MODULE-1

INTRODUCTION TO COMPOSITE MATERIALS

A composite is a material that is formed by combining two or more materials to achieve some superior properties.

Definition: Composites are engineered materials made by combining two or more distinct components to create a material with properties superior to those of the individual components. The primary components are typically a matrix (such as resin or metal) and a reinforcement (such as fibers or particles), which together create a material with enhanced mechanical, thermal, or chemical properties.

NATURAL FIBRES AND COMPOSITES

- Composites are classified into Natural composites and man-made composites
- Almost all the materials which we see around us are composites.
- These natural composites are either grown in nature or developed by natural processes.
- Wood is most widely used natural composite
- In wood, Fibrous material consisting of thread-like hollow elongated organic cellulose that normally constitutes about 60-70% of wood of which approximately 30-40% is crystalline, insoluble in water, and the rest is amorphous and soluble in water.
- This fibrous material is Flexible but possess high strength. The more closely packed cellulose provides higher density and higher strength.
- The walls of these hollow elongated cells are the primary load-bearing components
- The load acting on the structure directly influences the growth of cellulose in the cell walls
- This is called as self-strengthening mechanism is something unique.
- This self-strengthening mechanism is also observed in bones.
- Bones contain short and soft collagen fibres i.e., inorganic calcium carbonate fibres dispersed in a mineral matrix called apatite. The fibres usually grow and get oriented in the direction of load.
- Tooth is a special type of bone consisting of a flexible core and the hard enamel surface. The compressive strength of tooth varies through the thickness.
- The outer enamel is the strongest with ultimate compressive strength as high as 700MPa.
- Tooth seems to have piezoelectric properties i.e., reinforcing cells are formed with the application of pressure.
- The most remarkable features of woods and bones are that the low density, strong and stiff fibres are embedded in a low-density matrix resulting in a strong, stiff and lightweight composite,

Natural fibres are the fibres that are obtained from plants, animals or mineral sources. **Natural Composites** are materials composed of natural fibers embedded in a natural or synthetic matrix. These materials mimic the structure of biological composites found in nature, such as wood or bone, where fibers like cellulose provide strength and stiffness, and the matrix, often lignin or hemicellulose, binds the fibers together, providing cohesion and shape.

Classification of Natural Fibers: Natural fibers are classified based on their origin into three main categories: plant fibers, animal fibers, and mineral fibers.

1. **Plant Fibers**:

    - **Seed Fibers**: Obtained from the seeds of plants. Examples include cotton and kapok.
    - **Bast (Stem) Fibers**: Extracted from the inner bark or phloem of the plant. Examples include flax, hemp, jute, and ramie.
    - **Leaf Fibers**: Derived from the leaves of plants. Examples include sisal, abaca, and pineapple leaf fiber.
    - **Fruit Fibers**: Sourced from the fruit or surrounding husk. Examples include coconut coir and oil palm fiber.
    - **Grass and Reed Fibers**: Includes fibers from grasses and reeds such as bamboo and wheat straw.

2. **Animal Fibers**:

    - **Protein Fibers**: Derived from the hair, wool, or silk of animals. Examples include wool (from sheep), silk (from silkworms), and cashmere (from goats).
    - **Fur Fibers**: Sourced from the fur of animals like rabbits and beavers. Examples include angora (from rabbits) and mohair (from Angora goats).

3. **Mineral Fibers**:

    - **Asbestos**: The primary example of a natural mineral fiber, although its use has been significantly reduced due to health hazards. Asbestos fibers were historically used for their fire-resistant and insulating properties.

These natural fibers are utilized in various applications, including textiles, construction materials, automotive components, and biodegradable composites, due to their renewable nature, biodegradability, and mechanical properties.

Material	Density (kg/m^3)	Tensile modulus (Gpa)	Tensile strength (Mpa)
FIBRES			
Cotton	1540	1.1	400
Flax	1550	1	780
Jute	850	35	600
Coir	1150	4	200
Pineapple leaf	1440	65	1200
Sisal	810	46	700
Banana	1350	15	650
Asbestos	3200	186	5860

Material	Density (kg/m^3)	Tensile modulus (Gpa)	Tensile strength (Mpa)
COMPOSITES			
Bone	1870	28	140
Ivory	1850	17.5	220
Balsa	130	3.5	24
Spruce	470	11	90
Birch	650	16.5	137
Oak	690	13	90
Bamboo	900	20.6	193

MAN MADE COMPOSITES:

A man-made composite is a material engineered by combining two or more distinct components, often with different properties, to create a new material with enhanced characteristics. These components can include fibers, particles, or other reinforcements, which are typically bound together by a matrix material, such as resin or polymer, resulting in a unified structure with tailored properties suited for specific applications.

Material	Specific gravity (S)
Steel	7.8
Ti alloy	4.5
Al alloy	2.8
Mg alloy	1.8
Beryllium	1.8
GFRP	2.0
CFRP	1.6

Tensile modulus (E) (G Pa)	Tensile strength (X^t) (M Pa)	Compressive strength (X^c) (M Pa)	Sp. tensile modulus (E/S) (G Pa)	Sp. tensile strength (X^t/S) (M Pa)	Sp. compressive strength (X^C/S) (M Pa)	Tensile modulus (E) (G Pa)	Tensile strength (X^t) (M Pa)
206	400-2500	400-2500	26.4	50-320	50-320	206	400-2500
103	360-1400	360-1400	22.9	80-310	80-310	103	360-1400
69	55-700	55-700	24.6	20-250	20-250	69	55-700
47	150-300	150-300	25	83-166	83-166	47	150-300
303	400	400	168	222	222	303	400
40	1650	1400	20	825	700	40	1650
140	1450	1050	87.5	906.3	656.3	140	1450

The disadvantages of natural composites and fibres such as Poor interfacial adhesion between the matrix and the natural fibers, Moisture absorption, Poor fire resistance, Low impact strength, less durability led to development of new materials. The most striking example of an early man-made composite is the straw-reinforced clay which molded the civilization since prehistoric times. Watchtowers of the far western Great Wall of China were supposed to have been built with straw-reinforced bricks.

The twentieth century has noticed the birth of new materials that have further consolidated the foundation of modern composites. Numerous synthetic resins, metallic alloys and ceramic matrices with superior physical, thermal and mechanical properties have been developed. Fibres of very small diameter (<10μm) have been drawn from almost all materials. They are much stronger and stiffer than the same material in bulk form. The strength and stiffness properties have been found to increase, when whiskers are grown from some of these materials. One major advantage of using fibre reinforced plastics (FRP) instead of metals is that they invariably lead to a weight efficient design in view of their higher specific modulus and strength properties. Several high-performance polymers have now been developed. Substantial progress has been made in the development of stronger and stiffer fibres, metal and ceramic matrix composites.

The fibres like glass, carbon, boron and Kevlar, and plastics such as phenolics, epoxies and polyesters caught the imagination of composite designers. Every industry is now vying with each other to make the best use of composites. This worldwide interest during the last four decades has led to the prolific advancement in the field of composite materials and structures. The modern man-made composites have now firmly established as the future material and are destined to dominate the material scenario right through the twenty-first century. The aerospace industries took the lead in using fiber reinforced laminated plastics to replace several metallic parts.

ADVANTAGES OF COMPOSITE MATERIALS

Design Optimization - Carry loads more efficiently and reducing overall weight without compromising performance.

Cost-Effectiveness - Less amount of material used, lowering production costs while maintaining structural integrity.

Energy Absorption - Composites with lower compressive strength can absorb more energy during impact, enhancing safety features by dissipating energy more effectively in crashes.

Flexibility in Applications - The high tensile strength of composites makes them suitable for a wide range of applications where resistance to pulling forces is critical, such as in cables, ropes, and sports equipment, broadening their utility.

WHY COMPOSITES ARE BETTER THAN CONVENTIONAL MATERIALS:

1. **Higher Strength-to-Weight Ratio**:
   - Composites often provide greater strength at a lower weight compared to conventional materials like metals. This makes them ideal for applications where weight reduction is crucial, such as in aerospace, automotive, and sports equipment.
2. **Corrosion Resistance**:
   - Many composites, especially those with polymer matrices, exhibit excellent resistance to corrosion and environmental degradation, unlike metals that can rust or corrode over time. This extends the lifespan of composite materials and reduces maintenance costs.
3. **Design Flexibility**:
   - Composites can be molded into complex shapes and tailored to specific design requirements. This flexibility allows for innovative designs and the integration of multiple functions into a single component, which can reduce the number of parts and assembly costs.
4. **Tailored Properties**:
   - By selecting different types and orientations of fibers and matrices, the properties of composites can be precisely tailored to meet specific performance criteria. This customization is not possible with most conventional materials.
5. **Thermal and Electrical Insulation**:
   - Many composite materials offer superior thermal and electrical insulation properties compared to metals. This makes them suitable for applications requiring insulation, such as electrical housings and thermal barriers.

6. **Fatigue and Impact Resistance**:

    - Composites often have better fatigue and impact resistance than metals, which can lead to longer service life under cyclic loading conditions. This is particularly beneficial in applications like wind turbine blades and aircraft structures.

7. **Reduced Energy Consumption**:

    - The production of composite materials can be less energy-intensive than the production of metals. Additionally, the lightweight nature of composites contributes to energy savings in transportation applications by improving fuel efficiency.

8. **Sustainability**:

    - Composites made from natural fibers and bio-based resins offer a more sustainable alternative to traditional materials. These bio-composites reduce dependence on non-renewable resources and are often biodegradable or recyclable.

In summary, composites offer a combination of high strength, low weight, corrosion resistance, and design flexibility, making them superior to many conventional materials in a variety of applications. These advantages drive the widespread adoption of composites across industries seeking improved performance and efficiency.

Advanced Composites:

Advanced composites refer to high-performance materials that consist of a reinforcement phase, such as high-strength fibers (e.g., carbon fibers, aramid fibers, or glass fibers), embedded in a high-performance matrix (e.g., epoxy resins, thermoplastic polymers). These composites are engineered to provide superior mechanical properties, such as high strength, stiffness, and low weight, and are typically used in demanding applications like aerospace, automotive, marine, and sports equipment.

Limitations of Composite Materials:

1. **High Initial Cost**:

    - The production and processing of composite materials often involve advanced technologies and expensive raw materials, leading to higher initial costs compared to conventional materials like metals or plastics.

2. **Complex Manufacturing Processes**:
    - Fabrication of composite components can be complex and time-consuming, requiring specialized equipment and expertise. Techniques such as lay-up, filament winding, and resin transfer molding can be labor-intensive.
3. **Difficulty in Repair and Recycling**:
    - Repairing damaged composite structures can be challenging, often requiring specific techniques and materials. Additionally, recycling composites, particularly those with thermosetting matrices, is difficult due to the irreversible nature of the curing process.
4. **Sensitivity to Environmental Factors**:
    - Composite materials can be sensitive to environmental factors such as moisture, UV radiation, and temperature variations. Prolonged exposure to these elements can degrade the material properties, especially in polymer-based composites.
5. **Anisotropic Properties**:
    - Composites often exhibit anisotropic behavior, meaning their mechanical properties vary depending on the direction of the applied load. This anisotropy requires careful design and alignment of fibers, complicating the engineering and analysis processes.
6. **Limited Material Database**:
    - Compared to conventional materials like metals, composites have a relatively limited and less standardized database of material properties. This can make the design process more challenging and less predictable.
7. **Complex Inspection and Quality Control**:
    - Non-destructive testing (NDT) and quality control of composite materials can be complex and require advanced techniques, such as ultrasonic inspection and X-ray imaging, to detect internal defects and ensure uniform quality.

8. **Brittle Nature**:

    - Some composite materials, especially those reinforced with carbon fibers, can exhibit brittle failure modes. This means they may fail suddenly without significant plastic deformation, which can be a concern in safety-critical applications.

9. **Limited High-Temperature Performance**:

    - Many polymer-based composites have limited performance at high temperatures compared to metals. This restricts their use in applications involving extreme heat unless high-temperature-resistant matrices like ceramics are used.

Despite these limitations, the advantages of composites, such as their high strength-to-weight ratio, corrosion resistance, and design flexibility, often outweigh these drawbacks, driving their continued adoption and development in various industries.

DIFFERENTIATION OF NATURAL COMPOSITES AND MAN-MADE COMPOSITES:

Natural Composites:

Natural composites are materials that occur naturally and are composed of different constituents that give them enhanced properties. These materials are formed through natural processes and are found in biological systems.

Examples:

- **Wood**: Consists of cellulose fibers (reinforcement) embedded in a lignin matrix.
- **Bone**: Composed of collagen fibers (reinforcement) within a mineral matrix of hydroxyapatite.
- **Shells**: Made of calcium carbonate crystals (reinforcement) embedded in a protein matrix.

Characteristics:

- **Formation**: Naturally occurring through biological processes.
- **Components**: Typically involve natural fibers (like cellulose) and natural matrices (like lignin or proteins).
- **Biodegradability**: Generally biodegradable and environmentally friendly.

- **Mechanical Properties**: Optimized by nature for specific functions, such as load-bearing or flexibility.

Man-Made Composites: Man-made composites are engineered materials created by combining two or more distinct materials to produce properties superior to those of the individual components. These composites are designed and manufactured for specific applications and performance requirements.

Examples:

- **Fiberglass**: Made of glass fibers (reinforcement) embedded in a polymer resin (matrix).
- **Carbon Fiber Reinforced Polymer (CFRP)**: Composed of carbon fibers (reinforcement) in an epoxy or other polymer matrix.
- **Concrete**: Consists of aggregates (reinforcement) embedded in a cement paste (matrix).

Characteristics:

- **Formation**: Manufactured through various industrial processes like molding, layering, or extrusion.
- **Components**: Often include synthetic fibers (like glass, carbon, or aramid) and synthetic matrices (like epoxy, polyester, or metal).
- **Customization**: Properties can be tailored to specific needs by varying the type, orientation, and proportion of the reinforcement and matrix.
- **Durability**: Can be designed for long-term performance in harsh environments, although recycling can be challenging.

Material / **Features**	**Natural composites**	**Man made composites**
origin	Formed by natural biological processes	Typically include synthetic or engineered fibers and matrices.

components	Composed of naturally occurring fibers and matrices.	Typically include synthetic or engineered fibers and matrices.
Environmental impact	Generally biodegradable and environmentally friendly.	Can be more challenging to recycle and may involve non-renewable resources.
Control and customization	Limited to the properties provided by nature, though selection and breeding can optimize characteristics.	Highly customizable in terms of mechanical, thermal, and chemical properties through controlled manufacturing processes.
Applications	Used in applications where biodegradability and natural aesthetics are valued, such as in some building materials, textiles, and packaging.	Widely used in high-performance applications like aerospace, automotive, marine, sports equipment, and construction due to their tailored properties and superior performance.

ROLE OF COMPOSITE MATERIALS IN AERONAUTICAL AND AEROSPACE APPLICATIONS

One of the primary requirements of aerospace structural materials is that they should have low density and, at the same time, should be very stiff and strong. Early biplanes used wood for structural frameworks and fabrics for wing surfaces. The fuselage of World War I biplane fighter named Vieux Charles was built with wire braced wood framework. The monoplane, Le Monocoque, had an unusually smooth aerodynamic design. Its fuselage was made with laminated tulip wood, where one layer was placed along the length of the fuselage, the second in a right-hand spiral and the third in a left-hand spiral around the fuselage. This laminated single shell wood construction provided highly polished, smooth surfaces. There was a significant reduction in the drag, and the plane could achieve a high speed of 108 mph.

Around 1930-40, a gradual shift from wood to aluminium alloy construction is noticed. With the increase in the size and speed of airplanes, the strength and stiffness requirements for a given weight could not be met from wooden construction. Several new structural features, e.g., skin-stringer construction, shear webs, etc. were introduced. These aircraft were introduced in 1930, although they were not the first to use metals, had aluminium alloy monocoque fuselage and a wood wing. The switch over to light aluminium alloys in aircraft construction was no doubt, a major step in search for a lightweight design. Limitations of aluminium alloys are assessed with the speed of the aircraft increasing sharply (significantly more than the speed of sound), the demand for a more weight optimized performance, the fuel-efficient design and so on. The aluminium was stretched to its maximum limit. The search for newer and better materials was the only alternative.

Continuous glass fibres, which were commercially available since thirties, are found to be very strong, durable, creaseless, non-flammable and insensitive to weathering. The glass fibres coated with resin can be easily molded to any complex curved shape, especially, with fibres aligned in a desired direction as in the case of the three-layered wood fuselage. Fibre glass fabrics were successfully used in a series of Todai LBS gliders in Japan during the mid-fifties. Todai LBS-1 had spoilers made from fiberglass fabrics. Todai LBS-2 had a wood wing and a sandwich monocoque fuselage whose wall consisted of a balsa wood core sandwiched between two glass fibre reinforced composite face skins. The wing skin of another important glider, the Phoenix (first flight in 1957), developed in Germany was a sandwich with fiberglass-polyester faces and balsa wood core. The other successful glider SB-6, first flown in 1961, had a glass fibre-epoxy shell and a glass fibre composite-balsa sandwich box spar.

Glass fibres are strong, but not stiff enough to use them in high sped aircraft. The search for stiffer fibres to make fibre reinforced composite started in the fifties in several countries. The laboratory scale production of high-strength carbon fibres by Royal Aircraft Establishment, Farnborough, U.K. was reported in 1952. In USA, Union Carbide developed high-modulus continuous carbon fibres in 1958. High-strength graphite fibres were developed at the Government Industrial Research Institute of Osaka, Japan in 1959. Before the end of sixties, the commercial production of carbon fibres (PAN based) started in full scale. Very high modulus boron fibres were also introduced during this time. High strength, low density organic fibres, Kevlar 49, were also marketed by Dupont, USA during early seventies. A host of synthetic resins, especially structural grade epoxy resins, were also commercially available.

All these advanced materials provided the much-needed alternatives to less efficient aluminium alloy and fiberglass composites. The switch-over from the aluminium and GFRP to advanced composites in airframe construction was, however, very slow at the initial stage. It started with the F-14 fighter and the F-111 fighter bomber around 1972, but in the period of about two and a half decades, there were quite a few airplanes, in which almost all structures are made of composites. Similar trend in material uses can be observed in the development of helicopters as well. As early as 1959-60, the Vetrol Company, now Boeing Helicopters, developed helicopter rotor blades with glass-epoxy faces and aluminium honeycomb core. In course of time several structural parts such as horizontal stabilizer, vertical pylon, tail cone, canopies, fuselage, floor board, rotor hub and landing gears were developed with various composites, which later culminated in the development of the all-composite helicopter, Boeing Model 360 which was flight tested in 1987.

Vehicle	**Component**	**Composite**
Sailplane SB-10	Middle portion of the wing	
Sailplane SB-10, SB-11, SB-12, Nimbus, AS-W22	All composite	
A-4	Flaps, stabilizer	
F-5	Leading edge	
Vulcan	Air brakes	CFRP
Rafale	Wing structure	
Boeing 757 & 767	Control surfaces, carriage doors, fairings	
Voyager	All composite	
Starship	All composite	
F-14	Stabilizer	BFRP
F-15, F-16	Tail skin	
C-5A	Wing box	SiC/Al
F-111	Fuselage segment	Boron/Al

Materials for the next-generation aeroengines will go a see-through change in view of much hotter running engines to increase the thermal efficiency and enhance the thrust-to-weight ratio. It is envisaged that, for the future military aircraft, the thrust-to-weight ratio will double, while the fuel consumption will reduce by 50%. Metal-matrix composites (MMCs) and ceramic-matrix composites (CMCs), which are thermally stable and can withstand loads at high temperatures will be of immense use in such applications. Carbon-carbon composites, which are ceramic composites can withstand load beyond 2000^0C.

The use of these advanced materials in aeroengines is likely to pick up in the first decade of the 21st century. Fan blades, compressor blades, vanes and shafts of several aeroengines are now either employing or contemplating to use in the near future metal matrix composites with boron, boron carbide, silicon carbides or tungsten fibres and aluminium, titanium, nickel and super alloy (e.g. NiCrAly or FeCrAly) matrices. The material menu for rockets, missiles, satellite launch vehicles, satellites and other space vehicles is quite extensive and diverse. The trend is to design some structural components like payload structures, satellite frame works and central cylindrical shells, solar panel wings, solar booms, antennas, optical structures, thermal shields, fairings, motor cases and nozzles, propellant tanks, pressure vessels, etc. with composite materials to derive the maximum weight benefit. All space vehicles of recent origin have several composite structural systems.

CFRP is the obvious choice because of its excellent thermo-mechanical properties, i.e., high specific stiffness and strength, higher thermal conductivity and lower coefficient of thermal expansion. The future large space stations are likely to be built with CFRP. Although BFRP has several positive features, it is mainly used for stiffening purposes. Beryllium, although not a composite, possesses highly favourable properties but it is sparingly used due to safety hazards, especially during fabrication.

The examples of space applications of composites are too many. One of the early major applications is the graphite-epoxy mesh grid off-set parabolic antenna reflector developed by Hughes Aircraft Company for the Canadian ANIK satellite which was launched in 1972. The European Remote Sensing Satellite ERS-I has several composite parts plus a large 10m long metallized graphite-epoxy radar antenna array. The Voyager spacecraft contains a large 3.7m diameter CFRP parabolic antenna reflector. The fairing of ARIANE 4 is a graphite composite stiffened shell structure of maximum 4m diameter and 8.6m height.

ADVANCED COMPOSITES IN SELECTED AEROSPACE APPLICATIONS

Vehicle	Component	Composite
Tactical	Nose cone	quartz./polyamide
Tomohawk	Shaft for turbofan	Borosic/titanium
PSLV	Solid motor case	KFRP
Ariane	Dual-launch structures	CFRP
Insat, Italsat, Arabsat, Olympus	Antenna reflectors	
TDF-1	Solar array wing	
Eureca	Micro-gravity spacecraft platform truss structure	
Hubble space telescope	High gain antenna boom	Graphite 6061 Al
Space shuttle	Main frame, frame stabilizing braces, truss struts, nose landing gear	Boron/AL

OTHER STRUCTURAL APPLICATIONS

Civil Engineering

- The interest in the use of glass fibre reinforced polyesters in building structures started as early as sixties.

- The GFRP dome structure in Benghajj was constructed in 1968. The other inspiring example is the GFRP roof structure of Dubai Airport built in 1972 and is comprised of clustered umbrella like hyperbolic paraboloids.

- Several GFRP shell structures were erected during seventies.

- Another striking example is the dome complex at Sharajah International Airport, which was constructed during early eighties. The primary advantage of using composites in shell structure is that any complex shell shape, either synclastic, anticlastic or combination of both, which is of architectural significance and aesthetic value, can be easily fabricated.

- The composite folded plate system and skeletal structures also became popular.

- The roof of Covent Garden Flower Market at Nine Elms, London covering an area of 1ha is an interesting example which was based on a modular construction.

- The modular construction technique helps to build a large roof structure which is normally encountered in the design of community halls, sports complexes, marketing centres, swimming pools, factory sheds, etc.

- Several other applications, where GFRP has been successfully used, include movable prefabricated houses, exterior wall panels, partition walls, canopies, stair cases and ladders, water tanks, pipes and drainages and led to its wide use in radomes and antenna towers.

- In one particular construction, the top 100 ft of a radar microwave link tower was built with GFRP and the fibers were Kevlar fibres (also radio transparent) to reduce unwanted disturbances in air traffic control radar signals.

- Considering the future prospects of composites in civil structural application, ASCE Structural Plastics Research Council, as early as seventies endeavoured to develop design methods for structural plastics, both reinforced and unreinforced.

- However, the major deterrent for the popularity of composites in civil engineering structures is the material cost. But, in many applications, GFRP and KFRP may be cheaper considering the cumulative cost.

- Moreover, ease of fabrication and erection, low handling and transportation cost, less wear and corrosion, simpler maintenance and repairing procedures, non-magnetic properties, integrity and durability as well as modular construction will cumulatively reduce the cost in the long run.

- The Living Environment house, developed by GE plastics in 1989, is an illustrative example of the multipurpose use of composites in a building.

AUTOMOBILE AND AUTOMOTIVE APPLICATIONS

- In 1930, Henry Ford attempted to use soya oil to produce a phenolic resin and hence to produce a wood filled composite material for car bodies

- In 1940 flax reinforced spitfire fuselage was made at Duxford, Cambridgeshire

- In 1950s, glass fibre reinforcement material and cold setting polyester resins are available commercially leading to manufacturing of compound curved streamlined automobile bodies into reach of low volume, low capital companies.

- The first use of composite by a high-volume manufacturer was probably in 1954.

- Feasibility studies were carried out, since early 70s, to explore the possibilities of using composites in the exterior body panels, frameworks/chassis, bumpers, drive shafts, suspension systems, wheels, steering wheel columns and instrument panels of automotive vehicles.

- Ford Motor Co. experimented using three different composites: a vinyl-ester-based SMC and DMC and a glass fibre reinforced polypropylene sheet material.

- Analytical studies, static and dynamic tests, durability tests and noise tests demonstrated the feasibility of design and development of a highly curved composite automotive part.

- A composite GM heavy truck frame, developed by the Convair Division of General Dynamics in 1979, using graphite and Kevlar fibres (2:1 by parts) and epoxy resin (32%

by wt) not only performed satisfactorily but reduce the weight by 62% in comparison to steel for the same strength and stiffness.

- The hybrid glass/carbon fibre composite drive shafts, introduced around 1982 in Mazdas, provided more weight savings, lower maintenance cost, reduced level of noise and vibration and higher efficiency compared to their metal counterparts.

- The composite driver shaft is 60% lighter than the original steel shaft and possesses superior dampening and torsional properties.

- Fibre glass reinforced polypropylene bumper beams were introduced on Chevrolet Corvette Ford and GM passenger cars (1987 models). Other important applications of composites were the rear axle for Volkswagen Auto-2000, steering wheels for Audi models and composite wheels of Pontiac sports cars.

- Composites are recognized as the most appropriate materials for the corrosion resistant, lightweight, fast and fuel efficient modern automobiles, for which aerodynamics constitute the primary design considerations.

- All major automotive components like space frames, exterior and interior body panels, instrument panel assemblies, power plants, power trains, drive trains, brake and steering systems, etc. are now being fabricated with a wide variety of composites that include polymer, metal and ceramic matrix composites.

- The Ford`s probe V concept car is a classic example of multiple applications of composites in an automobile car. The present trend is to use composites even in the design of large size tankers, trailers, delivery vans and passenger vehicles.

- The metal and ceramic composites will be of significance in heated engine components and brake pads. The pistons and connecting rods of modern diesel and IC engines are invariably made of composites with alumina fibres and aluminium or magnesium alloy matrices.

OTHER APPLICATIONS

MARINE

- Strong, stiff and light composites are also very attractive materials for marine applications.

- GFRPs are being used for the last 3-4 decades to build yatchs, speed boats and other workboats.

- The hull of a modern racing yatch, New Zealand, is of sandwich construction with CFRP faces.

- A new cabin construction material that is being tried in the Statendam-class ship building is a metallic honeycomb sandwich with resin-coated facing, that may lead to substantial weight saving. The Ulstein water jet has a long moulded inlet tract for better control of dimensional accuracy.

- The carbon/aluminium composite has been used for struts and foils of hydrofoils, and the silicon carbide/aluminium composite has been employed in pressure hulls and torpedo structures.

- The composites are also being increasingly used in the railway transportation systems to build lighter bogeys and compartments.

- The other important area of application of composites is concerned with fabrication of energy related devices such as wind-mill rotor blades and flywheels.

MEDICAL APPLICATIONS

- The light artificial limbs and external bracing systems made of CFRP provide the required strength, stiffness and stability in addition to lightness.

- Carbon fibres are medically biocompatible. Composites made with carbon fibres and biocompatible metals and polymers have been found to be suitable for a number of applications in orthopedics.

- A carbon/carbon composite hip joint with an aluminium oxide head has performed satisfactorily. Matrices such as polyethylene, polysulfone and polyaryletherketone reinforced with carbon fibres are also being used to produce orthopedic implants.

ELECTRICAL AND ELECTRONICS

- Composites also have extensive uses in electrical and electronic systems.

- CFRP antennas are excellent due to very low surface distortion.

- Composite antenna dishes are much lighter compared to metallic dishes.

- Leadless ceramic chip carriers are reinforced with Kevlar or Kevlar-glass coweave polyimides to reduce the incidence of solder joint microcracking due to stresses induced by thermal cycling.