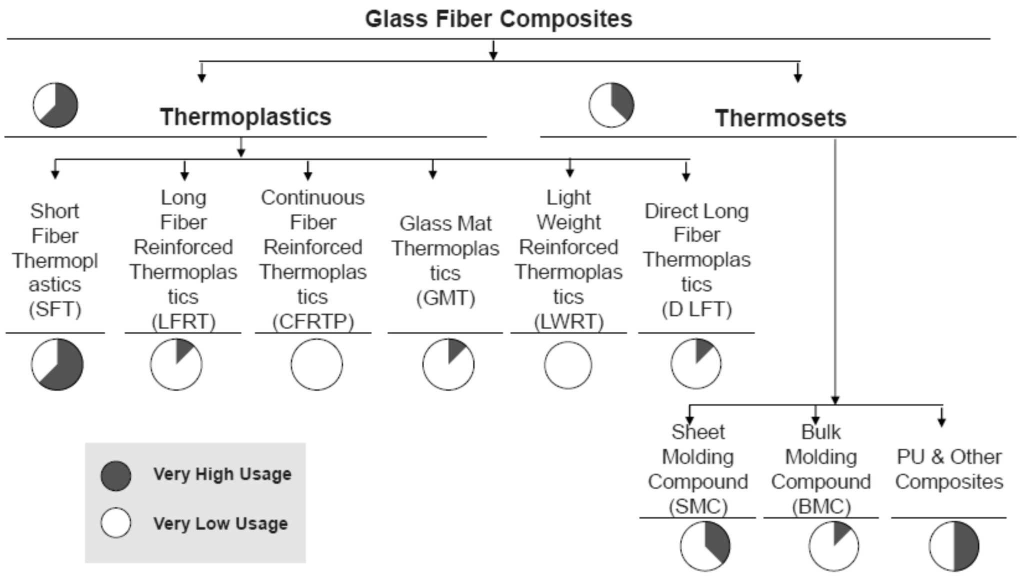
- Extremely light
- Very high stability
- Long-lasting
- Multifunctional
- Non-corrosive
- High energy absorption in a crash
- Economical
- Attractive appearance

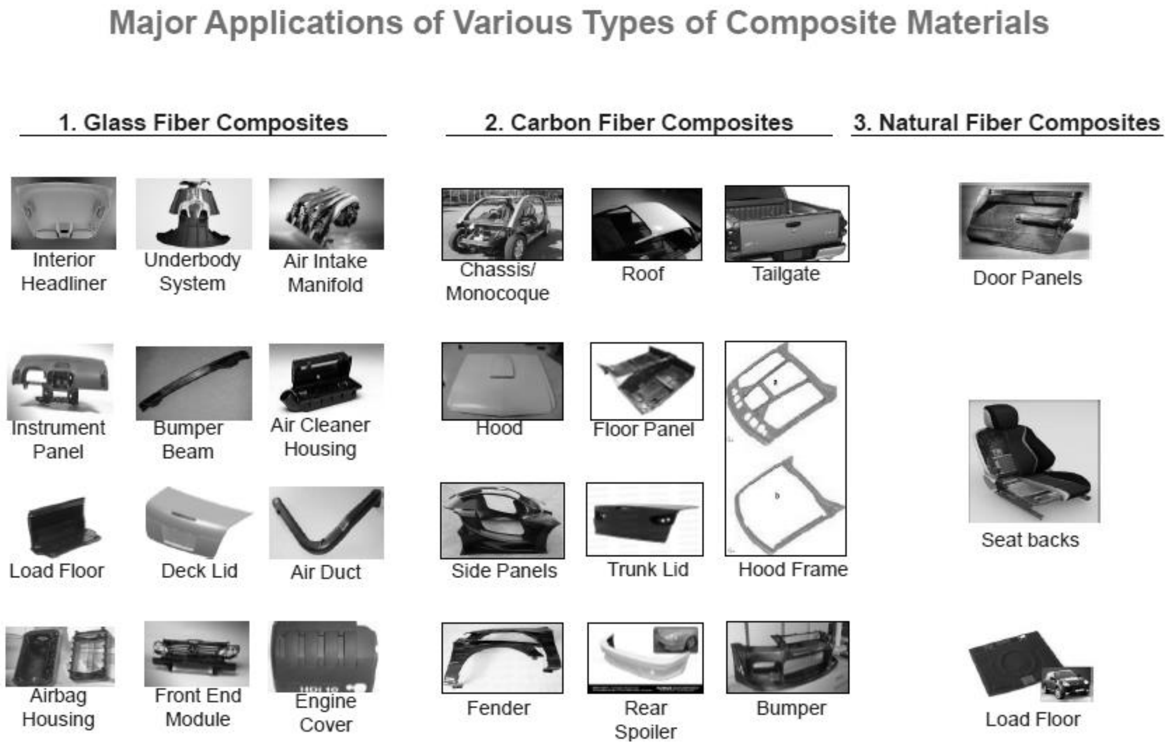
MANUFACTURING TECHNIQUES

The successful application of PMCs to automotive structures is more dependent on the ability to use rapid, economic fabrication processes than on any other single factor. The fabrication processes must also be capable of close control of PMC properties to achieve lightweight, efficient structures.

1. Compression molding of sheet molding compounds (SMCs)
2. High-Speed Resin Transfer Molding
3. Filament Winding
4. Prepreg layup

1. Types of Glass Fiber Composites Used in Automotive Industry





APPLICATIONS OF COMPOSITES IN MARINE INDUSTRY (6)

The first marine application of fiber reinforced polymer (FRP) composite material was in the construction of boats shortly after World War II. Boat builders began to use FRP composites instead of timber, which was traditionally used in small maritime craft, because wood was becoming increasingly scarce and expensive, timber was as losing favour with many boat builders and owners because wooden boats were easily degraded by seawater and marine organisms and therefore required ongoing maintenance and repairs that can be expensive. The earliest attempts to fabricate boat hull with FRP composites was in 1947 when twelve small surf boats were made for the UNITED STATES NAVY. The application of FRP composites to maritime crafts was initially driven by a need for lightweight, strong, corrosion resistant durable naval boats. Most of these early applications were driven by the need to over come corrosion problems experienced with steel or aluminum alloys or environmental degradation suffered by wood. Another reason for using composite was to reduce weight, particularly the topside weight of ships. The high acoustic transparency of composites also resulted in their use in rodomes on ships and sonar domes on submarines.

3.2 EARLY NAVAL APPLICATION OF FRP COMPOSITES:

1. Mine sweeper (15.5 meter)
2. Landing craft (15.2 meter)
3. Personnel boat (7.9 meter)
4. Sheathing of wood hulls
5. Submarine sonar dome

6. Submarine firs
7. Landing craft reconnaissance (15.8 meter)
8. Submarine non pressure hull casing

Increasingly, naval patrol boats are being built with an all-composite design or a composite hull fitted with an aluminum super structure. The growing popularity of FRP patrol boat is due mainly to their excellent corrosion resistance, which reduces maintenance costs, and lightweight. This can result in better speed and fuel economy. It is estimated that the composite patrol boats are usually approximately 10% lighter than an aluminum boat and over 35% lighter than a steel boat of the same size. Carbon fiber composites are rarely used on naval vessels because of their high cost.

LEISURE, SPORTING AND COMMERCIAL FRP COMPOSITE CRAFT:

The composite material most commonly used in leisure and commercial craft is GRP in the form of a thick laminate or a sandwich composite. Over 95% of all composite marine craft are built with GRP because of low cost. There is however a number of other reasons for the popularity of GRP composite in marine craft, and these include –

1. Ability to easily and inexpensively mould GRP to the near net shape, even for marine structure with complex shape, such as boat hulls thus making it suitable for mass production.

Excellent corrosion resistance

3. Light weight, resulting in reduced fuel consumption.
4. Simple to repair
5. Ability to absorb noise and dampen vibrations, which makes for a more comfortable ride on motor powered boats.

FABRICATION METHODS

Advanced fabrication processes, such as resin transfer, resin film intrusion, or auto craving are used in the construction of hull and decks to produce composites that are defect free, excellent dimensional balance and high fiber content for maximum stiffness, strength and fatigue resistance.

OFFSHORE APPLICATION OF FRP COMPOSITES:

The greatest problem with using steel in an offshore structure is the poor corrosion resistance against seawater and other highly corrosive agents, such as hydrogen chloride. It is estimated that the oil industry spends several billion dollars each year in maintaining, repairing and replacing corroded steel structures. Composites offer the potential to reduce these costs because of their outstanding corrosion resistance against most types of chemicals. It is estimated that composites provide a weight saving of 30 to 50% compared to steel for many nonstructural components. The most common types of composites used are GRP and phenolic composites, with the latter being used because of good fire resistance. Advanced composites containing carbon fiber, kelvar fibers, or epoxy resins are used sparingly because of their high cost.

Some of the current applications of FRP materials are

1. Low pressure pipes
2. Diesel Storage tanks, Lube tanks and utility tanks
3. Cable ladders and trays

DRAWBACKS OF FRP TO BE USED IN OFFSHORE APPLICATIONS

An important safety concern is that most FRP materials have poor fire resistant properties, such as short ignition time and high rates of heat release, smoke production and flame spread, while it is generally recognized that composites have much lower thermal conductivity than metallic material. These factors make it difficult for composites to meet the stringent fire safety requirements applied to offshore oil and gas platforms.

COMPOSITE PROPELLER:

The material used within the composite are commercially available, and it is the development of the right mix of fibers, resin and laminate lay-up that provide the desired mechanical and environmental performance for marine applications. The extensive development trials include durability testing in the marine environment, water uptake and fouling test.

OPTIMISING PROPERTIES OF THE COMPOSITE PROPELLER:

The fundamental mechanical properties required in this application include stiffness, strength and fatigue performance. The structure was optimized to be stiffest along the length of the blade and strong enough to have a significant factor of safety upon the design load. On material basis the composite was about half as stiff as NAB but had similar strength. Structural stiffness was regained through improved design of the propeller itself. Additionally the fatigue performance of the metal insert at the root also improved during the test, failure was initiated by flaws in the NAB while the composite remained undamaged.

IMPROVED CAVITATION PERFORMANCE:

Theoretical models give a cavitation inception speed of 30% higher for the composite propeller design, compared with the original NAB propeller. The use of the lighter composite materials meant that the blades could be thicker without significantly adding to the weight of the propeller. Thicker blades offer the potential for improved cavitation performance, so reducing vibration underwater signatures. The composite propeller is expected to last for the lifetime of the vessel where as a NBA propeller would be expected to suffer cavitation erosion and corrosion and needs to be replaced periodically.

THE USE OF POLYMER COMPOSITES IN CONSTRUCTION (7)

Polymer composites have enjoyed widespread use in the construction industry for many years in non-critical applications such as baths and vanities, cladding, decoration and finishing. In 1999, the construction sector was the world's second largest consumer of polymer composites representing 35% of the global market [1]. In recent times fibre composite materials have been increasingly considered for structural load bearing applications by the construction industry and have established themselves as a viable and competitive option for rehabilitation and retrofit of existing civil structures, as a replacement for steel in reinforced concrete and to a lesser extent new civil structures.

Reasons to Consider FRP Composites (8)

There are many different reasons to consider using FRP composites in civil engineering applications. The main criteria for engineers to use any material to satisfy the requirements of a job are durability, corrosion resistance, cost, weight, material properties, and ease of **construction.**

Structural Considerations

Tensile strength. Their tensile strength can range from about the **strength** of mild reinforcing steel to stronger than that of prestressing steels. As **such, they** offer good incentive for use in situations where high tensile strength is an asset. FRP composites generally exhibit linear tensile stress strain behavior throughout their load-carrying range and as such do not change their modulus over their loading history. Since FRP composites are materials composed of structural fibers in a plastic matrix, the fibers can be custom-oriented to suit individual needs.

Fatigue. Research to date indicates that FRP composites exhibit good fatigue resistance in tension tension cycling. Research has yet to document the effects of temperature, moisture, reverse loading, long-term and compression load cycling, and holes on fatigue resistance. Long-fiber composites generally retain a high proportion of their **short-term strength after** 107 cycles. Carbon-fiber composites exhibit the highest fatigue resistance, followed by aramid and then glass.

Low mass. Excessive structural mass is often a reason to consider alternate materials which will provide high load-carrying capacity as well as low density. FRP composites have densities in the range of 1,200 to 2,600 kg/m3 (75 to 162 lb/ft3) which make them attractive alternatives to structural materials such as steel with a density around 7,850 kg/m3.

Specific strength. The specific strength of materials, defined as the yield strength divided by the density, is often used to make comparisons between materials on the basis of strength and mass. FRP composites, because of their high strength and their very low density, have specific strengths which are up to 60 times that of high strength steels. The high specific strengths associated with FRP composites are very useful in applications such as structural cladding panels, low-density framing materials, and vehicle components. Their low weight makes the assembly and disassembly of temporary structures much easier and less time-consuming than similar structures made of wood or steel. Cost of many of the FRP composites, although higher than conventional construction materials on a pound-per-pound basis, are competitive when the specific strength of the materials is taken into consideration.

Vibration damping. The specific modulus of FRP composites, defined as the modulus of elasticity divided by the density, is also high and provides characteristics such as low vibration in situations where vibration may be a problem (Grace, Bagchi, and Kennedy 1991). Steel has a high density, high modulus, and low damping characteristics whereas composites have low densities, moderate moduli, and high damping characteristics. Use of composites in floors and bearing pads where damping of vibration is of concern can reduce these problems.

Repair using composites. Structural repairs of conventional materials using FRP composites can be advantageous from the standpoint of ease of installation and reduced maintenance costs. Conventional techniques for externally strengthening cracked concrete structures call for steel plates or bars to be installed across the crack to carry the structural loads no longer carried by the concrete. FRP plates can be structurally bonded across such cracks to replace the steel repair components. The low mass of these materials makes their handling more convenient, and their noncorrosive natwe eliminates the need to protect them from rusting deterioration.

Corrosion resistance. One of the most convincing reasons to consider the use of FRP composites is their resistance to corrosive **elements.** The plastic resins that form the matrix of most composites are resistant to deterioration from many chemicals as well as the effects of acidic, salt, and fresh waters. Acidic, salt, and fresh waters are corrosive to ferrous metals. The benefits of composites over steel in terms of resistance to corrosion are greatest in the areas of maintenanc and life-cycle costs. Components in marine construction such as piling, docks, and submerged construction would be applicable uses. Storage structures for corrosive liquids are suited to FRP composite materials. Fiberglass tanks have been used for storage of chemicals for **many years.**

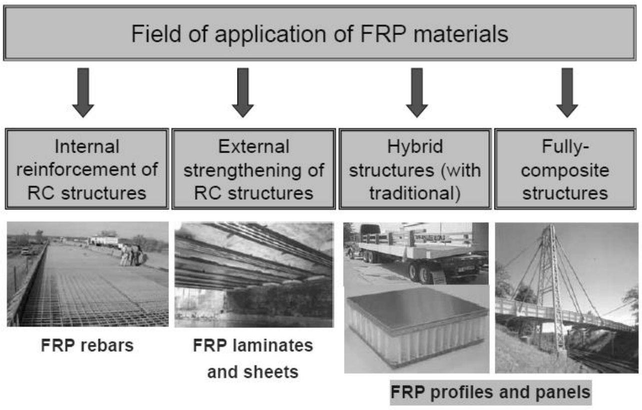
Production Options

a. Fabrication. The variety of fabrication techniques that are available with FRP's provide for many custom properties. Multiple types of fibers can be combined to produce materials with the advantages of each component; fibers can be oriented in specified directions to better suit specialized loading conditions; and material properties such as strength and stiffness can be controlled to meet the user need. Special molding techniques allow complicated pieces to be fabricated as one unit, eliminating joint conditions which can be a source of weakness. One method of producing FRP composites is by a technique known as pultrusion, other processes that are commonly used include filament winding, autoclave molding, and scrimp, capabilities of these materials is demonstrated in custom fabricated sandwich panels. In these panels, load bearing, FRP, honeycomb core structures are sandwiched between FRP skin plates producing a very strong, lightweight structural component.

b. Custom geometry. The length and geometry of a given pultruded cross section can be custom designed as well. The pultrusion process lends itself to custom fabrications. The length of the fabricated shape does not have to be a predetermined length. The designer can work with the fabricator to produce products in lengths and shapes needed for specific applications.

c. *Color and coating.* Since the matrix of FRP composites consists of resins that begin in the liquid state, many amhitectural treatments can be added before they harden. For example, custom coloring can be added to the resins in the manufacturing process, thereby eliminating the need for and cost of painting or other color application after the fact. Since the color is integrally mixed in the matrix, it cannot be scraped off or abraded during its lifetime. It is also possible to embed sand or other nonslip surface treatments as a secondary operation, and **the** treatment will become part of the component. Nonslip gratings and walkways are an example of this type of application.

STRUCTURAL APPLICATION OF FRP MATERIALS (9)



Where should FRP rebar be used? (9)

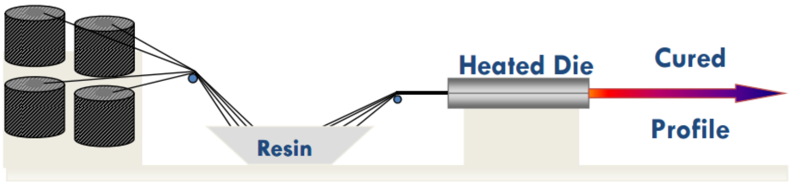
1. Any concrete member susceptible to corrosion by chloride ions or chemicals
2. Any concrete member requiring non-ferrous reinforcement due to Electro-magnetic considerations
3. As an alternative to epoxy, galvanized, or stainless steel rebars
4. Where machinery will “consume” the reinforced member ie. Mining and tunneling
5. Applications requiring Thermal non-conductivity

MANUFACTURING PROCESSES FOR FRP MATERIALS

1. Pultrusion
2. Hand layup
3. Filament winding
4. Centrifugation
5. Resin transfer moulding (RTM)

6. Resin infusion moulding (RIM)
7. Compression moulding
8. Vacuum assisted resin transfer moulding (VARTM)
9. Vacuum infusion

Pultrusion Process (commonly used)



Most products are manufactured with this process

FRP Bar Types

Materials

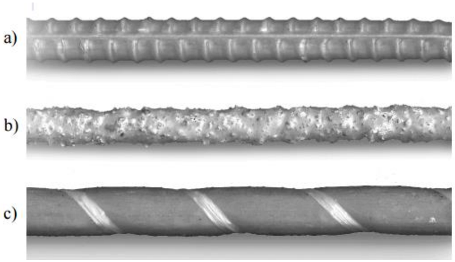
1. Glass/ vinylester
2. Carbon/ vinylester

Forms

1. Solid

Surface

1. Ribbed (a)
2. Sand Coated (b)
3. Wrapped and Sand/Coated (c)
4. Deformed
5. Helical
6. Innovation – hollow bar - coming soon

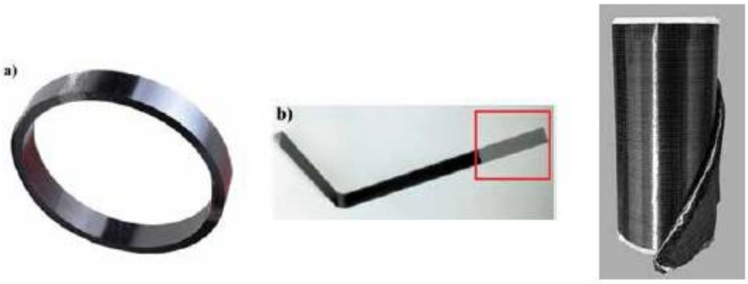


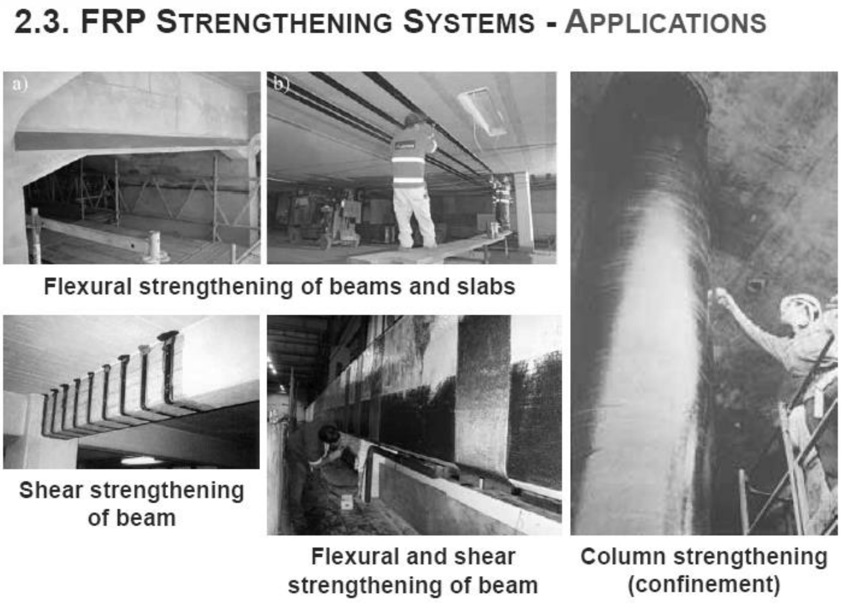
FRP REBARS – APPLICATIONS

1. Reinforcement of bridge deck
2. Aquaculture (Acuinova, Mira)
3. Repair of maritime structures, dock and pier

FRP STRENGTHENING SYSTEMS – TYPOLOGIES (classifications)

1. Laminates: unidirectional precured (carbon) fibre strips, adhesively bonded with epoxy adhesive.
2. Sheets: uni/multi-directional mats of continuous (carbon) fibres, moulded and cured *in situ*, impregnated and bonded with an epoxy matrix.





2.3. FRP STRENGTHENING SYSTEMS - APPLICATIONS

Flexural strengthening of beams and slabs

Shear strengthening of beam

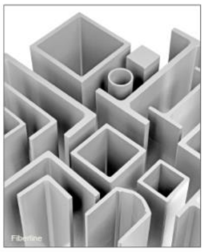
Flexural and shear strengthening of beam

Column strengthening (confinement)

FRP PROFILES – GEOMETRIES AND CONSTITUTION

First generation profiles

1. Thin-walled cross-sections mimicking metallic construction - High deformability
2. Susceptibility to instability phenomena under compression



First generation profiles

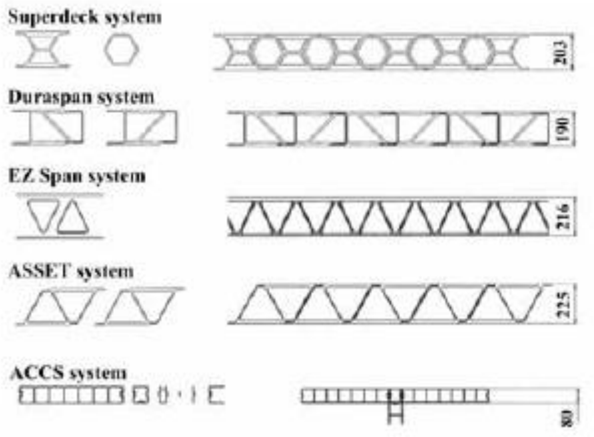
New generation profiles

Multi-cellular deck panels for new construction or rehabilitation

1. Panel-to-panel connection: adhesive bonding or snap-fit
2. Panel-to-girder connection: bolting/bonding

Advantages

- Lightness
- Quick installation
- High durability
- Low maintenance



FRP PROFILES – GEOMETRIES AND CONSTITUTION

Fibre reinforcement:

- Rovings - bundles of longitudinal continuous fibres

- Mats - (non-)woven chopped or continuous fibres in several directions

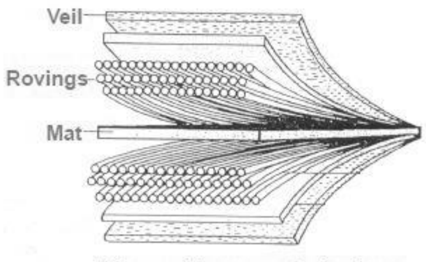
- Surface veil with randomly oriented chopped fibres

Polymeric matrix:

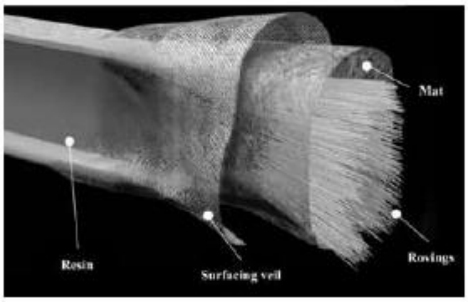
- Resin (polyester, vinylester, epoxy)

- Fillers

- Additives



Fibre architecture of a laminate



FRP PROFILES – PROPERTIES (GFRP)

Linear elastic behaviour up to failure (no ductility)

- Orthotropic behaviour
- High longitudinal strength (similar to steel)
- Low elasticity (10-20% of steel) and shear moduli
- Low density (20-25% of steel)

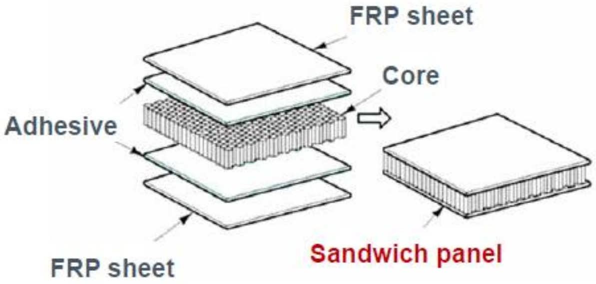
FRP PROFILES – APPLICATIONS

Rehabilitation

FRP SANDWICH PANELS – CONSTITUTION

FRP outer skins - thin, stiff, resistant

- Core - thick, light, more flexible, less resistant (rigid foam, balsa wood, etc.)
- Adhesive



Composite materials in sports equipment (10)

Introduction

With the development of economy, people's living standards improve, more and more modern people relaxing into all kinds of sports venues. And the development of the modern athletic sports in the sports experts focuses on scientific training at the same time, also attaches great importance to the improvement and development of sports equipment. Because of the fiber reinforced composite materials with light weight, high strength, large degrees of freedom of design, easy processing and forming characteristics, obtained widespread application in sports equipment.

The advantages of fiber reinforced composite material is applied to sports equipment.

As is known to all, before the advent of fiber reinforced composites is not, as a sports equipment materials mainly wood, steel, stainless steel, aluminum alloy, etc. Compared with these materials, fiber reinforced composite material has obvious advantages in the following aspects.

Light weight. Most of the sports equipment such as tennis racket, golf clubs, bikes, Skis, etc relies on human to make the movement, lighter the weight better the performance. Fiber reinforced composites in this aspect has the incomparable advantage.

Mechanical performance is good. Sports equipment should have good usable performance and must have excellent mechanical properties. Fiber reinforced composite has outstanding elastic modulus, more suitable for used in sports equipment. Composite material has good damping absorption.

Can design. Composites has the freedom than traditional materials for design. Any complicated design is possible with composites.

Reinforced with fiber materials and fabric structure

Fibre materials mainly include glass fiber, carbon fiber, aramid fiber, etc. These fiber materials can be processed into yarn, cloth, mat, chopped strand, etc.

There are many different kinds of sports equipment, the following are common fiber reinforced composite material sports equipment to make a simple list (see table 1), and makes detailed introduction of some products.

Table 1Examples of fiber-reinforced composite materials application in the sports equipment

Form	**Application**
Plate-like structure	Skis, surfboards, windsurfing, table tennis boards, slats and gliding wing spar etc.
Tubular structures	Tennis, badminton, fishing rods, golf clubs, baseball bats, hockey sticks, pole shaft, etc.
Sheet structure	All kinds of helmets, golf club heads, the hull structure of the various boat classes
Other structures	Match with a variety of vehicles, Sword, climbing ropes, various lines etc.

Skis

Type of Composite

1. Wet Layup Glass and Carbon Epoxy
    a. Di functional epoxy with amine curing agent
    b. Woven, non woven, stitched uni and braided glass and carbon
    c. Process: Wet Layup Compression Molding

Design Drivers

a. Stiffness and geometry driven
b. Manufacturing driven
c. Cost driven
d. Failures typically driven by:
    i. Bond Failures
    ii. Imperfections in structure

Material Selection Drivers

- Cost
- Bonding- Must join many dissimilar materials

Snowboards

Type of Composite

1. Wet Lay up Glass and Carbon Epoxy
    a. Di functional epoxy with amine curing agent

    a. Woven, non woven, stitched uni and braided glass and carbon
    b. Process: Wet La yup compression molding

Design Drivers

    a. Stiffness and geometry driven
    b. Manufacturing driven
    c. Cost driven
    d. Some weight considerations
    e. Failures typically driven by:
        a. Core Failures
        b. Imperfections in structure
        c. Bond Failures

Material Selection Drivers

    a. Cost
    b. Weight
    c. Bonding - Must join many dissimilar materials

Snowboard Bindings

Type of Composite

1. Injection molded glass nylon

Design Drivers

a. Shape complex
b. Strength
c. Weight
d. Cost

Material Selection Drivers

a. Strength
b. Low temp. high rate loadings
c. Complex shapes
d. Cost

Golf Club

A golf club is used to strike the ball in the game of golf. It has a long shaft with a grip on one end and a weighted head on the other end. The head is affixed sideways at a sharp angle to the shaft, and the striking face of the head is inclined to give the ball a certain amount of upward trajectory. The rules of golf allow a player to carry up to 14 different clubs, and each one is designed for a specific situation during the game.

Raw Materials

Golf clubs are manufactured from a wide variety of materials, including metals, plastics, ceramics, composites, wood, and others. Different materials are chosen for different parts of the club based on their mechanical properties, such as strength, elasticity, formability, impact resistance, friction, damping, density, and others.

Club heads for drivers and other woods may be made from stainless steel, titanium, or graphite fiber-reinforced epoxy.

Face inserts may be made from zirconia ceramic or a titanium metal matrix ceramic composite. Oversize metal woods are usually filled with synthetic polymer foam.

Club shafts may be made from chrome-plated steel, stainless steel, aluminum, carbon or graphite fiber-reinforced epoxy, boron fiber-reinforced epoxy, or titanium.

Grips are usually made from molded synthetic rubber or wrapped leather.

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