Composite Materials

An Introduction

What is a composite?

- An Engineered material
- A mixture of two or more materials

Definition:

"**Composite materials** are engineered materials made from two or more constituent materials that remain separate and distinct while forming a single component"

What is a composite?

Definition:

"**Composite materials** are considered to be any multiphase material that exhibits a significant proportions of the properties of the both constituents phases such that a better combination of properties (both physical and chemical) is realised"

Properties of composite can be tailored by varying the constituent phases

Components of composite

Matrix : A continuous phase (material) that holds second phase

Reinforcing phase: A phase (material) that provides reinforcement (Strength)

Criteria for a composite

Prerequisite for composite

- Two phases are distinguishable at micro and macro level (keeps their identity)
- Two phases are insoluble in each other
- Must be chemically inert with respect to each other so that no interaction occurs at high temperature until one of the components melt (exception small degree of interdiffusion is good for bonding)
- Composite should offer better properties or obtain new set of properties as a contribution from both matrix and reinforcing phase
- Different part bonded together have different properties or different dimensionalities

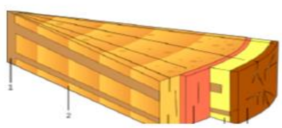
Composites are all around us

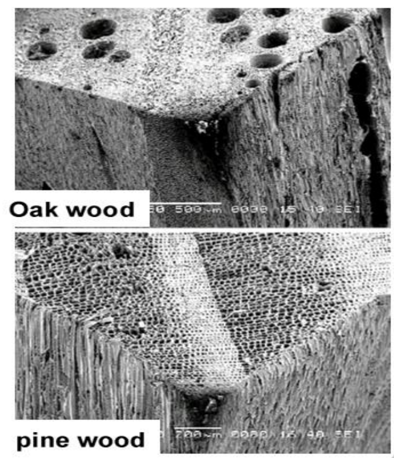
- Mud bricks made sturdier houses if lined with straw.
- Ancient Pharaohs made their slaves to make bricks by mixing straw. Pyramids made from such bricks are still standing.

Composites in nature

Natural composites can be found in both animal and plants

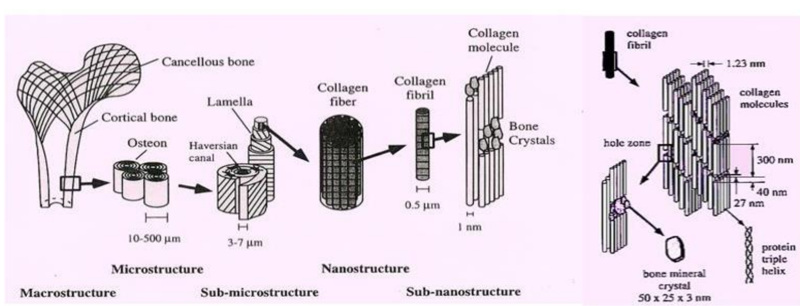
- Wood (Lignin+Cellulose)





Composites in nature

- Bone



The main constituents of bone are: collagen (20 wt.%), calcium phosphates (69 wt.%) and water (9 wt. %)

Additionally: proteins, polysaccharides, and lipids.

- Birds' feathers
- Spider web

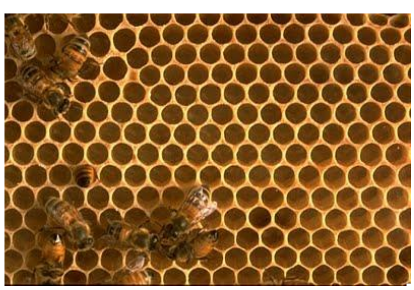
Sea shells

Abalone shell:
$CaCO_3$
+ 3% organic material
>3000* stronger than calcite

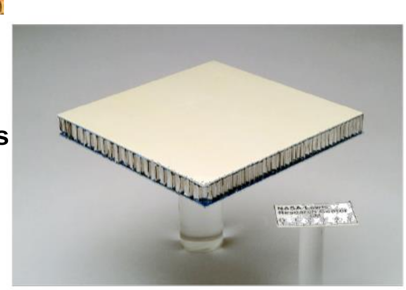
Why is spider silk so strong?

Dragline silk is a composite material comprised of two different proteins, each containing three types of regions with distinct properties. One of these forms an amorphous (noncrystalline) matrix that is stretchable, giving the silk elasticity. When an insect strikes the web, the stretching of the matrix enables the web to absorb the kinetic energy of the insect¿s flight. Embedded in the amorphous portions of both proteins are two kinds of crystalline regions that toughen the silk. Although both kinds of crystalline regions are tightly pleated and resist stretching, one of them is rigid. It is thought that the pleats of the less rigid crystalline regions not only fit into the pleats in the rigid crystals but that they also interact with the amorphous areas in the proteins, thus anchoring the rigid crystals to the matrix. The resulting composite is strong, tough, and yet elastic.

Beehive made by honey bee (inspiration for structural composites)

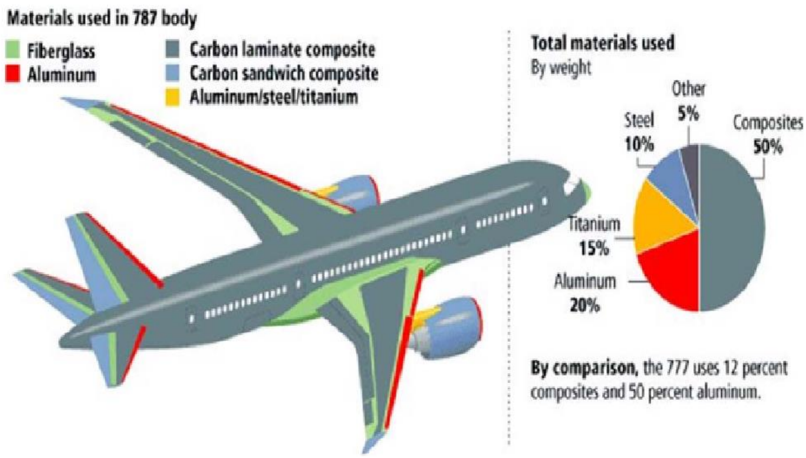


Honey comb panels used in air crafts



Visit this site for info
http://www.universalmetaltek.com/honeycomb_panel.htm

Composites are all around us



Which materials are composites?

- Wood (lignin +cellulose)
- Concrete (gravel+sand+cement)
- Reinforced concrete (gravel+sand+steel)
- Steel (ferrite and pearlite)
- Multiple polymer layers
- Reinforced plastic (it does not improve properties)
- Paper (only cellulose fibers)

Applications of composites

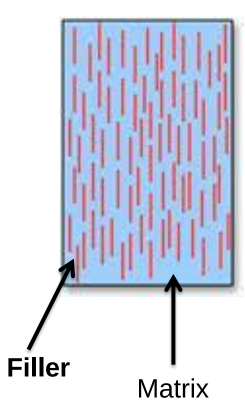
Composites can be found in:

-Boat hulls
-The aerospace industry (structural components as well as engines and motors)
-Automotive parts (panels, frames, dashboards, body repairs)
-Sinks, bathtubs, hot tubs, swimming pools
-Cement buildings, bridges
-Surfboards, snowboards, skis
-Golf clubs, fishing poles, hockey sticks
-Trees are technically composite materials, plywood
-Electrical boxes, circuit boards, contacts

And many more

Functions of the composite constituents

Matrix

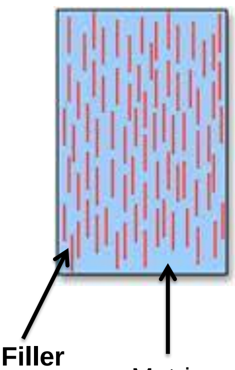


Matrix can be polymer, ceramic or metal

- Act as a glue to hold the reinforcing phase , homogenous and continuous phase
- Infiltrate the fibres or fillers and solidify at reasonable temperature and pressure
- Form a coherent bond, usually chemical in nature at the interfaces between the matrix and constituents
- Envelop the fibres or fillers which are very notch sensitive
- Transfer stresses to the reinforcing phase (fibres), stops crack propagation
- Isolate fibres or particles
- Debond from the fibres with absorption of significant amount of strain energy
- Remain physically and chemically stable after manufacture

Functions of the composite constituents

Reinforcing phase (dispersed phase)



- It is uniformly dispersed in the matrix
- Provides strength to the composites
- Act as load bearing material
- Should have high strength
- Chemically inert
- Often higher content of reinforcing phase improves strength
- Dimensionality of the reinforcing phase control the properties of the composites

Filler can be polymer, ceramic or metal based

When to consider composites?

- Composites have high stiffness, strength and toughness (comparable to the advance alloys) but they provide these at substantially very low loading of fillers/reinforcing phase and relatively low densities.

Composites offer high specific modulus and high specific strength

S.M = M.E/specific gravity,

S.S = UTS/specific gravity

Light weight materials are suitable for aerospace and aircrafts applications

Fuel consumptions also decreases

S.S of Aligned glass fibre-epoxy = 680 MPa
S.S of Steel = 244 MPa

When to consider composites?

- Composites can be anisotropic (i.e., they have different mechanical properties in different directions)

Example,

Rocket motor cases and pressure vessels (Stresses are two times higher in circumferential direction than axial direction)

Anisotropy offers more efficient structural components

When to consider composites?

- Composites have very high fatigue strength
- Better fatigue resistance than metal alloys
- Longer life of the components
- Often show evidence of fatigue damage but do not undergo damage catastrophically

Gives warning before failure
No sudden failure
Longer life
Part replacement possible before failure

When to consider composites?

- Composites have damping ability
- The absorbed mechanical strain energy is dissipated as heat
- Much higher damping ability than metals and can be tailored for desired level.

Mechanically induced vibrations can be damped
Offers noise reduction

When to consider composites?

- Composites can offer good lubrication or sliding friction
- Have high wear resistance
- Some composites are designed for very high friction

Tribological properties comparable or better than metals

When to consider composites?

- Composites do not rust or corrode
- Have good oxidation resistance
- Good resistance to environmental degradation
- Longer life cycle

Work in harsh, corrosive environment

When to consider composites?

- Composites can reduce number of components in the design
- Simple manufacturing
- Part reduction

Fewer joints, better integrity of the product

Are composites perfect ?

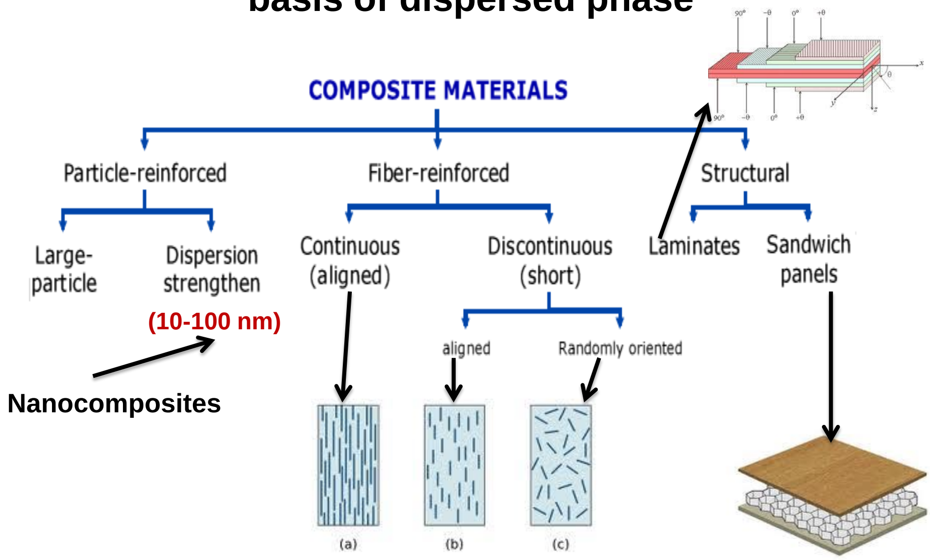
- Not all applications require light weight materials. Conventional steels may work fine at low cost
- Anisotropy, complicates the design analysis (limitations of stress analysis tools/softwares). Only expert design engineer can work with them.
- Cost can be issue (A designer must look for various composites' advantages to offset cost)
- Long term durability is concern
- Machining of composites is difficult
- Repair is not very effective
- Not recyclable
- Limited ease of fabrication
- Processing issues
- Some times properties deteriorate instead of improving

Classification of composites

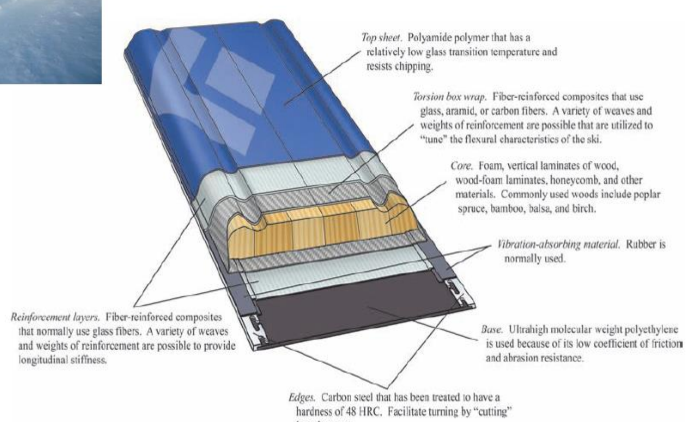
On the basis of Matrix Composites can be classified as:

- Polymer matrix composites (PMC)
- Metal matrix composites (MMC)
- Ceramic matrix composites (CMC)

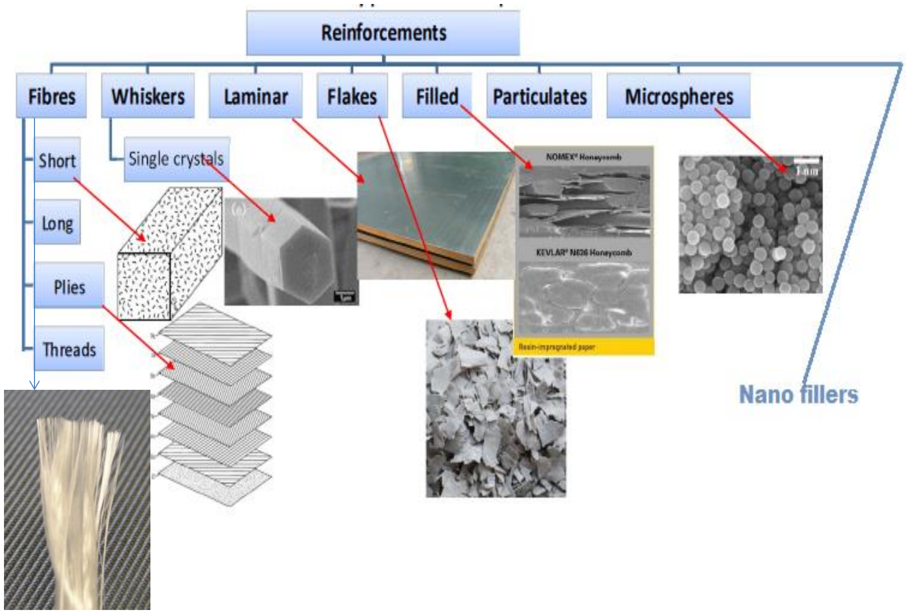
Classification of composite materials on the basis of dispersed phase



Composite materials in Skis



Various types of fillers



Types of Nanofillers

Carbon based

Graphite nanoplatelets, Graphene
Carbon black,
Carbon nanofibres
Graphite nanofibres
Carbon nanotubes

Non-Carbon based/ceramic/metallic

SiO_2, Al_2O_3, SiC, BN, ZrO, $CaCO_3$,
Clays, TiC, Cu, Ag, Al, etc.
In the form of cubic, spherical or flakes.
Hollow spheres or rods.

Fibres

- Natural fibres

Fillers coming from renewable resources or biodegradable (Green composites)

Cellulose, cotton, jute, hemp, flax, sisal, starch, etc.

- Synthetic fibres

Glass fibre, Aramid fibre (kevlar), Carbon fibre, boron, SiC, metal fibres, graphite fibres, etc.

Large Particulate Composites

- **Concrete**
- **Cermets**

Rule of Mixture predict the elastic modulus of LPC fall in between the upper and lower bound (limits) as given by following equations:

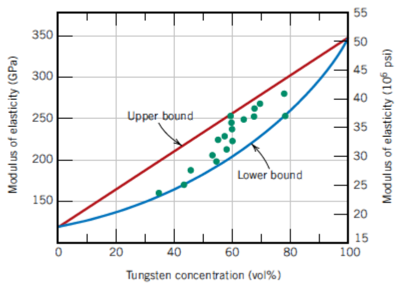
Upper bound :

$$E_c(u) = E_m V_m + E_p V_p$$

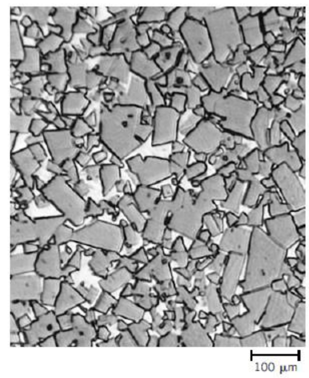
Lower bound :

$$E_c(l) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

CERMETS



For maximizing cutting action up to 90 vol.% of particulates are added.



Applications:

Cutting tools (WC/Co or WC/Ni or TiC/Co , etc.

Particulate composites

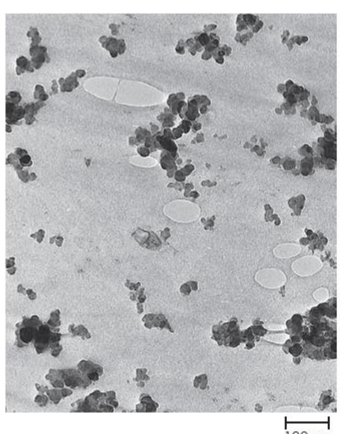
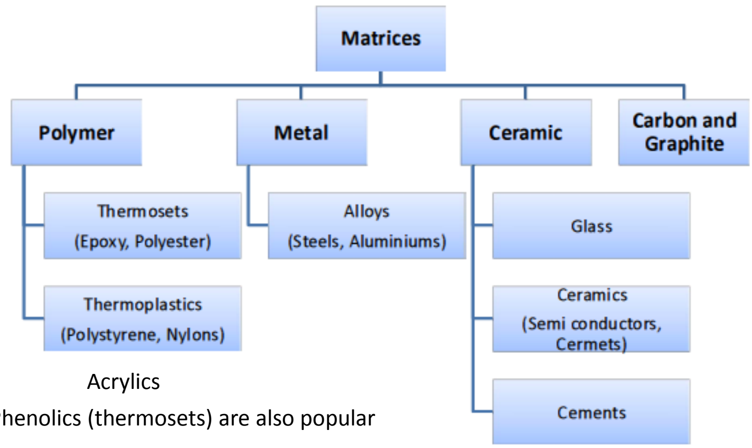


Figure 16.5 Electron micrograph showing the spherical reinforcing carbon black particles in a synthetic rubber tire tread compound. The areas resembling water marks are tiny air pockets in the rubber. 80,000×. (Courtesy of Goodyear Tire & Rubber Company.)

Elastomers reinforced with Carbon black particles

- 30-40 vol% carbon black (dia 20-50 nm) reinforced in rubber for tyre applications
- Tensile strength, toughness, tear and abrasion resistance increases
- Good dispersion and strong bonding between particles and matrix requires

Matrices for Composites



Acrylics

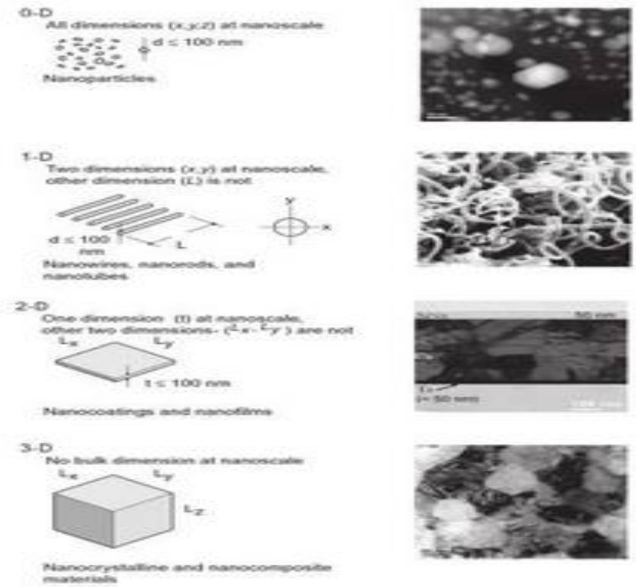
Phenolics (thermosets) are also popular

Advantages and Disadvantages of thermosets and thermoplastics

Table 1.2 Summary of advantages and disadvantages of thermosets and thermoplastics as Composite matrix resins [3]

Property	Thermosets	Thermoplastics
Formulations	Complex	Simple
Melt viscosity	Very low	High
Fiber impregnation	Easy	Difficult
Prepreg tac	Good	None
Prepreg drape	Good	None to fair
Prepreg stability	Poor	Excellent
Processing cycle	Long	Short to long
Processing temperature/ pressure	Low to moderate high	High
Fabrication cost	High	Low (potentially)
Mechanical properties		
-54 to 93℃, hot/wet	Fair to good	Fair to good
Environmental durability	Good	Unknown
Solvent resistance	Excellent	Poor to good
Damage tolerance	Poor to excellent	Fair to good
Database	Very large	Small

Dimensionality of the nanofillers



Dimensionality of the nanofillers

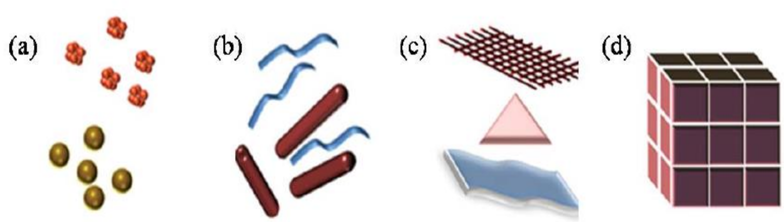
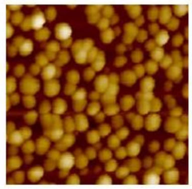
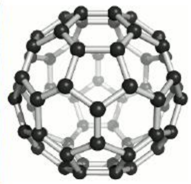


Fig. Classification of Nanomaterials (a) 0D spheres and clusters, (b) 1D nanofibers, wires, and rods, (c) 2D films, plates, and networks, (d) 3D nanomaterials.

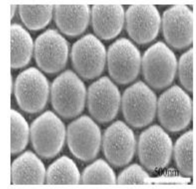
Morphologies of the nanofillers



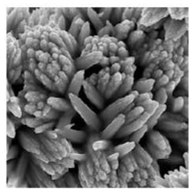
Au nanoparticle



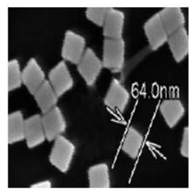
Buckminsterfullerene



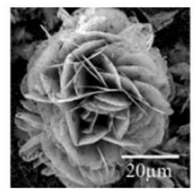
FePt nanosphere



Titanium nanoflower



Silver nanocubes



SnO2 nanoflower

Table 16.4 Characteristics of Several Fiber–Reinforcement Materials

Material	*Specific Gravity*	*Tensile Strength [GPa (10^6 psi)]*	*Specific Strength (GPa)*	*Modulus of Elasticity [GPa (10^6 psi)]*	*Specific Modulus (GPa)*
		Whiskers			
Graphite	2.2	20 (3)	9.1	700 (100)	318
Silicon nitride	3.2	5–7 (0.75–1.0)	1.56–2.2	350–380 (50–55)	109–118
Aluminum oxide	4.0	10–20 (1–3)	2.5–5.0	700–1500 (100–220)	175–375
Silicon carbide	3.2	20 (3)	6.25	480 (70)	150
		Fibers			
Aluminum oxide	3.95	1.38 (0.2)	0.35	379 (55)	96
Aramid (Kevlar 49)	1.44	3.6–4.1 (0.525–0.600)	2.5–2.85	131 (19)	91
Carbon[a]	1.78–2.15	1.5–4.8 (0.22–0.70)	0.70–2.70	228–724 (32–100)	106–407
E-glass	2.58	3.45 (0.5)	1.34	72.5 (10.5)	28.1
Boron	2.57	3.6 (0.52)	1.40	400 (60)	156
Silicon carbide	3.0	3.9 (0.57)	1.30	400 (60)	133
UHMWPE (Spectra 900)	0.97	2.6 (0.38)	2.68	117 (17)	121
		Metallic Wires			
High-strength steel	7.9	2.39 (0.35)	0.30	210 (30)	26.6
Molybdenum	10.2	2.2 (0.32)	0.22	324 (47)	31.8
Tungsten	19.3	2.89 (0.42)	0.15	407 (59)	21.1

[a] The term *carbon* instead of *graphite* is used to denote these fibers, because they are composed of crystalline graphite regions, and also of noncrystalline material and areas of crystal misalignment.

What is a Composite Resin (White Filling)?

Article Chapters

What is a Composite Resin (White Filling)?

A composite filling is a tooth-colored plastic and glass mixture used to restore decayed teeth. Composites are also used for cosmetic improvements of the smile by changing the color of the teeth or reshaping disfigured teeth.

How is a composite placed?

Following preparation, the dentist places the composite in layers, typically using a light specialized to harden each layer. When the process is finished, the dentist will shape the composite to fit the tooth. The dentist then polishes the composite to prevent staining and early wear.