8

COMPOSITE MATERIALS FOR OTHER APPLICATIONS

We have given in Chapter 1 an idea on the diversity of the products which can be made using composite materials.[1] In this chapter we examine a few of these products, which form a good part in the evolution of these materials, excluding the aerospace sector presented in the previous chapter.

8.1 COMPOSITE MATERIALS AND THE MANUFACTURING OF AUTOMOBILES

8.1.1 Introduction

Composite materials have been introduced progressively in automobiles, following polymer materials, a few of which have been used as matrices. It is interesting to examine the relative masses of different materials which are used in the construction of automobiles. This is shown in the graph in Figure 8.1. Even though the relative mass of polymer-based materials appears low, one needs to take into account that the specific mass of steel is about 4 times greater than that of polymers. This explains the higher percentage in terms of volume for the polymers. Among the polymers, the relative distribution can be shown as in Figure 8.2.

The materials called "plastics" include those so-called "reinforced plastics" for composite pieces that do not have very high performance. The graph in Figure 8.3 gives an idea for the distribution by zone of the "plastic" pieces in an automobile and also shows the evolution in time. One can see the increasing importance of high-performance parts.

8.1.2 Evaluation and Evolution

A few dates on the introduction of composite parts (fibers + matrix) include:

- The antiques as shown in Figure 8.4
- 1968: wheel rims in glass/epoxy in automobile S.M.Citroen (FRA)
- 1970: shock absorber shield made of glass/polyester in automobile R5 Renault (FRA)

[1] See Section 1.3.

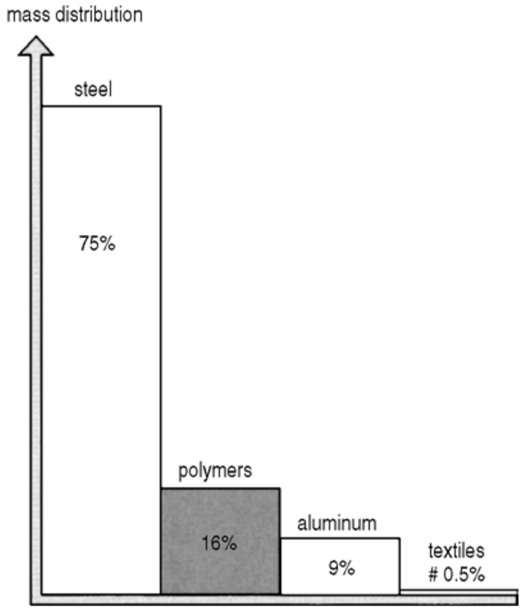

Figure 8.1 Use of Different Materials in Automobiles

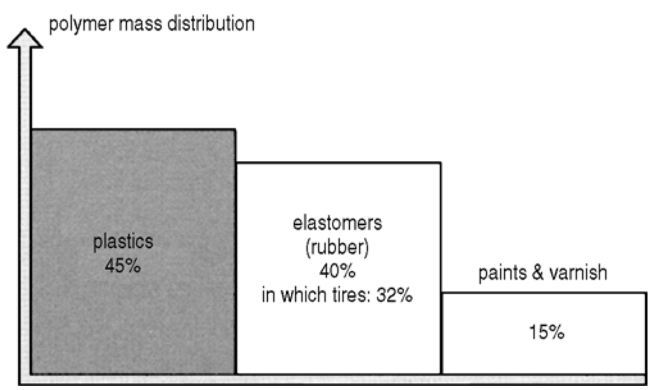

Figure 8.2 Mass Distribution Among Polymer Materials

Consequences of the introduction of composite pieces in automobiles are now well-known. They allow a number of advantages. One can find several common points with aeronautic construction. There are also disadvantages that are more specific to automobiles.

- Advantages include
  - Lightening of the vehicles: A reduction of mass of 1 kg induces a final reduction of 1.5 kg, taking into account the consecutive lightening of the mechanical components.

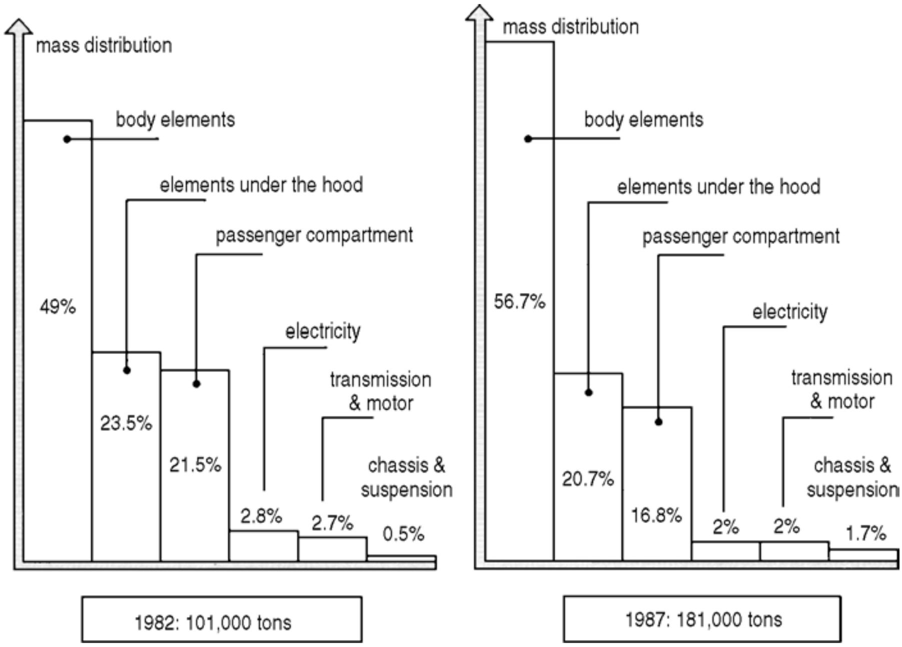

Figure 8.3 Distribution of "Plastic" Components in an Automobile

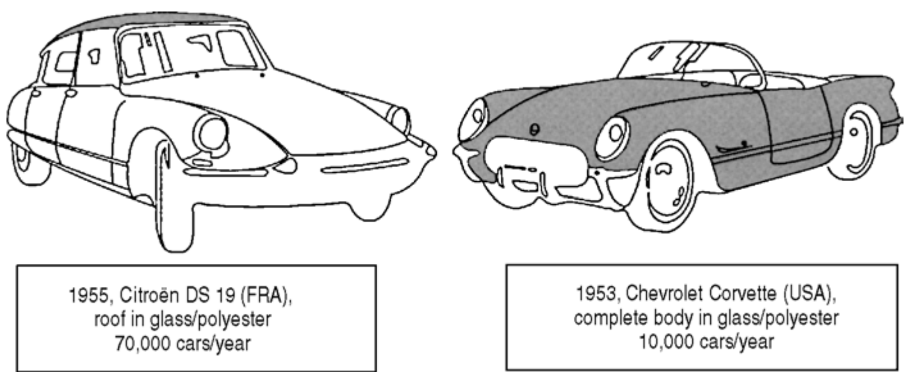

Figure 8.4 Composite Pieces in Antique Cars

- Cost reduction: This is due to the reduction of the number of pieces required for a certain component and to noise reduction and isolation.
- The better corrosion resistance of the composite pieces.

- Significant disadvantages are
  - It is difficult, for fabrication in large volume, to obtain as good a surface finish as that of painted sheet metals.
  - For the car body, the painting process and the treatment of the surfaces require high temperature exposure.

How to Evaluate the Gains:

In theory: These are the experimental vehicles; Ford, Peugeot (1979). As compared with the metallic pieces, composite parts have obtained mass reduction of

- 20% to 30% on the pieces for the body.
- 40% to 60% on the mechanical pieces

Example: Ford vehicle, which has a mass in metallic construction of 617 kg and a mass in composite construction of 300 kg for a global gain of 52%. It is convenient to consider this case as "technological prowess" far from the priority of economic constraints.

In practice: Over the past years, an increasing number of pieces made of glass fibers/organic matrices have been introduced. The following list contains pieces that are in actual service or in development.

- Components for the body
  - Motor cap
  - Hood cover
  - Hatchback door
  - Fenders
  - Roofs
  - Opening roof
  - Doors
  - Shock absorber
- Interior components
  - Seat frames
  - Side panel and central consoles
  - Holders
- Components under the hood
  - Headlight supports
  - Oil tanks
  - Direction columns
  - Cover for cylinder heads
  - Cover for distributor
  - Transmission shafts
  - Motor and gearbox parts
- Components for the structure
  - Chassis parts
  - Leaf springs
  - Floor elements

Figure 8.5 shows the importance of the volumes actually occupied by the composites in an automobile.

Example: Automobile BX Citroen (FRA)1983 with a total mass of 885 kg. Many of the molded pieces made of glass/resin composites as shown in Figure 8.6 are now commonly used by the automobile manufacturers. We note in particular the two elements below, the importance and large volume production of which (rate of production of more than 1000 pieces per day), indicate a significant penetration of composites in the manufacturing of automobiles.

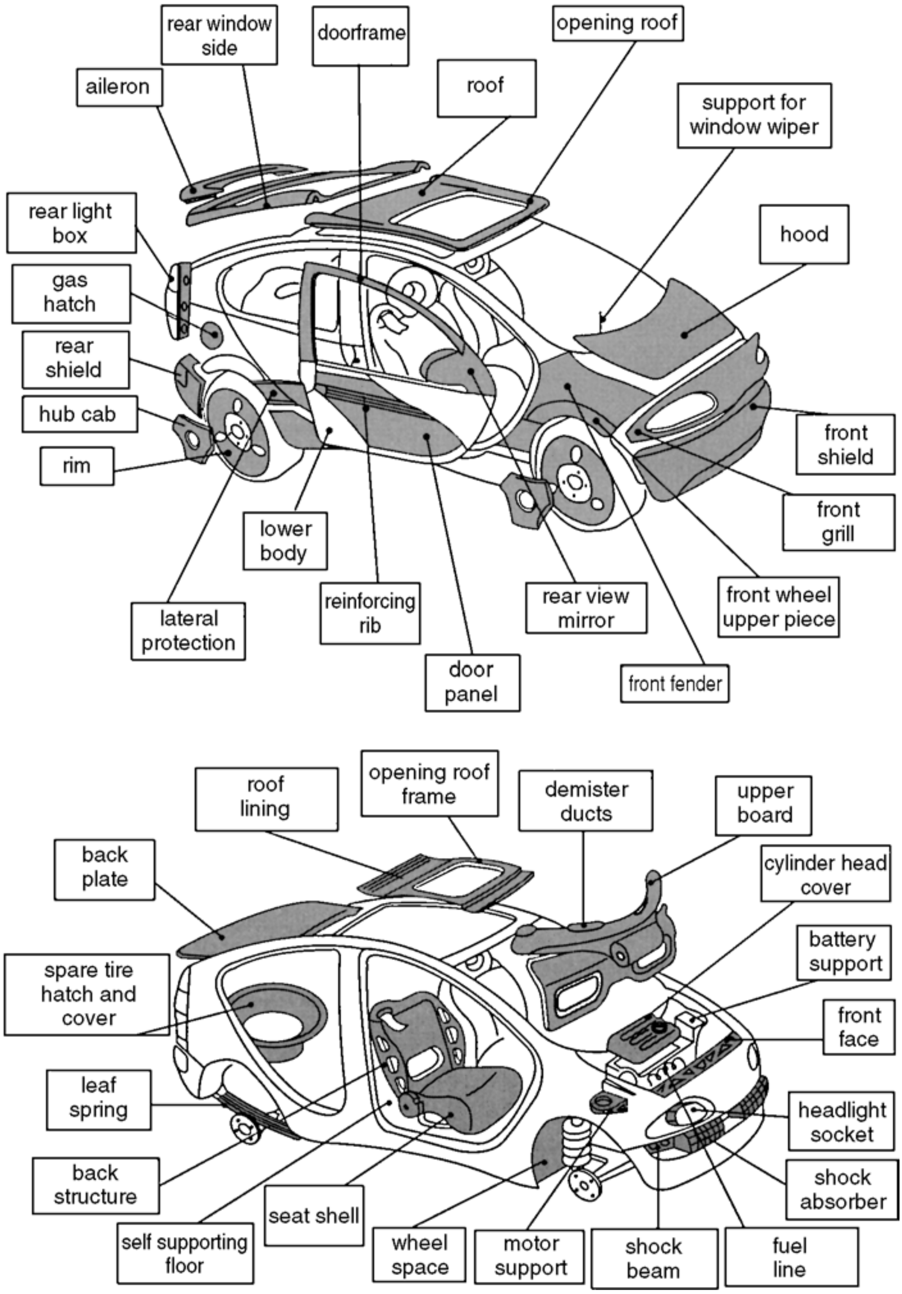

Figure 8.5 Composite Pieces in an Automobile

- The hood is made of glass/polyester molded at high temperature in a press (20,000 kN) with the deposition of a gel coat during molding[2] to assure the quality of the surface. The following comparison is eloquent:

[2] See Section 2.1.1.

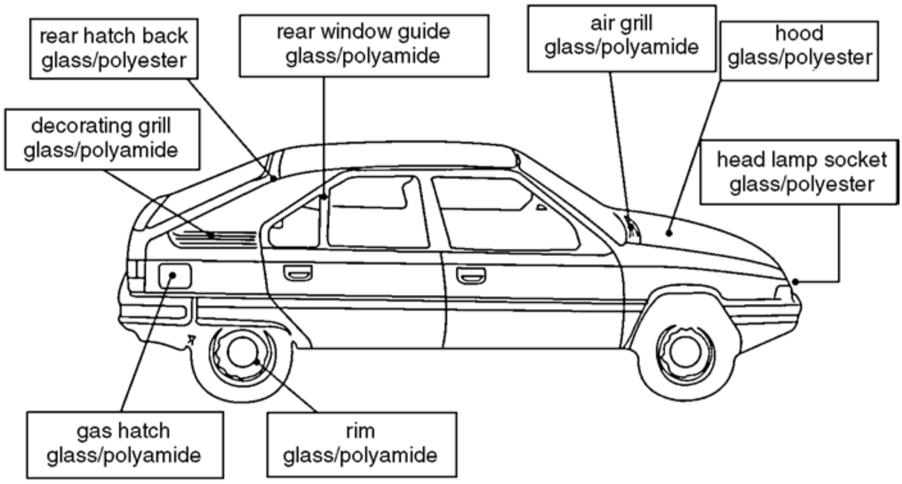

Figure 8.6 Composite Pieces in BX Citroen

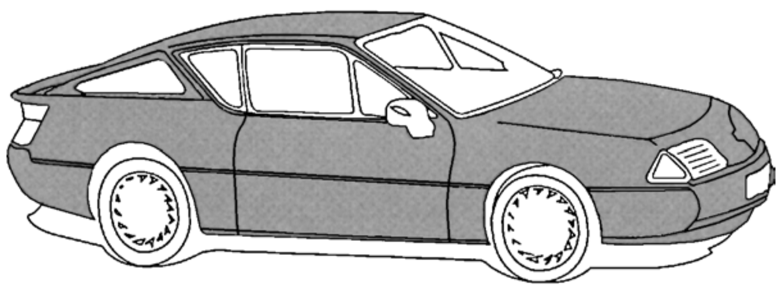

Figure 8.7 Automobile Alpine V6, Renault

- Conventional metallic construction (GS Citroen): 7 elements
- Composite construction: 1 element
- Mass gain: 7.8 kg or 46%.

■ The rear window frame is made of injection molded glass/polyester (23,000 kN press). The mechanical characteristics obtained with this method (fracture resistance, modulus, impact resistance) are in the vicinity of those obtained by compression molding. One obtains a single piece that can support the rear glass piece, the aerodynamic details, the hinges, and the lower part of the trunk. The advantages over the classical construction are great:
- Classical construction (GS Citroen): 27 elements
- Composite construction: 7 elements
- Mass reduction: 1.7 kg or 16%

Example: Automobile Alpine V6 Turbo, Renault (FRA), 1986 (Figure 8.7). The entire body in glass/polyester composites is not obtained by molding according to the technique used for the previous model A 310 (contact molding).[3] It is made by bonding around fifty elements in glass/polyester on a tubular chassis.

- The panels are made by molding using a press at low pressure and temperature (6 minutes at 45°C).
- Contouring is done using a high-speed water jet.[4]
- Structural bonding is done on a frame at 60°C. Robots control it. The classical mechanical nuts and bolts are replaced by 15 kg of adhesives.

Significant advantages include the following:

- There is reduction in fabrication time: 80 hours versus 120 hours for the construction of the previous model A 310.
- Excellent fatigue resistance is realized: (mileage > 300,000 km).
- There is good filter for noise from mechanical sources.
- The flexibility in the method of fabrication: The tooling in the press is interchangeable in order to produce small series of different pieces on the same press. This process is well adapted to a low rate of fabrication (10 cars per day).
- Mass reduction—as compared with the technique used in the previous model, which itself was using composites—is 100 kg.

For a cylinder size of 2500 cm^3 (power of 147 kW or 240 CV), it is one of the most rapid series of vehicles ever produced in France previously (250 km/h) with a remarkable ratio of quality/price as compared with other competing European vehicles (Germany in particular).

Example: Racing car "F.1" Ferrari (ITA) (Figure 8.8). This car body is a sandwich made of NOMEX honeycomb/carbon/epoxy. In addition, a crossing tube made of carbon/epoxy transmits to the chassis aerodynamic effects that act on the rear flap. This is attached to the chassis by light alloy parts, bonded to the composite part with structural araldite epoxy adhesive. There is weight reduction compared with previous metallic solution, and one also sees very good fatigue resistance, which is important in regard to mechanical vibrations.

8.1.3 Research and Development

A number of working pieces—traditionally made of metallic alloys—of road vehicles have been designed and constructed in composite materials, and they have actually been tested and commercialized:

8.1.3.1 Chassis Components

Research and Development work has been concerned with the spars, floors, front structures, rear structures, and also the complete structure.

- Principal advantage: Reduction in the number of parts and thus in the cost.
- Secondary advantage: Mass reduction (beams for truck chassis in Kevlar/carbon/epoxy lead to a mass reduction of 38%—46 kg versus 74 kg for metal).

[3] See Section 2.1.1.
[4] See Section 2.2.5.

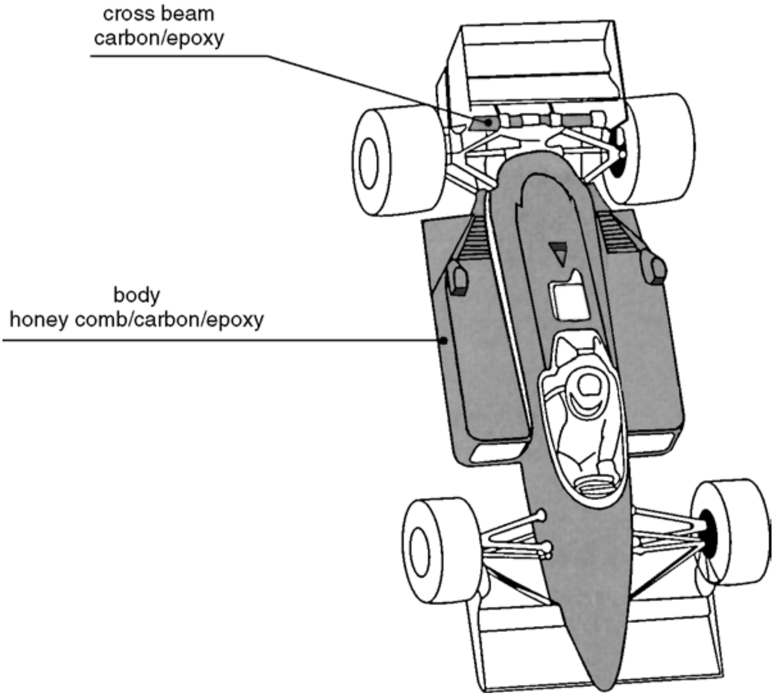

Figure 8.8 Ferrari F.1 Racing Car

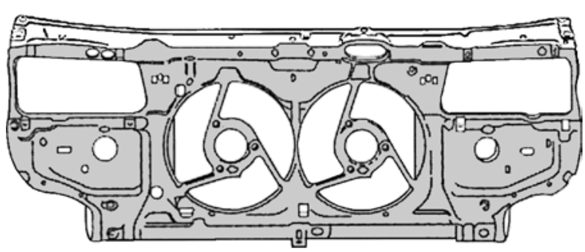

Figure 8.9 Front Face of 405 Peugeot

The problems involved are numerous:

- How to assemble the pieces.
- What will be the mechanical behavior when subjected to strong impacts?
- How is the rate of production to be augmented? The actual fabrication methods are too slow (decrease in the cycle time by using automation).

Example: The superior cross beam or "front face" of the automobile 405 Peugeot (FRA). This component (see Figure 8.9) is subjected to repeated load cycles in tension, flexure, and torsion. It also supports several dozens of

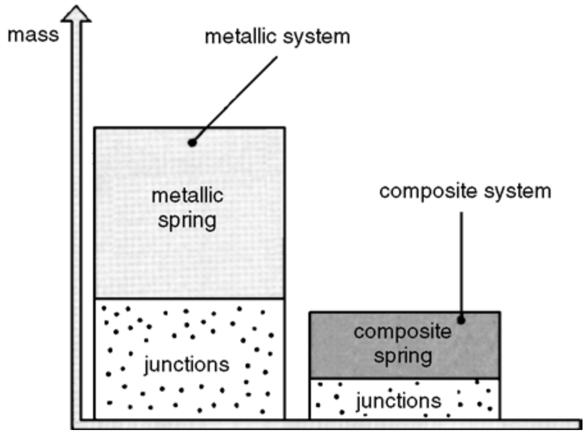

Figure 8.10 Comparison Between Metallic and Composite Springs

components and equipment that form the front face of the vehicle. Characteristics include:

Part molded in glass/polyester ($V_f = 42\%$)
Fabrication process: SMC[5]: Press 15,000 N
Rate of production: 1200 pieces/day
Machining/drilling (70 holes); installation of inserts (30) and components made by laser, numerical machining, and robots

8.1.3.2 Suspension Components

- Springs: One of the principal characteristics of the unidirectionals (namely glass/resin) is their capacity to accumulate elastic energy.[6] Herein lies the interest in making composite springs. In theory, a glass/resin spring is capable of storing 5 to 7 times more elastic energy than a steel spring of the same mass.

Other advantages include:

- The composite springs are "nonbreakable." Damage only translates into a minor modification of the behavior of the component.
- It is possible to integrate many functions in one particular system, leading to a reduction in the number of parts, an optimal occupation of space, and an improvement in road behavior.
- The mass reduction is important (see Figure 8.10)

The disadvantages: It is difficult to adapt the product to the requirements of the production. It is not sufficient to demonstrate the technical feasibility; one must optimize the three-criteria product-process-production rate (rates of production of

[5] S.M.C. process: See Section 2.1.3 and 3.2.
[6] See Section 3.3.2, comparison of load-elongation diagrams for a metal and a unidirectional.

Figure 8.11 Leaf Spring

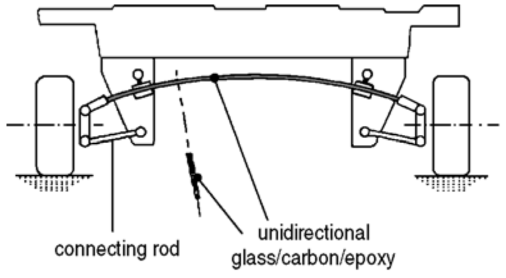

Figure 8.12 Combination of Functions

several thousands of parts per day in the automotive industry, to be made using a few processes, i.e., filament winding, compression molding, pultrusion, and pultrusion-forming).[7]

The current development and commercialization efforts deal with leaf springs and torsion beam springs.

Example: Single leaf spring (see Figure 8.11). A spring made of many metallic leaves is replaced by a single leaf spring made of composite in glass/epoxy. Many vehicles are sold with this type of spring, for example, Rover–GB; Nissan–JAP; General Motors–USA; Renault–FRA).

Example: Multifunctional system (Bertin–FRA). This prototype for the front suspension of the automobile combines the different functions of spring, rolling return, and wheel guide (see Figure 8.12).

Example: Stabilizing system. This is used for the connection between an automobile and a caravan (Bertin/Tunesi–FRA). The combined functions are shown schematically in Figure 8.13. The mass is divided by 4.5 in comparison with an "all metal" solution.

Example: The automobile suspension triangle has two parts (FRA) that are bonded to make a box (see Figure 8.14).

8.1.3.3 Mechanical Pieces

- Motor: The parts shown schematically in Figure 8.15 are in the experimental stage or in service in thermal motors. For pieces that have to operate at high temperatures, one should use the high temperature material system

[7] See Chapter 2.

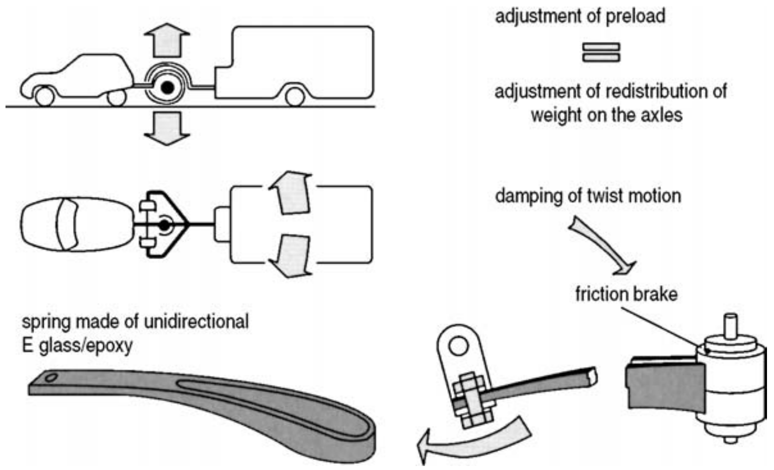

Figure 8.13 Stabilizing System

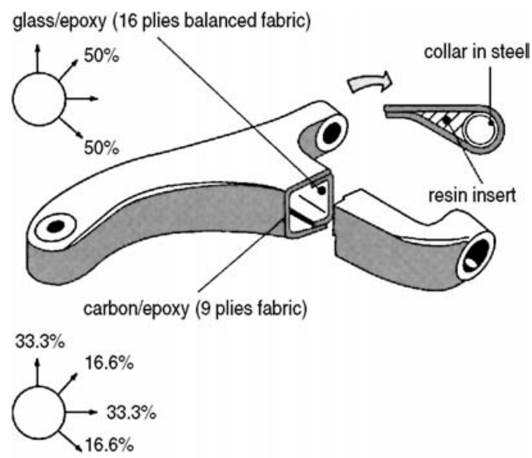

Figure 8.14 Composite Suspension Triangle

glass/polyamide (up to 300°C).[8] One can also mention the pump blades and the synchronizers in speed boxes made of glass/polyamide.

- Composite transmission shafts[9]: These are used in
  - Competition vehicles (rallies), allowing high speed of rotation with low inertia
  - Small and large trucks

Figure 8.16 shows how the low mass density associated with high rigidity in flexure allows the elimination of the intermediate bearing (this induces also a supplementary reduction in mass and cost).

[8] The polyamide resin is said to be "thermally stable;" that is, it can maintain its mechanical properties at high temperatures (up to 500°C for one hour).

[9] See Application 18.1.4.

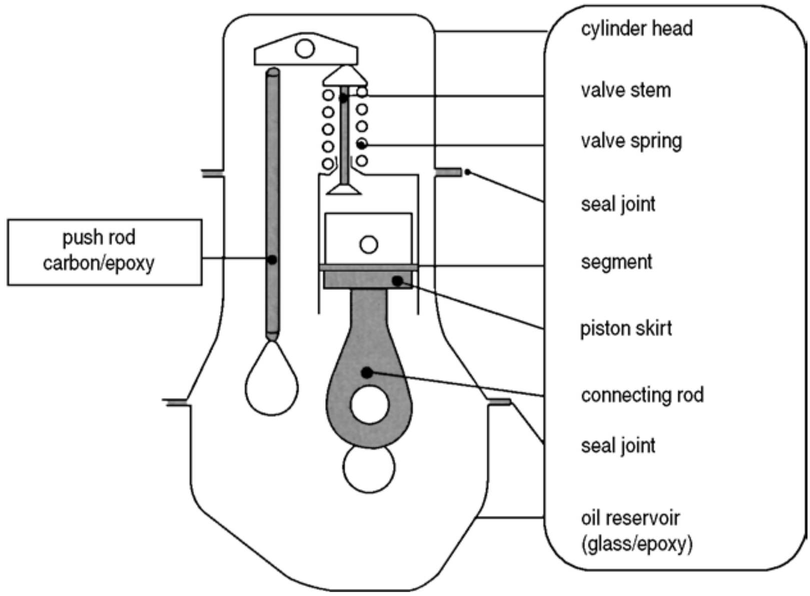

Figure 8.15 Composite Mechanical Components

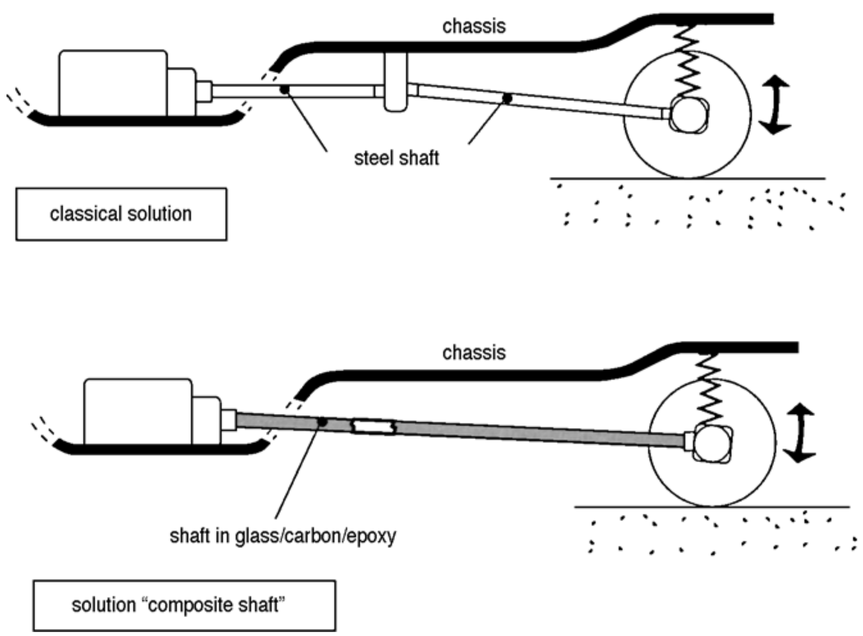

Figure 8.16 Composite Shafts

For the transmission shafts equipped with supports, one obtains the following advantages:

- Reduction of mass of 30% to 60% in comparison with the transmission shafts with universal cardan joints

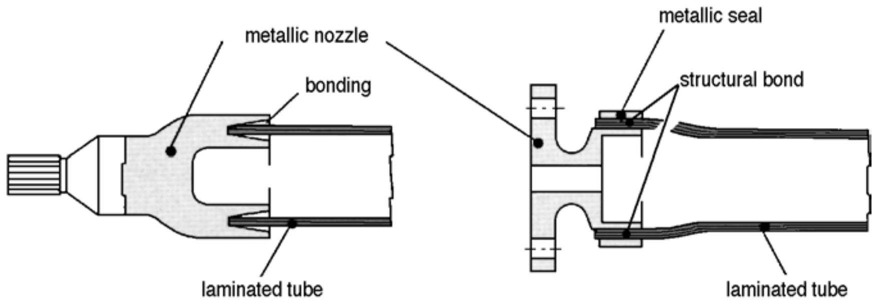

Figure 8.17 Composite-metal Shaft Bonding

- Reduction in mechanical vibrations
- Decrease in acoustic vibration level (in particular the "peak")
- Good resistance against chemical agents
- Very good fatigue resistance

- Lateral transmission shafts are used for vehicles with front drive. They are used to eliminate the homokinetic joints that are actually used. They are made of a weak matrix material and wound fibers that allow the freedom of flexure for the transmission shaft.

8.2 COMPOSITES IN NAVAL CONSTRUCTION

8.2.1 Competition

8.2.1.2 Multishell Sail Boats

In the past years there has been a spectacular development in the sailboat competition, with significant research activities on the improvement of the qualities of the boats, and the design of sail boats called "**multishells**" with large dimensions, made of high performance composites, characterized by

- Low mass leading to reduced "**water drafts**"
- New and more performing "**riggings**"[10]
- Resistance against intense fatigue loadings, namely for the joint mechanisms between the shells

Example: Catamaran Elf Aquitaine (FRA) 1983 (see Figure 8.18). This is a large boat (20 m) in high performance composite materials. It has the following principal characteristics:

- A mast-sail constituted of two half-shells in carbon/epoxy, 24 meters long
- Connecting arms for shells with "x" shape that work in flexure to take up the difference in pitching between the two shells

[10] There is a record speed of 34 knots with a class C catamaran (7.6 m in length).

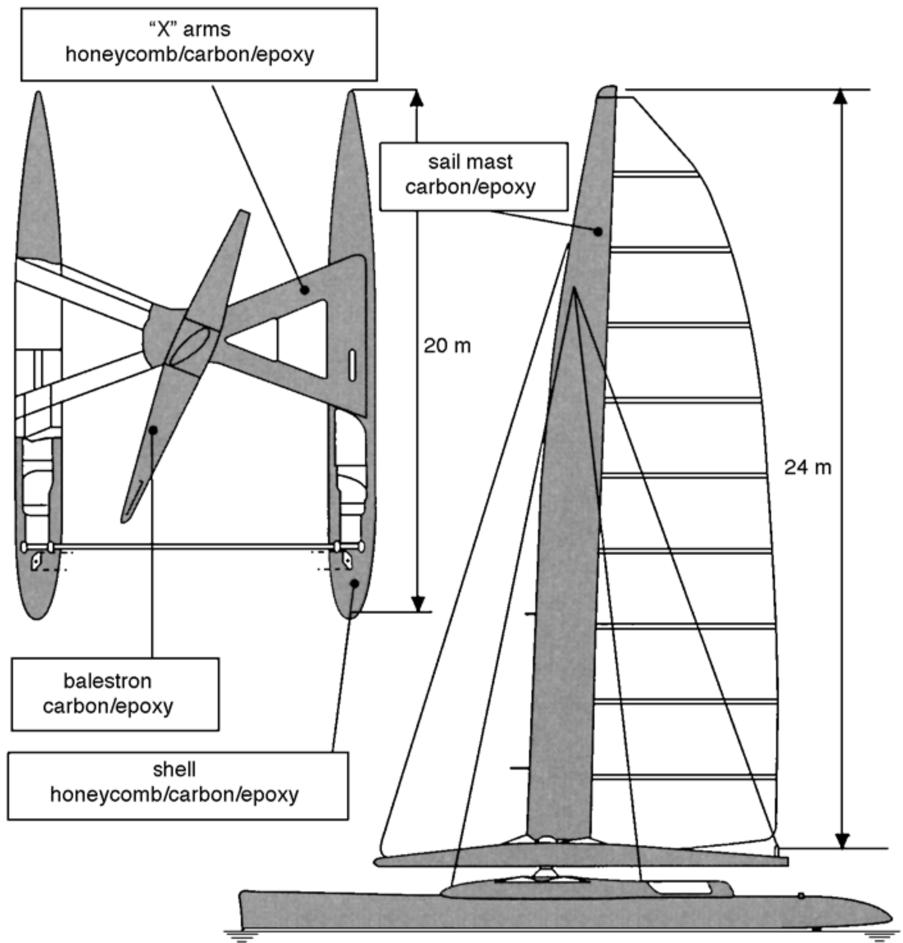

Figure 8.18 Elf Aquitaine Catamaran

- A total fully equipped mass of 5.3 tons, corresponding to a mass reduction of 50% as compared with a construction in light alloy

Example: Competition skiff WM (FRA) 1995 (see Figure 8.19).
Example: Surf board 1995 (see Figure 8.20).

8.2.2 Ships

In the defense domain, there are composite boats of large dimensions (>50 m): escort-patrollers are expected to be 90 m in length.

Example: Anti-mine ocean liner BAMO (FRA). The Catamaran shell is 52 m in length, 15 m in width, and molded in 8 parts. It has 250 tons of glass/polyester composites in monolithic and sandwich construction with balsa core for the bridges and walls (see Figure 8.21).

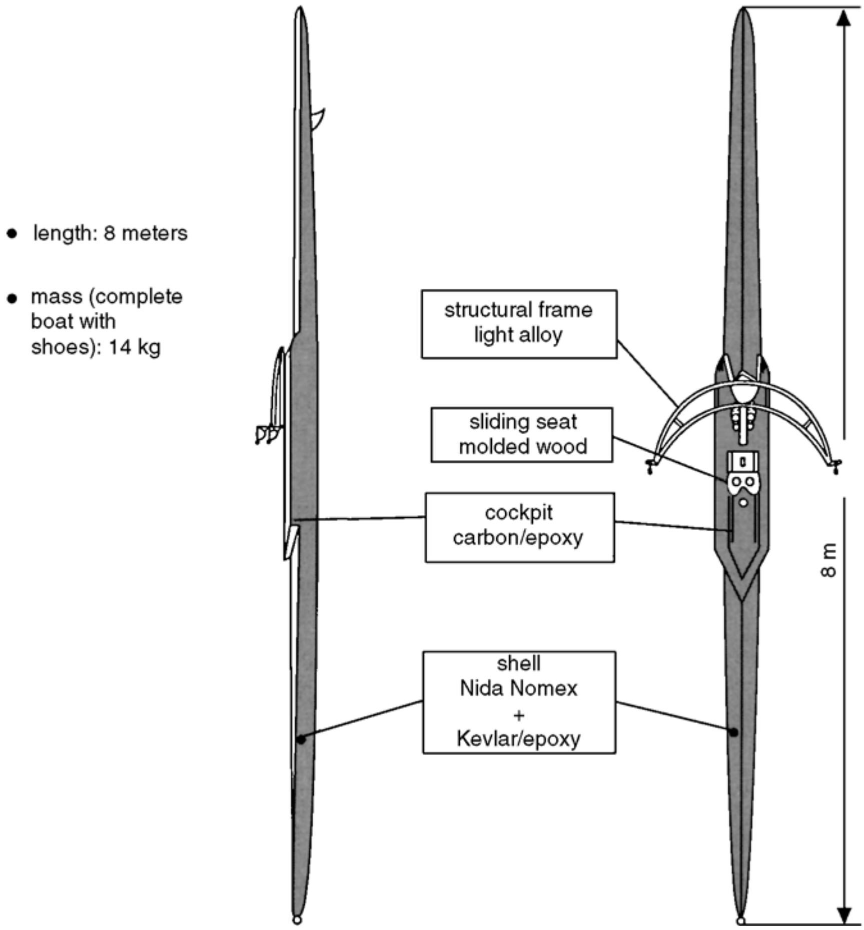

Figure 8.19 Competition Skiff

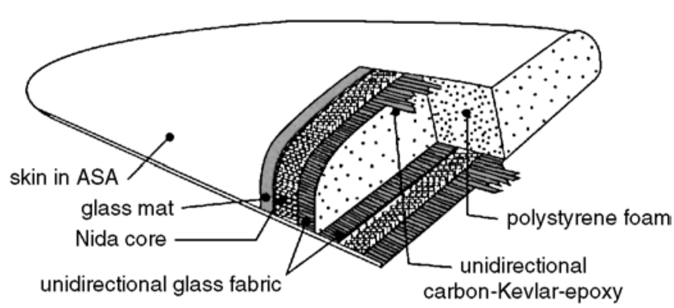

Figure 8.20 Surf Board

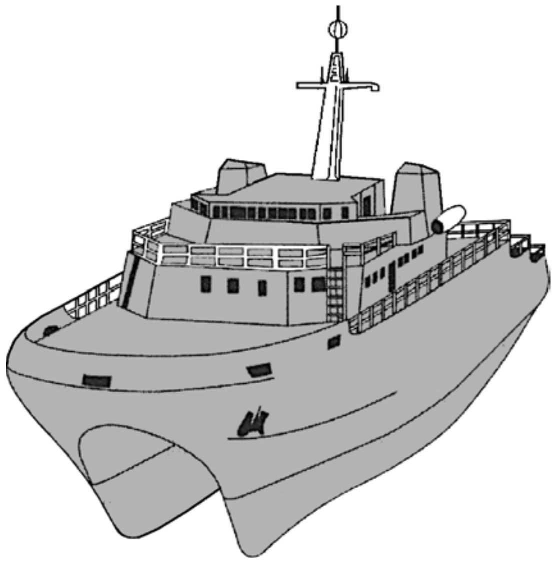

Figure 8.21 Anti-mine Ocean Liner

8.3 SPORTS AND RECREATION

8.3.1 Skis

Initially made of monolithic wood, the ski has evolved toward composite solutions in which each phase — each in itself a composite material — fulfills a determined function. Figure 8.22 illustrates a transverse cross section of a ski of a previous generation: steel for the elasticity of the element, wood to dampen the vibration, interspersed aluminum for its better adherence to wood.

Among the essential mechanical characteristics, the manufacturer has to master the following:

- Flexibility in flexure
- Ski stiffness in torsion (for turning)
- Elastic limit
- Fracture limit

One must also note the large diversities of the quality of

- The snow and the slopes (operating conditions)
- The skiers (different levels)

Taking into account the above specifications requires the manufacturers to provide a large variety of skis. The principal components include

- The **structure** is the part of the ski that assures the essential functions as mentioned previously. It may require a piece—or an assembly of several pieces—along the longitudinal direction of the ski, and the cross section

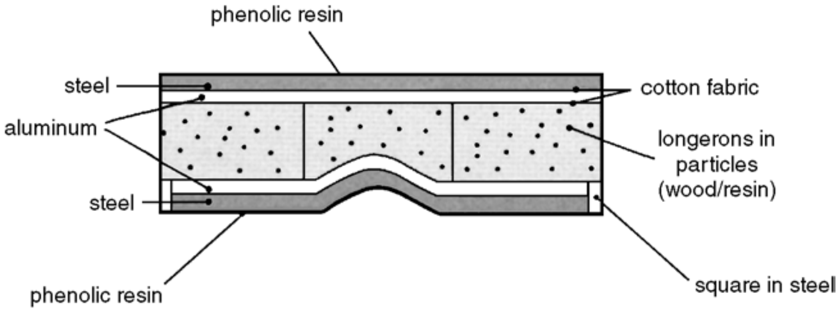

Figure 8.22 Cross Section of an Antique Ski

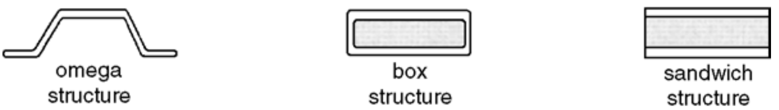

Figure 8.23 Different Ski Cross Section Forms

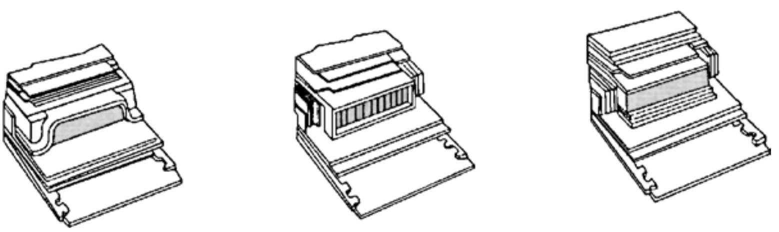

Figure 8.24 Section of Ski Dynastar

area may take the form shown in Figure 8.23. In fact, other elements can be added to these requirements, which will allow one to control separately stiffness in flexure and stiffness in torsion. The ratio of these two stiffnesses will determine the behavior of the ski, particularly during turning. For this, one uses mainly the following materials:

- Glass/epoxy
- Carbon/epoxy
- Kevlar/epoxy
- Honeycombs
- Zicral (AU 2 ZN)
- Steel alloy

Example: Skis *Dynastar* (FRA): The real appearance of a section is complex, as shown in Figure 8.24, on which one can recognize the "omega," the box, and the sandwich structures described previously.

- The **filling** contributes little to the mechanical characteristics of the whole structure (10% to 15%), but it constitutes the big part in the total volume

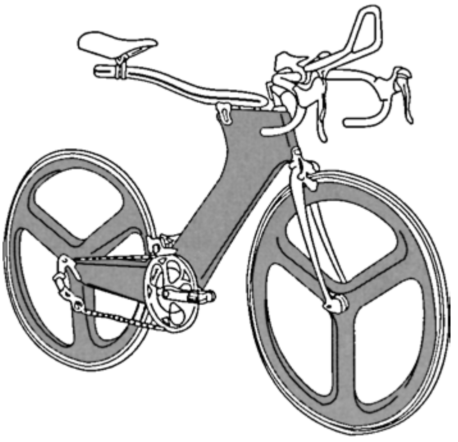

Figure 8.25 Composite Bicycle

(70 to 80%). Its specific mass has to be as small as possible. The filling can be of

- Wood, which is sensitive to humidity, with scatter in mechanical characteristics and specific mass depending on the lots
- Polyurethane foam, with weak mechanical characteristics
- Acrylic foam, which is very onerous

- The **covers** and the **edges** are in glass/phenol or in glass/granix.
- The **upper edges** are in zicral, the lower edges are in steel.
- The **synthetic inner soles** have high specific mass.

8.3.2 Bicycles

Initially reserved only for competition, numerous variations with frames and wheels made of carbon/epoxy can now be found (see Figure 8.25).

8.4 OTHER APPLICATIONS

8.4.1 Wind Turbines

The renewed interest in wind turbines has been caused by the use of composites in the fabrication of the blades. These can be of large dimensions (lengths exceeding 24 meters).

Example: Figure 8.26 gives an idea of the size of a wind turbine that develops a maximum power of 33 kW. The blades in glass/epoxy are made here by vacuum forming[11] using two half-shells assemblies by epoxy adhesive bonding.

The blades can also be done by filament winding, a process well suited for the construction of torsion box (Figure 8.27). Nevertheless, for longer lengths, the

[11] See Section 2.1.3.

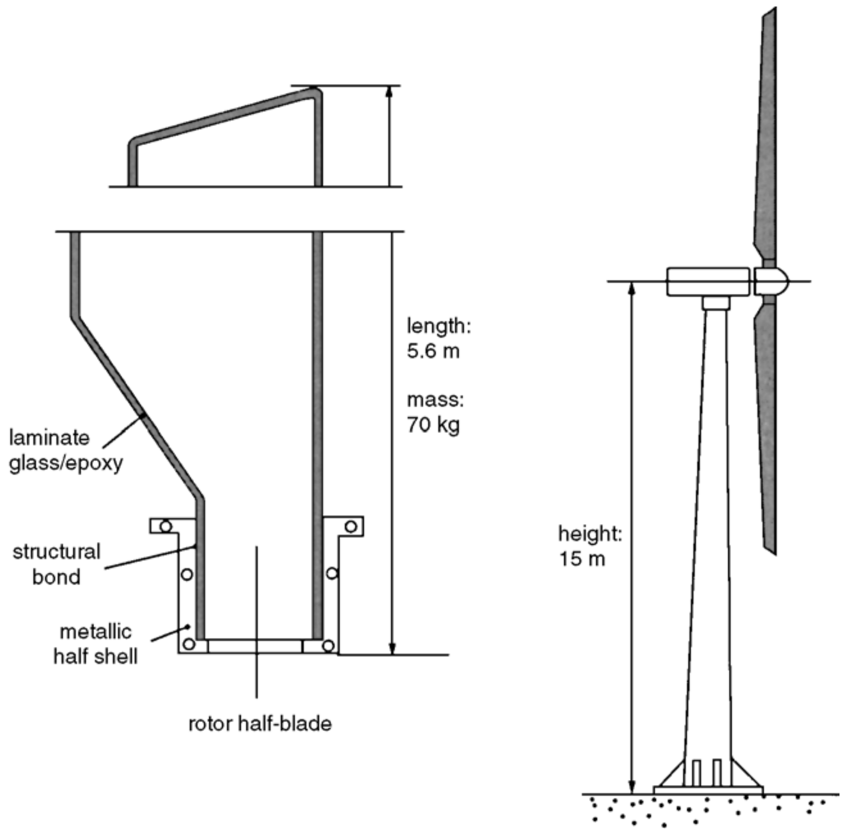

Figure 8.26 Wind Turbines

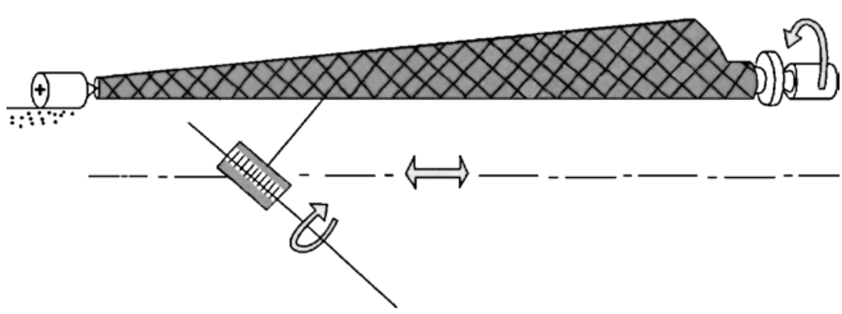

Figure 8.27 Filament Winding for Wind Turbine

flexure of the blade varies during winding (difference in flexural rigidity in one neutral plane from the other).

One can mention also the composite propeller blades for the cooling blowers, which borrow the technology of the aircraft propellers,[12] which have a speed of rotation larger than for the wind turbines.

[12] See Section 7.3.

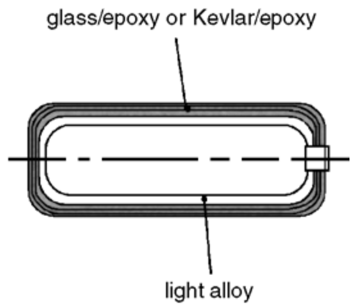

Figure 8.28 Composite Gas Bottles

8.4.2 Compressed Gas Bottles

These are made using filament-wound glass/epoxy or Kevlar/epoxy (see Figure 8.28) reinforcing a thin envelope in light alloy which is used for sealing purposes.

- The pressure can reach 350 bars in operating conditions (rupture at more than 1,000 bars).
- The ratio (gas volume/bottle mass) is multiplied by 4 in comparison with the steel solution.
- Applications include
  - Very light breathing apparatus (for scuba diving)
  - Reservoirs for gaseous fuels
  - Accessories for missiles

8.4.3 Buggy Chassis

These are made using glass/epoxy. They are very resilient and can help reduce noise. They are very light with a reduced number of pieces in comparison with the metallic solution. They also offer very good fatigue endurance, as has already been described above for glass/epoxy.[13]

Other advantages include the possibility of integration of the "spring" function in the structure of the chassis and increase in the "critical" speed from which a proper mode of vibration can develop in the suspension (see Figure 8.29).

8.4.4 Tubes for Off-Shore Installations

These are used in deep waters. The weight of the metallic tubes—or **risers**—increases proportionally with the depth and can attain high values (one third of the limit stress for a depth of 1000 m). This gives rise to interest in using tubes made of glass/carbon/resin, which are three to four times lighter than tubes made of steel.

Example: Production tubes for a cable-held platform. The platform is held with cables toward the bottom (see Figure 8.30). A large number of production

[13] See Section 5.4.4.

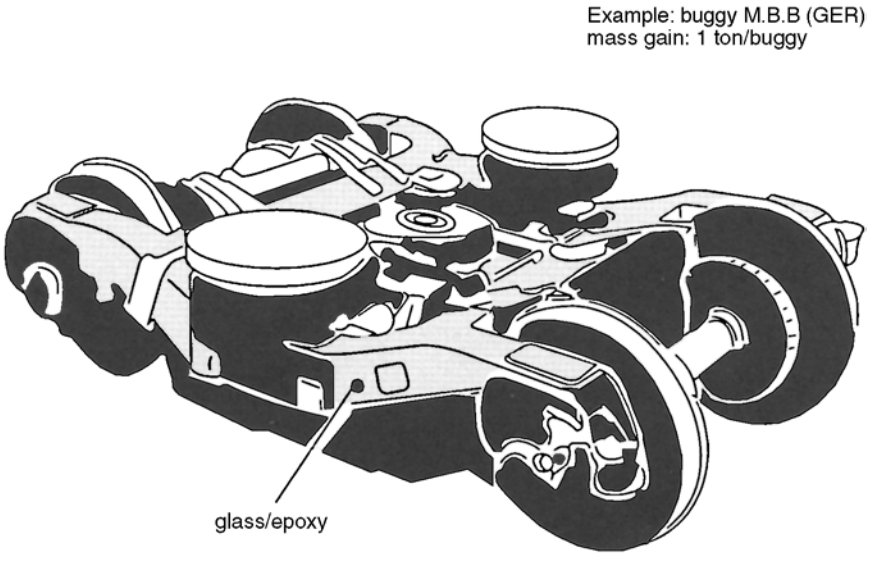

Figure 8.29 M.B.B. Buggy

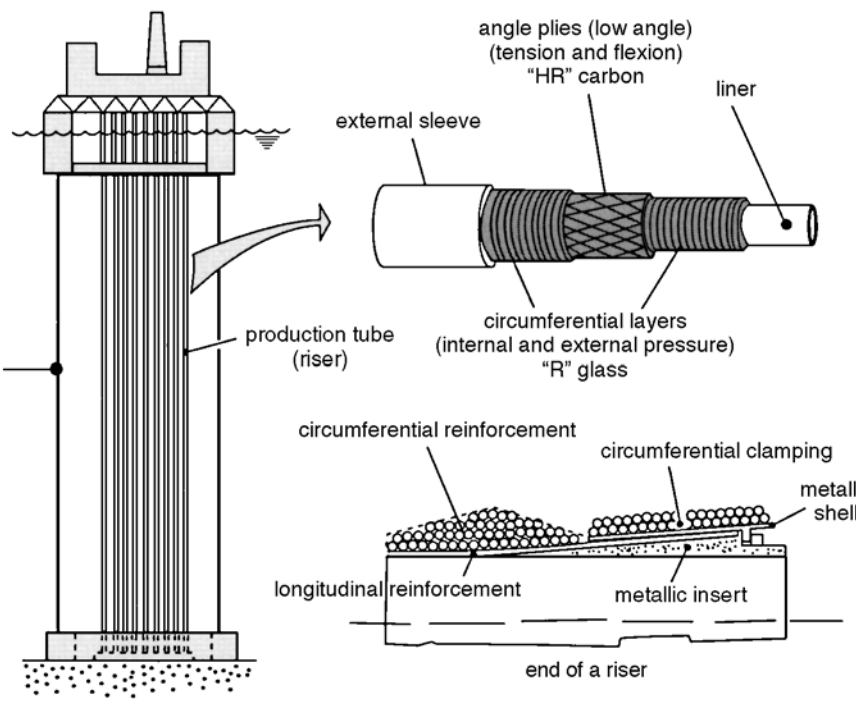

Figure 8.30 Riser Tubes

tubes connect the underwater bottom to the platform. They are subjected to the static and dynamic loadings (due to underwater currents) as:

- Tension
- Flexure
- Circumferential extension and contraction due to external and internal pressures

Characteristics: Safety factor as compared with complete rupture: 2 to 3.

The micro cracks in the resin require internal and external sealings using elastomers.

8.4.5 Biomechanics Applications

The carbon/carbon composites (see Section 3.6) have the rare properties of not provoking fibrous outgrowth when in contact with the blood stream; they are so-called **thrombo resistant**. In addition, the following qualities also favor their implantation in the human body:

- Chemical resistance and inertness
- Mechanical and fatigue resistance
- Controllable flexibility due to the nature of composite materials
- Low specific mass
- Transparency to different rays
- Possible sterilization at very high temperatures

The principal applications (to be expanded) for the moment are

- Hip and knee implants (in development)
- Osteosynthesis plates
- Dental implants
- Implant apparatus

8.4.6 Telepherique Cabin

A substitution using composites on the classical solution for the telepherique cars made of metals gives, at equal mass, a notable augmentation of the useful payload.

Example: Company Ingenex/telepherique of Argentieres (FRA): Increasing capacity while keeping existing installations, that is cables—pylons—motorization.

- Previous metallic telepherique: useful payload 45 passengers
- New composite telepherique, carbon/Kevlar/epoxy (Figure 8.31): useful load 70 passengers (with the same mass as the previous construction)
- Augmentation of capacity: 55%

- Cost comparison: renewal of all installation with the metallic solution ($11 million)
- Renewal of two telepherique cabins with the composite solution ($1.1 million): cost divided by 10

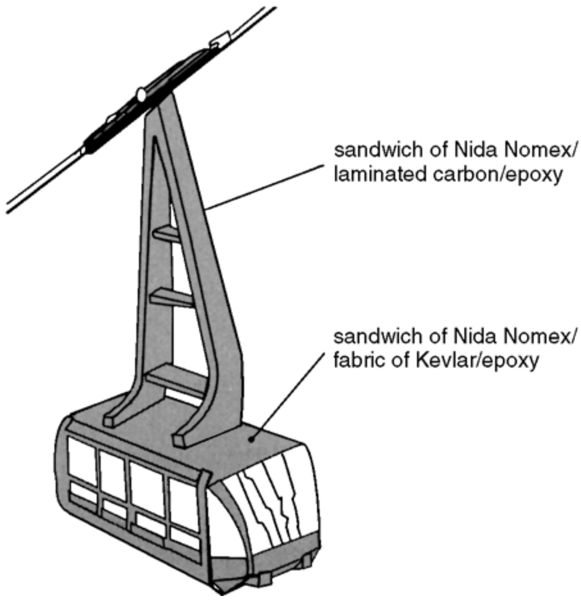

Figure 8.31 Telepherique Cabin