# Module11: Engineering Applications of Composite Materials

# Learning Unit-1: M11.1

# M11.1 Engineering Applications of Composites Materials

**Introduction:**

Composites are one of the most widely used materials because of their adaptability to different situations and the relative ease of combination with other materials to serve specific purposes and exhibit desirable properties.

In surface transportation, reinforced plastics are the kind of composites used because of their huge size. They provide ample scope and receptiveness to design changes, materials and processes. The **strength-weight ratio** is higher than other materials. Their stiffness and cost effectiveness offered, apart from easy availability of raw materials, make them the obvious choice for applications in surface transportation.

In heavy transport vehicles, the composites are used in processing of component parts with cost-effectiveness. Good **reproductivity** and **resilience** handling by semi-skilled workers are the basic requirements of a good composite material. While the costs of achieving advanced composites may not justify the savings obtained in terms of weight vis-a-vis vehicle production, carbon fibers reinforced epoxies have been used in racing cars and recently for the safety of cars.

Polyester resin with suitable fillers and reinforcements were the first applications of composites in road transportation. The choice was dictated by properties like low cost, ease in designing and production of functional parts etc. Using a variety of reinforcements, polyester has continued to be used in improving the system and other applications.

Most of the thermoplastics are combined with reinforcing fibers in various proportions. Several methods are used to produce vehicle parts from thermo plastics. Selection of the material is made from the final nature of the component, the volume required, apart from cost-effectiveness and mechanical strength.

Components that need conventional paint finishing are generally made with thermosetting resins, while thermoplastics are used to build parts that are moulded and can be pigmented. Press moulded reinforced polyester possess the capability to produce large parts in considerable volume with cost-effectiveness.

In manufacturing of automobile parts, glass and **sisal fibers** usually find the maximum use. Sisal costs very less and this alone has prompted extensive research to come up with applications in which sisal is the dominant reinforcing material in filled polyester resin, in parts where specific mechanical properties are required and appearance is not very important. Heater housings, which find uses for sisal, are produced by compression moulding. Since a variety of glass fibers are available, it is used as reinforcement for a large range of parts of different types. **Rovings**, **non-**

**woven mats** are the commonly used low cost versions. Woven cloth is applied in special cases, where particular properties are required as cloth is not known to be amenable to large quantity production methods.

Since the automobile industry is replete with models, options and changes in trends, the material selection and combinations offered by the materials is also wide-ranging. Along with a measure of conservation, the choice is also dictated by the demands of the competitive market for new and alternate materials.

A reinforced-plastic composite is likely to cost more than sheet steel, when considered on the basis of cost and performance. In such a case, other qualities must necessarily justify the high expenditure. Mechanical properties of the parts, which affect the thickness and weight, must offer enough savings to render them more effective than steel. It however shows a higher machining waste than reinforced plastics.

The fabrication costs of reinforced plastics is controlled by the devices and tooling used for producing them. In turn, it is dependent on the basis of the quantity of components needed.

Some complicated parts of light commercial vehicles, which need casting, may be compression moulded from composites of the sheet or bulk variety. State-of-art technologies of **moulding**, **tooling** and fabricating have thrown open possibilities of increased manufacturing of vehicles that use reinforced polyesters.

Materials used in automotive body parts show high tensile strength and flexural moduli. The material is not ductile and hence will not yield and the failure is accounted only in terms of fracture. These properties and thickness, determine the maximum bending moment which is several times higher than the point of fracture for steel sheets.

Reinforced plastics can be given the metal finish, although the cost of achieving this continues to be prohibitive. They are restricted in their use in car components. While the defects in painted sheet metal parts are easily overlooked, the fiber pattern texture is obvious, though the surface-roughness measurements report that it is smoother.

In commercial vehicles, appearance is also important as is the functional aspect. Since a commercial vehicle is more a capital investment, it is the returns from such investment that are considered. The rate of return depends on initial cost, durability and maintenance costs.

Reinforced plastic is a boon in the sense that it uses shorter lead times and tooling cost is considerably cheaper. Commitments to launch a new model are kept easily, since the time between production and introduction can be co-ordinate perfectly.

Studies have shown that composite panels may be used as the complete outer skin of the body to give a unique look. Sheet moulding compounds of resins are most suited for this purpose. Inner and outer reinforcing is done by panel assembled by adhesive bonding and riveting.

Good stability against corrosion or impact makes the composites widely used in vulnerable **valance panels** below the front and rear bumpers. Signal lamps, indicator lamps of vehicles are fabricated from glass-reinforced composites and tractors have a different selection methodology from that of passenger cars. The most crucial parameter is weight reduction as it directly affects efficiency, payload and the economy. Durability is the chief factor as these vehicles are normally realizations of capital investments. Time required, cost and frequency of maintenance add substantially to the total costs. Therefore it is natural to try and reduce these factors to a minimum. Fiber glass reinforced polyester is widely used in various parts of trucks.

The fatigue properties of the materials and the low weight, ability to sustain strains from the engine heat and low frequency road vibrations are features that favour composites in trucks and other heavy vehicles.

Reinforced plastics do not cost too much to tool, and they are now extensively used for automobile parts, indicator and signal lamp parts and other accessories.

Truck bodies and trailers use assemblies and parts made from reinforced plastics to a great extent. The use of light metals, which lends itself to simple shapes and extrudable forms, is also found to be economical. The low heat transfer coefficient of composites enables their use in refrigerated units. Glass reinforced polyester has all the properties that make it ideal for this purpose and has become the standard material.

Plywood panels laminated with thin layer of reinforced plastic are also widely used in truck carriages. Several methods are used to produce them and the low cost, and strength offered by plywood make it appealing. They may not be as light weight as desired, but are found to be considerably more durable than the conventional constructions, particularly in intensive service conditions.

There is also a growing market for products like pick-up trucks and trailers which are made using glass reinforced plastics at competitive prices.

Vehicles meant for consumer markets tend to be designed attractively, their appearance is different and the tooling is easy. Reinforced plastic moulds from the full size model of the part are taken. The pattern may be either made from wood, clay or plaster.

Sheet metal body of automobile is moulded in matched moulding dies with fiber glass or rovings as reinforcements. Large, complex parts can be produced and their reproduction can be made equally fast too. The parts made using this technique are generally of a uniform thickness, because the extra reinforcing fibers cannot be easily or accurately loaded.

Moulding compounds are used when small and rigid parts have to be made and they are usually prepared by casting. The bulk moulding compound is composed of polyester resin, glass fibers and filler. Strength is lesser than that obtained by other moulding processes. Moulding compounds can be prepared as continuous sheets. Due to the longer fibers and high glass content, their strength is better than those made in bulk moulding method.

Injection moulding and pultrusion are used to a limited extent to produce materials that may be applied in structural materials. After separate fabrication of parts by moulding or other methods, assembling the vehicles body has to be done. Tooling and fixtures similar to those used in metal parts are used for piercing and drilling operations.

Assembling of various parts is usually done by adhesive bonding, using resins that are catalyzed to cure at room temperature in a short time. Good bond strength is achieved even without pressure, although clamping fixtures are needed to locate the assembled parts correctly in relation to each other. High build primers are used to give high gloss finish so that surface imperfections do not become obvious.

Commercial aircraft applications are the most important uses of composites. Aircraft, unlike other vehicles, need to lay greater stress on safety and weight. They are achieved by using materials with high specific properties. A modern civil aircraft must be so designed as to meet the numerous criteria of power and safety.

Glass reinforced composites are the most desired materials as a result of advanced technology that has gone beyond the design and application.

In cases where high moduli of elasticity values are less important, fiberglass is the natural option because of the low cost of material. The matrix material used with fiber glass, however, limits its use to low temperatures, usually below 121°C, although it is not a debilitating limitation for the fiber, as its properties can still be used and maintained at temperatures beyond 426 to 482°C.

Fiber epoxy composites have been used in aircraft engine to enhance the performance of the system. The pilot's cabin door of aircrafts has also been made with fiber glass resin composites and these are now used in other transport systems.

The boron-graphite materials were initially designed for fighter aircraft components and their use in commercial aircraft has been very less. There are a few instances of applications of these composites in wide use currently although experimental applications are several. They are presently limited to secondary structures which can be used in commercial aircraft with considerable safety. The data from such experimentation on the long term effects of loads and stress on the structure provides input for design.

Both dynamic and static conditions are combined in the **turbojet engine** and research has always been directed towards this. These applications involve light weight materials and this combination offers advantages.

The weight of the rotors, compressors and bearings are reduced. Initially, turbojet engines were used in fighter aircraft and later in commercial planes. The need of a commercial plane is long service life and durability.

Some of the turbofan engines are designed to meet the manifold requirements of transport sector. The engine can be improved by improving the efficiency of propulsion or reducing the weight. The notable stiffness and strengths of composites permit reduction in the number of compressor stages by higher blade loading. The use of composites in rotors, compressors and engine parts are estimated to lead to weight savings.

Aeronautical engineering comprises of various distinct areas that produces vehicles capable of performing distinct flight programmes. Initially importance was given to weight, speed and power, but other parameters that influence market acceptance of the aircraft should also be considered during design. These conditions call for selection of materials that give less than optimum efficiency in terms of structure and systems. Hence, it is important to consider performance needs as well as service properties. Airframe design starts with evaluation of flight conditions which the aircraft will encounter. In recent designs, wind tunnel tests and analysis are being done to determine the lift and drag forces. Once determined, they are used to develop various related factors of structural engineering. The selection of material, it follows, enters naturally into the picture at the early stage of design itself. The high strength of composites allows designing of higher **aspect ratio** wings in aerofoil sections.

Nowadays, composites are used in peripheral structures of **aerodromes**. Conventional constructions of composites ought to cost much less in future and will not be a constraint. Automation along with high standard for filament and matrix materials will also decrease fabrication costs, as the rejection on grounds of quality will be less.

Performance, reliability and efficiency of operators alone can assure the success of any programme and the space program in particular. The potential and application of high-performance composites has revolutionized space structural technology.

Glass filaments have been used in space vehicles for several years now as laminations in secondary structures. As far as its importance as an engineering material is concerned, glass is attractive because of high specific strength, low cost, good forming characteristics, high impact resistance and thermal stability. Thanks to its insulating property, glass has been used to a great extent in thermal isolation components and structures. However, a drawback with glass is its low elastic modulus. Although glass is easily handled, it results in excessive tool wear while machining operations are conducted.

Graphite is a widely available economical reinforcement material with high stiffness, high modulus, high strength and high theoretical efficiency. However it is difficult to transfer load between layers. In addition, its compressive properties are less than its tensile properties. The positive points are that graphite has extremely good machining and forming capabilities and has a very low coefficient of expansion. It can also be easily woven into cloth and have high dimensional stability.

Generally, flaws in composites affect the degradation of the static strength more than in metals, but are unlikely to be as detrimental in fatigue loading. The strength is dependent on the shape of the flaws and the critical failure stress in the composite. By using glass fibers as doublers, stress softening can be done around cut-outs.

Joints often decide performance and reliability of the composites. Since composites do not exhibit good bearing strengths, conventional joints like mechanical fasteners cannot be used.

Moreover, as reinforcement do not fuse at high temperatures, welding is not very effective. There are three methods of joining composites. In scarf joint, the laminate layers are laid up against wedge shaped metal edge members. Bolt holes are placed through the metal and loads are transported in shear to composites held by adhesive along with them. Metal double-step lap joint has some layers in 90 degree orientation butted to the joint ends. Metal shims are interlaced and inserted and then bonded between composite layers. The load is borne by the shims which subsequently shifts it to the composites. But this has results in thick joints and displaced laminates.

A design concept developed to reinforce certain chosen areas of metal structures for localized strength has several advantages including significant reliability, cheaper in cost, significant weight reduction etc. This means that the risks that are associated with composite problems are minimal. This method also permits the use of conventional metal joints which include riveting and welding. Hence the joints are fairly reliable.

A major concern in management of space vehicle systems is the delivery of hardware that meets the important requirements of schedule, performance and cost. Increased reliability and performance can be achieved by changing the material among other options. Composites have great potential in this respect and performance can be achieved by extracting weight reduction of structure.

An important consideration in the use of composites is lightweight. Research studies of specific components have shown that using all composite structures a saving of 20 to 45% can be achieved while selectively reinforced metal structures offer about 10 to 25% only.

Sometimes weight reduction is required to maintain the **center of gravity** of the system. Specially, tail weight can be reduced by application of composites so that weights do not have to be added at the nose to maintain the center of gravity position.

Composites are selected to solve problems of critical payloads or balance. Few cost factors considered are the initial cost and life cycle cost. In the first case, the cost of generating data, developing new routes and inspection techniques etc., have to be considered.

Composite designs have been developed showing ample success in lowering manufacturing costs which recommend them over metal designs. It applies especially to composites with filament reinforcements, which use simpler tools and reduce time taken for fabrication process.

In Railway carriages it is desirable to reduce the weight of rail car bodies as well as heavy transport vehicles, which in turn reduce power and braking requirements. It also reduces maintenance costs. Vehicle type, colour selection is the major aspects of building rail cars.
Structural concepts on certain aluminium and steel vehicles which are designed from sheets and stiffened by extrusion are not always the most efficient in case of collision. Fire retarding properties, noise and heat insulation and crack resistance are additional qualities.

The high cost of material has restricted the use of fiber reinforced plastics in freight cars. Composite materials, however, have been used for component parts such as fasteners, levers, hatch covers in hopper cars etc. Glass fiber reinforced plastic, used for containers, is also used for paneling in rail cars. Fiberglass has been the flexible insulation material of choice for these vehicles.

The principal design criterion for transport vehicles involves conditions that the structural weight must be minimized to conserve raw material, tribological factors and at the same time remain the least polluting. The lifetime should be long and reliable. Reliability should be considerably improved to conserve materials and reduce maintenance costs. Designs should be considered giving importance to fatigue and fracture resistance. They should improve the level of safety and performance. The impacting absorption should be better than those of other vehicles and should have insulation against fire and smoke retarding capabilities.

Glass reinforced systems are used in many city transit cars. The accessories are made from cellular cellulose acetate foam cores, over laid with fiber glass for strength and rigidity. Few vehicles use glass-reinforced polyester for panel dividers. Structurally the exterior of these vehicles combine fiber glass moulded parts over truss-type structures.

Every structural design has to inevitably pass the economic viability criteria. These vehicles usually involve preventive maintenance and overhead expenses. While assessing cost impact of the design in question, the total life cycle costs and the computations must relate the improvement to the operating and ticket costs per passenger-mile.

## M11.2 Engineering Applications of FRP composites

### M11.2.1 Application of Composites in Aircraft Industry

The use of fibre reinforced composites has become increasingly attractive alternative to the conventional metals for many aircraft components mainly due to their increased strength, durability, corrosion resistance, resistance to fatigue and damage tolerance characteristics. Composites also provide greater flexibility because the material can be tailored to meet the design requirements and they also offer significant weight advantages. Carefully designed individual composite parts, at present, are about 20-30% lighter than their conventional metal counterparts. Although all-composite airplanes are now available in the world market, yet advances in the practical use of composite materials should enable further reduction in the structural weight of airplane. The composite materials used in aircraft industry are generally reinforced fibres or filaments embedded in a resin matrix. The most common fibres are carbon, aramid, glass and their hybrid. The resin matrix is generally an epoxy based system requiring curing temperatures between 120° and 180°C (250° and 350°F).

The first structural composite aircraft components, which were introduced during 1950-60, were made from glass fibre reinforced plastics. These components included the fin and the rudder of Grumman E-2A, helicopter canopies, frames, radomes, fairings, rotor blades, etc. Due to high strength and stiffness combined with low density, composites like Boron Fibre Reinforced Plastics (BFRP) and Carbon Fibre Reinforced Plastics (CFRP) .were preferred instead of aluminium for high performance aircraft structures. For lightly loaded structures, Aramid Fibre Reinforced Plastics (AFRP) which possess low density, have been used. The use of AFRP continues to be restricted to the lightly loaded structures due to the fact that although these fibres possess high tensile strength, they have very low compressive strength. For light aircraft and lightly loaded structural components, Glass Fibre Reinforced Plastics (GFRP) has become one of the standard materials. Over the years, use of composite materials has also increased from few small access panels and canopy frames to almost complete airframe surfaces thereby providing weight savings leading to improved performance, reduced drag and also improved durability and corrosion resistance. Consequently, now-a-days, composite materials like GFRP, CFRP and AFRP have become standard materials for flight control surfaces, engine cowlings, fairings, radomes, landing gear doors, floor panels, fan ducts, etc. in aircraft application.

Weight savings provided by composites vary considerably with the type of aircraft and component. Weight savings, in terms of composite weight fraction are shown in Figure M11.1. These tend to decrease as the overall composite weight fraction increases.

Composite aircraft components used for structural application are generally fabricated with a sandwich construction having face sheets of carbon fibre or carbon fibre combined with aramid or glass fibres with a honeycomb core. For interior aircraft applications, composite parts are required to meet mechanical properties and processability requirements. In addition, materials used within pressurized portion of aircraft must meet the flammability resistance requirements. Interior parts such as overhead bins, sidewall panels, ceilings, floor boards, galleys, partitions, cargo floor board liners, etc. are made of composite materials which are generally fibre reinforced epoxy or phenolic resin. For interior applications, phenolic resin system is mainly used because of its excellent fire resistant properties including low flammability and low smoke and toxic gas emission. The predominant design considerations for interior components are impact resistance, stiffness and surface smoothness. The commonly used fibres for interior aircraft application are glass fibres.

In the present day scenario, use of advanced composite materials has been extended to a large number of aircraft components, both structural and non- structural, based on various factors namely, in-service loading, environmental conditions, etc. This chapter discusses application of composites on different types of aircraft, salient in-service defects experienced and possible solutions.

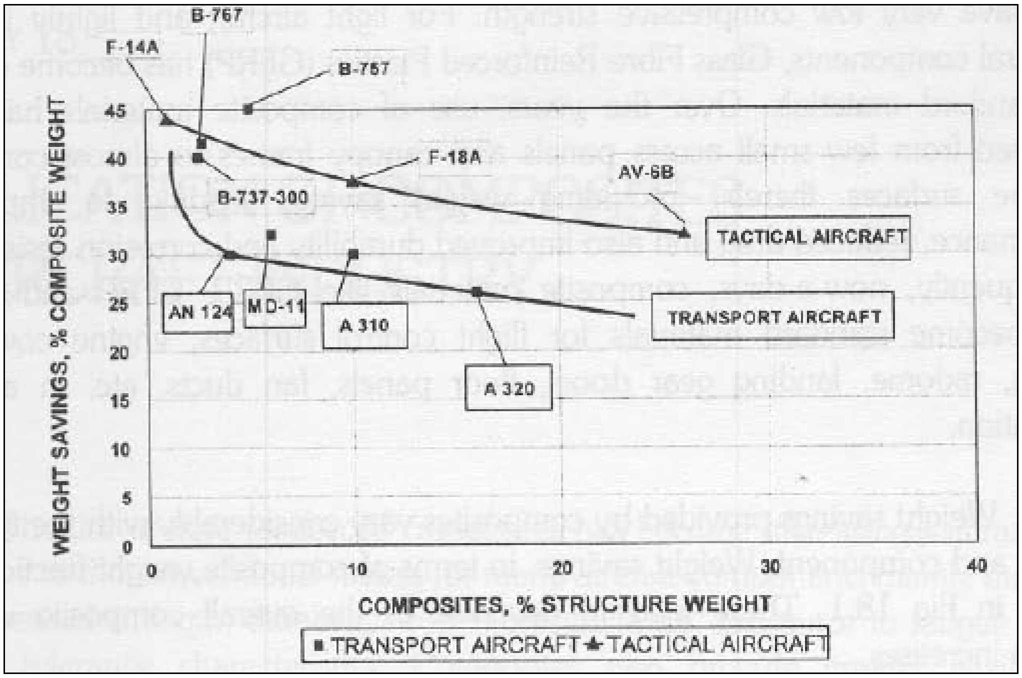


**Figure M11.1 The comparison plot to find weight saving with respect to type of Aircraft**

## M11.2.1.1 Typical Applications in Aircraft Industry

### M11.2.1.1.1 Civil Aircraft Applications

Airbus Industries used advanced composites on the Airbus A300 aircraft which first flew in 1972. The composite material was used in fin leading edge and other glass fibre fairing panels (as shown in Figure M11.2).

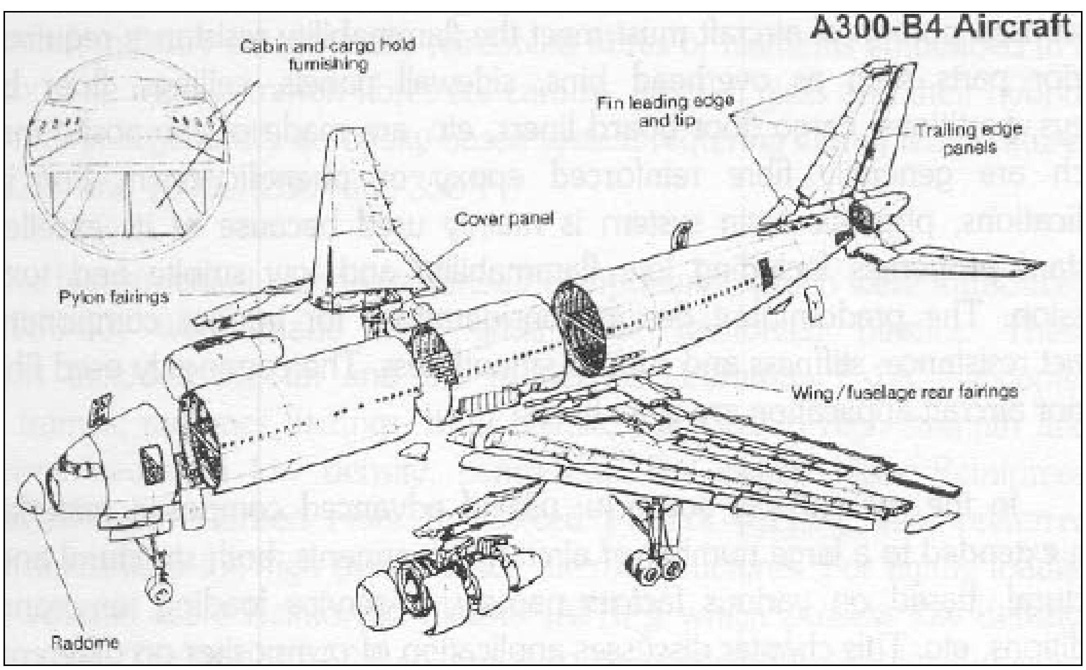

**Figure M11.2 The composite material was used in fin leading edge and other glass fibre fairing panels**

In 1979, the in-service evaluation of Airbus A300 aircraft led to further use of composite components on Airbus A300 aircraft namely CFRP spoilers and rudders, air brakes, CFRP landing gear doors, etc. Use of composites was extended to Airbus A310 aircraft during 1980-85, and thereafter to Airbus A320 aircraft in 1987.

Various composite components used on Airbus series of aircraft are given in the Table11.2.

| Aircraft Type | Components Made of Composite Materials |
|---|---|
| Airbus A300B2/B4 | Radome, fin leading edge and tip, fin trailing edge panels, cabin and cargo hold furnishings. Fairing -pylon, wing/ fuselage rear. |
| Airbus A310-300 | Rudder, elevator, vertical stabilizer, spoilers, cowl (inlet & fan), thrust reverser, main & nose landing gear door of wing leading & trailing edge panels, nacelles. Fairings -Ion, flap track, win fuselage. |
| Airbus A320/A319 & A321 | Aileron, horizontal and vertical stabilizer, elevator, rudder, spoilers, flaps, engine cowl, radome, landing gear doors (main & nose), floor panels, wing panels (leading & trailing edge), other access panels, nacelles. Fairings -flap track, wing/fuselage (forward & rear), and main landing gear leg. |
| Airbus A330 | Ailerons, rudder, flaps, spoilers, elevator, horizontal and vertical stabilizer, wing panels (leading & trailing edge), landing gear doors (main & nose), nacelles. Fairings -flap track, wing/fuselage (forward & rear). |
| Airbus 340 | Ailerons, rudder, flaps, spoilers, elevator, horizontal and vertical stabilizer, wing panels (leading & trailing edge), landing gear doors (main & nose), nacelles. Fairings -flap track, wing/fuselage (forward & rear). |

**Table M11.2:** The components used on Airbus series of aircraft

Total weight of composites used on different aircraft of Airbus series is as shown in Table M11.3:

| Aircraft Type | Weight of Composites |
|---|---|
| Airbus A300 | ≈4000 lb. (5%) |
| Airbus A310 | ≈7400 lb (7%) |
| Airbus A320 | ≈9000 lb (15%) |
| Airbus A330/A340 | ≈16000 lb (12%) |

**Table M11.3:** Weight of composites used in different Airbus

On Airbus A300B2/B4 aircraft, only glass fibre structures have been used. AFRP and CFRP structures have been used on Airbus A310-200 aircraft. For Airbus A320 and Airbus A330/340 aircraft, GFRP, CFRP and AFRP have been utilized in the composite structures. Use of composites in Airbus family of aircraft has consistently increased from Airbus A300 aircraft onwards. Composites account for about 15% of the structure of Airbus A320 aircraft. Although the total weight of composite structures is much higher in Airbus A330/A340 aircraft, the percentage of weight in relation to total weight of aircraft is nearly 12%. Use of composites on A340 aircraft is shown in Figure M11.3.

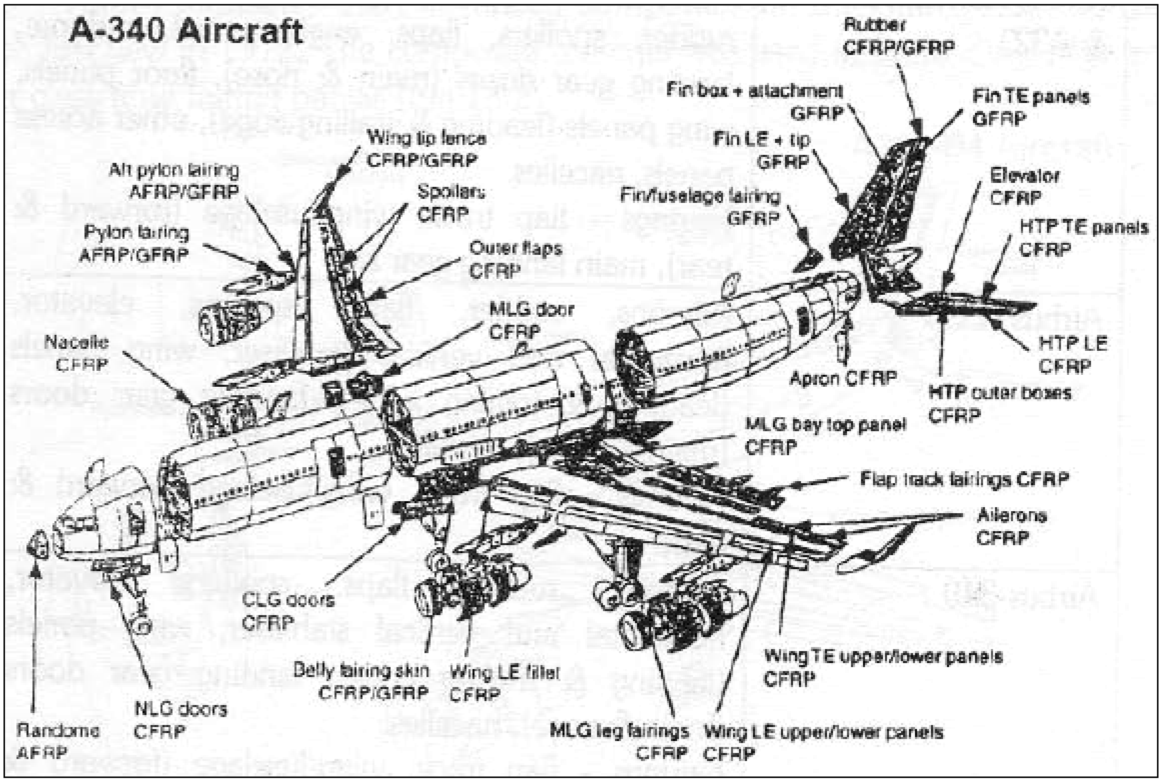


**Figure M11.3 Composite used for different part of A-340 Aircraft**

The first US commercial transport aircraft to fly in 1970, with advanced composite components was Boeing 707 aircraft, which had Boron/Epoxy fore-flap. However, this was only a development production. Commercial aircraft advanced composites development essentially began when Aircraft Energy Efficiency: ACEE) programme was initiated by NASA in 1972. The programme determined properties of different carbon/epoxy material system after long-term worldwide environmental exposure and spectrum fatigue loading equivalent to 20 years or 36,000 flight of airline service. The programme also included flight service of numerous composite components to obtain confidence in the long- term durability of advanced composite structures and materials. The experience gained from the ACEE programme provided the confidence needed by Boeing Co. to select CFRP for the B-757, 8-767 and B-737-300 aircraft control surfaces. Boeing Aircraft Co. designed and 'built Carbon/Epoxy spoilers that were used on Boeing 737-200 aircraft in 1973. The programme included 108 B-737 spoilers, ten B-727 elevators and four B- 737 horizontal stabilizers. Some spoilers were later made from different Carbon/thermoplastic materials, which had to be taken out of service due to matrix degradation by hydraulic fluids.

Various composite components used on Boeing series of aircraft are given in the Table M11.4.

| Aircraft Type | Components Made of Composite Materials |
|---|---|
| Boeing 737<br>-200<br>-300<br>-400 | <br>Spoilers and horizontal stabilizer (both limited production), trailing edge flaps.<br>Aileron, elevator, rudder, nacelles.<br>Aileron, elevator, rudder, nacelles. |
| Boeing 747-400 | CFRP winglets and main deck floor panels. CFRP and AFRP used in cabin fittings engine nacelles. |
| Boeing 757 | Aileron, elevator, rudder, spoilers, flaps (in-board & outboard), fairings and nacelles. |
| Boeing 767 | Ailerons, elevator, rudder, spoilers, landing gear doors (nose & main), fairings and nacelles. |
| Boeing 777 | Ailerons, elevator, rudder, spoilers, flaps (in-board & outboard), floor beams, landing gear doors (nose & main), fairings and nacelles. |

**Table M11.4:** The composite components used on Boeing series of aircraft

Use of composites on different versions of new generation B- 737 aircraft is shown in Figure M11.4.

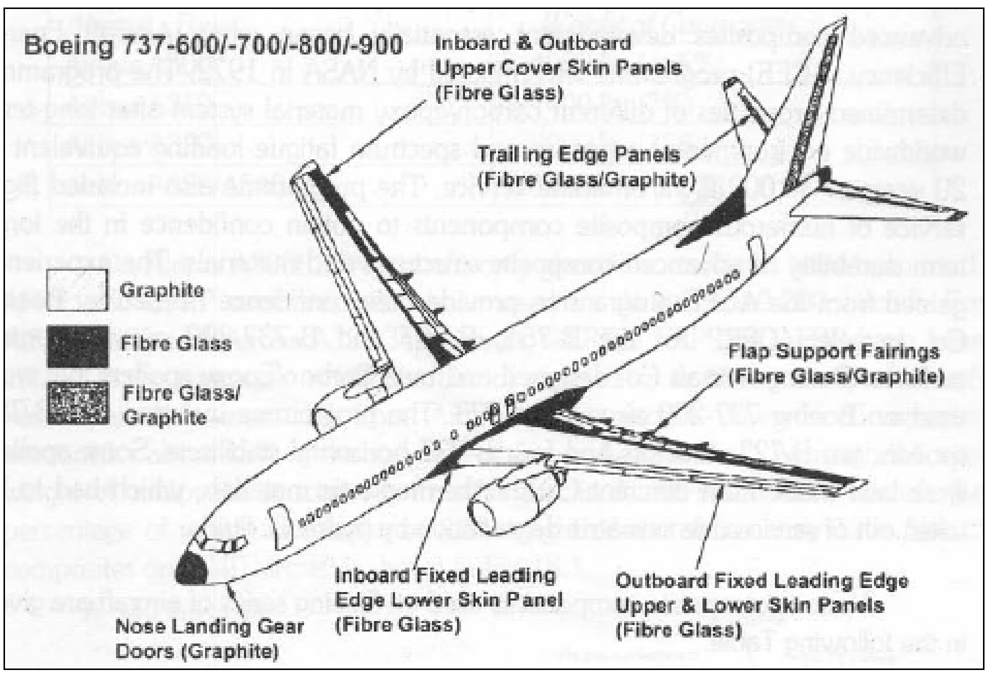


**Figure M11.4** Composite used for different part of B- 737 aircraft

Total weight of composites used on different aircraft of Boeing series is as shown in Table M11.5:

| Aircraft Type | Weight of Composites |
|---|---|
| Boeing 737 - 200 | ≈100 lb. Spoiler (1973)<br>≈1150 lb. Horizontal Stabilizer |

| | |
|---|---|
| | (1984)<1% |
| Boeing 737 - 300 | $\approx$1150 lb. (3%) |
| Boeing 737 - 400 | $\approx$1150 lb. (3%) |
| Boeing 757 | $\approx$3400 lb. (3%) |
| Boeing 767 | $\approx$3400 lb. (3%) |
| Boeing 777 | $\approx$33000 lb. (10%) |

**Table M11.5:** Weight of composites used in the different Boeing series

CFRP is used for aileron, elevator, rudder, fairing and engine cowl doors of Boeing 737-300 aircraft. For both Boeing 757 and Boeing 767 aircraft, CFRP composite has been used for elevator, rudders, spoilers, landing gear doors and engine cowlings. The flaps of Boeing 757 aircraft are also made of CFRP. Most of the Boeing 757 and 767 fairings and fixed panels were originally aramid/epoxy or aramid/carbon/ epoxy hybrid-honeycomb sandwich construction. Because of surface and matrix cracking, much of the aramid/epoxy was replaced with glass/epoxy, to improve surface protection. In case of newly manufactured Boeing 777 aircraft, out of 33000 lb. of composite used, about 10000 lb. is CFRP which includes entire tail, control surfaces, floor beams, main landing gear doors and engine nacelles. The stabilizers have laminated skins with co-cured stringers, solid laminate spars, simple honeycomb sandwich ribs and non-structural forward torque box. They are designed for simple repair. At the moment, Boeing Airplane Co. does not appear to be considering a more extensive use of composites on commercial aircraft. Boeing 777 aircraft, for example, does not use a higher proportion of composites than Airbus A- 320 aircraft. The composite structure on B- 777 and A-320 aircraft is shown in Figure M11.5 and 11.6 respectively.

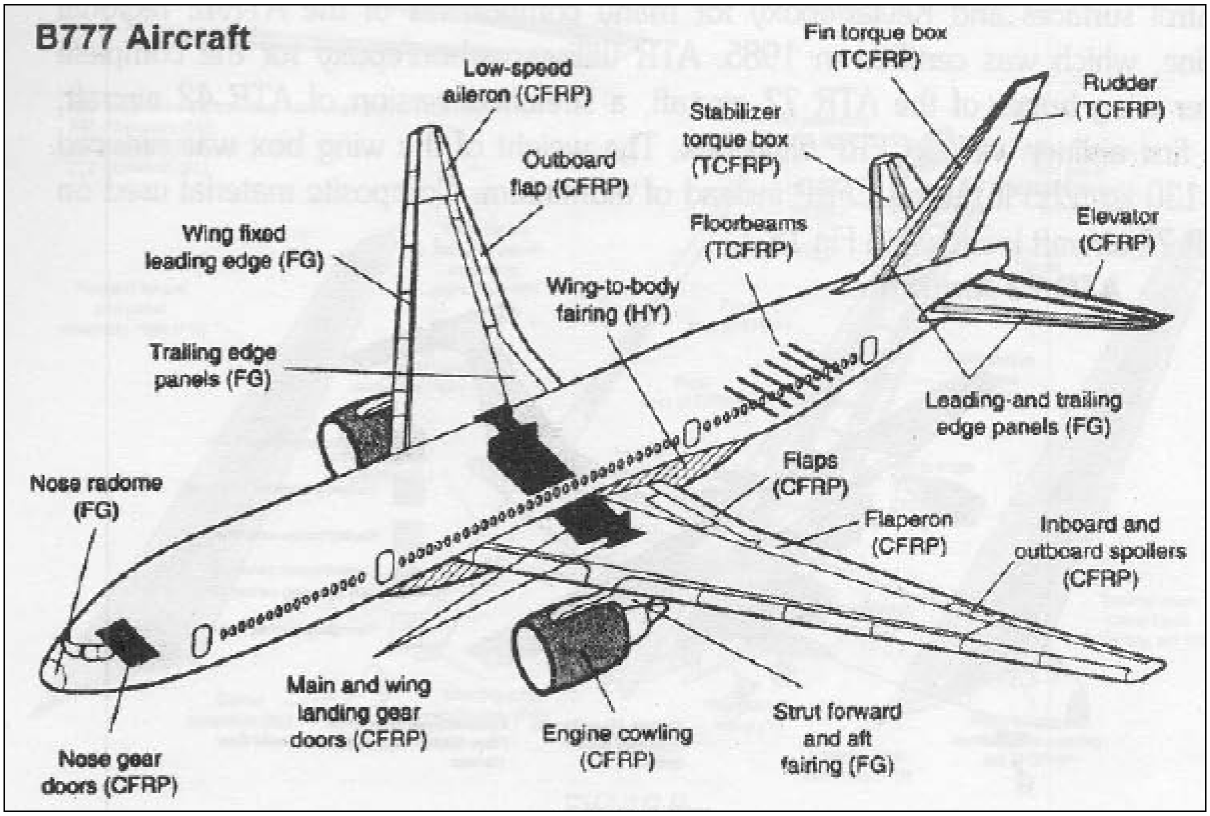


**Figure M11.5 Composite used for different part of B- 777 aircraft**

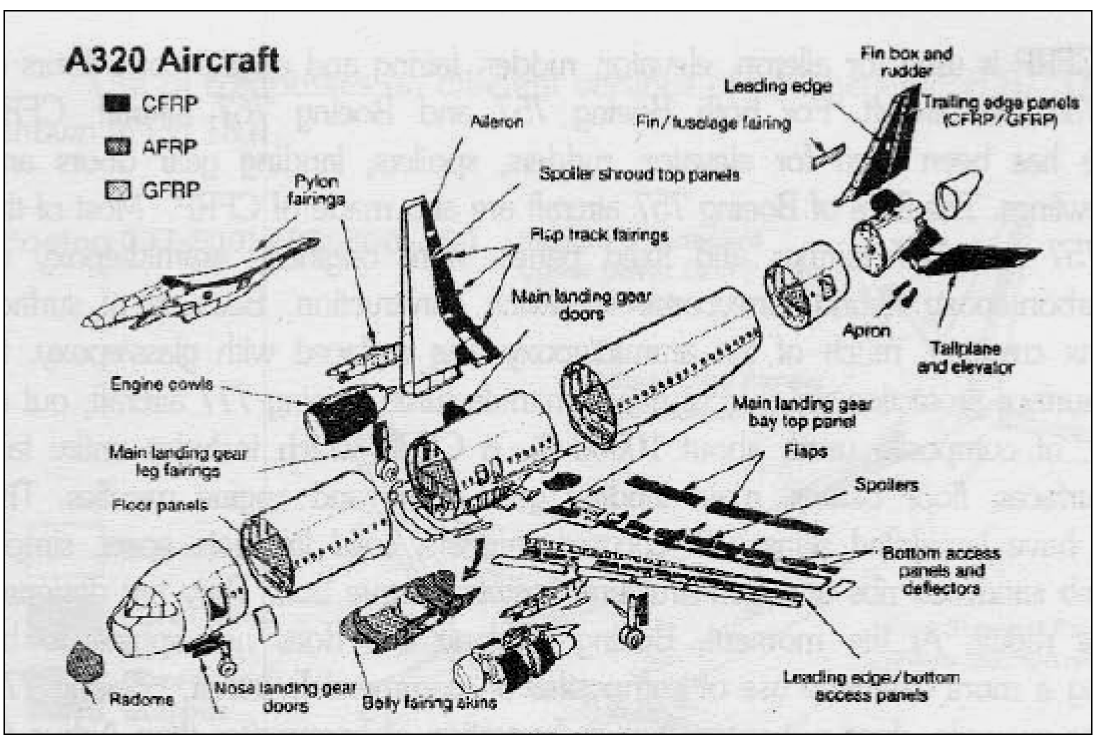


**Figure M11.6 Composite used for different part of A-320 aircraft**

Avions de Transportation Regionale (ATR) uses carbon/epoxy for all the control surfaces and Kevlar/epoxy for many components of the ATR42 regional airline which was certified in 1985. ATR utilizes carbon/epoxy for the complete outer wing boxes of the A TR 72 aircraft, a etched version of A TR 42 aircraft, the first airliner with a CFRP wing box. The weight of the wing box was reduced by 130 kg (286 lb) using CFRP instead of aluminium. Composite material used on ATR-72 aircraft is shown in Figure M11.7.

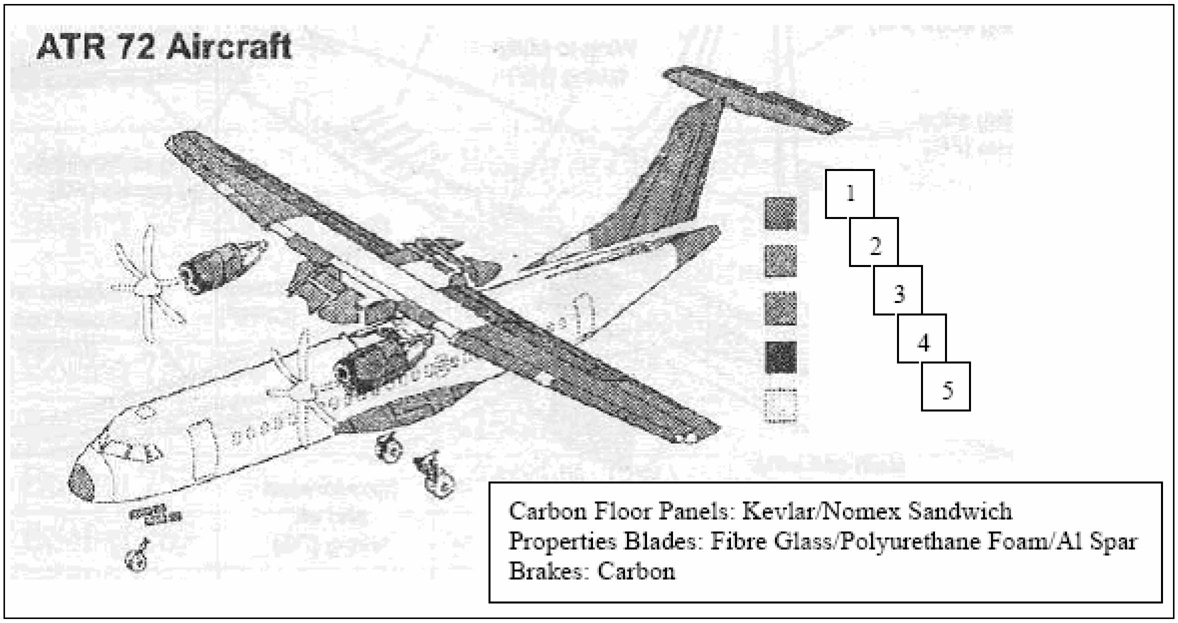


**Figure M11.7** Composite used for different part of ATR-72 aircraft

In Figure M11.7, numbers indicates that,

| Numbers | Indication meaning |
|---|---|
| 1 | Carbon/Nomex sandwich |
| 2 | Carbon monolithic structure |
| 3 | Kevtar/Nomex sandwich |
| 4 | Kevtar/Nomex sandwich with stiffening carbon plies |
| 5 | Fibre-glass/Nomex sandwich |

### M11.2.1.1.2 Military Aircraft Applications

Most military aircraft applications use carbon fibre reinforced epoxy composites. About 26% of the structural weight of AV-8B aircraft of carbon fibre reinforced composite comprises the wing box, forward fuselage, horizontal stabilizer, elevators, rudder and other control surfaces. Various composite components used on different military aircraft are given in the Table M11.6.

| Aircraft Type | Components Made of Composite Materials |
|---|---|
| F-14 | Doors, horizontal tail and fairings |
| F-15 | Rudder, vertical tail, horizontal tail and speed brake |
| F-16 | Vertical tail and horizontal tail |
| F-18 | Doors, vertical tail, horizontal tail, wing box, fairings and speed brake |
| B-1 | Doors, vertical tail, horizontal tail, flaps and slats |
| AV-8B | Doors, rudder, vertical tail, horizontal tail, aileron, flaps, wing box, body and fairings |
| Typhoon | Wing, fin, rudder, in-board aileron and fuselage |
| Light Combat Aircraft (LCA) | Wing, fin, rudder, control surfaces, radome. |

**Table M11.6:** The composite components used on different military aircraft

On the F-18 aircraft, carbon fibre reinforced composites made up approximately 10% of the structural weight and more than 50% of the surface area (Figure M11.9).

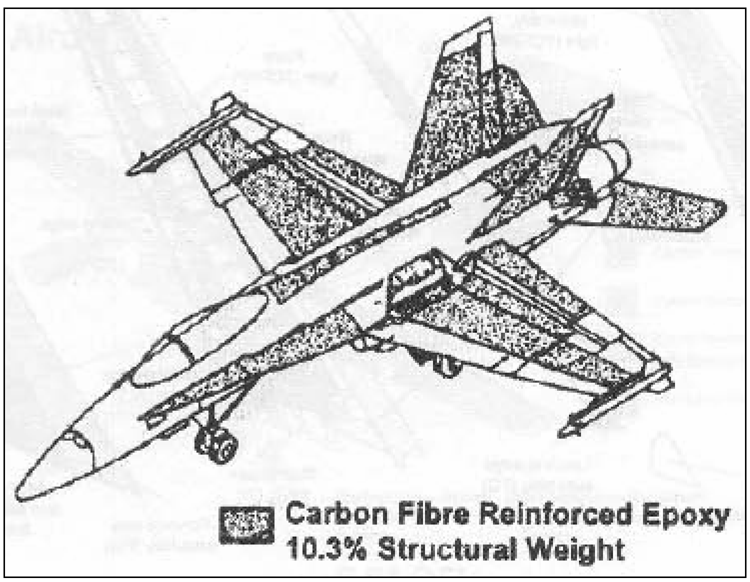


**Figure M11.9** F-18 aircraft

Similarly, on the Typhoon aircraft, carbon fibre reinforced composites make up approximately 30% of the structural weight and more than 70% of the surface area (Figure M11.10).

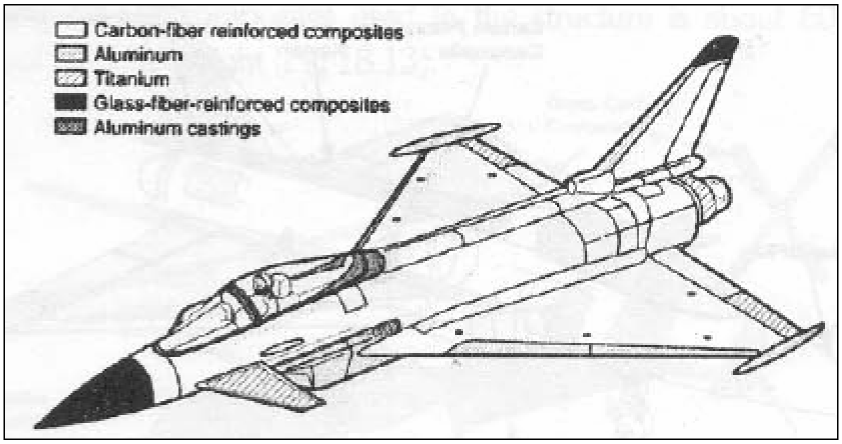


**Figure M11.10** Typhoon aircraft

The skins of the Typhoon's wing are made of solid laminate, which are shown in Figure M11.11.

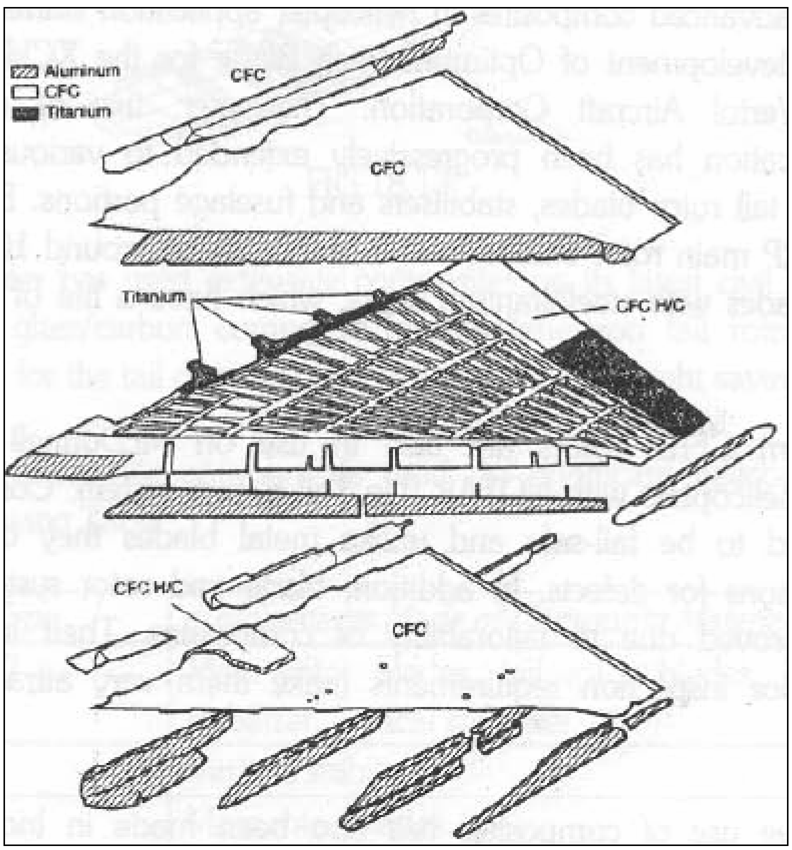


**Figure M11.11** Skins of the Typhoon's wing are made of solid laminate

On the LCA aircraft, more than 40% of the structural weight of the aircraft is built in advanced composite materials. Entire wing, vertical tail and control surfaces are made of carbon fibre composites (Figure M11.12).

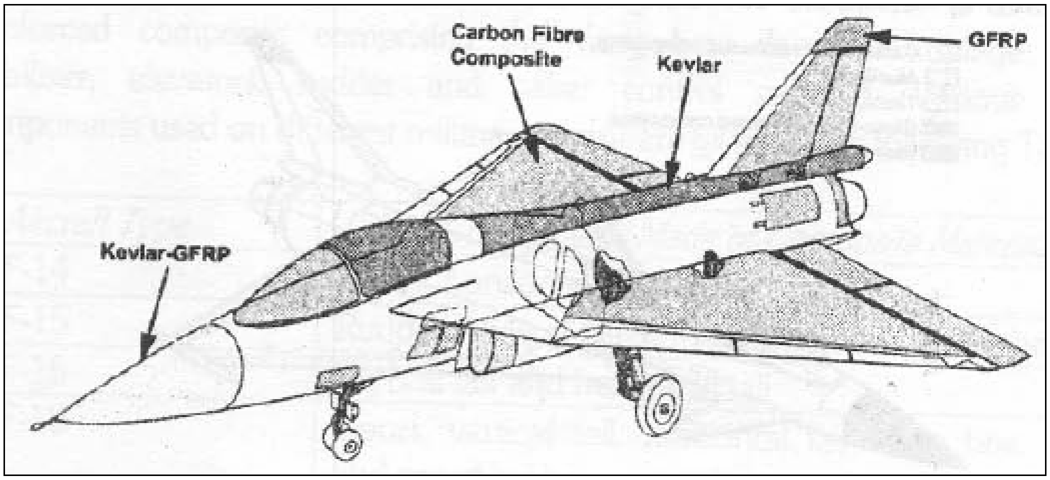


**Figure M11.12** Entire wing, vertical tail and control surfaces are made of carbon fibre composites

### M11.2.1.1.3 General Aviation Applications

Composite materials are being used for different helicopter components as well. Use of advanced composites in helicopter application started way back in 1959 with the development of Optimum Pitch Blade for the XCH-47 twin rotor helicopter of Vertol Aircraft Corporation. There-after, use of composites in helicopter application has been progressively extended to various parts, which include main & tail rotor blades, stabilizers and fuselage portions. Experience has shown that GFRP main rotor blades have a service life of around 10,000 hours as compared to blades with steel/titanium spars, which have a life of around 1000- 2000 hours.

Flex-beam CFRP rotors are also in use on McDonnell Douglas MD 520N/MD 900 helicopters with NOTAH (No Tail Rotor) system. Composite blades can be designed to be fail-safe and unlike metal blades they do not require frequent inspections for defects. In addition, blade and rotor system efficiencies have been improved due to tailorability of composites. Their longer life and reduced in-service inspection requirements make them very attractive and cost effective.

Extensive use of composites has also been made in India's Advanced Light Helicopter (ALH). In ALH composite material is employed in whole of the secondary structure and several parts of the primary structure. The nose is made of aramid and tail section of carbon fibre reinforced plastic. Rotor hub, main and tail rotor blades are made of composites. Entire cockpit is also made of composite material. The extent of composites used in the structure is about 60% by wetted area and about 29% by weight (Figure M11.13).

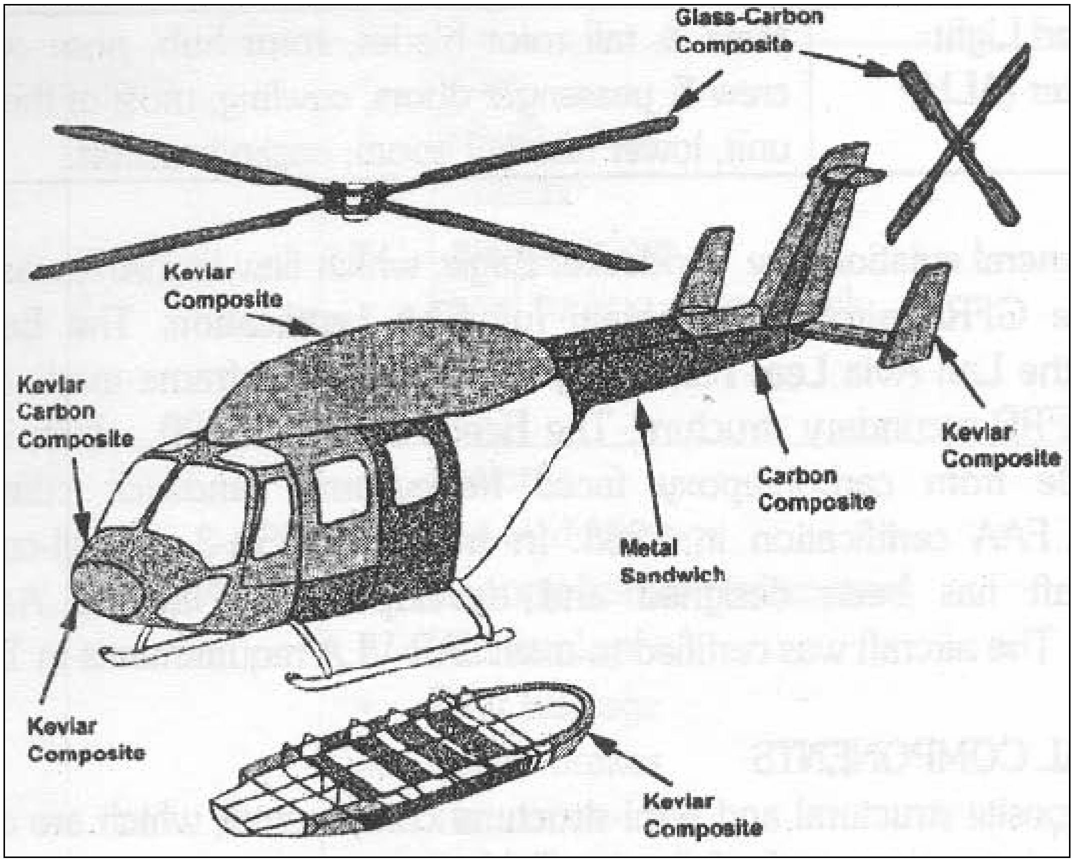


**Figure M11.13** The Cockpit is also made of composite material

Eurocopter has used extensive composites on its latest civil helicopter, the EC 135. Using glass/carbon composite for the fenestron tail rotor shroud and carbon sandwich for the tail cone has yielded appreciable weight savings.

Various composite components used on significant helicopter types are given in the Table M11.7.

| **Helicopter Type** | **Components Made of Composite Materials** |
|---|---|
| MBB BK 117 | Main rotor blades, tail rotor blades, horizontal stabilizer, vertical stabilizer. |
| Bell 206L | Vertical stabilizer. |
| Bell 402 | Main rotor blades |
| Dauphin | Main rotor blades, vertical stabilizer. |
| McDonnell Douglas MD 520N | Main rotor blades, tail boom. |
| McDonnell Douglas MD 900 | Main rotor blades, fuselage mid section, tail boom, canopy frame, internal fuselage, horizontal stabilizer, vertical stabilizer. |
| Advanced Light Helicopter (ALH) | Main & tail rotor blades, rotor hub, nose cone, crew & passenger doors, cowling, most of the tail unit, lower rear tail boom, cock it section. |

**Table M11.7:** The composite components used on significant helicopter types

In general aviation, the Windecker Eagle, which flew in 1967, was the first all composite GFRP airplane to obtain full FAA certification. The Eagle was followed by the Lan Avia Lear Fan 2100, which had an airframe made of CFRP with some AFRP secondary structure. The Beech Starship 2000, which is almost entirely made from carbon/epoxy faced honeycomb sandwich construction, received full FM certification in 1988. In India, HANSA-3, an all-composite trainer aircraft has been designed and developed by National Aerospace Laboratories. The aircraft was certified to meet JAR-VLA requirements in 1999.

**Structural components**

Composite structural and semi-structural components, which are currently being produced, are given in the Table M11.8.

| Component | Details |
|---|---|
| Wing | • Box beam skins<br>• Box beam sub-structure<br>• Winglets<br>• Leading edge flaps/slats<br>• Ailerons/flaperons<br>• Raps & Spoilers<br>• Fixed leading edges<br>• Fixed trailing edge panels<br>• Rap track fairings<br>• Actuator fairings |
| Empennage | • Horizontal stabilizers<br>• Skins<br>• Sub-structure<br>• Elevators<br>• Leading edges<br>• Fixed trailing edge panels<br>• Tips |
| Vertical Stabilizers | • Skins<br>• Sub-structure<br>• Rudders<br>• Leading edges<br>• Fixed trailing edge panels<br>• Ventral fins<br>• Tips |
| Fuselage | • Radome<br>• Forward fuselage<br>• Canopy frames (helicopters)<br>• Mid fuselage |

| | |
|---|---|
| | • Rear fuselage<br>• Speed brakes<br>• Tail cone<br>• Floor beams<br>• Floors<br>• Rotor-domes<br>• Cabin doors (helicopters)<br>• Lining and partitions<br>• Overhead baggage compartment<br>• Air ducts |
| Helicopter | • Main rotor blades<br>• Tail rotor blades<br>• Rotor drive shafts |
| Doors and Fairings | • Landing gear doors<br>• Landing gear fairings<br>• Landing gear pods<br>• Wing-fuselage fairings<br>• Stabilizer fairings<br>• Equipment access doors |
| Propulsion System | • Engine fan blades<br>• Engine casing<br>• Nozzle flaps<br>• Thrust reversers<br>• Engine nacelle and cowling<br>• Fan cowls<br>• Turbine blade containment rings<br>• Pylon fairings<br>• Fuel tanks<br>• Propeller blades |

**Table M11.8:** Composite structural and semi-structural components

## Note: Italic font information is advanced/additional information.

### *M11.2.2 Additional Informations*

#### *M11.2.2.1 Design Principles*

*The general structural design and certification requirements apply to both composites and metal aircraft structures. However, there are variations associated with the intrinsic differences between the structural behaviour of metals and composites. Although the design requirements are applicable to both metal and composite structures, certification of composite structures is more extensive and requires many more tests. The manufacturer must fabricate and test* *thousands of specimens and hundreds of sub-components to qualify a single new carbon/epoxy system and associated structural details.*

*The design principles for all the above aircraft applications of composite materials are broadly described below:*

a) *The composite primary structures are designed to withstand ultimate loads in all environmental conditions throughout the operating life of the aircraft and are tested, accordingly, on a full-scale test component.*
b) *Repairs of the composites are tested together with the certification component to prove that:*
    i. *The structure withstands ultimate load after the repair.*
    ii. *The repair fulfils the damage tolerance principles.*
c) *No aramid is used on loaded structure because although these fibres do possess high tensile strength, they have very low compressive strength.*
d) *Variation of stiffness with age is measured on a full-scale test component. " e) One component is used for both static and fatigue test.*
e) *Carbon fibre reinforced plastics are used on loaded structures with layers of glass fibre reinforced plastics to act as:*
    i. *Bridging layer between honeycomb and skin,*
    ii. *Galvanic corrosion protection, and*
    iii. *Dielectric coating in lightning strike zone.*
f) *Lightning strike protection is assured by aluminium straps bolted all around the carbon fibre reinforced parts.*
g) *Aluminium and titanium trailing edges are applied to all carbon fibre reinforced surfaces.*
    i. *Primary structures are of monolithic design.*

***Salient In-Service Defects Experienced On Composite Parts of Aircraft***

*Some of the salient in-service defects experienced on composite parts of aircraft are given in the Table M11.9 By and large these defects are due to delamination, debonding, erosion, galvanic corrosion, damage to honeycomb, and in-service impact damages like bird hit, foreign object damage, etc.*

| ***Component*** | ***Construction*** | ***Defect*** |
|---|---|---|
| *Belly fairing* | *Aramid fibre sandwich construction* | *Debonding due to soaking of Skydrol, oil and moisture.* |
| *Radome* | *Aramid fibre sandwich construction* | *Debonding of inner/outer skin due to aerodynamic loads and moisture. Damage to honeycomb.* |
| *Air inlet cowl* | *Inner barrel of carbon fibre reinforced sandwich construction covered with stainless steel wire mesh acoustic lining.* | *Wire mesh debonding, inner surface carbon fibre delamination. Damage to honeycomb.* |

| | | |
|---|---|---|
| *Trailing edge flap fairings (rear of engine)* | *Aramid fibre sandwich construction.* | *Debonding due to heat effect as it is located in the exhaust area.* |
| *Air conditioning duct* | *Glass fibre reinforced composite.* | *Cracks and debonding.* |
| *Air inlet cowl aft bulkhead* | *Carbon fibre reinforced sandwich construction.* | *Debonding due to heat effect and vibrations.* |
| *Horizontal stabilizer leading edge* | *Carbon fibre reinforced composite* | *Leading edge erosion. Erosion is arrested by bonding stainless steel cap to the leading edge.* |
| *Passenger cabin floor boards* | *Glass fibre reinforced sandwich construction.* | *Crushing and debonding.* |
| *Fin leading edge* | *Carbon fibre reinforced composite.* | *Leading edge erosion. This is taken care by filling the affected area with epoxy and covering the leading edge with anti- erosive tape.* |
| *Engine thrust reverse* | *Carbon fibre reinforced sandwich construction.* | *Debonding of upper skin translating sleeve near double latch area due to excess load and heat effect.* |
| *Engine thrust reverser fixed structure (C-Duct)* | *Aluminium face sheet bonded to aluminium honeycomb core.* | *Galvanic corrosion, debonding, heat damage.* |

***Table M11.9:*** *In-service defects experienced on composite parts of aircraft*

## *M11.2.1.2 Typical Case History of In-Service Repair in Aircraft Industry*

### *M11.2.1.2.1 Repair of Air Intake Cowl Inner Barrel Acoustic Panel of a Turbofan Engine*

***Construction***

*Inner barrel acoustic panel is a sandwich construction. It consists of acoustically treated carbon fibre/Nomex honeycomb core, which is bolted to the engine fan casing front flange. The face material is stainless steel wire mesh bonded to a layer of CFRP. The honeycomb core is bonded to a layer of GFRP. General construction of air intake cowl and sectional view of inner barrel acoustic panel is shown in Figure M11.14.*

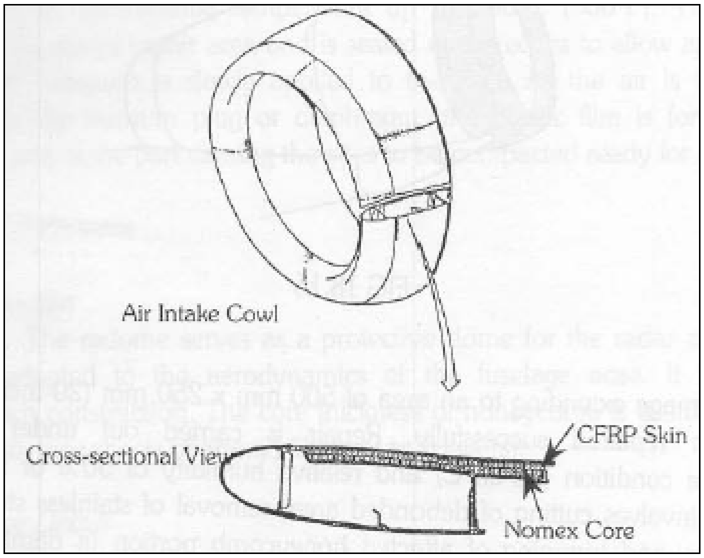


***Figure M11.14*** *Sectional view of inner barrel acoustic panel*

***Damage Details***

*Several cases of debonding of stainless steel wire mesh and CFRP layer have been observed in the recent past. Location of the damage is shown in Figure11.15.*

*In a few cases, damage was observed in honeycomb core too. The above phenomenon has been experienced due to one of the following factors:*

1. *Manufacturing defects attributed to material failure.*
2. *Foreign Object Damage (FOD) or due to bird hit.*
3. *Relatively small damage due to FOD that remained undetected at initial stage and progressively increased resulting into moisture ingress, etc.*

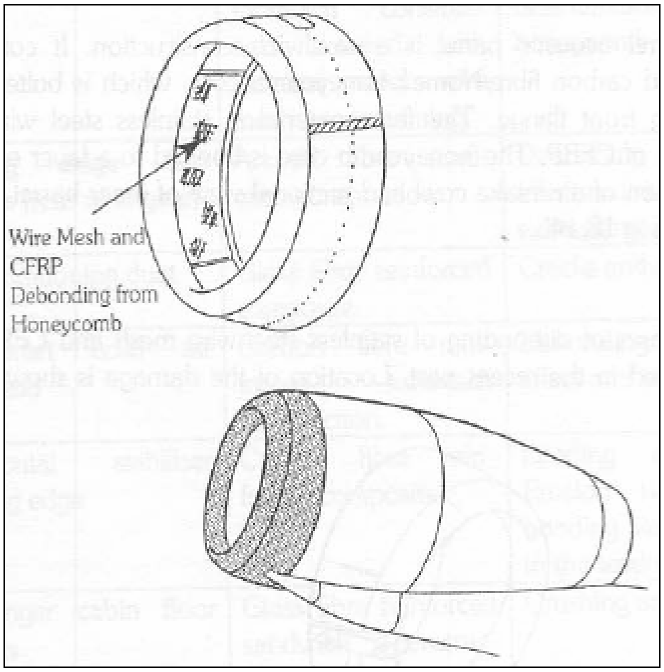

***Figure M11.15*** *Location of the damage*

***Repair***

*Damage extending to an area of 500 mm x 250 mm (20 inch xl0 inch) has been repaired successfully. Repair is carried out under controlled temperature condition (20-25°C) and relative humidity of 50% or less. Repair procedure involves cutting of debonded area, removal of stainless steel mesh & CFRP layer, and trimming of affected honeycomb portion (if damaged). After removing the damaged portion, the affected area is thoroughly cleaned with Methyl Ethyl Ketone and dried, before proceeding with repair, by using heat lamp to keep the temperature at the repair area around 80°C (176°F) for approximately 6 hours. If the damage to honeycomb core is confined to small area, the portion from where the damaged honeycomb core is removed is filled with low density filler material followed by surface smoothening. On the other hand, if the damage to honeycomb core involves relatively large area, the honeycomb core is replaced. Wet lay up procedure is adopted. A layer of CFRP is laid with an overlap of about 2S mm (1 inch) on either side of the damaged portion and fibre direction so oriented as to achieve the strength of the repair equal to that of original value.*

*Final curing is done by vacuum bagging at 93°C (200°F) with a soak time of 3 hours. Vacuum bagging procedure used to cure the repair consists of placing a Teflon sheet over the CFRP ply, which acts as a separator. It allows volatiles and air to escape from the lay-up and excess resin to be bled from the lay-up into the bleeder ply during cure. It will also give the cured part a smooth surface finish. Glass fibre bleeder cloth is placed over the Teflon sheet to absorb excess resin content during cure. Heat blankets are placed over the bleeder cloth followed by breather cloth. It allows uniform application of vacuum pressure over the lay-up and removal of entrapped air or volatiles during cure. The repair area is covered with a heat resistant vacuum bag. The vacuum bag is actually a plastic film capable of withstanding temperature up to 260°C (SOO°F). The vacuum bag covers the entire repair area and is sealed at the edges to allow* *application of full vacuum. Vacuum is slowly applied to the part. As the air is withdrawn from beneath the vacuum plug or diaphragm, the plastic film is forced against the repair area of the part causing the plies to be compacted ready for curing.*

***M11.2.1.2.2 Repair of Radome***

***Construction***

*The radome serves as a protective dome for the radar antenna and has been adapted to the aerodynamics of the fuselage nose. It is of laminated sandwich construction. The core thickness of honeycomb is usually between 8-10 mm with face sheets of aramid fibres (3 to Slayers).*

***Damage Details***

*The main in-service defect experienced in the industry on radome is delamination of inner/outer skin, which has been mainly attributed to:*

i. *Varying aerodynamic loads,*
ii. *Moisture ingress,*
iii. *FOD like bird hit,*
iv. *Local black marks due to lightning strike, etc.*

***Repair***

*For delamination up to a diameter of about 500 mm (20 inch), repair is carried out using either hot molding repair (prepreg material) or wet lay-up (dry fabric). For damage of lesser dimensions, repair is done by resin injection method. However, for damage to comparatively large area, up to diameter 500 mm, repair is carried out by replacing the damaged composite material. Before selecting the type of repair, damage assessment is made zone-wise to have a fair idea as to the extent of damage. Such a damage assessment on one of the radomes, belonging to a large commercial transport aircraft is given in Figure M11.16.*

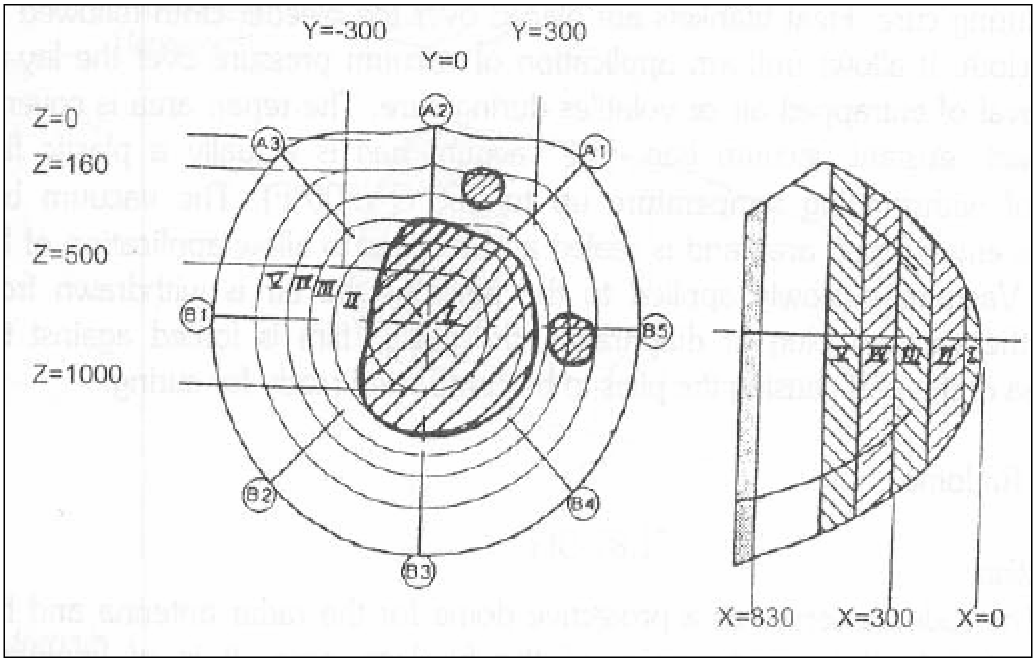


***Figure M11.16***

| X | Y | Z | Surface Area (mm) |
|---|---|---|---|
| 500 | 150 | 160 | ϕ120 |
| 0 | 0 | 750 | 1000 x 600 |
| 400 | 400 | 800 | ϕ 120 |

*Repair procedure of replacing the damaged composite material is exactly similar to what has been explained in the preceding para. As explained above, repair of minor/medium delamination is done by resin injection method. This is marking done by firstly marking a circle having diameter about 20 mm greater than the area. Holes of 3 mm diameter are drilled over the entire area within the marked circle, at a constant pitch of 7 mm, up to the honeycomb cells. After cleaning the holes, they are filled with resin until it overflows. The resin is then left to cure at room temperature for one hour. The excess resin is then the surface is cleaned. Thereafter, sufficient number of coats of is applied.*

***M11.2.1.2.3 Repair of Engine Reverser Translating Sleeve***

***Construction***

*Engine thrust reverser translating sleeve is a sandwich construction. The honeycomb core is of Titanium. The face sheet on outer surface is of CFRP, and on inner surface is of CFRP and stainless steel wire mesh for noise suppression. Thrust reverser translating sleeve structure is shown in Figure M11.17.*

***Damage Details***

*Delamination/debonding of upper CFRP skin is experienced near the double latch area, which is attributed to:*

1. *Extra load in the double latch area;*
2. *Hot zone due to presence of Air Cooled Air Cooler (ACAC) exhaust.*

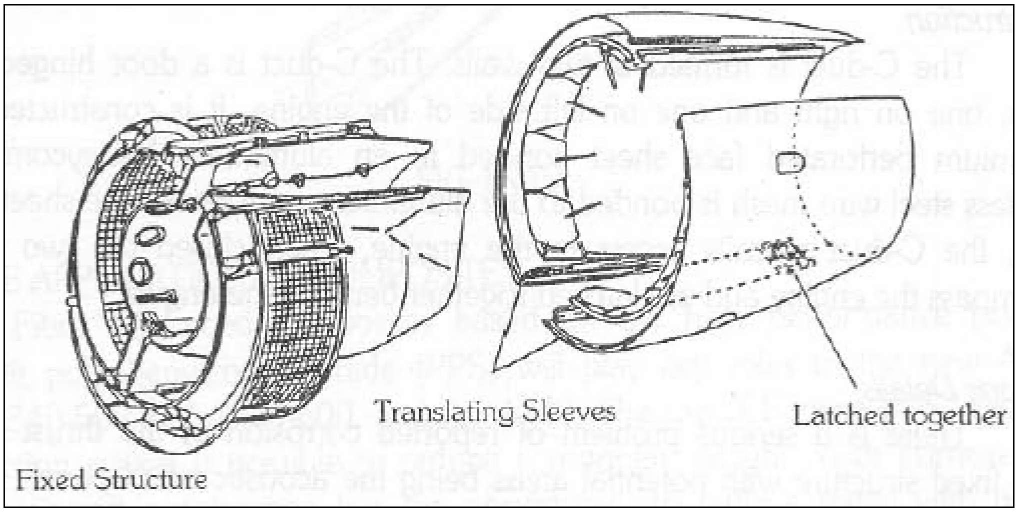


***Figure M11.17*** *Thrust reverser translating sleeve structure*

*Location of the damage experienced in the translating sleeve is shown in Figure M11.18.*

***Repair***

*Damage to the extent of 250 mm x 250 mm (10 inch x 10 inch) has been successfully repaired. Repair procedure for replacing the damaged composite material is exactly similar to what has been explained in the preceding para.*

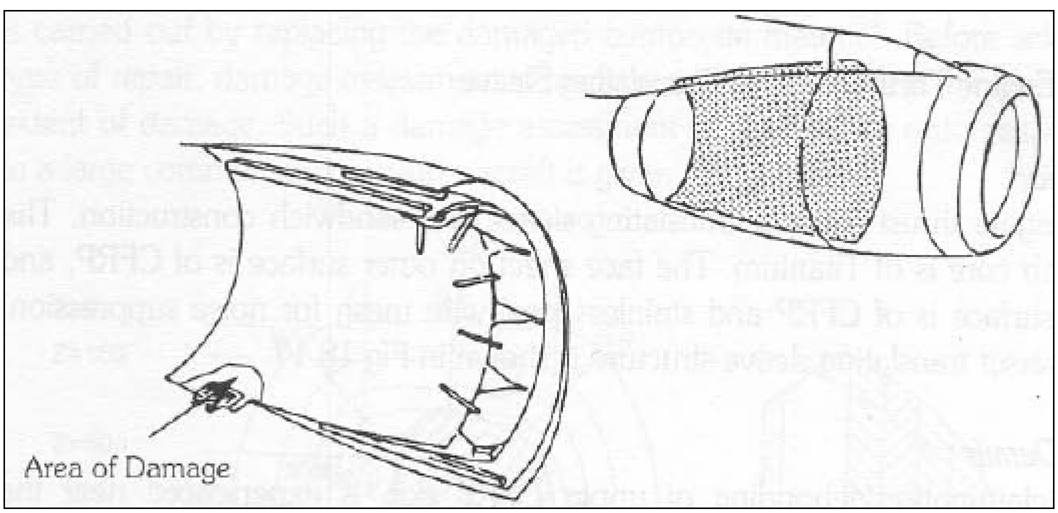


***Figure M11.18*** *Location of the damage experienced in the translating sleeve*

***M11.2.1.2.4 Repair of Engine Thrust Reverser Fixed Structure (C-Duct)***

*Construction*

*The C-duct is formed of two walls. The C-duct is a door hinged to the pylon, one on right and one on left side of the engine. It is constructed of an aluminium perforated face sheet bonded to an aluminium honeycomb core. Stainless steel wire mesh is bonded to the aluminium perforated face sheet. When open, the C-duct permits access to the engine, when closed the two C-ducts encompass the engine and are latched together beneath the engine.*

*Damage Details*

*There is a serious problem of reported corrosion of the thrust reverser inner fixed structure with potential areas being the acoustic bond panels and the lower bifurcation panels. Whereas galvanic corrosion has been experienced between aluminium perforated skin and the stainless steel wire mesh, and exfoliation corrosion has been experienced in the lower bifurcation panels. Location of damage experienced in the C-duct is shown in Figure M11.19.*

*Repair*

*Bond panels and skins of thrust reverser inner fixed structures have been replaced to address the problem of extensive corrosion. The problem of galvanic corrosion has been resolved by complete removal of stainless steel wire mesh.*

*An alternate solution to deal with the problem of galvanic corrosion is the use of micro porous polyurethane film, which can replace the stainless steel wire mesh and at the same time will meet the acoustic requirements also.*

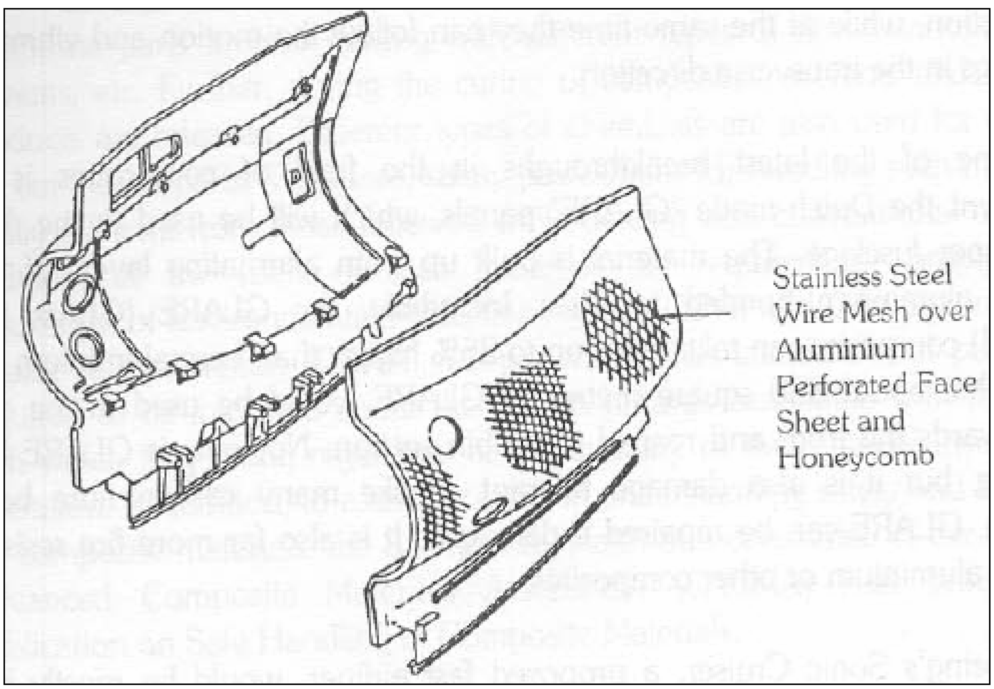


***Figure M11.19** Location of damage experienced in the C-duct*

## M11.2.2 Composites for Structural Applications

Composites have long been used in the construction industry. Applications range from non-structural gratings and claddings to full structural systems for industrial supports, buildings, long span roof structures, tanks, bridge components and complete bridge systems. Their benefits of corrosion resistance and low weight have proven attractive in many low stress applications. An extension to the use of high performance FRP in primary structural applications, however, has been slower to gain acceptance although there is much development activity. Composites present immense opportunities to play increasing role as an alternate material to replace timber, steel, aluminium and concrete in buildings.

**Construction**

Construction holds priority for the adaptation of composites in place of conventional materials being used like doors and windows, paneling, furniture, non-structural gratings, long span roof structures, tanks, bridge components and complete bridge systems and other interiors. Components made of composite materials find extensive applications in shuttering supports, special architectural structures imparting aesthetic appearance, large signages etc. with the advantages like corrosion resistance, longer life, low maintenance, ease in workability, fire retardancy etc. Some of the composite structural applications are listed in the Table M11.10

| Composite | Applications |
|---|---|
| Coconut/jute/sisal fibre and gypsum plaster | Boards for partitions, ceiling and wall panel |
| Coconut/jute/sisal fibre and glass fibre with gypsum plaster | Solid and perforated building blocks |
| Poplar wood with polymer | Door shutters, doors and window frames |
| Vegetable fibre/red mud and polyester | Flat and corrugated roofing sheets, shutters and tiles |
| Jute fibre polyester/epoxy with red mud | Panels and sheets, wall cladding, partitions and door shutters |
| Bagasse & UF/PF resin | Panels and blocks |
| Coir fibre with fly ash & lime or cement | Bricks & blocks for walling |
| Glass fibre reinforced polyester | Roofing sheets, partitions, ceilings, sanitary ware, water storage tanks, pipes etc. |
| Glass fibre reinforced PP/nylon | Door hinges |
| Red mud plastic (PVC, polyester) reinforced with sisal fibre | Paneling, roofing, partitions, door panels |
| Acrylic resin and quartz sand composite | Kitchen sinks |

**Table M11.10: Composite Applications in Building & Construction**

Usage of composites for damage repairing, seismic retrofitting and upgrading of concrete bridges finds increased adoption as a way to extend the service life of existing structures, they are also being considered as an economic solution for new bridge structures.

Composite based 2D and 3D grid-type reinforcement for concrete structures shows considerable potential for use as reinforcement of concrete in tunnels because of its corrosion and chemical resistance, its lightweight and its ease of forming to fit curvatures. Grid-type reinforcement for concrete structures consists of high-performance fibres such as glass, carbon, aramid and hybrids impregnated with resin systems ranging from vinyl esters and other thermosetting resin systems to thermoplastics. The significant systems-level savings were achieved due to the factors of weight.

Other critical applications of composites in the civil engineering area are:

- Tunnel supports
- Supports for storage containers
- Airport facilities such as runways and aprons
- Roads and bridge structures
- Marine and offshore structures
- Concrete slabs
- Power plant facilities
- Architectural features and structures such as exterior walls, handrails, etc.

The key restricting factors in the application of composites are initial costs due to raw materials and also inefficient moulding processes. With the adoption of advanced technologies and some extent of standardization, these problems could be easily taken care of. A growth rate of 11-13% p.a. in the usage of composites is expected after 2005 AD in this sector.

### M11.2.2.1 Road Bridges

Bridges account for a major sector of the construction industry and have attracted strong interest for the utilization of high performance FRP. FRP has been found quite suitable for repair, seismic retrofitting and upgrading of concrete bridges as a way to extend the service life of existing structures. FRP is also being considered as an economic solution for new bridge structures. Polymer composites are seen to offer advantages that are lacking in the traditional materials, particularly for their resistance to corrosive attack in those areas that rely on the application of de-icing salts to maintain road access. Design approaches and manufacturing efficiencies developed for road bridge applications will benefit their introduction into a broader range of civil construction fields.

Decks for both pedestrian and vehicle bridges across waterways, railways and roadways are now a commercial reality; with some pedestrian bridges being built entirely from composites. The lightweight of composites is especially valuable for the construction of waterway bridges incorporating a lift-up section to permit the passage of boats, and for ease of transportation and erection in remote areas without access to heavy lifting equipment. The composite deck has six to seven times the load capacity of a reinforced concrete deck with only 20 percent of the weight.

Because of the superior durability of composite, only cosmetic maintenance requirements are expected for at least 50 years. The composite will not spall like concrete during freeze-thaw cycles and will not rust like metal in the moist, corrosive sea environment. The composite bridge decks are quite suitable for replacing conventional/old bridge decks having super structure intact. The replacement can be carried out in a short time with minimal disturbance to the traffic.

The ability to use composites to design a lightweight, prefabricated module brings about immediate cost savings by minimizing the disruption of traffic and commerce. The lightweight composite module can be installed in a matter of hours instead of the days or weeks it takes to replace a deteriorated bridge deck with a conventional one. The high strength-to-weight ratio of the composite deck reduces the costs associated with heavy equipment. Lower deck weight also offers the potential for a higher load rating. Composites can significantly reduce maintenance and replacement costs because of the material's excellent resistance to corrosion and fatigue. In essence, composite durability not only improves life-cycle costs but extends the life-cycle itself.

The bridge deck sections, composed of hexagon and double-trapezoid profiles are bonded with a high-strength adhesive under controlled conditions. The prefabricated sections are then transported to the job site, ready for installation. Composite bridge decks replace deteriorated concrete or timber bridge decks and their lighter weight permits easier & quicker installation.

FRP composite bridge decks are made of pultruded components that are bonded and interlocked. They are placed transversely to the traffic and are supported by longitudinal beams. The FRP decks comprise of double trapezoid composite connected with full depth hexagons that provide mechanical interlock and an extensive bonding surface. Construction of highway bridges with modular FRP decks requires the understanding of the deck performance under traffic loads.

Traffic loads induce repetitive stress cycles on bridge decks during the service life of the structure. The composite bridge decks are modular in design and can be produced in continuous lengths because of the inherent process adopted (pultrusion technique) and these lengths can be cut to size depending on the user’s requirement. Hence, it furnishes greater flexibility in fabrication of the composite bridge decks to suit various product dimensions.

The first FRP modular bridge decks in USA were installed in rural roads in West Virginia. Composite bridge decks performed satisfactorily for 2 million cycle loads without major fatigue. In addition to the deck, the Laurel Lick installation uses composite, stringers, piling and short-column abutments. The decks exhibited a safe failure mode with considerable energy absorption and adequate post failure reserve strength. The installations in West Virginia demonstrate how the performance characteristics of fiber-reinforced polymer (FRP) composites are ideally suited for highway bridge construction. This has been a significant step in the development of modular bridge decks made with standardized "off-the-shelf" components.

The Fiber-line Bridge, **Kolding**, Denmark was designed by the Danish engineering Company, Ramboll using the pultruded profiles. The 40-m (131-ft.) long, 3-m (9.8-ft.) wide crossing carries pedestrians, bicycles and motorbikes over a previously dangerous set of railroad tracks. As the bridge was designed to support a 500 $kg/m^2$ (102 $lb./ft.^2$) load, the structure can also Composite Bridge Decks accommodate snow removal vehicles weighing up to 5 MT. This impressive strength is provided by a composite deck that weighs only 12 MT. In steel and concrete, a bridge deck of comparable strength would weigh 28 MT and 90 MT respectively. The bridge is suspended from a high support tower (18.5-m (61-ft.)) that is bolted to a concrete foundation. The composite tower weighs only 3 MT. Fiber-line Composites used its pultruded profiles to pre-fabricate the tower and three bridge sections for final assembly at the bridge site. The lightweight composite allowed the bridge to be easily erected in only 18 night-time hours, thus minimizing disruption to rail traffic.

**Figure M11.20:** The road bridge

**Bridge Structures**

E.T. Techtonics Inc., Philadelphia, USA, designs Prestek truss and pre-stressed cable bridges that are assembled of structural composite. The components are standard pultruded profiles. The Prestek design is especially attractive for areas where the impact of construction must be minimized. The bridges' pultruded composite components deliver critical mechanical properties at a much lower weight than steel. As a result, a Prestek span is easily installed without heavy equipment or large work crews. Prestek bridges have been specified for such exotic locations as a national park on the island of Maui and a ridgeline leading to a historic lighthouse off the Golden Gate. Typical composite bridge decks as shown in Figure M11.21.

**Figure M11.21: Composite bridge decks**

**Pultruded Profiles**

Among a wide array of composite products, pultruded profiles such as gratings, ladders, cable trays, solid rods & other sections are used in many structural application with Class I flame retardancy. Pultrusion is the most cost-effective method for the production of fibre-reinforced composite structural profiles. It brings high performance composites down to commercial applications such as lightweight corrosion-free structures, electrical non-conductive Pultruded FRP Sections systems, offshore platforms and many other innovative new products. The pultruded profile is shown in Figure M11.22(a) & - (b).

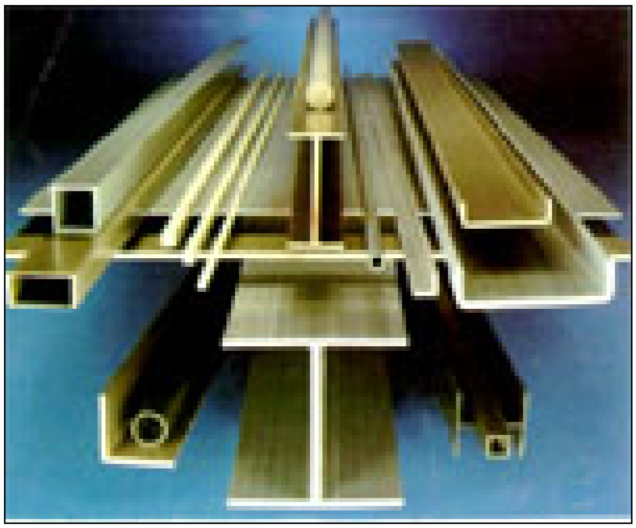

**Figure M11.22(a):** The pultruded profile

Pultruded sections are well-established alternative to steel, wood and aluminium in developed countries and are fast catching up in other parts of the world. Structural sections have ready markets in oil exploration rigs, chemical industries etc. The amount of energy required to fabricate FRP composite materials for structural applications with respect to conventional materials such as steel and aluminium is lower and would work for its economic advantage in the end. The pultruded products are already being recognized as commodity in the international market for construction.

In pursuit of developing advanced performance materials for building and construction, railways, automobiles, bio-medical etc., the **Advanced Composites Programme** was launched by Technology Information, Forecasting and Assessment Council (**TIFAC**), an autonomous organization under the Department of Science and Technology (DST), Govt. of India. Under a project of the aforesaid programme, **FRP Pultruded profiles** (industrial gratings, solid rods for electrical insulation, cable-trays, ladders etc.) with excellent surface finish and flame retardancy as per international standards have been developed by M/s. Sucro Filters Pvt. Ltd., Pune. The profiles developed have met all the desired properties. Table M11.11 lists the mechanical/ chemical properties of FRP pultruded sections vs. other structural materials. Table M11.2 lists the advantages of pultruded products. Table M11.13 lists out the characteristics of the pultruded products.

Under a project of the Advanced Composites Mission programme of the Govt. of India, FRP Pultruded profiles (industrial gratings, solid rods for electrical insulation, cable-trays, ladders etc.) with excellent surface finish and flame retardancy as per international standards have been developed by M/s. Sucro Filters Pvt. Ltd., Pune Orders were received from various industries for supplying cable trays, fittings and other accessories. An order was also executed for supplying cable trays, fittings and other accessories to M/s Dabhol Power Project as per the specifications of M/s Bechtel FRP Pultruded Profiles International Inc. The profiles developed have met all the desired properties.

**Figure M11.22(b):** The pultruded profile

| **Mechanical Properties** | **Pultruded FRP** | | **Rigid PVC** | **Mild Steel** | **Stainless Steel** | **Wood** |
|---|---|---|---|---|---|---|
| | **Polyester** | **Vinyl Ester** | | | | |
| Tensile Strength ($N/mm^2$) | 382 | 401 | 44 | 340 | 340 | 80 |
| Flexural Strength ($N/mm^2$) | 468 | 508 | 70 | 380 | 380 | 12 |
| Flexural Modulus ($N/mm^2$) | 22489 | 48260 | 2400 | 196000 | 196000 | 700 |
| Izod Impact (Kg-m/cm) | 1.36 | 1.63 | 0.09 | 1.5 | 0.53 | --- |
| Specific Gravity | 1.80 | 1.80 | 1.38 | 7.8 | 7.92 | 0.52 |
| Safe Working Temp. (° C) | 120 | 170 | 55 | 600 | 600 | 160 |

**Table M11.11**: Mechanical/Chemical Properties of FRP Pultruded Sections Vs. Other Structural Materials

| **Features** | **Description** | **Benefits** | **Applications** |
|---|---|---|---|
| Strong | Unit strength in | Optional strength as | Structural process |

| | | | |
|---|---|---|---|
| | tension & compression is approx. 20 x that of steel when these properties are combined on the basis of unit density | desired. Exceptionally high impact strength reduces damage potential | equipment support. Tank supports. Cooling tower ancillaries. Flooring supports. Trusses & joints. |
| Light Weight | Density of pultruded components is about 20% of steel and 60% of aluminium | Higher performance at less weight. Lower shipping, handling & installation costs. Less operational energy demand. | Automotive leaf springs & bumpers. Prefabricated walkways & platforms. Bus components. |
| Corrosion Resistant | Unaffected by exposure to a great variety of corrosive environment & chemicals. | Minimum maintenance costs. Long term safety. Longer life. | Chemical plant hand railings, gratings, walkways & bridges. Cable trays. Pipe supports. |
| Electrical Insulation | Provides strength & rigidity with dielectric properties. | Lesser no. of components. Non-magnetic & safe. Predictable insulation values for wide range of frequencies. | Ladders, Cable trays. Switch gear components. Mounting braces and backboards. |
| Thermal Insulation | Pultruded components have a low thermal conductivity, 1/250 of aluminium & 1/60 of steel. | Reduces installation thickness. Eliminates condensation problems. Reduces energy operation requirements. | Bulk head frames. Walk in refrigerator door jams. Window frames. Insulated roll up panel doors. |
| Consolidation | Many individual components can be combined into a large profile. | Reduced assembly cost. Reduced inventory. Fewer parts improve reliability. | Window latch supports. Roll up door |
| Dimensional Stability | Pultruded components are highly resistant to warping stretch/swelling over a wide range of temperature & stresses. | No permanent deformation under high stress. Close tolerances. | Spring bumpers. Crossing gate arms. Scrubber components. |
| Safety | The pultruded components are very strong & safe | Many gratings suffer from the problem of microbes etc. due to | This property makes them ideal choice for pharmaceutical & food |

| | | | |
|---|---|---|---|
| | to work with. They are microbes and insect proof. | wet or unhygienic working conditions. | industries. |

**Table M11.12:** Advantages of Pultrusion
(Source: Product Information Brochure; DK Fibre Forms, Pune, India)

| | |
|---|---|
| **Size** | Forming guide system and equipment pulling capacity influence size limitation |
| **Shape** | Straight, constant cross sections, some curved sections possible |
| **Length** | No limit |
| **Reinforcement** | Fibre glass, aramid fibre, carbon fibre, thermoplastic and natural fibres |
| **Mechanical Strength** | Medium to high, primarily unidirectional approaching isotropic |
| **Labor intensity** | Low to medium |
| **Mould cost** | Low to medium |
| **Production rate** | Shape and thickness related |

**Table M11.13:** Pultruded Product Characteristics

The profiles like gratings, solid rods for electrical insulation, cable trays, ladders etc. were developed successfully by M/s. Sucro Filters Pvt. Ltd., Pune with technology support from National Chemical Laboratory (NCL), Pune with excellent surface finish and flame retardancy as per international standards. NCL had worked & established various critical parameters such as using 3-cataylst system for improved curing, high pultrusion speed (1.0 – 1.5 m/min) and flame retardancy characteristics for the products. The comparison chart of the properties of FRP pultruded sections and other structural materials are listed in Table M11.14.

| **Properties** | **Pultruded FRP** | **Rigid PVC** | **Mild Steel** | **Stainless Steel** | **Wood** |
|---|---|---|---|---|---|
| Specific Gravity | 1.8 | 1.38 | 7.8 | 7.92 | 0.52 |
| Thermal Conductivity (Kcal/hr/m2/° C) | 24.4 | 6.4 | 1220 | 732.00 | 0.4 |
| Coeff. of Linear Expansion (cm/cm° C) x 10-6 | 5.2 | 37 | 8 | 10 | 1.7 |
| Safe Working Temp. (° C) | 130 | 55 | 600 | 600 | 160 |
| Flame Resistance | Good* | Poor | Excellent | Excellent | Poor |
| **Corrosion Resistance** | | | | | |
| **a.** Acidic | Excellent | Good | Poor | Excellent | Poor |
| **b.** Alkaline | Good | Fair | Good | Excellent | Poor |
| **c.** Solvents | Fair | Poor | Good | Excellent | Fair |

| | | | | | |
|---|---|---|---|---|---|
| **d.** Coastal Environment | Excellent | Good | Poor | Excellent | Fair |
| **e.** Outdoor Exposure | Excellent | Poor | Fair | Excellent | Fair |
| **f.** Effluent Water | Excellent | Good | Poor | Excellent | Fair |
| **g.** Steam | Good | Poor | Fair | Excellent | Fair |

* Excellent with special additives

**Table M11.14:** Physical & Chemical Properties of Pultruded Profiles Vs. Other Structural Materials

Towards market seeding of the pultruded products, the Company targeted three major segments viz. new projects, replacement market in industrial and non-industrial applications. The products such as cable trays, fittings and other accessories are being inducted by various industries in India and abroad.

### M11.2.2.2 Power Transmission

High voltage electrical transmission towers are now being constructed from pultruded composite sections using a "snap and build" assembly procedure, which eliminates the use of fasteners and adhesives. Weighing less than one third of conventional steel equivalent structures, the composites tower components can be readily airlifted into remote areas and assembled by small teams, thus eliminating the need to construct access roads. In addition, the inherent insulating characteristics of composite permits closer placement of attached insulators, thus enabling overall tower size and environmental obtrusiveness to be reduced. In coastal environments, the corrosion resistance of composite towers offers a huge advantage. Test towers located at California's Pacific coastline have now been in service for over three years and have withstood heavy salt contamination without development of arcing which results in insulator & consequent system failure. By contrast, galvanized steel towers require frequent washings to remove conductive, corrosion induced salt deposits.

### Power Distribution and Lighting

Composite power and lighting poles are finding increased application for both performance and environmental reasons. Traditional wooden poles contribute to forest depletion. In order to protect them against rot and termite attack, they also require treatment with highly toxic chemicals, which have been found to leach out into the surrounding environment. Lightweight composite poles are easily transported and erected; they resist corrosion, rot and insect attack, provide superior insulation properties, and can be designed to substantially reduce the possibility of collision fatalities when close placement to roads is unavoidable.

### Repair, Retrofit and Rebars

Composite plates are successfully used to repair masonry beams, columns, buildings and other structures damaged/weakened by impact, earthquake or subsidence and can usually be adhered in place by hand without the need for heavy lifting equipment. Such repairs can be carried out much more rapidly than by traditional techniques. Composite reinforcing bars may be used to replace steel in conventional reinforced concrete in order to prevent "concrete cancer" problems resulting from internal corrosion of the reinforcement. Although initially costlier, the use of **composite rebars** is justified where the nature of the construction would render possible future repairs inaccessible or otherwise unduly costly.

### M11.2.2.3 FRP Doors and Door Frames

With the scarcity of wood for building products, the alternative, which merits attention, is to promote the manufacturing of low cost FRP building materials to meet the demands of the housing and building sectors. The doors made of FRP skins, sandwiched with core materials such as rigid polyurethane foam, expanded polystyrene, paper honeycomb; jute/coir felt etc. can have potential usage in residential buildings, offices, schools, hospitals, laboratories etc. As structural sandwich construction has attained broad acceptance and usage for primary load bearing structures, the FRP doors can be manufactured in various sizes and designs using this technology.

The principal fabrication technique employed is contact moulding or hand lay-up process. The front and back sheets of the doors are fabricated separately. Wooden inserts are placed between two sheets for various fittings. The PU foam is sandwiched between the sheets by in-situ foaming process followed by painting and polishing to meet aesthetic requirement. Proper usage of additives imparts fire retardant properties to the doors. In addition, usage of composite material for the doors makes them totally water & termite resistant. FRP doors are much cheaper than the wooden ones. The FRP doorframes can also be fabricated by contact moulding.

The FRP doors and doorframes have been designed & developed using the aforesaid technology by the RV-TIFAC Composite Design Centre (CDC) at Bangalore under the Advanced Composites Mission programme of the Govt. of India. The FRP doors developed by CDC conform to BIS specifications (IS: 4020). After successful field trials and users’ feedback, the technology for FRP door has been transferred to over 30 entrepreneurs for commercial exploitation.

The rapid expansion of the use of sandwich construction in many fields has yielded a more precise knowledge of design methods, test procedures and manufacturing techniques of cost-effective composite products. A low-density core made of honeycomb or foam materials provides a structural performance with minimum weight. Other considerations such as sound insulation, heat resistance, vibration-damping etc. dictate the particular choice of material used as core material. The FRP door is shown in Figure M11.23.

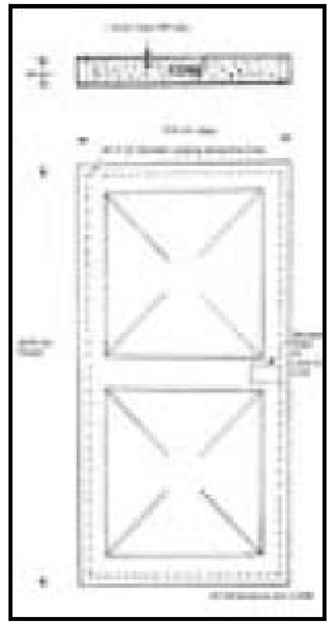

**Figure M11.23: FRP Door & Door Frame**

**Plumbing Components**

Lightweight fibre glass composite components for toilet are easy to install and they are corrosion resistant. Due to poor thermal conductivity, the composite surface is warm to the touch unlike porcelain and steel. Ease in moulding technique for composite allows more aesthetic shapes and excellent surface finishes.

**Ceiling Panel**

The fibre glass veil facing used while moulding the panels for suspended ceilings increases panel stiffness and resists puncturing. Due to their easy printability, the veil imparts good panel aesthetics. The suspended ceilings are used to cover up electrical wiring, ducting, piping and fittings. The veil with an optimum porosity contributes to improved acoustical quality of the working or living space.

**M11.2.2.4 Natural Fibre Composites in Building Materials**

Natural fibres, as a substitute for glass fibres in composite components, have gained interest in the last Composite Ceiling Panel decade, especially in the housing sector. Fibres like flax, hemp or jute are cheap, have better stiffness per unit weight and have a lower impact on the environment. Structural applications are rare since existing production techniques are not applicable and availability of semi-finished materials with constant quality is still a problem. Typical composite material is shown in Figure M11.24.

**Figure M11.24:** Typical composite building

The moderate mechanical properties of natural fibres prevent them from being used in high-performance applications (e.g. where carbon reinforced composites would be utilized), but for many reasons they can compete with glass fibres. Advantages and disadvantages determine the choice. Low specific weight, which results in a higher specific strength and stiffness than glass is a benefit especially in parts designed for bending stiffness.

Recently the use of natural fibres for composite applications is being investigated intensively in Europe. As a result, many components are now produced in natural composites, mainly based on polyester or polypropylene and fibres like flax, jute, sisal, banana or ramie. Until now however, the introduction in this industry is lead by motives of price and marketing ('processing renewable resources') rather than technical demands. The use of renewable natural fibres contributes to sustainable developments.

Natural fibre composites (NFC) can be used as a substitute for timber as well as for a number of other applications. It can be moulded into sheets, boards, gratings, pallets, frames, structural sections and many other shapes. They can be used as a substitute for wood, metal or masonry for partitions, false ceilings, facades, barricades, fences, railings, flooring, roofing, wall tiles etc. It can also be used in pre-fabricated housing, cubicles, kiosks, awnings, sheds/shelters. Natural fibres due to their adequate tensile strength and good specific modulus enjoy the right potential for usage in composites thus ensuring a value-added application avenue. The maximum tensile, impact and flexural strengths for natural fibre composites reported so far are 104.0 $MN/m^2$ (jute-epoxy), 22.0 $kJ/m^2$ (jutepolyester) and 64.0 $MN/m^2$ (banana-polyester) respectively.

Although the tensile strength and Young's modulus of natural fibre like jute are lower than those of glass fibres, the specific modulus of jute fibre is superior to that of glass and on a modulus per cost basis, jute is far superior. The specific strength per unit cost of jute, too, approaches that of glass. The need for using jute fibres in place of the traditional glass fibre partly or fully as reinforcing agents in composites stems from its lower specific gravity (1.29) and higher specific modulus (40 GPa) of jute compared with those of glass (2.5 and 30 GPa respectively). Apart from much lower cost and renewable nature of jute, much lower energy requirement for the production of jute (only 2% of that for glass) makes it attractive as a reinforcing fibre in composites. The Table M11.15 shows the properties of Natural fibres.

| **Properties** | **E-glass** | **Flax** | **Hemp** | **Jute** | **Ramie** | **Coir** | **Sisal** | **Cotton** |
|---|---|---|---|---|---|---|---|---|
| Density $g/cm^3$ | 2.55 | 1.4 | 1.48 | 1.46 | 1.5 | 1.25 | 1.33 | 1.51 |
| Tensile Strength * $10E^6$ $N/m^2$ | 2400 | 800-1500 | 550-900 | 400-800 | 500 | 220 | 600-700 | 400 |
| E-modulus (GPa) | 73 | 60-80 | 70 | 10-30 | 44 | 6 | 38 | 12 |
| Elongation at Failure (%) | 3 | 1.2-1.6 | 1.6 | 1.8 | 2 | 15-25 | 2-3 | 3-10 |
| Moisture Absorption (%) | ---- | 7 | 8 | 12 | 12-17 | 10 | 11 | 8-25 |
| Price / kg ($), raw | 1.3 | 0.5-1.8 | 0.6-1.8 | 0.35 | 1.5-2.5 | 0.25-0.5 | 0.6-0.7 | 1.5-2.2 |

**Table M11.15:** Properties of Select Natural Fibres

* Tensile strength strongly depends on type of fibre, being a bundle or a single filament

**Jute-Coir Composites** - an alternative to wood products is one of the application avenues for construction industry. It involves the production of coir-ply boards with oriented jute as face veneer and coir plus waste rubber wood inside. A very thin layer of jute fibres impregnated with phenolic resin is used as the face veneer for improved aesthetics and to give a wood like finish. The orientation & uniformity of jute fibre improve with carding and this also helps in better penetration of resin into the fibre. The coir fibre contains 45.84% lignin as against 39% in teakwood. Therefore, it is more resistant than teakwood against rotting under wet and dry conditions and has better tensile strength. Similarly low cellulose content in coir (43%) as against 63% cellulose in wood makes it more durable than teakwood. The composite boards namely, coir-ply boards (jute + rubber wood + coir) as plywood substitute and natural fibre reinforced boards (jute + coir) as MDF substitute can be used in place of wood or MDF boards for partitioning, false ceiling, surface paneling, roofing, furniture, cupboards, wardrobes etc.

These boards have been employed as doors & door frames as an alternate to conventional material like wood, steel etc.

The properties of jute-coir boards developed by the 'Natura' Division of M/s. Duroflex Ltd., Bangalore under the Advanced Composites Mission programme were tested as per IS-12406 against the specified values of MDF a board is given in Table M11.16(a) & -(b).

| **Sl. No.** | **Tests** | **Observed Values(Average)** | | | **Specified Values** |
|---|---|---|---|---|---|
| | | **Board Thickness** | | | |
| | | **8 mm** | **6 mm** | **4 mm** | |
| 1. | Cross Breaking Strength (Kgs./cm2) -Perpendicular to Grain Direction) | | | | |
| (a). | Before Boiling | 318 | 391 | 373 | 275 (min.) |
| (b). | After 8 Hrs. Boiling | 266 | 270 | 240 | 150 (min.) |
| 2. | Bulk Density (Kgs./cm3) | 700 | 739 | 760 | 500-900 |

**Table M11.16(a):** Properties of jute-coir boards tested as per IS-12406

| **l. No.** | **Tests** | **Observed Values (Avg.)** | | | **Specified Values** | |
|---|---|---|---|---|---|---|
| | | **Board Thickness** | | | | |
| | | **8 mm** | **6 mm** | **4 mm** | **Exterior Grade** | **Interior Grade** |
| 1. (a) | Moisture Content (%) | 5.73 | 5.90 | 5.92 | 5-15 | 5-15 |
| (b) | Variation from mean moisture content (%) | -2.1 | +0.9 | +1.2 | +3.0 | +3.0 |
| 2. | Max. Water absorption (%) | | | | | |
| (a) | After 2 Hrs. soaking | 4.5 | 5.1 | 2.9 | 6 | 9 |
| (b) | After 24 Hrs. soaking | 9.1 | 9.2 | 6.8 | 12 | 18 |
| 3. | Max. linear expansion (% swelling in water) | | | | | |
| (a) | Due to general absorption after 24 Hrs. soaking | | | | | |
| i. | Thickness | Average value : 1.0 | | | 4 | 7 |
| ii. | Length | Average value : 0.13 | | | 0.3 | 0.4 |
| iii. | Width | Average value : 0.21 | | | 0.3 | 0.4 |

**Table M11.16(b):** Properties of jute-coir boards tested as per IS-12406

The bamboo based composites can be used in construction sector for blocks, flooring tiles, false ceilings, partition walls, furniture etc. with laminated or polymerized surface. Bamboo after treatment with chemicals for termite and fungi is stored in solar chamber for drying. Bamboo poles are cut manually to sizes. The slats are measured using different gauges to arrive at proper sizes. Bamboo slats are impregnated with polyester resin and moulded in the hydraulic press.

The moulded product is machined for exact dimensions and lacquer coated for finishing. The bamboo based composite furniture as shown in Figure M11.25.

**Figure M11.25:** The bamboo based composites furniture

Due to the easiness to drill, tap, shape and assemble these blocks are used for making fixtures tools handles sports goods, etc. Pre-fabricated housing elements for sheds, shelters, cubicles, huts, pyramids etc. are also fabricated by using bamboo composites. These elements comprise of structural frames, beams, columns, trusses, rafters etc. and are erected by cladding with NFC sheets. They are ideal for remote and inaccessible laces and very much suitable for hill forts, isolated beaches, inclement weather stations, conventional as well as unconventional tourist spots, farmhouses, retreats and small islands. Other product that is developed using bamboo is decorative board. It is made by sized flats of bamboo having matching thickness, which are then joined / bonded together by pouring polymer resin. Due to the inherent lightness of the bamboo the decorative boards that are developed also gain this feature of bamboo, therefore it becomes lighter than the other wood and plywood boards.

**Bamboo Composite Boards and Laminates**

Bamboo is one of the fastest renewable plants with a maturity cycle of 3-4 years, thus making it a highly attractive natural resource compared to forest hardwoods. Bamboo offers good potential for processing it into composites as a wood substitute. Bamboo laminates could replace timber in many applications such as furniture, doors and windows and their frames, partitions, wardrobes, cabinets, flooring etc.

Bamboo laminates are made from slivers milled out from the bamboo culm. After primary processing comprising cross cutting, splitting and 2-side planing, the slivers are treated for starch removal and prevention of termite/borer attack. The slivers are then subjected to hot air drying followed by 4-side planing for attaining uniform thickness. These slivers are coated with glue on the surface and are arranged systematically. They are subjected to a curing in a hot press (6'X4' 2-day light) at temp. ~ 70 $^0$C using steam & pressure ~ 17 Kg/cm$^2$. The pressed laminate (panels/tiles) is then put through trimming, sanding and grooving machines to give a pre-finish shape. The flow chart & intermediate quality control parameters for manufacturing bamboo composites are enclosed.

The project on production of bamboo composites and laminates is based on the following premises:

- Value-added products from Bamboo.
- Cost-effective compared to good solid wood sections for furniture.
- Diversification from traditional plywood to bamboo based products.
- Complete range of bamboo composite laminates for furniture, flooring tiles, boards, door & window frames to replace the use of timber for domestic as well as international market.

**Expected Benefits**

- Bamboo composite based flooring tiles, boards (used for partitions, cupboards, racks, and door and window panels) and blocks (used for furniture, rails and styles for doors and windows etc.) as wood substitute would help develop and promote high value-added products from bamboo.
- Bamboo composite laminates with a low-temperature curing resin system for reduced energy requirement.
- Promotion of eco-friendly use of bamboo while building a sustainable infrastructure for plant multiplication, propagation and cultivation.
- Boosting the usage of bamboo based products in India towards generating good employment and income opportunities at rural level.

Towards effective bamboo utilization and exploring the value-addition potential, the project on development of bamboo composite laminates was launched by the Advanced Composites Programme of TIFAC in partnership with M/s. Emmbee Forest Products Pvt. Ltd., Manabari with technology support from the Department of Polymer Science and Technology, University of Calcutta. The project aimed at developing value-added products from bamboo with an innovative resin system for reduced processing energy requirement. Bamboo based products such as flooring tiles, laminate boards; blocks (for door and window frames, rails and styles, furniture etc.) as wood substitute are being developed under the project.

For preventing bamboo composites from any deterioration by moisture absorption and imparting long-term storage life, a water based acrylic pre-coat has been developed. This pre-coat would prevent any fungal attack during transit for the reconstituted wood sections for furniture. Further, a UV cured melamine acrylate system as the finishing coat has also been developed for flooring tiles made of bamboo composites. A water based PU resin system has also been tried for final finish of the flooring tiles.

Various stages of bamboo processing starting from cross-cutting, parallel splitting, knot removal, two-side planning, anti-fungal treatment, drying; four-side planning, glue application and hot pressing were fine tuned. Products such as flooring tiles, furniture sections, reconstituted wood, air locked sections, mat boards etc. have been developed under the project.

**Composite Materials towards Re-building and Rehabilitation**

In the wake of disastrous damages by the earthquake in Gujarat, the Advanced Composites Programme has contributed to the national efforts of re-building and rehabilitation. Under the TIFAC Rehab Project for Kachchh, the following initiatives were taken up for the quake affected people:

- 392 low-cost semi-permanent shelters (20'x12') made of natural fibre composite materials such as jute-coir composite boards and rice husk particle boards with bamboo mat face veneer etc. were supported on MS angles & channels. For improved aesthetics and also to augment the thermal insulation, natural fibre composite board roofing of the shelters was covered with terracotta tiles.
- In order to cater to the shelters, 128 community toilet blocks (4'x4') made of modular FRP section for walls and roof were constructed.
- 15 shops (12'x8') were constructed in the township along with a Post Office in the township, which has commenced its services.
- In addition to the semi-permanent residential shelters constructed at Bhuj, 25 school blocks-cum-community centers (24'x 20') were also constructed at various locations in Kachchh.

The TIFAC Rehab Project was a model initiative of technology demonstration with novel building materials with the delivery in the quickest possible time addressing the crucial need for post-disaster relief.

**Composite Building Materials – Technology Demonstration**

For augmenting the reception block of Technology Bhavan campus in Delhi, the Advanced Composites Programme took initiatives by building a 3000 sq. ft. temporary structure for post office, CR section, and technology demonstration-cum -display area and additional office space towards showcasing composite building materials. The array of products developed under the programme such as jute-coir boards, FRP doors, bamboo composite flooring tiles and rice husk particle boards for false ceiling were used in the construction of the shelter towards technology demonstration. Jute-coir composite boards made of coir felt and waste rubber-wood as inside veneers and oriented jute as face veneer is a unique value-added application for agro-wastes and positioned as an effective wood substitute building material. While the shelter structure was fabricated out of standard steel sections, jute-coir boards were used for double-wall construction ensuring excellent thermal insulation. They were also used for roofing overlaid with terracotta tiles. Elegant looking bamboo composite tiles were used for the flooring. The door shutters made of sandwich panels of glass fibre reinforced polyester resin, have good aesthetic appeal with adequate mechanical strength and water resistance.

**Conclusion**

Globally, composite technology and its applications had made tremendous progress during the last two decades or so, as evident from the present level of consumption of composite materials at about 2.2 million MT, with the Asia-Pacific region accounting for about 24% of this usage.

Currently, about 40,000 composite products are in use for an array of applications in diverse sectors of the industry all over the world. While China and India started making use of composites almost simultaneously about 30 years ago, the progress made by China is rather astounding with a consumption level of about 2,00,000 MT, as compared to about 30,000 MT in India.

The most important feature governing the choice of material and form of construction for any component is its structural integrity. Whereas high specific strength and lightweight were often the dominant criteria to be achieved, particularly for aerospace applications, there is today an increasing emphasis on other criteria such as environmental durability, embedded energy, fire resistance. The materials previously regarded as being synonymous with high performance FRP, such as carbon fibre, are more affordable today and hence not always used to the limit of their capabilities.

The survey of international technology trends establishes the fact that the composites occupy a prominent position as the building material dislodging many conventional ones. Composites are an attractive proposition considering the embedded energy (energy required to manufacture) especially against steel, aluminium and other metals. Other important properties such as impact resistance, corrosion resistance, thermal and acoustic insulation all contribute favourably to composite claiming its position as an ideal building material.

Innovative thermoset composite products as well as thermoplastic composites would go a long way in developing new application areas thus enhancing its market reach. India with an excellent knowledge-base in various resins, catalysts and curing systems coupled with an adequate availability of various raw materials can certainly carve out a niche in the upcoming technology of composite fabrication.

With more and more realization on conversation of nature and natural resources, scarcity of wood looms large for the construction and housing sector. This calls for an immediate attention for developing suitable wood substitutes. From the point of view of wood substitution, natural fibre composites would enjoy wider acceptance. India enjoys a niche for the natural fibre composites as the country is endowed with large varieties of natural fibre. Value-added novel applications of natural fibre composites would also ensure international market for cheaper substitutes. Apart from exporting the products, India should seriously explore the technology export opportunities to countries rich in natural fibre as in Africa and SE Asia. The products when locally manufactured would actually become cost competitive for other wood substitutes.

While considerable expertise in composite technology exists in India in the national laboratories (NAL, VSSC-ISRO, CSIR, and DRDL etc.) and academic institutions, the commercial exploitation of composites is yet to catch up with the international advancements. Assessing the importance of composites as an advanced performance material in various sectors such as railways, automobiles, building and construction, marine, medical etc., the Advanced Composites Mission was conceptualized by the Department of Science and Technology (DST) and Defence Research and Development Organization (DRDO). The Mission-mode activities are being implemented by the Technology Information, Forecasting and Assessment Council (TIFAC), and an autonomous organization under DST.

The Advanced Composites Mission aims to improve upon the laboratory-industry linkages towards application development and commercialization. The Mission has been successful in launching 22 projects across the country in active collaboration with the industry and national laboratories. Some of the important projects launched by the Mission in the civil engineering sector include FRP pultruded profiles, jute-coir composite boards as wood substitute, FRP door & door frames etc. The Mission has been quite instrumental in bridging the knowledge gaps and bringing together the industries and the users for technology development, transfer and subsequent commercialization. Such an objective oriented, demand driven and time bound programme on composite technology with the involvement of stake holders would go a long way in developing innovative composite applications meeting international quality and wider acceptance by the users thus contributing to the growth of knowledge-based business in India.

## M11.2.3 Composite houseboat helps tourists explore India

Wafting along the placid Vembanad Lake, one of Asia's largest freshwater lake systems in God's own country, Kerala in a houseboat can truly be an ethereal experience! Originally known as 'kettuvallom' and used for carrying rice and other grains in the villages dotting along the backwater canals of Kerala, houseboat is a rather recent innovation positioned as the unique attraction for an already thriving tourism industry in the state.

**Note:** A houseboat is traditionally made of wood and it takes 8-10 trees to build one.

A houseboat can be the ultimate statement in luxury. Imagine highly furnished bedrooms complete with all modern gadgets like home theatre, DVD player, music system etc., a well stocked bar, attached bath with hot water supply, toilets with enzymatic treatment of bio-mass for pollution free discharge, all packed in a 25-28 m long wooden hull! And the innovation has not stopped there. The tour operators in Kerala have experimented with many variants of the houseboat. While the standard houseboat is equipped with two or three bedrooms, some have been made into a honeymooner's haven with one large bedroom and semi-open toilet. Some have also been designed with a double-deck configuration with top deck being used for conference and the lower one serving as the dining hall. Conceptualized around 10 years ago, houseboat in the backwaters of Kerala has become quiet a rage with a current population of around 200 and about 10-15 boats being built every year for catering to an ever rising demand.

### Traditional construction

A houseboat is traditionally made of resinous wood and it takes 8-10 trees (70-80 years old) to build one. Apart from denuding the forest cover, building a traditional houseboat is extremely manpower intensive and nearly 40 man months of skilled labour are required to shape it up. The wooden hull is highly prone to decay due to its continuous contact with water calling for regular tarring of the hull and frequent outages of the houseboat. The superstructure outer surface thatched with woven bamboo mat requires replacement every year due to an excessive fungal attack in a moist environment. Thus the maintenance becomes quite prohibitive for the houseboat for the tourists to enjoy that ultimate in luxury and the cost of occupancy rises! Besides introduction of diesel engines into houseboats has made them economical to operate, but it has become uncomfortable due to noise and vibrations. All these made houseboat a good candidate to be developed in composite for corrosion resistance, mouldability and maintenance free service.

**Composite construction**

The development of composite houseboat for tourism was taken up as a project under the Advanced Composites Programme of TIFAC for improved aesthetics, boat stability, comfort level and maintainability. The project was launched in partnership with M/s. Samudra Shipyard Pvt. Ltd., Aroor near Cochin. A multi-agency approach was adopted for seeking expertise in hull design, testing, fabrication assistance, design of superstructure, interiors, amenities etc.

**Figure M11.26:** The composite houseboat

NGN Composites-Chennai has assisted in mechanical design and fabrication of hull, deck and superstructure. The technology support from NGN Composites included design and development of patterns and moulds for boat hull and superstructure and quality control during fabrication process. The Dept. of Ocean Engineering of IIT-Madras has provided hydrodynamic design of boat hull, bulkheads, and ballasts and conducted the necessary tests for boat stability. The Industrial Design Centre (IDC) of IIT-Bombay has extended design support for superstructure for improved space utilization of the available envelop, aesthetics and ergonomics of the living area with the detailed design of bedrooms, toilets, dining area, lounge, kitchen etc. including design of panels, partitions and other interiors. The important milestone of IDC's contribution has been modular design approach of the entire superstructure.

The scaled down (1:17) version of composite hull was designed and fabricated by IIT-Madras and tested for its hydrodynamic stability in their towing tank. The model hull behaviour was studied at various speeds and the hull profile was determined for scaling up. Finally the full-scale hull measuring 26 m long x 4.50 m wide x 1.50 m deep was firmed up as given in the Figure M11.25. The major hydrostatic data at load water line are given in Table M11.17. IIT-Madras has also designed the propeller profile, shaft and the drive mechanism for the propulsion system.

| Sl. No. | Design Parameter | Values |
|---|---|---|
| 1. | Draught | 0.45 m |
| 2. | Displacement | 22.427 t |
| 3. | Meta-centric radius | 4.29 m |
| 4. | Moment to change trim by 1cm | 1.08 t-m |
| 5. | Centre of gravity | 1.30 m |
| 6. | Meta-centric height for assumed Cg | 3.17 m |

**Table M11.17:** The major hydrostatic data at load water line

The sandwich hull with PUF foam core was fabricated in composite. The decking for the houseboat has always been a problem area with a whole lot of wooden planks being used in the conventional ones. This problem was addressed under the TIFAC project by using moulded resin infused composite gratings, each grid measuring 4.30 m x 1.00 m x .03 m with a 75-mm flange resting along the hull profile. The gratings were vertically supported along the centre line of the hull.

For superstructure, efforts were made to retain the traditional look with curved wall profiles and pagoda type roofing. The entire superstructure was made into five modular parts requiring only three moulds for fabricating the half modules. The pagoda style roofing with flat false ceiling inside the bedrooms provides good thermal insulation due to the available air gap. The superstructure was configured to accommodate two bedrooms each measuring 4.00 m x 3.50 m with large windows, attached toilets, a 1.0-m wide passage, living room with open deck, kitchen, crew toilet etc. Hard wood like flooring, made of bamboo composite, was used in the bedrooms. It is heartening to note that the hull, deck and the superstructure of the houseboat would weigh about 19.20 tons of composites.

A 104 HP Cummins diesel engine used for the propulsion system has been housed inside the hull with anti-vibration mountings. An acoustic barrier in the form of high resilience foam was used in the engine enclosure for a noise free operation. A 10-KVA DG set has been installed inside the hull for the power back-up when the engine is not in operation as the boat is anchored during the night. Polymer concrete ballasts weighing 1.50 tons have been added inside the hull to improve boat stability. Three bulkheads have been provided in the hull to isolate the hull puncture and water leakage.

**Note:** While boat building in India has been a traditional activity, it is now important to introduce new materials such as composites.

The composite houseboat has been a small step in technology development but this would go a long way in saving the environment. The involvement of the multi-agency expertise and a user-oriented approach has been instrumental in reducing the product development cycle limiting the entire exercise to less than one year. While boat building in India has been a traditional activity, it is now important to introduce new materials such as composites and processes such as vacuum infusion technique. With vast pool of technical expertise available in naval architecture in the leading academic institutes in India, boat building could be an important business opportunity for the industries. India is an emerging market for leisure activities with higher disposable incomes per family. With very long coast lines along the peninsula, large natural inland water bodies and long rivers, development of composite boats of various forms & functions in India would certainly assume importance and attract investment in the near future.

## M11.2.4 Composites - The Wonder Material: Miscellaneous applications

Steel and concrete are the materials of choice for offshore oil and gas production platforms, with steel dominant in the topside applications. Composites have found their way into limited applications, particularly where corrosion and the need to reduce high maintenance costs have been an issue. As the industry moves to greater water depths, the significance of weight saving has become increasingly important in conjunction with the application of buoyant tension for the leg structures. Composites may find excellent usage in fabrication of the following:

- Profiles for oil pollution barriers
- Gratings, ladders and railings on oil-drilling platforms and ships
- Walkway systems
- Sucker rods

Assessing the importance of composites as an advanced performance material in various sectors such as railways, automobiles, building and construction, marine, medical etc., the **Advanced Composites Programme** is being implemented by Technology Information, Forecasting and Assessment Council (**TIFAC**), an autonomous organization under the Department of Science and Technology, Govt. of India. The programme has been an attempt to enhance the utilization and application of composites as an important performance material in various sectors and to improve the laboratory-industry linkages towards development and commercialization. A large array of products developed successfully under the programme has reached the threshold of commercialization. Some of the salient Programme achievements include the following:

### M11.2.4.1 Jute-Coir Composite Boards as Wood Substitutes:

**Figure M11.27: Jute-coir composite boards**

The project launched in collaboration with the Natura Division of M/s Duroflex Limited, Bangalore, aimed at developing jute-coir composite boards with oriented face jute veneer and coir/rubber wood inside. A very thin layer of jute fibres impregnated with phenolic resin was used as the face veneer for improved aesthetics and to give a wood like finish. Two major categories of composite boards namely, coir-ply boards (jute + rubber wood + coir) as plywood substitute and natural fibre reinforced boards (jute + coir) as MDF substitute were developed with superior performance, properties and price advantages. The detailed properties of jute-coir boards tested as per IS-12406 against the specified values of MDF boards are given in Table M11.18.

The natural fibre composite boards have attractive natural look as it can be painted, polished or laminated. They are water proof with minimum surface absorption, strong & rigid, environment-friendly and can be nailed, screwed and cut sharply. Jute-coir boards (8 ft. x 4 ft. x 6 mm thick) are being inducted in railways for their applications as berth backings on regular basis. Jute-coir composite board has made excellent in-roads to CPWD, BSNL, Govt. of Karnataka and others.

| Sl. No. | Tests | Observed Values (Avg.) | | | Specified Values | |
|---|---|---|---|---|---|---|
| | | Board Thickness | | | | |
| | | 8 mm | 6 mm | 4 mm | Exterior Grade | Interior Grade |
| 1. | Cross Breaking Strength (Kgs./cm$^2$)- Perpendicular to Grain Direction | | | | | |
| a) | Before Boiling | 318 | 391 | 373 | 275 (min.) | |
| b) | After 8 Hrs. Boiling | 266 | 270 | 240 | 150 (min.) | |
| 2. | Bulk Density (Kgs./cm3) | 700 | 739 | 760 | 500-900 | |
| 3. (a) | Moisture Content (%) | 5.73 | 5.90 | 5.92 | 5-15 | 5-15 |
| (b) | Variation from mean moisture content (%) | -2.1 | +0.9 | +1.2 | +3.0 | +3.0 |
| 4. | Max. Water absorption (%) | | | | | |
| (a) | After 2 Hrs. soaking | 4.5 | 5.1 | 2.9 | 6 | 9 |
| (b) | After 24 Hrs. soaking | 9.1 | 9.2 | 6.8 | 12 | 18 |
| 5. | Max. linear expansion (% swelling in water) due to general absorption after 24 Hrs. soaking | | | | | |
| i. | Thickness | Average value : 1.0 | | | 4 | 7 |
| ii. | Length | Average value : 0.13 | | | 0.3 | 0.4 |
| iii. | Width | Average value : 0.21 | | | 0.3 | 0.4 |

**Table M11.18: Properties of Jute-Coir Composite Boards**

**Energy Efficient Axial Flow FRP Fans**

The axial flow fans are widely used for providing required airflow for heat and mass transfer operations in various industrial equipment and processes. Energy efficient axial flow FRP fans were developed under the Advanced Composites Programme by M/s. Parag Fans and Cooling Systems Ltd., Dewas (MP) with the technology support from IIT-Bombay. The project focused on improving aerodynamic profile of the impellers by selecting appropriate aerofoil and providing composite structural design to suite specific airflow and pressure requirements towards replacing aluminium and mild steel impellers. Hollow FRP blades reduce material & installation costs and possibility of damage to the fan & drive during sudden stops.

Five types of fans for cooling towers for power plants, mine ventilation for Western Coal fields Ltd., air heat exchanger (as per EIL specs.), diesel locomotive radiator cooling fan (as per RDSO specs.) and textile mill humidifier (as per ATIRA specs.) were developed. The performance of all the above fans was tested in actual field conditions with an efficiency differential as high as 25% over conventional fans with aluminium impellers. The test results of FRP fans vis-à-vis metallic fans are listed in Table M11.19. These fans promise a pay-back period of 3-9 months at current energy rates. The fans are being supplied by Parag Fans to a no. of users in India & abroad.

| Sl. No. | Type of FRP Fan | Flow Rate M3/Sec. | Total Pressure mm water gauge | Shaft Power (kW) | FRP Fan Efficiency as Certified by User Agencies | Efficiency Improvement over Conventional Fan | FRP Fan Energy Savings over Conventional Fan |
|---|---|---|---|---|---|---|---|
| 1. | Cooling Tower Fan+ | 240.47 | 8.48 | 23.24 | 86.06% | Superior | Superior |
| 2. | Textile Mill Humidifier Fan * | 19.04 | 34.83 | - | 78.01% | 24.58% | Superior |
| 3. | Mine Ventilation Fan+ | 48.60 to 81.00 | 92.83 | 89.63 | 59.40% | 8.22% | 21.96% |
| 4. | Radiator Cooling Fan for Railway Diesel Locomotives* | 49.76 to 60.21 | 88.56 to 102.98 | 74.95 to 78.60 | 65.67% to 70.24% | 2.33% to 9.62% | 1.86% to 4.60% |
| 5. | Air-heat Exchanger Fan+ | 91.43 to 96.94 | 8.26 to 8.56 | 10.1 to 10.17 | 74.01% to 80.04% | 20.79% to 21.09% | 28.96% to 34.93% |

**Table M11.19: Test Results of FRP Fans Vs. Conventional Metallic Fans**
* Tested on the Test Rig as per ANSI/AMCA 210-85 + Tested on Site

**M11.2.4.2 Composite Artificial Limbs for Physically Handicapped**

The artificial limbs made up of composites are shown in Figure M11.28.

**Figure M11.28:** Composite artificial limbs

The project was lunched in collaboration with M/s. Mohana Orthotics & Prosthetic Centre, Chennai and technology support from Madras Institute of Technology (MIT), Chennai. Below-knee endoskeleton type artificial limbs are lighter in weight and better appearance than ever before with improved gait for the patients. The limb consists of five parts: a FRP tubular structure, top & bottom connectors, PU foot with composite keel embedded in it and a polypropylene socket to accommodate the amputee stump. The socket made of polypropylene is patient specific and does not create any problems like pressure sores even for diabetic patients. All the five parts and the socket are adjustable to meet individual requirements and to take care of static & dynamic alignment patterns. Such indigenously developed below-knee artificial limb is cheaper than the important ones. The artificial limb was awarded the prestigious **National R&D Award 2001** by the Department of Scientific & Industrial Research (DSIR), Govt. of India.

### M11.2.4.3 Modular FRP Toilets for Railway Coaches

The typical FRP toilet for railway coaches is shown in Figure M11.29.

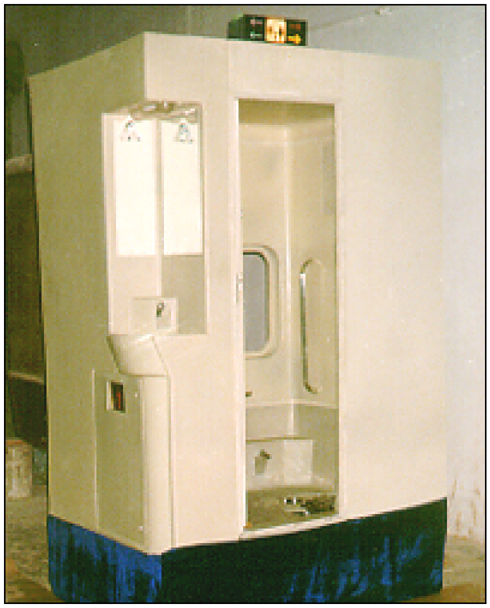

**Figure M11.29:** Modular FRP toilets for railway coaches

The project was launched in partnership with M/s. Hindustan Fibre Glass Works, Vadodara and technology support from IIT-Bombay. The FRP toilet unit developed consists of four parts: the flooring trough, one L-shaped side-wall, another C-shaped side wall and roof. All the four parts could be assembled inside the coach. The FRP toilet is lightweight, corrosion resistant, and fire retardant and it has longer life with easy maintainability.

FRP toilets have been inducted on large scale by Indian Railways. The project bagged the **Certificate of Merit** under the prestigious **National Award for Excellence in Consultancy Services-2001** given by the Consultancy Development Centre of the Department of Scientific & Industrial Research, Govt. of India.

### M11.2.4.4 Composite Pressure Vessels

The project was launched in partnership with M/s. Kineco Pvt. Ltd., Panaji and with technology support from IIT-Bombay. The project aimed at developing filament wound pressure vessels for the following applications:

- Undercarriage FRP tanks (450 mm diameter with 2.00 bar operating pressure to be fitted to the railway passenger coaches for water supply to the toilets
- Two sizes of pressure vessels (500 mm & 600 mm diameter) for water treatment application; operating pressure : 3.50 bar

The above vessels were designed as per BS 4994:1987. For fabricating composite pressure vessels with dished/hemispherical ends, a multiple axes CNC filament winding facility was designed and developed indigenously for the first time in the country by CNC Technics Pvt. Ltd., Hyderabad. As an integral part of the project, design, development and fabrication of a **5-axes CNC filament winding system** was taken up by **CNC Technics Pvt. Ltd.; Hyderabad for fabricating the aforesaid pressure vessels.** Pressure vessels/pipes with diameter ranging from 50 mm – 4.00 m can be wound on the system; length of the job varies from 1.00 to 9.50 m. **For**

**developing undercarriage water tanks for Indian Railways, inflated roto-moulded LDPE liner was used as mandrel in the filament winding machine.**

The system has the following unique features:

- The filament-winding machine is powered and controlled by SIEMENS 840 D control system.
- Pressure vessels/pipes with diameter ranging from 50 mm – 4.00 m can be wound on the system.
- Length of the job being wound can vary from 1.00 – 9.50 m
- The unique design of the cross axis allows the winding pattern to be unaltered from 50 mm – 4.00 m dia.
- The main filament winding carriage feeding the impregnated glass fibre moves at a very high speed of 60 m/minute.
- The creel stand for fibre-glass rovings accommodates 24 spools and has adjustable mechanical tensioning device at its spool. The tension can be accurately controlled for each roving.
- The drum type resin bath with micrometric adjusting doctor's blade can control resin pick-up accurately. Top wetting rollers assure proper wetting of rovings and squeeze blades remove excess resin. A temperature controller and a hot water pump controls the resin bath temperature within ± 20 C enhancing the pot life of epoxy resins.
- The CNC control system is enclosed in a fully sealed panel, which has a piggyback air conditioner and can work in any environment.
- The multi-axis filament winding system is equipped with CADWIND software to facilitate various design configurations of composite parts.

The typical Pressure vessel made up of Composites is as shown in Figure M11.30.

**Figure M11.30:** Composite pressure vessels

### M11.2.4.5 Compressed GRP Grids/Gratings

The project was launched in partnership with M/s. Technocraft, Chennai with technology support from IIT-Madras. The project aims at designing and developing GRP grids/gratings by compression moulding technique to replace the existing grids/grating made of heavy steel/cast iron. The product proposed under the project would have potential applications in oil platforms, chemical plants etc. such as walkways, foot-bridges, roofing systems partition paneling etc. in chemical /pharmaceutical, transportation & civil/infrastructural sectors. While a pultruded grating has load carrying capacity only in one direction, the GRP grating has three dimensionally curved shapes with equal load carrying capacity in both the directions. As an integral part of the project, a computer controlled automatic glass fibre laying machine was designed and fabricated for manufacturing of grids and gratings of different sizes with beams at various sections. Moulding of the grating (3m x 1m) would commence by end July 2004. Technocraft plans to offer the process technology complete with the equipment for computer controlled fibre laying & compression moulding of composite grating to other manufacturers.

The compressed GRP grids are shown in Figure M11.31.

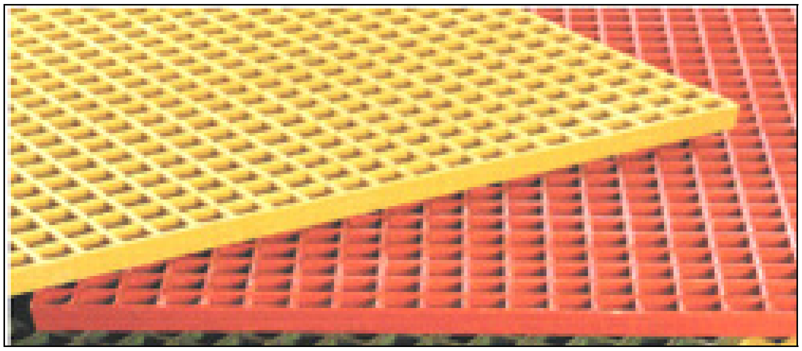

**Figure M11.31:** Compressed GRP grids

### M11.2.4.6 Composite Modular Acoustic Enclosures for DG Sets

The Composite modular acoustic enclosures for DG (Diesel Generator) sets are shown in Figure M11.32. The (Stationary) Diesel Generator (DG) sets used to control of Noise Pollution.

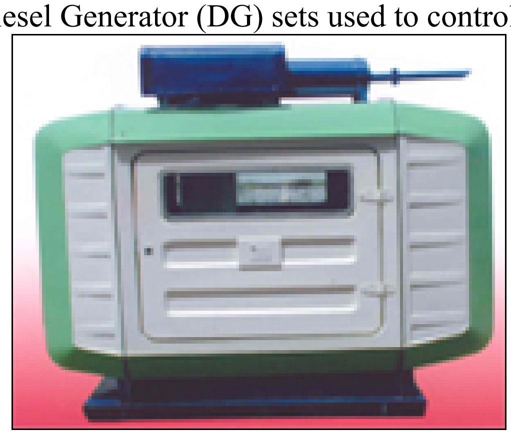

**Figure M11.32:** Composite modular acoustic enclosures for DG sets

The project was launched in partnership with M/s. Supal FRP Pvt. Ltd, Hyderabad with design inputs from the Industrial Design Centre (IDC) of IIT-Bombay. The project aims at designing & developing composite modular acoustic enclosures for DG sets of capacities of 15 KVA & 100 KVA to meet 25 dB noise attenuation levels as prescribed by Environment (Protection) Act, 1986. A prototype composite enclosure for 15 KVA DG set was successfully tested and certified by the Naval Science & Technology Laboratory (NSTL)-Visakhapatnam, an agency authorized by the Govt. of India, for meeting the required noise level. The enclosure was supplied to M/s

Kirloskar Oil Engines Ltd., Pune for testing and its performance was found quite satisfactory. Negotiations with potential buyers for commercial exploitation of the product are currently underway. The prototype composite enclosure for higher rating DG sets (75-125 KVA) has also been developed. It's testing & approval is expected to be completed by end May 2005. The composite enclosure offers resistance to corrosion and provide high internal damping & low noise transmission. In order to achieve the required noise attenuation, insulation with FT-70 foam has been provided at desired locations. The foam is non-ignitable type, easy to fix, light in weight and it can also withstand temperature up to 170 $^{0}$C.

#### M11.2.4.7 Composite Sky Bus Coach

A unique idea in mass transit: the **'Sky Bus'**, which is all set to bring in a revolution in mass transportation system was conceptualized by Konkan Railway Corporation Ltd. Sky Bus coaches, suspended from bogies, would run on overhead rails running along the length and supported over vertical columns at regular intervals in the road median. Each coach is designed to carry 150 passengers and a set of two coaches would run in tandem. A project was launched in association with M/s. Kineco Pvt. Ltd., Panaji with technology support from IIT-Bombay for mechanical & structural design of Sky Bus coach. While most of the coach (exterior & interior) is made of composites & plastics, the entire load would be carried by SS structure, sandwiched between the composite skins. Sky Bus coach fabricated with improved design & safety features was delivered in August 2004. Trial runs for the Sky Bus have been reported as successful; it had covered a distance of 1.6 Kms. and reached the maximum speed of 70 Kms/hr. In addition, the suspended behaviour of the Sky Bus had proved satisfactory. Composite Sky Bus coach has contributed significantly to its lightweight & aesthetics. Konkan Railway would be licensing Sky Bus technology for commercial usage to agencies in India or abroad.

#### Conclusion

The Advanced Composites Programme activities have proliferated encompassing number of composite applications and its presence is now being felt across the large geographical canvas of the country as well as diverse user segments. An efficient mechanism such as this has been successful in infusing the knowledge component to industrial practices. Effective knowledge networking by the programme among the academia/research institutions, standards & certifying agencies as well as the experts from the actual users has gone a long way in reducing product development cycle time and thus reaching the value-added products to the market in time.

## M11.2.5 Composites for Offshore Applications

### Introduction:

Composites are fast taking over as superior alternative to other traditional materials even in high pressure and aggressive environmental situations. Applications of composite are increasing tremendously along with the concurrent need for knowledge generation in the area. With technology innovations and developments in processes and products, composites have become attractive candidates for applications in oil gas, piping system, topside applications, down-hole tubing in sub-sea, and others.

Composites meet diverse design requirements with significant weight savings and exhibit high strength-to-weight ratio compared to conventional materials. Composites have proved to be a worthy alternative to other traditional materials even in the high-pressure and aggressive environmental situations. Besides superior corrosion resistance, composite materials exhibit excellent fatigue performance, good resistance to temperature extremes and wear, especially in industrial sectors. The tailorability of composites to suit specific applications has been one of its greater advantages such as imparting low thermal conductivity and low coefficient of thermal expansion, high axial strength and stiffness etc.

Composites have found extensive applications in the oil and gas industry since last two decades. Significant advances have been made in the areas of composite pipe work and fluid handling. The high cost to replace steel piping in retrofit applications and increased longevity in new construction are driving the use of composites, which withstand severe conditions as experienced in offshore environment. In the offshore oil and gas industry, the cost of manufacturing and erecting oil rigs could be reduced significantly if heavy metal pipelines could be replaced with lighter ones made of composites. Composite pipes also could be used for fire water piping, sea water cooling, draining systems and sewerage. The cost advantages of composite products are much greater when they replace expensive corrosion-resistant metals such as copper-nickel alloys, duplex / super duplex stainless steel, titanium etc. used in offshore platforms for various applications. Their resistance to corrosion helps in improving reliability and safety and also leads to lower life cycle costs. These results in reduced problems, like corrosion and blockage of fire lines, reduction in structural support sizes and material handling during construction.

Applications of composite piping are increasing tremendously along with the concurrent need for knowledge generation in the area. Research at the Composite Engineering and Applications Center of University of Houston includes prediction of life expectancy, joining technology, inspection methods, standardization of materials, and database development. The Marshall Space Flight Center, Louisiana State University and Specialty Plastics Inc. at Baton Rouge are working on high-performance composite materials to dramatically enhance the physical properties of hardware used in offshore oil drilling rigs. With technology innovations and developments in processing/products, composites have become an attractive candidate for topside applications, down-hole tubing in sub-sea and others.

The selection of suitable resin plays an important role for imparting durability of the composites when exposed to aqueous fluids. The important issues relating to materials selection are smoke and toxicity in fires, mechanical properties including resistance to impact and adverse environments.

### M11.2.5.1 Composite Piping System

#### M11.2.5.1.1 Composite Pipes and Pipe Fittings

On assessing greater application potential for composite piping system, a new project has recently been envisaged under the Advanced Composite Programme in partnership with the industry. The project aims at design & development of glass-reinforced epoxy (GRE) pipes &

pipe fittings as per API standards by using CNC filament winding system. It is proposed to develop a 2-axes CNC filament winding system along with CADWIND software for fabricating long pipes and 6-Axes filament winding system for fabricating pipe fittings. The GRE piping system could be effectively used in oil refineries, offshore platforms, desalination, chemical/ pharmaceutical industry, sewerage etc.

Glass Reinforced Epoxy (GRE) piping system offers complete solution for offshore environment against highly corrosive fluids at various pressures, temperatures, adverse soil and weather conditions (especially in oil exploration, desalination, chemical plants, fire mains, dredging, portable water etc.)

**Figure M11.33:** Composite piping system

GRE pipes are commonly used in oil transportation where resistance to crude oil, paraffin build-up as well as ability to withstand relatively high pressures is required. GRE piping system is also being used on offshore rigs for sea water cooling lines, air vent systems, drilling fluids, fire fighting, ballasts and drinking water lines in offshore application. The lightweight helps reduce heavy and expensive construction cost. Established Oil fields use GRE pipes for high pressure and steam injection lines for the recovery of oil preserves. GRE piping system can withstand the detrimental effect of brackish water when expelled under pressure from fire mains. The effect of rupture free GRE pipes under such shocks makes the system more reliable. The chemical resistance & service temperature of such composites in a particular fluid depends on resin formulations, additives used etc.

GRE pipe is commonly manufactured by filament winding technique. A typical GRE pipe is fabricated with an optimum wind angle of ± 54.75° to the longitudinal (0°) axis. The filament winding helps in providing better strength & stability for internal and external loadings in both the circumferential and longitudinal directions for the pipes and pressure vessels. Such wound pattern attains resistance to high internal pressures, thermal variations and the impact loads induced by thrust due to water pressure. The appropriate joining procedures for composite piping, supporting systems etc. assume importance for better system performance.

In order to ensure high degree of stability and safety, generally filament wound fittings such as elbows, T-joints, laterals, reducers, crosses and Y-joints are made of same materials used for fabricating the composite pipe itself. The proven corrosion resistance, strength and light weight of composite piping coupled with increased confidence level has been instrumental in reducing load and cost on off-shore platforms. Standards for the use of composite piping and qualification procedures are being facilitated by various certifying agencies.

In general, three types of joining techniques are adopted for composite piping viz. adhesive bonding, laminating type (butt & wrap joints) and mechanical means of jointing (rubber seal joint or the threaded joint). For higher pressure applications, socket and spigot joints with moulded threads are successfully used, sometimes in conjunction with a thread sealant and adhesive. The thread design is often similar to the API tapered threads used with steel tubing. For evaluating the structural integrity of piping system, hydraulic test is carried out at 1.5 times the operating pressure.

### M11.2.5.1.2 Wrapping it up

Efficient and economical adaptation of composite materials to offshore applications is becoming an attractive research area. The important issues such as the aging effects in a marine environment and the load transfer between different fibers have to be dealt with in designing & fabricating composite products for offshore applications. These issues are studied with an integrated experimental/ analytical approach. With the growth in petroleum sector, the demand for fiberglass products have increased manifold. Also the amount of energy required for fabricating FRP composite materials for structural applications with respect to conventional materials such as steel & aluminium is lower and it thus works for its economic advantage.

Until recently, the use of high performance GRE piping was demonstrated for **onshore fluid transport** (i.e. oil, fresh water, injection water, seawater and other fluids). Efforts were being directed by the composite industry to extend usability of GRE piping for aqueous fluids (fire water, aqueous waste, ballast water, seawater cooling etc.) in transport on offshore platforms.

The weight of the topside assembly could drastically come down by using composite products such as pultruded glass/phenolic gratings for floors, walkways and handrails, along with enclosures and heat protection walls etc. Composites have been successfully demonstrated for applications such as accumulator bottles for riser tensioning systems, blast relief systems, fire walls, enclosures, modular housing panels etc.

### Top Side Applications

Composite grids/gratings, hand rails, cable trays, ladders, decking, flooring have been used on fixed and floating off-shore platforms world over for more than two decades. In topside applications, the inherent corrosion resistance of composite materials reduces life cycle costs by minimizing its maintenance. BP-Amoco had totally replaced metallic grids/gratings by the composite ones in two small-scale off-shore platforms in shallow water for technology demonstration. Low cost, minimum topside weight and ease of transport were important features in their monopod design construction.

### M11.2.5.2 Composite Grids/Gratings

Conventionally, grids/gratings are made of mild steel/cast iron. Due to the limitations on corrosion resistance, weight, durability, lifecycle costs etc. for the metallic gratings, composite grids/gratings perform much better due to their superior properties under aggressive environments as in chemical process industry.

**Figure M11.34:** Composite handrails and grids/gratings

The Figure M11.35 shows the Pultruded grids/gratings.

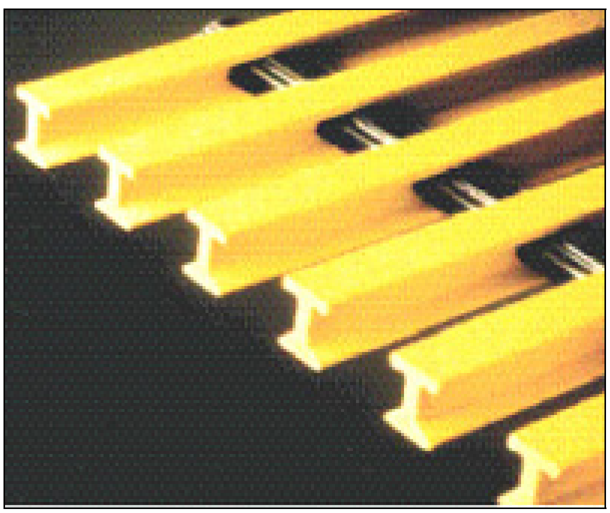

**Figure M11.35:** Pultruded grids/gratings

Worldwide many industries are manufacturing pultruded or compression moulded composite grids/gratings for their applications as industrial walkways, hand rails, ladders, cable trays, etc. in chemical/pharmaceutical, transportation & infrastructural sectors. The performance of the composite product mainly depends on the process of fabrication. The pultruded FRP grating is an assembly of pre-shaped FRP pultruded sections joined together by various mechanical means.

Pultruded structural profiles provide extremely useful options to offshore designers. Pultruded products due to high fibre-to-resin ratio (70:30), helps in achieving higher load bearing capacity. Pultruded gratings have longer span with less deflection as compared to moulded gratings.

The pultruded grating panels can easily be cut and modified to fit almost any plant requirement. In recent times phenolic gratings have achieved significant offshore usage in situations where fire integrity is important. The main advantage of phenolic gratings lies not only in their performance during fire but in their ability to retain significant level of functionality after fire exposure including low smoke emission. The Compression moulded grids/gratings are shown in Figure M11.31.

On the other hand, compression moulded gratings have high resin content (fibre to resin ratio of about 60:40) – this contributes to greater corrosion resistance properties compared to pultruded gratings. Bi-directional reinforcement in moulded gratings leads to higher impact strength. The grating limits the use of mechanical fasteners for fixation at any desired location. These types of gratings are used mainly at splash zones in offshore platforms.

### M11.2.5.3 Composite Ladder and Handrail Components

Composites enjoy a significant market share of industrial ladders in replacing aluminium and wood in residential ladders. The ladders were originally developed for electrical utilities but have increasingly gained acceptance for general industry & residential uses. The Figure M11.36 shows the fiberglass ladder system.

**Figure M11.36:** Fiberglass ladder system

Composite ladders are stronger than wood or aluminium and do not absorb water, rot or corrode. The products could be pigmented with a suitable colour along with the resin during the pultrusion process. With the colour throughout the part, there is no chipping or peeling. Unlike aluminium, fiberglass has excellent insulation properties which substantially reduce the hazard of electrocution by contacting high voltage power lines. For rough jobs where a ladder takes a beating, composite provides the ultimate ruggedness and long-term durability. The Figure M11.37 shows the Hand rails made up with composites.

**Figure M11.37:** Hand rails

Strong-well, a composite ladder manufacturer from North America has designed & developed ladder rails for a variety of uses and requirements including stepladders ranging from 3 to 12 feet, extension ladders that stretch up to 40 feet, articulating ladder, step-stands and mobile maintenance platforms.

### M11.2.5.4 Flexible Thermosetting Tube

Composite coil tube replaces the existing steel coil tubing for high pressure down-hole applications in offshore platforms. The tube can be coiled or uncoiled on a drum and can easily be transported to the desired location of the wells. The Figure M11.38 shows the Coil of composite tubes.

**Figure M11.38:** Composite coil tubes

The tube comprises of thermoplastic liner at inner surface over-wound with a structural thermosetting laminate. Flexible tubing can be classified into two categories viz. bonded & unbonded type. In case of bonded coil tube, the thermoplastic liner and structural laminates are bonded together as one unit. On the other hand, unbonded tubing has flexibility to have a relative movement between each other.

Unlike steel coil tubes, composite tubes are effective for their insertion in horizontal wells. Flexible thermoset coil tubing can withstand high pressure rating up to 500 bars. In general, E-glass is used as the reinforcement but for specific applications carbon fibres could be used.

The liner material can also be tailored to suit the application requirement. At present a few composite components are being used by various industries for flexible riser construction. Until now the use of flexible coil tube has been restricted to below 100 mm diameter. However, future developments are underway for exploring the usage of composite tube for down-hole applications.

### M11.2.5.5 Composite Pressure Risers

The Figure M11.39 shows the Caissons at offshore platforms.

**Figure M11.39:** Caissons at offshore platforms

Composite riser is the pipeline that connects the rig of the water surface to the well bore at the seabed. They must separate the oil, gas and drilling fluids from seawater. The weight of riser can drastically come down with the use of composite material as alternative to heavy metallic risers. The composite risers could be designed to withstand highly corrosive chemicals, salts and fluids under different environmental conditions. The durability and life cycle costs in offshore platforms can be improved.

### High Pressure Accumulator Bottles

To accommodate the relative motions between the platform and the riser, in case of tension leg platforms, a telescopic joint is used at the upper extremity of each riser. These joints require a tensioning system capable of storing and releasing large amounts of energy as movement takes place. Tension is applied through gas-pressurized tensioners with accumulator bottles. In older designs steel accumulator bottles were used but recently considerable success has been achieved with composite bottles. The composite bottles offer significant weight and cost saving being less than 1/3 of the weight of equivalent steel bottles. These bottles can withstand very high internal pressures.

### Composite Caissons and Pull tubes

Caissons are attractive applications for composites as an offshoot of GRE piping technology. In general, caissons are used to provide the service fluids to enter or leave the sea. These are located at splash zones in the sea water. Caissons are designed to withstand flexural fatigue loads created by waving loads and corrosion to aqueous fluids in the sea.

**Composite Applications for Off-Shore**

A few current applications of composites for off-shore are listed in Table M11.20.

| Sl. No | Application |
|---|---|
| 1 | Composite Grids/ Gratings |
| 2 | Hand rails & Ladder Components |
| 3 | Aqueous Piping System |
| 4 | Water & fuel storage tanks, Vessels |
| 5 | Low pressure composite valves |
| 6 | Spoolable type thermosetting tubes |
| 7 | Sump Caissons and pull tubes |
| 8 | Cable support systems |
| 9 | Modular paneling for partition walls |
| 10 | High pressure accumulator bottles |
| 11 | Flexible & Floating Risers, Drill pipe |
| 12 | Sub – sea structural components |
| 13 | Boxes, housings and shelters |
| 14 | Fire water pump casing & sea water lift pump casing |
| 15 | Tendons |
| 16 | Offshore bride connecting between platforms |
| 17 | Blast & Fire protection |

**Table M11.20:** Off-shore composites applications

## M11.2.6 Towards Faster Trains: Role of Composites

Composite materials are increasingly being used in the Railway industry where the resulting performance improvements are significant. Weight saving of up to 50% for structural and 75% for non-structural applications bring in associated benefits of high-speed, reduced power consumption, lower inertial, less track wear and the ability to carry greater pay-loads. A modular construction (interchangeable components) of composites is easy to handle & install and offers rapid fitting. By impating fire resistant characteristics to composites, it can ensure full safety to the entire system. Composites find major applications in passenger coaches worldwide for excellent structural properties and improved aesthetics. For mass transit systems, lighter bodied coaches are instrumental for achieving higher speed. Now, more and more parts are made of GFRP, which also resists corrosion and has excellent workability. The train made up of composites is as shown in Figure M11.40.

**Figure M11.40** The train made up of FRP composites

A fast paced indigenous development and induction of composites is required urgently for Indian Railways for various potential applications. In view of the crucial need for developing indigenous capability in composite technology, the Advanced Composites Programme of Technology Information, Forecasting and Assessment Council (TIFAC) has launched quite a few projects focusing on development of composites for application in Indian Railways. The following section would highlight some of the successful case-studies:

**FRP Gear-Case for Railway Locomotives**

The project was launched at M/s Permali Wallace Ltd., Bhopal with technology support from the Regional Research Laboratory, Bhopal. The project aimed at developing FRP gear-cases for the traction motors for diesel and electric locomotives as replacement of existing steel gear-cases. Unlike steel gear-case, FRP gear-cases prevent the leakage of lubricating medium and are safe from damages by ballast hits. These gear-cases have longer service life compared to steel ones. In addition, weight saving to the tune of 400 Kg. Per six-axle system has been achieved. The FRP gear-cases on extensive and large-scale field-trials are now being inducted by the railways.

**FRP Sleepers for Railway Girder Bridges**

The project aimed at fabricating composite sleepers to replace conventional wooden sleepers on girder bridges and offer good rail holding, bearing toughness and vibration absorption characteristics. The project was instituted at Research and Development Establishment (Engineers), Pune in active collaboration with Bridges and Structures Directorate of RDSO, Lucknow. These sleepers due to their long durability and identical physical properties as that of wooden sleepers offer high operational efficiency, improved maintainability, long life and lesser replacement efforts. The full-length FRP sleepers developed by Resin Transfer Moulding (RTM) process as per RDSO specifications have withstood the pulsating test for simulating loading and the static load as specified by RDSO. The sleepers after extensive tests at RDSO, SERC-Chennai and also at actual field conditions are being inducted by the railways. The Railway Grider Bridges made up of FRP Sleepers is shown in Figure M11.41.

**Figure M11.41** FRP Sleepers for Railway Girder Bridges

### Jute-Coir Composites Boards

**Jute-coir composite** boards (Figure M11.42) with oriented jute face veneer and **coir/rubber** wood inside were developed with Natura Fibretech Pvt. Ltd., Bangalore. Two major categories of composite boards namely, **coir-ply boards** (jute+rubber wood+coir) as plywood substitute and natural fibre reinforced boards (jute+coir) as MDF substitute were developed with superior performance, properties and great price advantages. The natural fibre composite boards have attractive natural look as it can be painted, polished or laminated at will. They are water proof with minimum surface absorption, strong and rigid, environment-friendly & can be nailed, screwed and cut sharply. Jute-coir boards have been inducted by Indian railways for their applications as berth backings and partitions in railway coached. The panel & flush doors made of jute-coir composite boards have also been developed.

**Figure M11.42**

### Energy efficient FRP Axial Flow Fans

The project was launched in partnership with M/s Parag Fans & Cooling Systems Ltd., Dewas. The technology support in terms of aerodynamic design of axial flow fan impellers, composite structural design, fabrication process and performance evaluation of fans was provided by the Department of Aerospace Engineering, IIT-Bombay. Five types of fans for cooling towers, mine ventilation, textile humidification, radiator cooling for diesel locomotives & air heat-exchangers were developed and tested successfully; an efficiency differential of around 20-30% with commensurate energy saving was achieved over conventional fans with aluminium impellers. The energy efficient FRP axial flow fans have been inducted for cooling tower, mine ventilation and other applications by Reliance Industries, WCL, Indian Railways etc. The Figure M11.43 shows the Axial-flow fan made up of FRP composites.

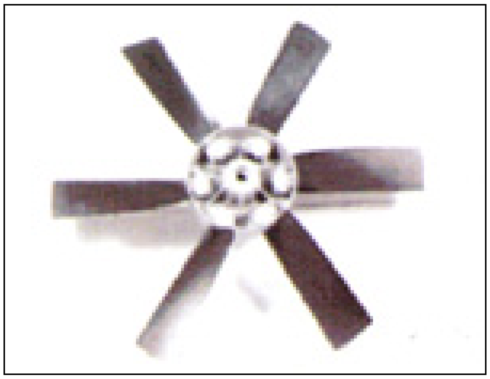

**Figure M11.43** FRP Axial Flow Fans

**Development of FRP Pultruded Profiles**

The project was launched in partnership with M/s Sucro Filters Pvt. Ltd., Pune and technology support from the National Chemical Laboratory, Pune. FRP profiles for industrial gratings, solids rods for electrical insulation, cable trays, ladders etc were developed with excellent surface finish and flame retardancy as per international standards. The profiles developed under the project have potential applications in railways for frame sections for doors & windows, luggage racks, strips, ladders, rods etc. The Company has already started supplying pultruded sections for toilet door side channels for the coaches to Integral Coach Factory, Chennai.

**FRP Modular Toilet Units for Railway Coaches**

The project was launched in partnership with M/s Hindustan Fibre Glass Works, Vadodara and technology support from IIT-Bombay. The Industrial Design Centre of IIT-B helped in concept development, detailed design and preparing a scaled down version with improved aesthetics & ergonomics. The Department of Aerospace Engineering of IIT-B extended assistance in terms of mechanical/structural design, support arrangement, reinforcement lay-up, process of fabrication and providing QA/QC norms for modular toilets. The FRP toilet unit developed under the project consists of the flooring trough, one L-shaped side-wall another C-shaped side wall and roof. All the four parts could be fastened together and assembled in a short span inside the coach. The FRP toilets is lightweight, corrosion resistant, fire retardant, has longer life with easy maintainability.

A large number of FRP toilets have been already fitted to new passenger coaches at ICF. The project bagged the Certificate of Merit under the prestigious National Award for Excellence in Consultancy Services-2001given by the Consultancy Development Centre of Department of

Scientific and Industrial Research, Govt. of India. The Figure M11.44 shows the Toilet Units for Railway Coaches made up of FRP Modular.

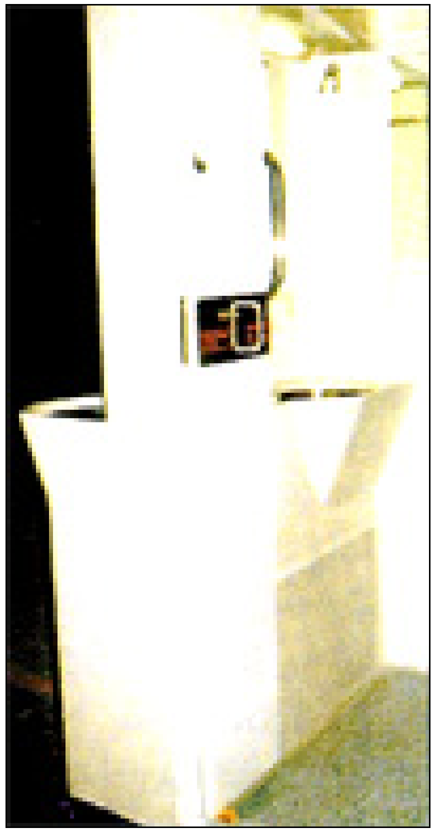

**Figure M11.44** FRP Modular Toilet Units for Railway Coaches

**FRP Main Door for Passenger and EMU Coaches**

Lightweight, cost effective, and corrosion resistant FRP main doors for passenger and EMU coaches as replacement of heavy steel doors were designed and developed in partnership with M/s Urbane Industries, Chennai and technology support from IIT-Bombay. The doors call for less maintenance requirement with reduced wear and tear of mechanical components. They also provide excellent crash worthy features. Over 3000 doors have so far been inducted by Indian Railways. The Figure M11.45 shows Main Door for Passenger and EMU Coaches made up of FRP modular.

**Figure M11.45** FRP Main Door for Passenger and EMU Coaches

**Under-Carriage Water Tanks**

This project launched by in partnership with M/s Kineco Pvt. Ltd., Panaji and IIT-Bombay aimed at developing filament wound pressure vessels such as under carriage FRP tanks (450 mm dia) with 2.0 bar operating pressure to be fitted in railway passenger coaches for water supply to the toilets. As an integral part of the project, a multiple axes CNC filament winding facility was designed and fabricated for the first time in the country by CNC Techniques Pvt. Ltd., Hyderabad. Two prototype under-carriage tanks, fabricated by 4-axis CNC filament winding machine, are now being fitted to a passenger coach for actual field trials.

Composites have been identified a wonder material especially for the transportation sector all over the world. In India, the composites have a unique edge over metals in railways as they prevent pilferage due to their non-reusage. The usage of composites is expected to grow manifold and there would be exacting needs from the local suppliers for components of stringent quality. This would urgently call for an infusion of technology & expertise to the composite fabricators of the country.

## M11.2.7 Composite Materials for Orthopaedic Aids

### M11.2.7.1 Introduction

**Prothetists** and **Orthotists** help people who acquire disability or were born with physical defects, by fitting them with artificial supports. Prosthesis is an artificial substitute for a missing part of the body. The artificial parts that are most commonly thought of as prostheses are those that replace lost arms and legs, but bone, artery, heart valve replacements, artificial eyes, teeth are also termed prostheses. The term is sometimes extended to cover such things as optical lenses and hearing aids, which improve the functioning of a part. The medical specialty that deals with prostheses is called prosthetics.

For thousands of years, inventors have tried to replicate what nature cannot replace. Prosthetics have been used since at least 300 BC, when crude devices containing metal plates hammered over a wooden ore, were attached to an amputated limb. The origin of prosthetics as a science is attributed to the 16th-century French surgeon Ambroise Paré. The solid metal hand of the 16th and 17th centuries later changed to a single hook or a leather-covered, nonfunctioning hand attached to the forearm by a leather or wooden shell. Advances in the science of prosthetics burgeoned during and immediately after World Wars when large numbers of people need to be fitted with artificial limbs. New lightweight materials and better mechanical joints were introduced after wars. The advancement of prosthetics has been supplemented by interactions between new surgical techniques, the availability of new materials for making the devices, and innovative engineering concepts. The common surgical practice for compound fractures was to amputate at the thigh. With the advancement in the surgical techniques, the patient now had a foundation for fitting an artificial limb instead of cutting off the entire leg.

### New materials for Prosthetics

Bio-medical prosthetic devices are artificial replacements that are used in the human body to function as original parts. Materials used for such prosthetic aids must non-toxic, biologically and chemically stable, and have sufficient mechanical integrity and strength to withstand physiological loads. Relevant materials belong to many classes including synthetic materials such as metals, polymers, ceramics, glasses, composite materials and natural materials such as polysaccharides, proteins, enzymes and lipids. Corrosion is one of the major processes that cause failures of the implant devices. The necessity for innovation and development of smart materials/coatings with improved functional and bio-compatible properties, either by employing surface engineering or through improving process parameters has been felt. Materials like 316L stainless steel, Co alloys, Ti alloys, ceramics and polymers (PMMA, PE, poly-sulphone, PTFE) are being used extensively.

Composite material has been identified as the new class of synthetic bio-materials. An important development has been the usage of carbon-fibre reinforced polymer-matrix for composite limb. The matrix includes polysulfone or poly-ether-ketone. The uses of these materials are ongoing efforts to make artificial limbs and braces lighter result in great benefit to those needing such appliances. Lighter weight prosthesis also greatly reduces sores and abrasions that were more frequent with the earlier heavier prostheses.

The rehabilitation industry is moving towards composite material, as they are lighter in weight, easier to work with & more durable, as lighter prosthesis requires less energy expenditure during walking, running and other activities, weight is extremely important in an artificial leg. A lighter prosthesis reduces the shear forces and **pistoning motion** about the residual limb/stump. The reduction of weight results in a more comfortable fitting prosthesis. In addition, the reduction of weight eliminates the need for auxiliary suspension straps and waist belts. Thus, it is imperative to develop materials for lighter & stronger products with the mechanical properties matching those of the bone in order to provide a uniform distribution of stresses (load sharing). Over the past twenty years, with the rapid development of new plastics and metal alloys, such as co-polymer, titanium etc. there has been significant efforts to make lighter and stronger products.

Composite is made of fibrous materials held in place by a matrix system. The matrix system grips or supports the fibrous material and transfers the stress to the fibre to carry the load. There is a wide array of matrix materials available like polymers, metals & ceramics. They derive most of their unique characteristics from the reinforcing fibres. Fabricating a composite part is simply a matter of placing & retaining fibres in the direction & form that provides specified mechanical characteristics while the part performs its design function. Reinforcements are supplied in a variety of types and physical forms, which determine the physical performance characteristics of the final components. Glass fibre is the most widely used reinforcing agent. Aramid fibres contribute lightweight in combination with high impact performance, while carbon fibres confer high stiffness in conjunction with high strength. Most reinforcing fibres are available in continuous, chopped and woven (fabric) forms. Fabrics confer directional strength characteristics and different weave patterns (unidirectional, multi-axial, etc.) are employed to take advantage of this.

## Indian Scenario

In developing countries like India, road accidents inflict grievous injuries to people. Loss of a limb by amputation can be a traumatic experience for such accident victims. Other factors such as congenital defects, bone deformities and constricted bone growth also add to the number of physically challenged people in our country.

Artificial Limbs Manufacturing Corporation, working under the Ministry of Social Justice & Empowerment, is engaged in manufacturing aids & appliances required by orthopaedically & visually handicapped persons. The product range includes orthotic & prosthetic appliances for both upper and lower extremities, spinal braces, wheel chairs, crutches etc. ALIMCO manufactures both above & below knees artificial leg made of wood and also markets 'solid ankle & cushion heel' type of foot.

The Corporation has helped established 170 limb fitting centers in various parts of the country to ensure proper fitting of aids and appliances. They also conduct camps in association with various voluntary agencies, for fitting aids and appliances in rural and semi urban areas of the country.
The **Mahaveer Vikalang Sahayata Samithi (MUKTI)**, Jaipur is engaged in creating awareness among the unfortunate orthopaedically handicapped people. MUKTI extends adequate medical attention and care to these physically handicapped.

The Mahaveer Vikalang Sahayata Samithi, Jaipur developed an artificial leg that functioned better then the limbs available before. The MUKTI limb, made of high-density polyethylene (HDPE), is lighter in weight and looks like a natural foot. This is waterproof, simple, durable and utilizes very simple technology for its fabrication. The design of this foot permits squatting and walking on uneven ground. In addition, calipers and other rehabilitation aids or appliances, medicines and special shoes, etc. are also provided to polio affected and other disabled persons. MUKTI's technicians have introduced improvisations for knee-joints and lightweight calipers for children.

The following material is used to fabricate MUKTI limb:

- Skin coloured HDPE.

- Jaipur foot, which is flexible and shaped like the human foot (up-to the ankle), giving the natural "feel" to the user.
- Leather straps to be fitted onto the socket at the knee area to strap the limb onto his thigh.
- Knee joints, for limbs made for amputations above the knee.

**Rotary Jaipur Limb** project aims at providing physical, economic and social rehabilitation to physical disabilities, enabling them regain their confidence to become useful members of the community. **Jaipur** is the birthplace of a prosthesis or artificial limb known as the **Jaipur foot**, which has revolutionized the life of millions of physically handicapped. The Jaipur foot is made of rubber, wood and aluminium and can be assembled locally. The foot is light in weight, economical and comfortable to walk with. There is an ongoing effort to improve the Jaipur foot and create new artificial limbs that will be as real and useful as humanly possible.

The artificial leg developed initially in the world has been an exoskeleton, which was more of a cosmetic replacement than a functional one. Though these appear like natural limbs, they cannot provide normal gait to the handicapped and also comfortable usage. The world has already directed its efforts to fabricate endoskeleton type artificial limbs. The endoskeleton replicates the functionality of bones for load bearing and involves proper mechanical joints for normal gait. It essentially consists of a tubular unit, which meets the mechanical properties of the bones in order to provide uniform distribution of stresses (load sharing). The entire tubular unit is provided with a durable and cosmetic leg shaped covering made of polymeric foam. The endoskeleton type of artificial limbs uses more and more light weight composites with carbon or glass fibre and polymer matrix.

## Note: Italic font information is addition/advanced material.

### *M11.2.7.2 Case Studies: Composite Materials for Orthopaedic Aids*

#### *M11.2.7.2.1 Case Study 1: Development of Below-Knee Composite Artificial Limbs*

*In India, commonly used artificial legs are exoskeleton type made of high density polyethylene. Though the imported endoskeleton types of limbs are available in India, they are very expensive. As physical deformities aggravate the economic woes of the victims in our country, it calls for an indigenous development to restore the functional normalcy of physically challenged people at an affordable price. In view of the crucial need for developing indigenous capability in composite technology, the* ***Advanced Composites Mission*** *was launched by the Department of Science and Technology (DST), Govt. of India. The Mission mode activities are being implemented by* ***Technology Information, Forecasting and Assessment Council (TIFAC)****, an autonomous organization under DST. The Mission initiatives encompass the entire gamut of composite product developmental projects ranging from hi-tech brake-discs for aircraft to down-to-earth societal applications such as artificial limbs to alleviate human suffering.*

*On assessing the present scenario towards improving design, functional needs & aesthetics of the artificial limbs in India, the Advanced Composite Mission of TIFAC /Department of Science and Technology, Govt. of India launched a project on developing '****endoskeleton type below-knee***

***artificial limbs for physically handicapped****' in collaboration with M/s. Mohana Orthotics & Prosthetic Centre, Chennai and with technology support in terms of design, prototype development and complete testing from Madras Institute of Technology (MIT), Chennai. The Bio-Medical Engineering group of IIT-Madras also helped in design reviews, advised on test plans and methods.*

*Below-knee endoskeleton type artificial limbs, developed under the project are lighter in weight and better appearance than ever before with improved gait for the patients. This below-knee endoskeleton limb consists of five parts:*

- *FRP tubular structure fabricated by filament winding of glass fibre in epoxy matrix*
- *Top & bottom connectors made by injection moulding of glass filled nylon*
- *Polyurethane foot with composite keel embedded in it and*
- *Polypropylene socket to accommodate the amputee stump*

*The socket made of polypropylene is patient specific and does not create any problems like pressure sores even for diabetic patients. The FRP tube connects the socket to the foot. All the five parts and the socket are adjustable to meet individual requirements and to take care of static & dynamic alignment patterns.*

*A very innovative design approach 'constant strength beam' has been adopted for designing FRP keel for providing improved strength and flexibility in the foot piece. A composite keel has been fabricated by compression molding technique. Provisions have been made to take care of the alignment when they are being fitted to the patient. The new polyurethane foot developed allows feet to press and spring on the ground very much like a real foot. All the five parts and the socket are adjustable to meet individual requirements and to take care of static and dynamic alignment patterns.*

*The evaluation of individual components and also of the entire endoskeleton assembly for compressive and bending strength has been carried out. A simulated endurance test has been conducted for guaranteeing minimum 5-year service life of the artificial limb considering average stance duration of 0.5 seconds for normal gait and three hours walking time per day thus testing the limb for 39.42 million cycles to simulate the life of 5 years. A 3-D modelling of the endoskeleton with all the embedded components considering actual properties of various materials was also carried out. The artificial limbs developed have high modulus, long-term dimensional stability, high fatigue resistance, long-term bio-stability excellent abrasion resistance and bio-compatibility.*

*The indigenously developed artificial limb looks like a natural foot; it is sturdy, durable, waterproof and made of locally available material. The unique design of this composite limb permits walking, cycling and even driving a vehicle by a person physically challenged otherwise. A whole lot of innovative technology inputs from MIT & IIT-Madras have been instrumental in developing a user friendly and world-class artificial limb with excellent market potential in India and abroad. The newly developed endoskeleton artificial limbs are much superior than the old wooden exoskeleton type of limbs. More than 500 nos. artificial limbs have been fitted to the* *patients from in and around Chennai, Delhi and also Gujarat earthquake victims. About 50 limb kits have been dispatched to Sri Lanka and Cambodia.*

*Such indigenously developed below-knee artificial limb cost maximum Rs.5000/- only as against Rs.40, 000/- for the imported ones.*

*The endoskeleton type below-knee artificial limb developed by Mohana Orthotics under the Advanced Composites Mission programme of DST/TIFAC has been awarded the prestigious **National R&D Award 2001** by the Department of Scientific and Industrial Research (DSIR), Govt. of India.*

### *M11.2.7.2.2 Case Study 2: Development of Carbon Fibre Composite based External*

### *Fixator Rings*

*Focusing on societal needs, the Advanced Composites Mission launched another project in collaboration with **M/s. SH Pitkar Orthotools Pvt. Ltd.**, Pune for developing orthopaedic appliances and instruments with carbon fibre composites as per the international standards and thereby offering improved rehabilitation systems. Under the project, instruments like osteotomes, chisels have been developed using **polyethersulphone (PES) matrix reinforced with carbon fibre** to make the handles. This makes the product lighter but of adequate strength to take beating with a hammer during surgical procedure. It is also radiolucent and dose not interferes with image intensifier for observing procedure on screen. Polyethersulphone is a high temperature engineering, thermoplastic, which can be used continuously at 180 $^{o}$C and can still support a load at 200 $^{o}$C. It is tough having high tensile and impact strengths. Polyethersulphone shows good resistance to chemical attack. The water absorption is low being about 2.3% at saturation. As the surgical chisels require high temperature sterilization, PES is found suitable for the purpose.*

*Appliances like limb reconstruction system, ring fixator system (half rings, short connection plates, foot rings, Italian femoral arches, long connection plates, and carbon fibre rods) were developed based on carbon fibre composites. This new material has been developed as a substitute for stainless steel currently being used for the external ring fixator for the bone-healing system.*

### *Ring Fixator*

*It is an exceptionally versatile circular external fixator. The system has good range of fasteners and other supporting devices of various sizes and lengths, which produce an excellent combination of bone segments including angulations, rotation, translation, lengthening and compression. The basic principle behind the use of this apparatus is tissue regeneration through the principles of distraction histogenesis of bone and tissues. The apparatus is quite stable permitting weight bearing and joint functioning during the treatment. This technique of fitting external fixator on human body is commonly known as Ilizarov technique.*

### *Ilizarov Technique*

*The technique, first developed by Russian surgeon G A Ilizarov in 1951 but which remained little known till recent times, is extensively used today to correct both congenital bone deformities and those acquired due to polio, bone infection and accidents. It has been used with great success for a wide range of limb disorders such as fresh fractures, disunited and infected fractures with gaps and deformities. This technique is able to fix bony fragments with minimal invasion of the tissues and retained function.*

*Ilizarov's method is a compound system consisting of rings and wires, in order to fix the bone. Extremity lengthening, deformity correction and reconstruction techniques are based on the principle of distraction Osteogenesis, which opens a new era, breaking the strict belief that bones cannot be lengthened. Extremity lengthening is performed by an osteotomy and gradual lengthening, while the created gap is filled with new bone (Osteogenesis). In this way, bone can be lengthened by 15-100% of its original length. This technique has already gained immense popularity in Mumbai, Bangalore and Chennai & is now becoming popular in Delhi as well.*

***How is it performed?***

*External fixators are appropriate in cases of open, comminuted, unstable fractures. Ring fixator is a set of around 20 simple mechanical devices including rings, threaded rods, nuts, bolts and hinges. The stainless steel pins are joined to steel rings/carbon composite rings with bolts and put under ideal tension. The two sets of rings are fixed at the two ends of a deformed bone. These rings are supported by special 2-mm thick pins those are drilled into the bone as well as manually adjustable threaded roads that connect the rings at the two ends. By gradually strengthening the two rings apart, pressure is exerted on the bone below, stimulating cell growth and elongation. Growth of the associated muscle, nerve, skin and blood vessel tissues takes place simultaneously. The patients are advised to distract the rods at the rate of 0.25 mm every six hours. The distraction is initiated at the recommended rate of 1 mm daily. On an average, it usually takes one month to increase the length by 1 cm. There is perfect lengthening without complications and every deformity can be corrected. The wires slightly larger than hypodermic needles cause minimal damage and have a low risk of infection.*

*The benefits associated with the ring fixators are the following:*

- *Simultaneous correction of multi-plane deformities*
- *Wide variety of indications, treatable with one system*
- *Provides stability and good alignment of fracture*
- *Early mobilization of adjacent joints*
- *Decreased risk of deep infection and nonunion*
- *Early patient ambulation*
- *Single surgical procedure*
- *Light-weight, high-strength and radio-lucent.*

***Other Benefits***

- *Minimal trauma of soft tissues*
- *Full or partial load bearing possible*
- *Quick healing through* ***vasculorization***

- *Axially directed load bearing*
- *Callus modulation by compression or distraction*
- *Small metal/tissue interface*

*However, Ilizarov method is not without its pitfalls. Sometimes the bony cut may heal too rapidly and may not allow the gap, and thus may prevent the new bone to form. This would require a repeat cut in the bone under anesthesia. Moreover, the wires inserted into the limb can cause potential problems such as injury to blood vessels and nerves entailing infection. While the former is rare and preventable by a thorough knowledge of anatomy, the latter can be treated with antibiotics. The versatility of the fixator permits fine-tuning and precise control over the process. The cost of this technique works out to be Rs.30, 000 to over Rs.1.00 Lakh, depending on the treatment duration.*

***Composite Ring Fixators***

*The conventional stainless steel external fixators are heavy for the patients. The external fixators made of composite are not only lighter but also due to their radiolucency, they enable the surgeons read the X-rays with better accuracy.*

*The importance of advanced composites for future lightweight materials is derived from the high stiffness combined with high strength and low density of fibre backbone. In this respect, carbon fibre surpasses the more economic glass fibre. More than 90% of the carbon-fibres are used today are high-tension fibres with a tensile strength of above 3500 MPa. The young's modulus of this type of fibres with values around 250 GPa is much higher than the values of the aramid and glass fibres.*

*Carbon fiber fabric when combined with high temperature epoxy systems produces composites having high flexural strength and modulus and tensile strength. They are also light weight, having a specific gravity of approximately 1.45 versus 1.90 for high strength epoxy glass laminates.*

*Under the project launched by the Advanced Composites Mission, the following items were developed using carbon fibre reinforced epoxies and polyethersulphone matrix:*

- *Ring fixator system like Italian femoral arches*
- *Long connection plate*
- *Foot rings*
- *Carbon fibre half rings*
- *Carbon fibre rods*
- *Limb reconstructive systems as external fixator*

*The above products developed under the project launched by the Advanced Composites Mission are being used extensively in India & abroad.*

*As of now, the imported fixators, by way of rehabilitation aids, have limited reach due to their high costs. This project has achieved, in a self-reliant fashion, to ensure that such rehabilitation aids reach the commoners.*

# M11.2.8 Composites: Automobile/Transportation Sector

## M11.2.8.1 Automobiles

Despite the potential benefits of lighter weight and durability resulting from corrosion resistance, advanced composites are not recognized as a material of choice in the near term for automotive applications. Significant changes on a broad spectrum would be required to make advanced composites attractive for widespread commercial use in cars and trucks. The principal barrier is the high cost of the raw & fabricated materials when compared to existing options.

However there are opportunities for advanced composites in specific components in the commercial automotive sector. In specialty vehicles of several types, produced in small numbers advanced composite materials have an opportunity to demonstrate their performance benefits, apart from the requirements of the competitive marketplace.

The composite industry worldwide is investing in process improvements for the moulding of polymer composites using forms of conventional E-glass in mid-level performance resins, both thermoplastic and thermoset. Automobiles segment of composites accounts for about 50% of the thermoplastic and 24% of the thermoset composite market in the world. Glass-reinforced thermoplastic polymer is a promising material for weight reduction because of the relatively low cost of the fibre, its fast cycle time and its ability to facilitate parts integration. Carbon fibre reinforced polymer is another candidate but will require breakthroughs in cost and manufacturing techniques to be cost effective for high volume production.

Pressure for reductions in energy use and lower emissions levels makes advanced composites a favourable option for the automotive sector. The composites usage in this sector is estimated around 3500 TPA by 2005 AD. The likely future business opportunities in automotive sector are mentioned below:

- Pultruded Driveshafts
- RTM Panel
- Fiber Glass/Epoxy Springs for Heavy Trucks and Trailers
- Rocker Arm Covers, Suspension Arms, Wheels and Engine Shrouds
- Filament-Wound Fuel Tanks
- Electrical Vehicle Body Components and Assembly Units
- Valve Guides
- Automotive Racing Brakes & Train Brakes
- Clutch Plates

Though not much progress has been made in India towards product development efforts, this area merits attention and holds a lot of promise. The prospects of export of composites currently are low because India does not enjoy any comparative advantage either in raw materials or in processing costs.

The other area which holds promise for the coming decade is the use of metal matrix composites for certain auto components. The main advantage of such composite material systems is that their physical, mechanical and thermal properties are tailorable and can drastically surpass those of reinforced metals. MMC can be extruded, forged, investment cast, rolled, machined, and heat treated. Transportation applications represent one of the largest demand segments for MMCs, and include turbine and combustion engine components, disc brakes and brake parts, and drive shaft components. Because of their unique properties, metal matrix composites are also gaining interest in a host of high performance applications across a number of industries. Demand for MMCs is growing in the transportation, electronics, telecommunications and pollution control sectors. It is expected that MMCs may experience a double-digit increase across these industrial markets through 2003.

### M11.2.8.2 Marine

With composites exhibiting excellent resistance to the marine environment, their applications have made good inroads in the marine sector worldwide. Complex configurations and the advantages of seamless hulls were the main driving factors in the development of FRP boats. Racing power-boats employ advanced and hybrid composites for a higher performance craft and driver safety. Major structural elements viz. deckhouses, hatch covers, kings posts and bow modules appears to be very well suited for FRP construction. In India, composite applications in marine segment has made some beginning in the last decade in high speed boats, naval vessels, sail boats, fishing boats, high capacity trawlers, barges and other ship components. The consumption of composites by this industry is mainly glass fibre reinforced polyesters.

Advanced composites materials on vessels have a potential to reduce fabrication and maintenance cost, enhance styling, reduce outfit weight and increase reliability. The usage of composites is reckoned at about 750-1000 TPA by 2010 in India. Potential ship applications for composite materials are:

- Shafting Overwraps,
- Life rails, Handrails,
- Masts, Stacks and Foundations
- Stanchions
- Propellers vanes, Fans and Blowers
- Gear cases
- Valves and Strainers
- Condenser shells

### M11.2.8.3 Bicycles

Composite bicycle frames have been a largely American phenomenon, as a spin-off technology from the aircraft and boating industries. Manufacturing of composites requires greater technical expertise and investment for product development. Carbon composite bike frame is a complex structure with performance characteristics that include lightness, rigidity, durability, shock absorption etc. As composites fabrication offers variation over the length of the tube providing different fiber angles; the different plies, different ply thickness, and different combinations of materials. So the properties of the end product made from composites can be tailored to specifications. Hybrid fibre (carbon and aramid), carbon/kevlar epoxy materials are ideal composite materials for bicycle components. The composites are finding application in bicycle components such as

- Forks
- Handle bars and Connecting bar ends
- Seat posts

India is yet to make a beginning in utilizing the benefits of composites in bicycle sector. In the near future, India can visualize rapid penetration in the bicycle components market as well as finished cycles. This would however need the back-up of design/ processing technology of a high order, to be able to meet the international standards.

## M11.2.9 Electrical and Electronics

Composites equipped with good electric insulation, antimagnetic & spark-free, good adhesion to glue & paint, self-extinguishing qualities are used for the construction of distribution pillars, link boxes, profiles for the separation of current-carrying phases to prevent short circuits etc. The other potential applications of composites in this sector are:

- Third rail covers for underground railway
- Structures for overhead transmission lines for railway
- Power line insulators
- Lightning poles
- Power pole cross arms
- Fibre optic tensile members
- Switchgear frames
- Aerial lift-truck booms

The volume of usage of composites in this segment is projected to increase from the present level of 3000 TPA to about 5000 TPA by 2005 in India.

A major portion of early development and application of composites was focused on the electrical industry. Experimentation with material systems spawned a generation of composite materials which are widely used in material combinations that show optimum performance in the selected environment.

Electrical contacts are junctions at which current passes from one conductor to another. They are required to operate in varying conditions. The composites used have to withstand resistive or inductive loading, the environment controlled or highly corrosive conditions etc.

The exacting demand of contact technology necessitates the development of composite materials which combine high conductivity (both thermal and electrical) with high melting and boiling points for high current applications. Composites that are used as electrical contacts and those used to interrupt very high currents and sustain mechanical action are made from refractory metals combined with metals.

Sometimes high capacity current carrying terminals are made with very thin silver and nickel-copper material attached to the blade at the hinge.

Many composite materials used as sliding contact brushes are metals with graphite added on for lubricity. Graphite having lubricated property is used in many metals which function as sliding contact brushes, while a few are electro-graphite to give lubricity in absence of oxygen. Although various manufacturing methods exist, pressing and sintering are widely used for making metal graphite brushes if metal content is over 85%.

Composite materials are used in the instrumentation applications where rotational speeds are slow and hence, a steady resistance is needed for reducing electrical noise.

Chromium-copper is extensively used and shows excellent resistance to deformation during their service life and may be used in several combinations for balancing the temperature effects in welding assemblies in which components have different materials. These materials are heat treatable to get hardness and higher strength.

In tungsten inert gas welding, in which the electrode is non-consumable, few popular composites used are tungsten based. Tungsten composite types are popular because they retain a pointed-end, suited for welding in restricted areas like narrow joints in steel piping, and allow current density to be kept to a very high level throughout the operation.

Metal inert gas welding in which, the electrode is consumable, has a component which directs the consumable electrode wire through a nozzle, apart from supplying current to the wire. High conductivity copper is being used for contact tips, but composites are found to be increasingly suited for this purpose.

## M11.2.10 Chemical Industry

Supplemented by the advantages of composites of lightweight, mouldability, fire resistance properties, resistance to chemicals has made the material popular in the chemical industry. Composites are extensively used in industrial gratings, structural supports, storage tanks, scrubbers, ducting, piping, exhaust stacks, pumps and blowers, columns, reactors etc. for acidic & alkaline environments.

Some of the potential applications are:

- Composite vessels for liquid natural gas for alternative fuel vehicle
- Racked bottles for fire service, mountain climbing
- Double-wall FRP vessels with an early warning system for leakage detection
- Underground storage tanks
- Casings for electrostatic precipitator
- Drive shafts
- Fan blades (for both axial and centrifugal fans)
- Ducts and Stacks
- Aerial man-lift device.

Internationally, a composites application in chemical industry is a relatively small segment in relation to the total usage of composites. However, in India, this forms the major segment accounting for nearly 28% of total domestic market for composites. With the rapid growth of the chemical industry, this segment is expected to further strengthen with increasing acceptance by the users. The usage of composites in this segment in India is estimated to grow at about 10% p.a. to a level of 11000 TPA by 2005 from the present level of about 5000 TPA.

## M11.2.11 Consumer and Sports Goods

The optimum design of sports equipment requires the application of a number of disciplines, not only for enhanced performance but also to make the equipment as user-friendly as possible from the standpoint of injury avoidance. In designing sports equipment, the various characteristics of materials must be considered. Among these characteristics are strength, ductility, density, fatigue resistance, toughness, modulus (damping), and cost. To meet the requirements of sports equipment, the materials of choice often consist of a mixture of material types - metals, ceramics, polymers and composite concepts. Following are the general consumer and sports goods where there is lot of potential for composites in the near future:

- Canoes and Kayaks
- Vaulting Pole
- Golf & Polo rods
- Archery equipment
- Javelin
- Hand gliders
- Wind surfer boards
- Protective sportswear

Indian composites industry is at a nascent stage with respect to this market segment.

## M11.2.12 Application in Nuclear Industry

Some composite materials are exclusive to the nuclear industry, such as nuclear fuels requiring specific fission gas retention properties.

Ceramic fuels used in metal matrices have roused a great deal of interest from the initial years of research. The use of ceramic fuels in a stainless steel matrix as in the case of plutonium-uranium dioxide solid solution in a steel cermet for fast reactors has been fairly successful.

Positrons are materials that exhibit greater possibility of absorbing neutrons. Control rods are the most often used type of positrons. Non-reactor fuels supply auxiliary power for working of the equipment in a spaceship.

Control rods are the main moderators used in reactors. The solid solubility of boron is less in most metals and alloys. Therefore this element has been extensively researched on to examine its applications in a composite form. The use of composites permits regulations of particle size eliminates or reduces intrinsic brittling of the alloy.

Graphite is also used as a moderator in both reactor and non-reactor systems and exhibits good moderating characteristics. Its good structural properties also make it suitable for non-reactor applications. Graphite is the important composite used in space applications. Properties like thermal conductivity, strength etc., are of vital importance.

Cladding is required to separate reactor core from the coolant. Generally ceramic composites are used for this purpose. Most cermets have high melting points which make them popular as claddings. But they have low thermal conductivity and poor stability against thermal stress, which decreases their applicability.

## M11.2.13 Nano-Composites

Nano-composites are a class of materials that has gained much interest recently. The potential of producing these materials with tailored properties at low cost are attractive for applications ranging from drug delivery to corrosion prevention. They will also be more recyclable because there is less additive material in the plastic mix. The aerospace and defence industries will also benefit from new lightweight, high strength nano-composite materials, as will biomedical applications, for example in stronger hip prostheses with extended life expectancy.

The nano-composite material is an innovative product having fillers on a nanometer (one-billionth of a meter) scale dispersed in the resin. Owing to the dispersion of extremely tiny fillers, flame retardance and rigidity of the resin improves substantially with the addition of only a small amount of fillers. By optimization of the fabrication process and controlling the nano-sized second phase dispersion, thermal stability and mechanical properties such as adhesion resistance, flexural strength, toughness and hardness can be enhanced - this exhibits the great advantage of nano-dispersion. Nano-composite materials can be used in electronic and automotive parts, industrial equipment and others.

### Natural Fibre Composites

The use of natural fibres such as jute, sisal, banana, hemp, ramie, coir etc. as reinforcements in plastics is increasing tremendously. Wood flour and other fibres are primarily used as fillers in thermoplastic decking, building materials, furniture and automotive components. Long agricultural fibres such as flax, kenaf, bast, hemp and jute are used as structural reinforcements in thermoplastic/thermoset composites as a replacement of glass fibre. Natural fibre composites can easily be recycled than glass composites. The Table M11.21 lists the properties of Natural & Glass Fibres.

| Property | Jute | Banana | Sisal | Pine-apple | Coir | Cotton | Glass |
|---|---|---|---|---|---|---|---|
| Width or Diameter (mm) | - | 80-250 | 50-200 | 20-80 | 100-450 | 12-20 | 7-8 |
| Density (gms./cc) | 1.3 | 1.35 | 1.45 | 1.44 | 1.15 | 1.52 | 2.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Volume Resistivity at 100 volts (W cm x $10^5$) | - | 6.5-7 | 0.4-0.5 | 0.7-0.8 | 9-14 | - | 9-10 |
| Micro-Fibrillar Angle (degree) | 8.1 | 11 | 10-22 | 14-18 | 30-49 | 20-23 | - |
| Cellulose/Lignin Content (%) | 61 /12 | 65 /5 | 67 /12 | 81 /12 | 43 /45 | 96/94 | - |
| Elastic Modulus ($GN/m^2$) | - | 8-20 | 9-16 | 34-82 | 4-6 | 27 | 85.5 |
| Tenacity ($MN/m^2$) | 440-533 | 529-754 | 568-640 | 413-1627 | 131-175 | 267-345 | 4585 |
| Elongation (%) | 1-1.2 | 1.0-3.5 | 3-7 | 0.8-1.6 | 15-40 | 3-10 | 5.7 |
| Moisture Absorption after 24 h (%) | 6-9 | - | - | - | 12 | 7-8 | 0.5 |
| Aspect Ratio (L/D) (mm) | 152-365 | - | - | - | - | 500-1300 | 100-140 |

**Table M11.21: Properties of Select Natural & Glass Fibres**

Advantages of Natural fibre composites for automotive components includes weight reduction of 10-30%, excellent acoustical absorption properties, good impact properties with convenience of forming complex shaped parts in a single moulding process. Products such as car underbody coverings, interior door panels, dash & back panels, package trays, truck liners, door trims are being fabricated by natural fibre composites.

Natural fibre is a very potential candidate in making of composites, especially for partial replacement of high-cost glass fibres for low load bearing applications. The glass provides strength and stiffness while natural fibre reduces the overall weight.

From the point of view of wood substitution, natural fibre composite boards could offer an excellent eco-friendly solution. With ever-depleting forest reserves and premium on wood, a composite based on renewable resources such as jute, coir, sisal etc. is poised to penetrate the market. Any value-added application avenues for these fibres would directly contribute to the economic benefits of their growers. Indigenous wood supply for plywood industry having been stopped virtually and with increasing landed cost of imported plywood veneers in India, the jute-coir composite boards provide very good value for the customers without any compromise in properties. Value-added novel applications of natural fibre composites would not only go a long way in improving the quality of life of people engaged in jute cultivation, but would also ensure international market for cheaper substitution. The Table M11.22 lists the comparative Features of Natural Fibre Composites (NFC) & Other Materials.

| Properties | NFC | MDF | Particle Board |
|---|---|---|---|
| Density (gms/cc) | 1.72 – 1.76 | 0.5 – 0.9 | 0.5 – 0.9 |
| Moisture content % | 0.2 – 0.38 | 5 – 8 | 5 – 15 |
| Modulus of rupture $N/mm^2$ | 85 - 95 | 12.5 – 15 | 12.5 – 15 |
| Tensile strength $N/mm^2$ | 22 – 24 | 0.6 – 0.7 | 0.4 – 0.45 |
| Flexural strength $N/mm^2$ | 78.48 – 101 | - | - |
| Water absorption %<br>2 hrs.<br>24 hrs. | 0.15 – 0.4<br>1.1 – 1.5 | 6 – 10<br>10 – 12 | 6 – 10<br>17 –20 |
| Fire retardancy | Self extinguishing | - | - |

**Table M11.22: Comparative Features of Natural Fibre Composites (NFC) & Other Materials**

(Source: BMTPC, New Delhi)

Bamboo is one of the fastest renewable plants with a maturity cycle of 3-4 years, thus making it a highly attractive resource compared to forest hardwoods. Bamboo offers good potential for processing it into composites as a substitute of solid wood for structural uses. Bamboo composite based flooring tiles, boards (for partitions, cupboards, racks, door and window panels) and blocks (for door and window frames, rails and styles etc.) could be a cost-effective wood substitute.

Bamboo laminates are made from bamboo strips (slivers) milled out from the bamboo wall core. These slivers are than subjected to an anti-fungal treatment. After drying, these strips are passed through the glue applicator for surface and edge gluing with the thermoset resin. The slivers are arranged systematically and subjected to a hydraulic hot press. The pressed panels/tiles are then put through trimming, sanding and grooving machines to give a pre-finish shape before surface coating (Polyurethane coating and UV curing).

While phenolic and melamine based resin systems are used traditionally for bamboo laminates, polyurethane based new resin system could be explored for major advantages viz. reduced energy requirement and no phenolic emissions as desired in the international market.

The natural fibres are currently extracted from plants; animals can also provide a source of fibres. Research is underway to develop composites reinforced with fibres made from poultry feathers. Tests of these revealed that they are roughly equal in strength to nylon fibres. The length of feather fibre fibrillation is of the order of 10 times the fibre diameter. This provides additional strength and toughness to the composites. Feather fibres can reduce weight of composite by 50% and increase tensile strength by 20%. The Plant fibres containing natural sugar tend to caramelize at temperature above $150^0$C; thus limiting their processing with high temperature polymers such as nylon and PPS. Whereas the thermal degradation of poultry fibres begins after $235^0$C thus widening their usage. US companies are testing feather fibres as a replacement of glass fibre in moulded automotive components. The advantages of the feather fibres over glass include lower abrasion, easier recycling and reduced health risks from inhalation.

Fibres are not the only agriculture products that can be used in composites. A polyol, called **soyOyl** has been developed from soyabean oil. Properties of the SoyOyl based polyurethane are similar to petrochemical systems, finding application in spray-on bedliners for farm delivery trucks, moulded seats for tractors and trucks, office furniture and structural foam.

The use of natural fibre in composites is on the rise. Initially these products were chosen for their environmental benefits. However, these materials offer both processing and structural benefits. As the quality and uniformity of natural materials continues to improve, they will appear they ever-increasing number of products.

## Note: Italic font information is addition/advanced material.

### *M11.3 Future Business-Opportunities and Application of Composites*

*Strong developmental activities focusing primarily on products & processes need to be pursued in India. Towards such an objective, a multi-agency approach involving the industry, Government, academia, research laboratory, certification/standardization and user agencies would be required for a quantum jump in composite technology in the country. Thus, the key thrust areas may be summarized as hereunder:*

- *Short & long term R&D*
- *Application development*
- *Fabrication & testing support*
- *Fabrication & testing support*
- *Availability & pricing of raw materials*
- *Manpower training*
- *Technical support services for materials & process selection, process optimization & design, product quality improvement etc.*
- *Standardization*

*Adaptation of automated technologies (such as RTM, pultrusion) along with proper technical/training support would help achieving the improved quality & quantity of composite products. The biggest advantage of composite processing is that unlike with metals, it is not capital intensive and a smaller volume production can be justified.*

*"The future is in composites" is the realization of many decades of high-technology progress toward different materials and parts assembled and combined as monolithic units that would provide a combination of versatility, strength and other properties beyond the possibilities of conventional materials like metal, wood or concrete.*
*Assessing the importance of composites as an advanced performance material the Advanced Composites Mission programme was launched by the Department of Science & Technology (DST), Govt. of India. The Mission-mode activities are being implemented by the Technology Information, Forecasting & Assessment Council (TIFAC), an autonomous organization under DST.*

*The Advanced Composites Mission aims to improve upon the laboratory-industry linkages towards application development & commercialization. The Mission has been successful in launching 26 projects across the country in active collaboration with the industry and national laboratories. The Mission has been catalytic in bridging the knowledge gaps and bringing together the industries & the users. Such an objective oriented, demand driven and time bound programme on composite technology with the involvement of stake holders would go a long way in developing innovative composite applications meeting international quality and wider acceptance thus contributing to the growth of knowledge-based business in India.*

*An efficient mechanism such as the* ***Advanced Composites Mission*** *can help in synergizing the users & industry thus reaching the products to the market with a shorter gestation period.*

*In India, the indigenous achievements are very scattered compared to the large geographical area. There is an urgent need to launch very directed, concerted & planned efforts for developing & demonstrating novel composite products. This would call for an improved awareness, technology adaptation, and technology sourcing & subsequent transfer etc. all at one place.*

*While the national centers of excellence in India possess very rich expertise in composite technology, the knowledge flow to the industry has not come up to the desired level. It is high time to bring the technology sourcing avenues and industries together on one platform for technology development, transfer & subsequent commercialization. This calls for '****Composites Technology Park****' promoting such activities. This could generate a significant boost to the usage of composites while simultaneously evolving specialized products towards commercialization.*

***Future Application of Composites***

*Fibre reinforced composites based on the high performance polymer Fortron® polyphenylene sulphide (PPS) will play key roles in the new Airbus series A340-500 and A340-600, and the A380. The use of Fortron PPS in aircraft construction makes it possible to reduce component weight. With Fortron PPS, modem aircraft construction has the opportunity to replace metal with plastic, even in applications with demanding materials specifications. Some 20-30% of the components for the Super Airbus A380, which will carry 550 passengers, are expected to be made of CFRP. Fortron PPS will be the matrix for the extremely light and robust composites used for the wing leading edge nose of the new A380. Composites based on Fortron PPS are now used for numerous applications in aircraft construction, including the ailerons and the keel beam* *of the aircraft. The composites are produced at about 300°C under high pressure from Fortron PPS films and fibrous reinforcing materials. The parts are joined together in an autoclave to form a solid, inseparable unit. Switching from aluminium to Fortron PPS composites also made it possible to change the profile of the parts. Instead of the traditional D-nose, it has become possible to create a more efficient J-nose. Its design allows it to house electrical, de-icing and other systems. The J-nose elements are reinforced by arch-shaped ribs so that they are extremely rigid in the flight direction, while at the same time they can follow the motion and vibrations of the wings in the transverse direction.*

*One of the latest breakthroughs in the field of composites is the development the Dutch-made 'GLARE' panels, which will be used in the A380 aircraft upper fuselage. The material is built up from alternating layers of fibre glass and aluminium bonded together. Incredibly, the GLARE (GLASS fibre Reinforced) composite can take loads up to 25% higher than bare aluminium. It is expected that about 380 square meters of GLARE would be used in the skin, mainly towards the front and rear of the cabin section. Not only is GLARE light and strong, but it is also damage tolerant. Unlike many carbon fibre based composites, GLARE can be repaired if damaged. It is also far more fire resistant than either aluminium or other composites.*

*Boeing's Sonic Cruiser, a proposed fast airliner, would be mostly built from advanced composite materials. It is expected that about 60% of its structure, including the wing, would probably be of CFRP.*