



**THE UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL
ENGINEERING**

**MEC 2309 – PROPERTIES OF ENGINEERING
MATERIALS I**

GMM/FKC 2022

LECTURE 13



COMPOSITE MATERIALS

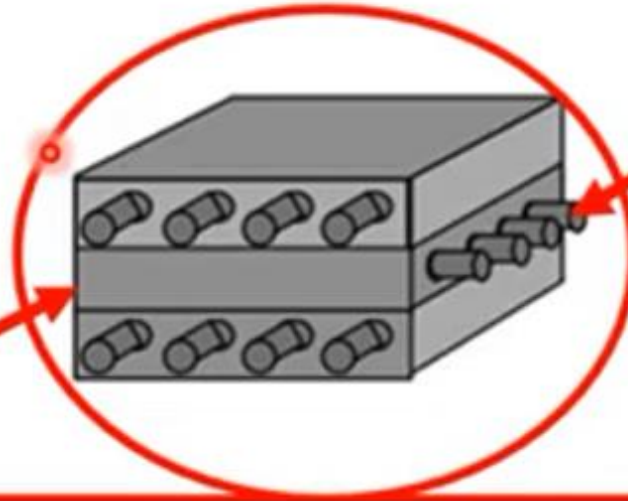
GM **G. M. MUNAKAAMPE / F. K. CHITALU (2022)**

WHAT IS A COMPOSITE MATERIAL

A broad definition of composite is: Two or more **chemically distinct** materials which when combined have improved properties over the individual materials. Composites could be natural or synthetic.

WHAT IS A COMPOSITE MATERIAL

Material B in the form of Matrix, easily distinguishable



Material A in the form of fiber, easily distinguishable

Composite: Material A and B do not dissolve or blend into each other

TYPES OF COMPOSITE MATERIAL

Types of Composite Materials

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graph TD; A[Types of Composite Materials] --> B[Natural Composites]; A --> C[Synthetic Composites];
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Natural Composites

Natural composites exist in both animals and plants

Synthetic Composites

Synthetic composites are man made composites

TYPES OF COMPOSITE MATERIAL

Example 1

Wood

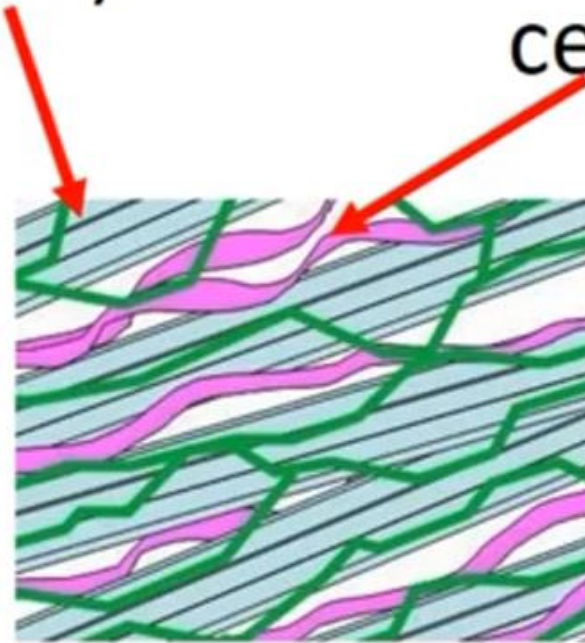


cellulose
fibres (a
polymer)



Lignin (a much
weaker substance
as compared to
cellulose)

- Wood is much stronger than lignin and cellulose
- Cellulose is also found in cotton, but without the lignin to bind it together it is much weaker.



TYPES OF COMPOSITE MATERIAL

Example 2

Bone



Hydroxyapatite
(which is mainly
calcium phosphate)
Is hard but brittle
material called



Collagen(which is a
protein)
is a soft and flexible
material.

SYNTHETIC COMPOSITE EXAMPLES

Example from Early Composites

- ❑ **Mixing mud and straw** together to make bricks that are resistant to both squeezing and tearing and make excellent building blocks.
- ❑ Bricks alone are strong under compression and have good compressive strength. However, they break quite easily when you try to bend them (poor shear and tensile strength).
- ❑ In more recent times, it has been found that adding metal rods, wire or wire mesh to concrete can increase its tensile strength. Such concrete is called **reinforced concrete**.

SYNTHETIC COMPOSITE EXAMPLES

Example from Modern Composites

- ❑ **Fibreglass** is still widely used today for boat hulls, sports equipment, building panels and many car bodies. The matrix is a plastic and reinforcement is glass that has been made into fine threads and sometimes even woven into a sort of mesh.
- ❑ Glass alone is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by distributing and sharing out the forces acting on them.
- ❑ Some advanced composites are now made using **carbon fibres** instead of glass. These materials are lighter and stronger than the fibreglass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs. They also offer possibilities for making lighter aircraft and cars.

COMPONENTS OF COMPOSITE MATERIALS

Components of Composite Materials

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graph TD; A[Components of Composite Materials] --> B[Matrix]; A --> C[Reinforcement]
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Matrix

Reinforcement

COMPONENTS OF COMPOSITE MATERIALS

- ❑ **Composites** are combinations of two materials in which one of the material is called the **reinforcing phase**, is in the form of fibers, sheets, or particles, and is embedded in the other material called the **matrix phase**.
- ❑ Typically, reinforcing materials are strong with low densities while the matrix is usually a ductile or tough material. If the composite is designed and fabricated correctly, it combines the strength of the reinforcement with the toughness of the matrix to achieve a combination of desirable properties not available in any single conventional material.

COMPONENTS OF COMPOSITE MATERIALS

Reinforcement: Fibres	Matrix Materials	Interface
Glass Carbon Organic Boron Ceramic Metallic	Polymers Metals Ceramics	Bonding surface

COMPOSITE MATERIALS

The essence of the concept of composites is that the load is applied over a large surface area of the matrix. Matrix then transfers the load to the reinforcement, which being stiffer, increases the strength of the composite. It is important to note that there are many matrix materials and even more fiber types, which can be combined in countless ways to produce just the desired properties.

In the USA, composites manufacturing is a 25 billion dollar a year industry with about 6000 composites related manufacturing plants and materials distributors, employing over 235,000 people. 250,000 additional people are employed in businesses that support the composites industry, e.g. materials suppliers, equipment vendors, etc.

About 90% of all composites produced are comprised of glass fiber and either polyester or vinylester resin. Composites are broadly known as reinforced plastics.

However, research is now on-going in reinforcing organic/natural fibres, e.g. sisal, jute, palm, hair, feathers, etc.

COMPOSITE MATERIALS

Material

Characteristics

Fibers

Glass	High strength, low stiffness, high density; lowest cost; E (calcium aluminoborosilicate) and S (magnesia-aluminosilicate) types commonly used.
Graphite	Available as high-modulus or high-strength; low cost; less dense than glass.
Boron	High strength and stiffness; highest density; highest cost; has tungsten filament at its center.
Aramids (Kevlar)	Highest strength-to-weight ratio of all fibers; high cost.
Other fibers	Nylon, silicon carbide, silicon nitride, aluminum oxide, boron carbide, boron nitride, tantalum carbide, steel, tungsten, molybdenum.

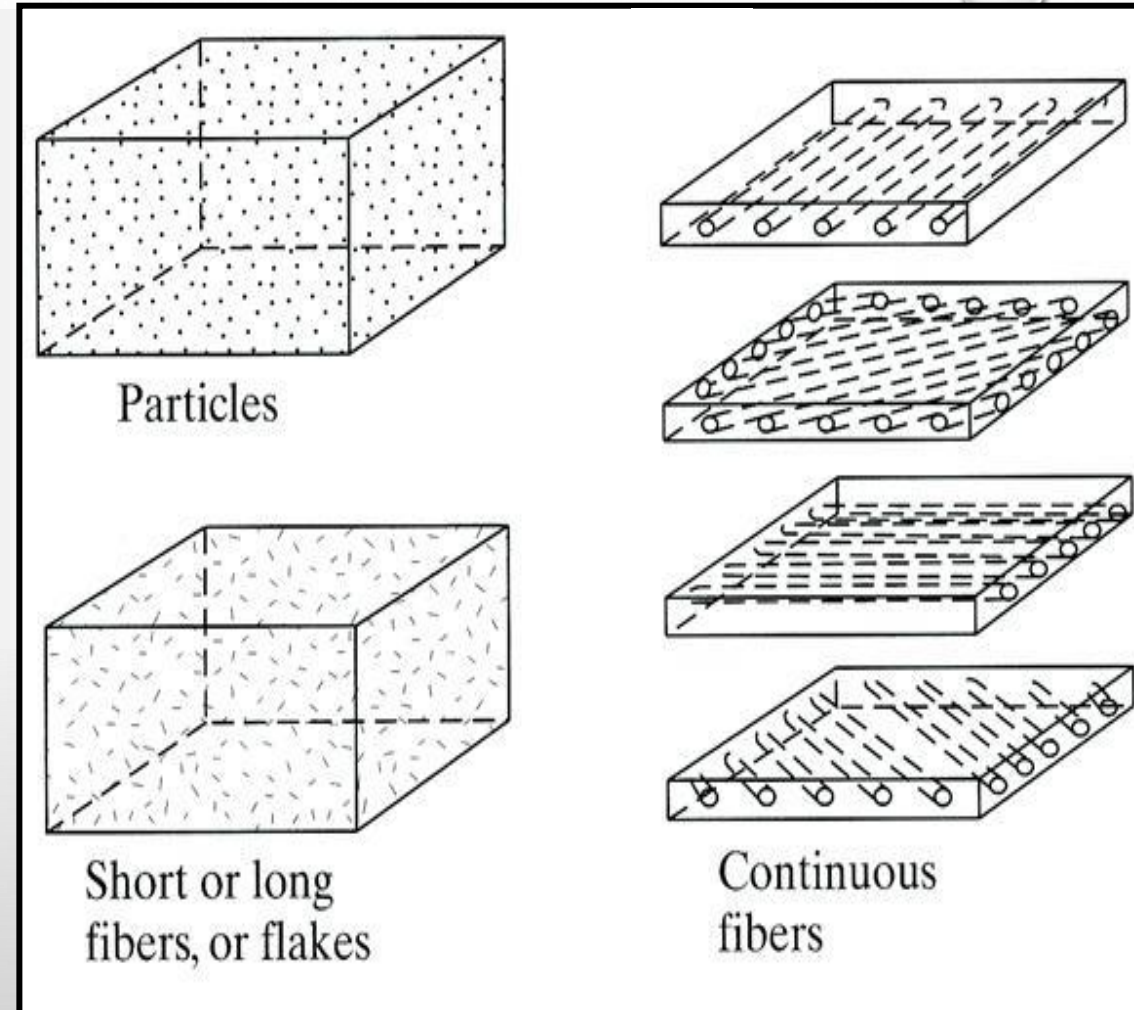
Matrix materials

Thermosets	Epoxy and polyester, with the former most commonly used; others are phenolics, fluorocarbons, polyethersulfone, silicon, and polyimides.
Thermoplastics	Polyetheretherketone; tougher than thermosets but lower resistance to temperature.
Metals	Aluminum, aluminum-lithium, magnesium, and titanium; fibers are graphite, aluminum oxide, silicon carbide, and boron.
Ceramics	Silicon carbide, silicon nitride, aluminum oxide, and mullite; fibers are various ceramics.

COMPOSITES – POLYMER MATRIX

Polymer matrix composites (PMC) and fibre reinforced plastics (FRP) are referred to as **Reinforced Plastics**. Common fibres used are glass (GFRP), graphite (CFRP), boron, and aramids (Kevlar). These fibers have **high specific strength** (strength-to-weight ratio) and **specific stiffness** (stiffness-to-weight ratio)

Matrix materials are usually thermoplastics or thermosets; polyester, epoxy (80% of reinforced plastics), fluorocarbon, silicon, phenolic.



COMPOSITES – POLYMER MATRIX

Reinforcing Fibres

Glass – most common and the least expensive, high strength, low stiffness and high density. GFRP consists 30-60% glass fibres by volume.

Graphite (99% carbon) or Carbon (80-95% carbon) – more expensive than glass fibres, but lower density and higher stiffness with high strength. The composite is called carbon-fibre reinforced plastic (CFRP).

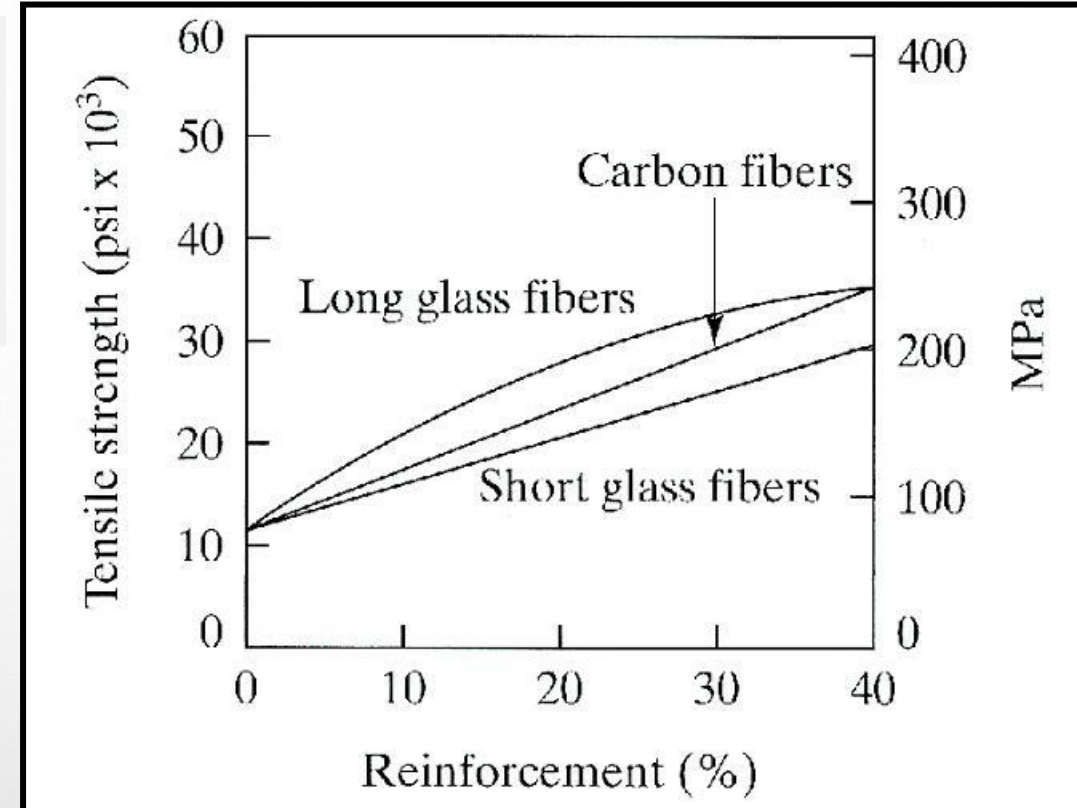
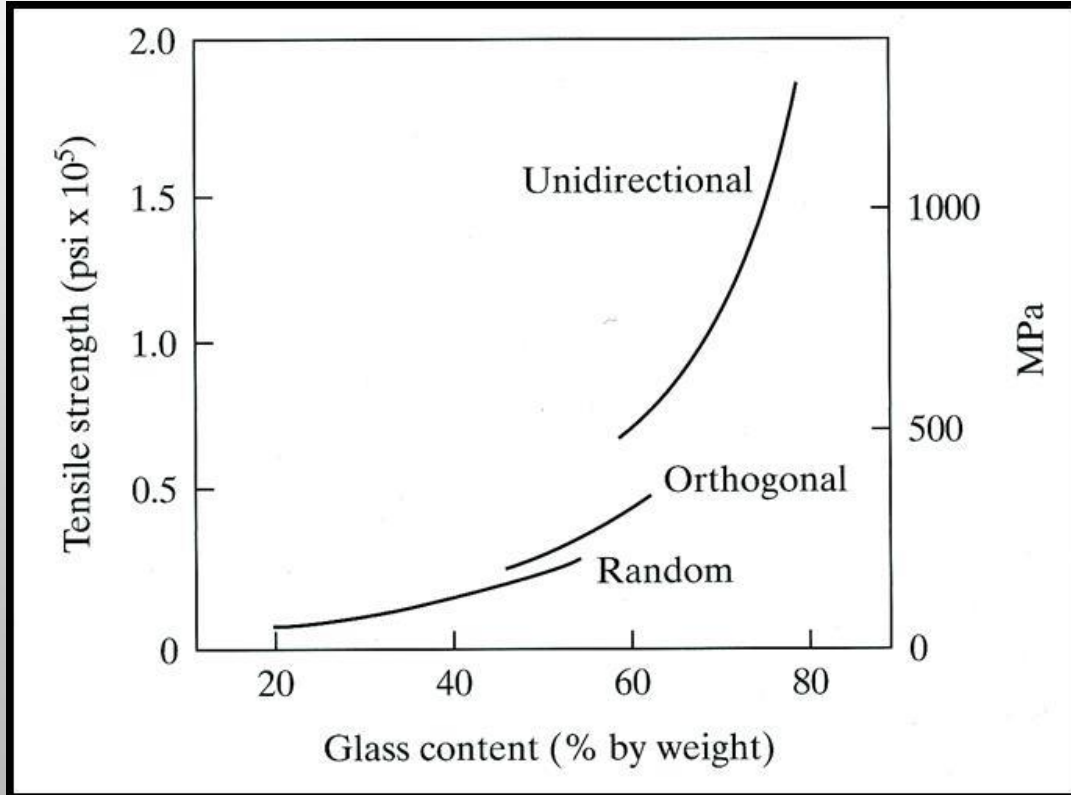
Boron – boron fibres consist of boron deposited on tungsten fibres, high strength and stiffness in tension and compression, resistance to high temperature, but they are heavy and expensive.

Aramids (Kevlar) – highest specific strength, toughest fibre, undergoes plastic deformation before fracture, but absorbs moisture, and is expensive.

The average diameter of fibres used is usually less than 0.01 mm. The tensile strength of a glass fibre could be as high as 4,480 MPa (bulk glass $S_u = 34-1,030$ MPa)

PROPERTIES OF REINFORCED PLASTICS

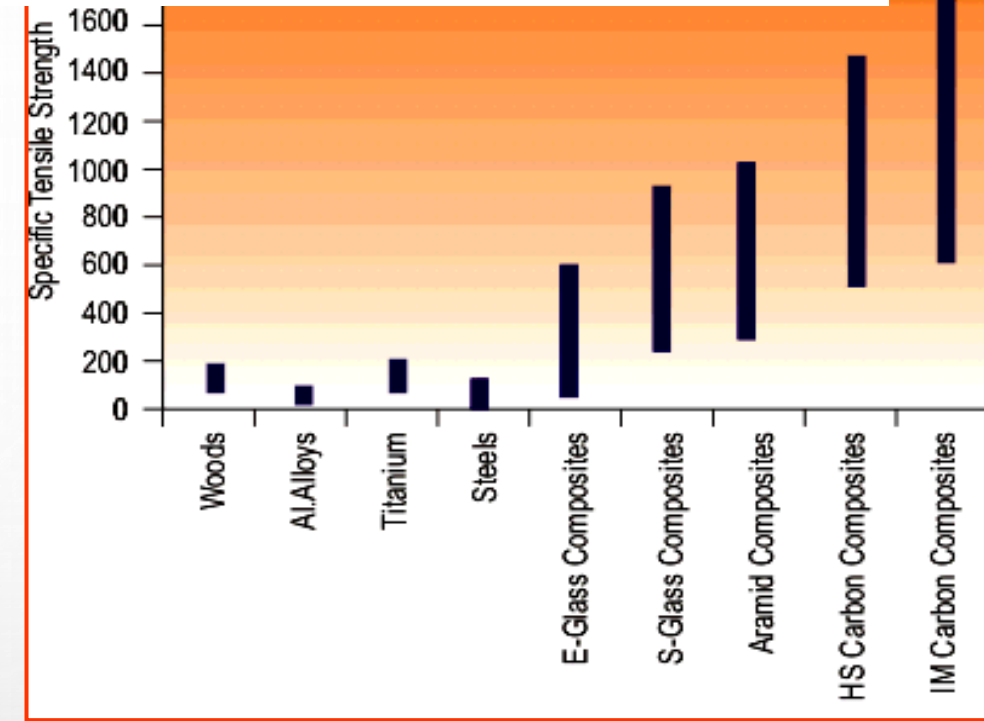
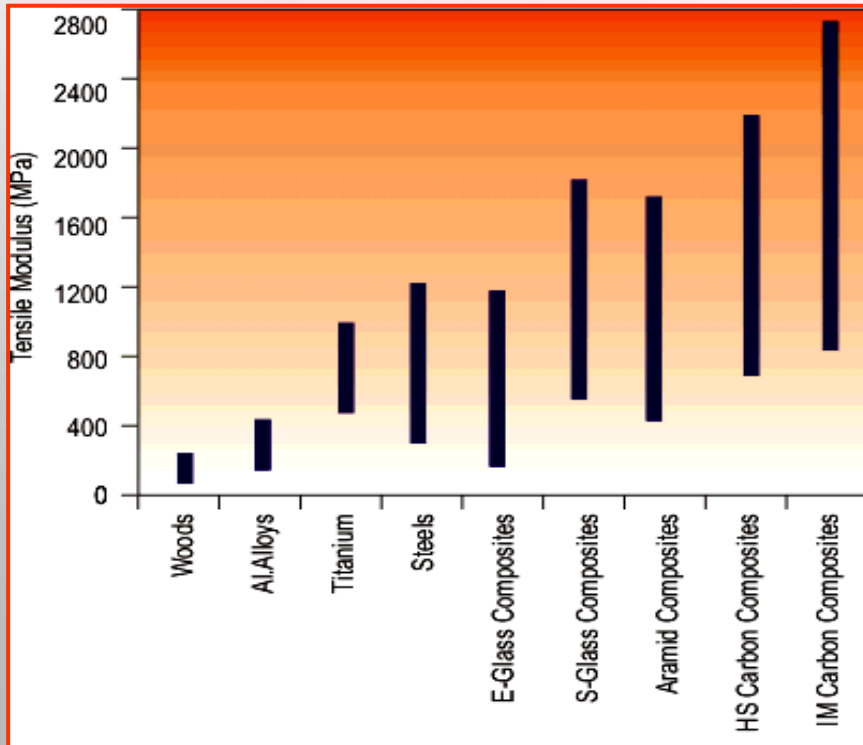
The mechanical properties of reinforced plastics vary with the kind, shape, relative volume, and orientation of the reinforcing material, and the length of the fibers.



Effect of type, length, % volume, and orientation of fibers in a fiber reinforced plastic (nylon)

SPECIFIC STRENGTH (STRENGTH-TO-WEIGHT RATIO)

Composites have a higher specific strength than many other materials. Many combinations of resins and reinforcements can be used, and therefore, mechanical and physical properties can be tailored.



Lower properties for each material are associated with simple manufacturing processes and material forms (e.g. spray lay-up glass fibre), and higher properties are associated with higher technology manufacture (e.g. autoclave moulding of unidirectional glass fibre), the aerospace industry.

APPLICATIONS OF REINFORCED PLASTICS

Phenolic as a matrix with asbestos fibers was the first reinforced plastic developed. It was used to build an acid-resistant tank. In 1920s it was Formica, commonly used as counter top., in 1940s boats were made of fiberglass. More advanced developments started in 1970s.

Consumer Composites

Typically, although not always, consumer composites involve products that require a cosmetic finish, such as boats, recreational vehicles, bath wear, and sporting goods. In many cases, the cosmetic finish is an in-mold coating known as gel coat.

Industrial Composites

A wide variety of composites products are used in industrial applications (corrosion resistance and performance in adverse environments). Generally, premium resins such as isophthalic and vinyl ester formulations are required to meet corrosion resistance specifications, and fiberglass is almost always used as the reinforcing fiber. Products include underground storage tanks, scrubbers, piping, fume hoods, water treatment components, pressure vessels, and a host of other products.

APPLICATIONS OF REINFORCED PLASTICS

Advanced Composites

This sector of the composites industry is characterized by the use of expensive, high-performance resin systems and high strength, high stiffness fiber reinforcement. The aerospace industry, including military and commercial aircraft of all types, is the major customer for advanced composites.

These materials have also been adopted for use in sporting goods, where high-performance equipment such as golf clubs, tennis rackets, fishing poles, and archery equipment, benefits from the light weight – high strength offered by advanced materials. There are a number of exotic resins and fibers used in advanced composites, however, epoxy resin and reinforcement fiber of aramid, carbon, or graphite dominates this segment of the market.

COMPOSITES – METAL MATRIX

The metal matrix composites offer higher modulus of elasticity, ductility, and resistance to elevated temperature than polymer matrix composites. But, they are heavier and more difficult to process.

Fiber	Matrix	Applications
Graphite	Aluminum	Satellite, missile, and helicopter structures
	Magnesium	Space and satellite structures
	Lead	Storage-battery plates
	Copper	Electrical contacts and bearings
Boron	Aluminum	Compressor blades and structural supports
	Magnesium	Antenna structures
	Titanium	Jet-engine fan blades
Alumina	Aluminum	Superconductor restraints in fission power reactors
	Lead	Storage-battery plates
	Magnesium	Helicopter transmission structures
Silicon carbide	Aluminum, titanium	High-temperature structures
	Superalloy (cobalt-base)	High-temperature engine components
Molybdenum, tungsten	Superalloy	High-temperature engine components

COMPOSITES – CERAMIC MATRIX

Ceramic matrix composites (CMC) are used in applications where resistance to high temperature and corrosive environment is desired. CMCs are strong and stiff but they lack toughness (ductility)

Matrix materials are usually silicon carbide, silicon nitride and aluminum oxide, and mullite (compound of aluminum, silicon and oxygen). They retain their strength up to 1650 °C.

Fiber materials used commonly are carbon and aluminum oxide.

Applications are in jet and automobile engines, deep-sea mining, cutting tools, dies and pressure vessels.

COMPOSITES – CERAMIC MATRIX CONCRETE

- ❑ Concrete is a common large-particle composite in which both matrix and dispersed phases are ceramic materials. Because the terms concrete and cement are sometimes incorrectly interchanged, perhaps it is appropriate to make a distinction between them.
- ❑ In a broad sense, concrete implies a composite material consisting of an aggregate of particles that are bound together in a solid body by some type of binding medium, that is, a cement. The two most familiar concretes are those made with portland and asphaltic cements, in which the aggregate is gravel and sand.
- ❑ Asphaltic concrete is widely used primarily as a paving material, whereas portland cement concrete is employed extensively as a structural building material.

COMPOSITES – CERAMIC MATRIX CONCRETE

Reinforced Concrete

- ❑ The strength of portland cement concrete may be increased by additional reinforcement.
- ❑ This is usually accomplished by means of steel rods, wires, bars (rebar), or mesh, which are embedded into the fresh and uncured concrete.
- ❑ Thus, the reinforcement renders the hardened structure capable of supporting greater tensile, compressive, and shear stresses.
- ❑ Even if cracks develop in the concrete, considerable reinforcement is maintained.

FACTORS AFFECTING PROPERTIES OF COMPOSITE MATERIALS

The **type, distribution, size, shape, orientation and arrangement of the reinforcement** will affect the properties of the composite material and its anisotropy.

ADVANTAGES OF COMPOSITE MATERIALS

Design flexibility

Composites have an advantage over other materials because they can be molded into complex shapes at relatively low cost. This gives designers the freedom to create any shape or configuration. Boats are a good example of the success of composites.

Corrosion Resistance

Composites products provide long-term resistance to severe chemical and temperature environments. Composites are the material of choice for outdoor exposure, chemical handling applications, and severe environment service.

ADVANTAGES OF COMPOSITE MATERIALS

Low Relative Investment

One reason the composites industry has been successful is because of the low relative investment in setting-up a composites manufacturing facility. This has resulted in many creative and innovative companies in the field.

Durability

Composite products and structures have an exceedingly long life span. Coupled with low maintenance requirements, the longevity of composites is a benefit in critical applications. In a half-century of composites development, well-designed composite structures have yet to wear out.

In 1947 the U.S. Coast Guard built a series of forty-foot patrol boats, using polyester resin and glass fiber. These boats were used until the early 1970s when they were taken out of service because the design was outdated. Extensive testing was done on the laminates after decommissioning, and it was found that only 2-3% of the original strength was lost after twenty-five years of hard service.

DISADVANTAGES OF COMPOSITE MATERIALS

Composites are heterogeneous

Properties in composites vary from point to point in the material. Most engineering structural materials are homogeneous.

Composites are highly anisotropic

The strength in composites vary as the direction along which we measure changes (most engineering structural materials are isotropic). As a result, all other properties such as, stiffness, thermal expansion, thermal and electrical conductivity and creep resistance are also anisotropic. The relationship between stress and strain (force and deformation) is much more complicated than in isotropic materials.

The experience and intuition gained over the years about the behavior of metallic materials does not apply to composite materials.

DISADVANTAGES OF COMPOSITE MATERIALS

Composites materials are difficult to inspect with conventional ultrasonic, eddy current and visual NDI methods such as radiography.

American Airlines Flight 587, broke apart over New York on Nov. 12, 2001 (265 people died). Airbus A300's 27-foot-high tail fin tore off. Much of the tail fin, including the so-called tongues that fit in grooves on the fuselage and connect the tail to the jet, were made of a **graphite composite**.



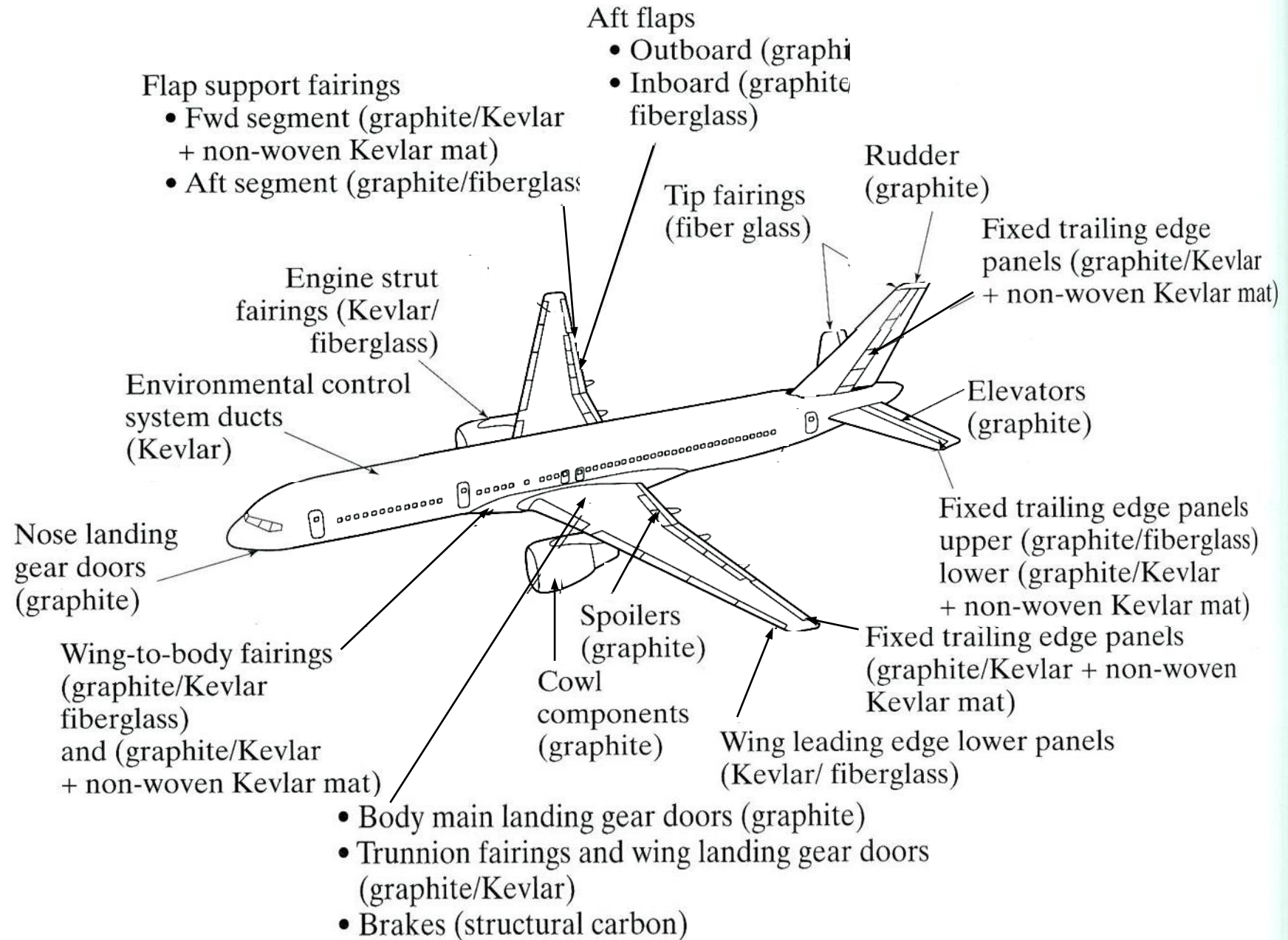
The plane crashed because of damage at the base of the tail that had gone undetected despite routine nondestructive testing and visual inspections.

DISADVANTAGES OF COMPOSITE MATERIALS

In November 1999, America's Cup boat "Young America" broke in two due to debonding face/core in the sandwich structure.



APPLICATION OF COMPOSITES IN AIRCRAFT INDUSTRY



APPLICATION OF COMPOSITES IN AIRCRAFT INDUSTRY

Boeing 777	Boeing 787/Dreamliner
<i>Launched in 2000</i>	<i>To be launched in 2007</i>
11% composites	50% composites
70% aluminum	20% aluminum
7% titanium	15% titanium
11% steel	10% steel
1% other	5% other

20% more fuel efficiency and 15,900 kg lighter³²

APPLICATIONS OF COMPOSITES



Lance
Armstrong's 1-kg
Trek bike, 2004
Tour de France



Pedestrian bridge
in Denmark, 40 m
long (1997)



Swedish Navy,
Stealth (2005)

APPLICATIONS OF COMPOSITES



APPLICATIONS OF COMPOSITES



Plywood



Chipboard



END OF LECTURE 13