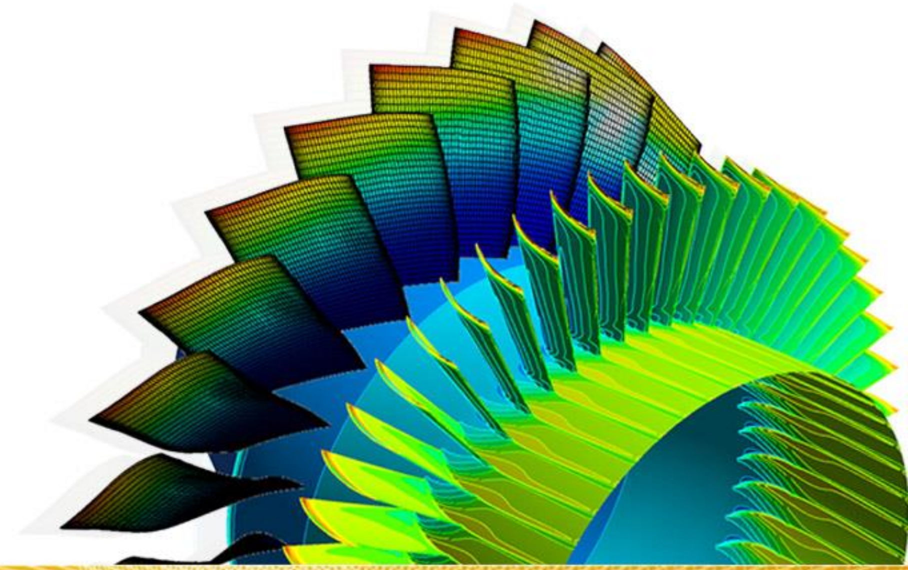
ANSYS Composite PrepPost 19.0

Appendix 1: Composite Introduction



1. Composite Introduction

Agenda

- General Introduction Composites
- Classification of Composites
- Matrix and Fiber Materials
- Reinforcement Forms
- Manufacturing Methods
- Draping
- Ply Drop Offs
- Positive and Negative Features of Composites

1. Composite Introduction

Agenda

- Raw Materials
- Numerical Approaches
- Single Plies
- Rules of Mixture
- Anisotropic, orthotropic, transversal isotropic
- From three dimensional stress state to plane stress
- Measuring Ply Properties
- Failure Indicator

1. Composite Introduction

Manufacturing Methods

There are two general methods of manufacturing composites. Open molding describes processes with materials being exposed to the atmosphere during the manufacturing process while closed molding processes use two-sided mold sets or vacuum bags.

- **Open Molding**
- **Closed Molding**

1. Composite Introduction

Manufacturing Methods

- **Open Molding**
  - Hand Lay-Up
  - Spray-up
  - Filament Winding

1. Composite Introduction

Manufacturing Methods

- **Closed Molding**
  - Vacuum Bag Molding
  - Vacuum Infusion Processing
  - Compression molding
  - Pultrusion
  - Resin Transfer Molding (RTM)
  - Reinforced Reaction Injection Molding (RRIM)
  - Centrifugal Casting
  - Continuous Lamination

1. Composite Introduction

Manufacturing Methods

- **Hand Lay-Up**
  - Composite layer are placed manually on a mold
  - Resin is applied by pouring, brushing or spraying
  - Layers are added to build laminate thickness
  - ➕ Low tooling costs and minimum investments in equipment
  - ➕ Simple processing
  - ➕ Wide range of part sizes
  - ➕ Skilled operators allow good production rates and consistent quality
  - ➖ Low volume and labor intensive

Hand Laying Carbon Fiber

1. Composite Introduction

Manufacturing Methods

- **Using PrePreg Materials**
  - Fibers or fabrics with a pre-catalysed resin system impregnated by a machine
  - Resin system reacts slowly at room temperature and is usually cured by heating at cure temperature
  - ➕ Higher fiber contents achievable
  - ➕ Allows strong resins with high viscosity

1. Composite Introduction

Manufacturing Methods

- **Autoclave Curing**
  - Curing of thermoset composites uses mechanical and chemical processes
  - Pressure is applied to remove trapped air and volatiles
  - Plies and fiber are consolidated by pressure
  - Crosslink reaction, usually initiated by heating, is necessary to cure material
  - Autoclave controls temperature and pressure
  - ✚ Allows high strength to weight ratios

YouTube

Construction of a composite fuselage section (Boeing 787)

1. Composite Introduction

Manufacturing Methods

- **Spray Up**
  - Chopped fiber reinforcements and catalyzed resin is placed onto a mold surface using a chopper/spray gun
  - Laminate is rolled to compact chop
  - Woven or knitted fabrics can be added
  - ⊕ Simple processing
  - ⊕ Low-cost tooling
  - ⊕ Portable equipment
  - ⊕ No part size limitations
  - ⊖ Chopped fibers

Sealine spray layup from Motor Boat & Yachting

1. Composite Introduction

Manufacturing Methods

- **Filament Winding**
  - Resin impregnated fibers or laminates are wound around a mandrel in predefined pattern
  - Fibers and laminates can be pre-impregnated or running through a resin bath before wound
  - Composite is usually cured using autoclaves or ovens
  - + High strength to weight ratios
  - + Good control over uniformity and fiber orientation
  - + Allows highly engineered products and strict tolerances
  - + Automatic process
  - − Limited designs (although new developments allow non cyl. and non spherical designs)

Filament winding of a subsea sphere by Windtec.no

1. Composite Introduction

Manufacturing Methods

- **Vacuum Bag Molding**
  - Improves mechanical properties of open mold processes
  - A release film is placed over the laminate
  - Followed by a bleeder ply of fiberglass cloth, non-woven nylon, polyester cloth, or other material that absorbs excess resin from the laminate
  - A breather ply of a non-woven fabric is placed over the bleeder ply
  - A vacuum bag is mounted over the entire assembly
  - Vacuum is applied and the atmospheric pressure eliminates voids and excess resin

1. Composite Introduction

Manufacturing Methods

- **Vacuum Bag Molding**
  - More uniform consolidation
  - Removing entrapped air
  - Avoids hand layups being resin rich
  - Improved core-bonding
- **Vacuum Infusion**
  - The resin is introduced into the mold after the vacuum has pulled the bag down and compacted the laminate
  - Resin completely saturates the reinforcements
  - No resin excess offers substantial emission reductions

YouTube

How-To Use a Vacuum Bag

1. Composite Introduction

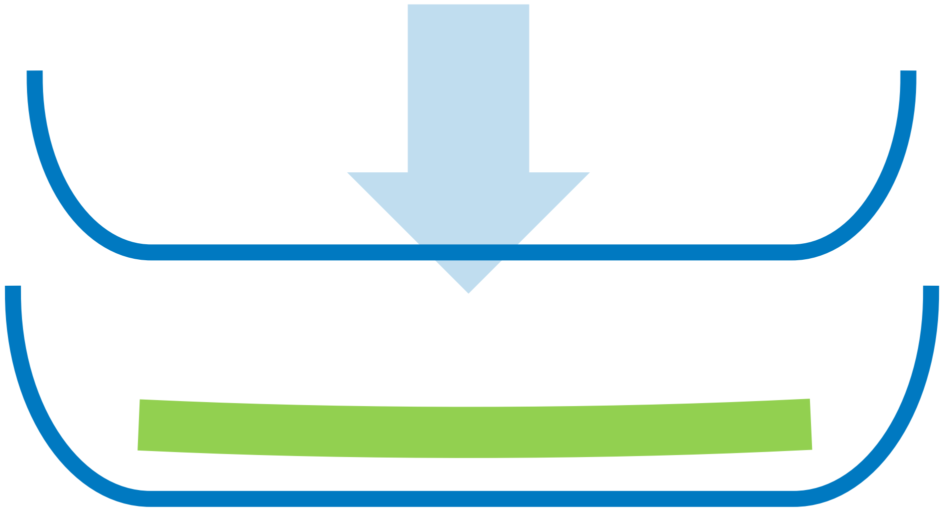
Manufacturing Methods

- **Compression Molding**
  - A mechanical or hydraulic press with heated molds forms composite parts using sheet molding compound, bulk molding compound or liquid composite molding
  - Sheet Molding Compound (SMC); Fiber reinforced polyester material using long strands of chopped fibers *(> 1 inch)*
  - Bulk Molding Compound (BMC); Highly filled resin paste combined with short fibers *(0.125- 0.5 inch)*
  - Liquid Composite Molding (LMC); Uses preforms matching the finished design or mats (in case of plane shapes). Resin is added into the open dies. High strength to weight ratios

1. Composite Introduction

Manufacturing Methods

- **Compression Molding**
  - ➕ Fast molding cycles
  - ➕ High part uniformity
  - ➕ Good surfaces available
  - ➕ Automatic process
  - ➖ Chopped fibers or preforming necessary



1. Composite Introduction

Manufacturing Methods

- **Pultrusion**
  - Continuous method to manufacture composite parts having a uniform cross section
  - Rovings or fiber mats are pulled through resin bath and then formed and cured in a heated die
  - Cured parts are cut into desired lengths
  - ➕ Continuous process
  - ➕ High strengths
  - ➖ Limited to uniform cross sections

YouTube

The Pultrusion Process

1. Composite Introduction

Manufacturing Methods

- **Combining Braiding & Pultrusion**
  - combines the braiding performing technique and composite pultrusion process to fabricate constant cross-section products
  - Fiber angles can be oriented in the braiding process to achieve a specific angle along to the beam axis
  - ⊕ Continuous process
  - ⊕ High strengths
  - ⊕ Orientation of fiber angles
  - ⊖ Limited to uniform cross sections

YouTube

Braid-Trusion of an L-shaped thermoplastic composite beam

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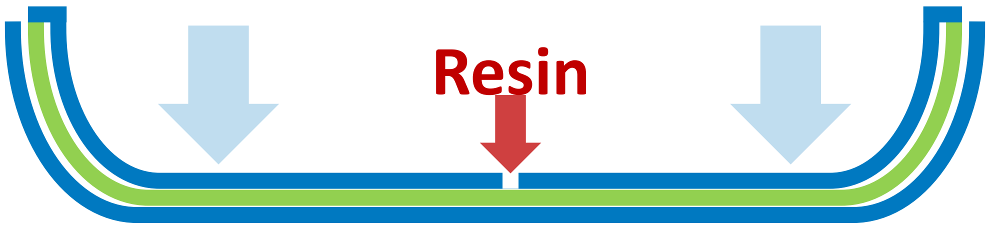
1. Composite Introduction

Manufacturing Methods

- **Resin Transfer Molding (RTM)**
  - Reinforcement material (can be continuous fibers, mats, preforms, or woven fabrics) is placed between two matching mold surfaces
  - Resin is injected into the mold and wets out all surfaces of the reinforcing materials
  - Curing at room temperature or by heated molds (cycle time)
  - Vacuum can be applied to increase resin flow
  - ⊕ High quality finish
  - ⊕ Fast production
  - ⊕ Allows complex surface designs
  - ⊖ High tooling costs
  - ⊖ Limited part sizes



1. Composite Introduction

Manufacturing Methods

- **Reinforced Reaction Injection Molding (RRIM)**
  - Reinforcement material and resin are mixed and injected into a closed mold
  - Short fibers or flakes are usually used to create a more isotropic material behavior
- **Structural Reaction Injection Molding (SRIM)**
  - This process uses two resin components which are combined and mixed together, then injected into a mold cavity containing reinforcement. In the mold cavity, the resin rapidly reacts and cures to form the composite part

1. Composite Introduction

Manufacturing Methods

- **Centrifugal Casting**
    - Used for making cylindrical, hollow shapes such as tanks, pipes and poles
    - Chopped strand mat is placed into a hollow, cylindrical mold, or continuous roving is chopped and directed onto the inside walls of the mold
    - The resin is applied to the inside of the rotating mold

1. Composite Introduction

Manufacturing Methods

- **Continuous Lamination**
  - Creates composites in sheet form such as composite glazing, corrugated or flat construction panels, and electrical insulating materials
  - Reinforcement is combined with resin and sandwiched between two plastic carrier films
  - Sheet takes shape under forming rollers, and the resin is cured to form the composite

1. Composite Introduction

	Hand Layup	Automated Prepreg	Winding	RTM
Geometry	Complex	Complex	Near to rotational	Complex
Holes/Inserts	Possible	Possible	Difficult	Possible
Stiffeners	Possible	Possible	Difficult	Possible
Back Tapering	Possible	Possible	Not possible	Difficult
Surface	Moderate – Good[1]	Good[1]	Moderate[1]	Good[2]
Fiber Architecture	Any	Any	Limited	Any
Typ. Fiber Volume Content	40%	65%	50%	50%
Mechanical Properties	Middle	High	Middle	Middle
Quality	Moderate	Very good	Middle	Good
Reproducability	Moderate	Very good	Good	Good
Tooling Costs	Low	Very High	High	High

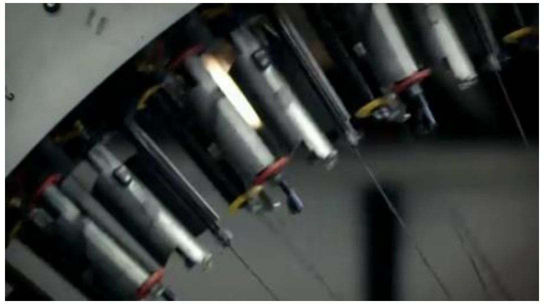
According to Ermanni, ETH Zürich

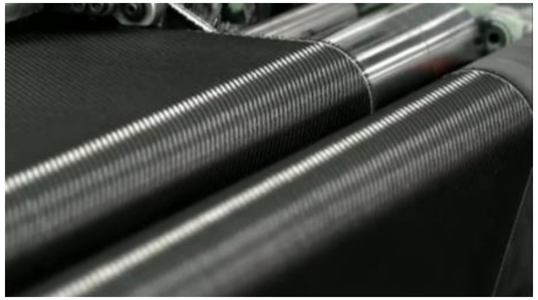
[1] only one side

[2] both sides

1. Composite Introduction

From Fibers to Finished Composite Components



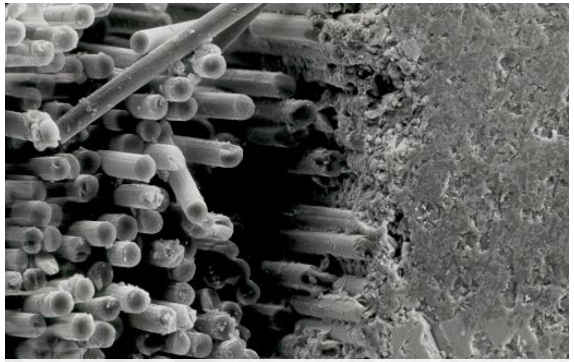


By SGL Group
The Carbon Company

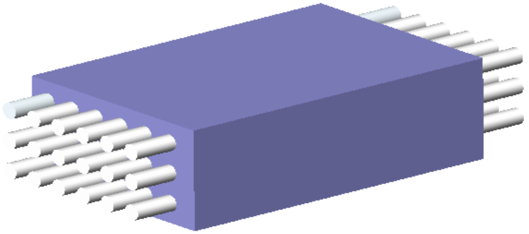
1. Composite Introduction

Raw Materials

- Composite materials are made of at least two distinct materials
- One component (fiber) is used as a reinforcing material for the matrix
- The matrix holds fibers
- The matrix will guarantee a load transfer in between the fibers as well as external loadings into the fibers



Carbon Fiber - Epoxy



1. Composite Introduction

Relative Importance of Fibers and Matrix

	Fiber	Matrix
Mechanical Properties		
Stiffness	◕	◔
Strength	◕	◔
Fatigue	◕	◔
Damage tolerance	◔	◕
Impact behavior	◕	◔
Thermo-mechanical properties	◕	◔
Fiber-matrix bonding	◑	◑

Ermanni, ETH Zürich

○ No Importance ● High Importance

1. Composite Introduction

Relative Importance of Fibers and Matrix

	Fiber	Matrix
Physical Properties		
Corrosion Behavior	◔	◕
Thermal Stability	○	●
Chemical Stability	○	●
Electrical properties	◑	◑

Ermanni, ETH Zürich

○ No Importance ● High Importance

1. Composite Introduction

Glass Fibers

- Basically silica(SiO_2)
- Isotropic properties
- E-glass („electrical“ glass)
  - Most common fiber
  - Moderate stiffness, high strength
  - Relatively heavy
  - Good chemical, environmental conditions and fire resistance
  - inexpensive

Glass Fiber Roving

1. Composite Introduction

Glass Fibers

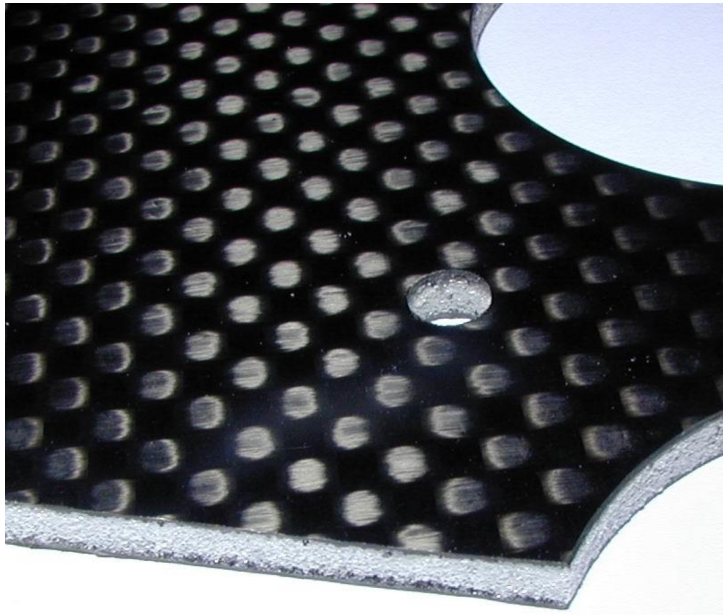
- R-, S-glass („strength“ glass, other chemical mixture)
  - higher stiffness (+20%) and strength compared to E-glass
  - expensive

Glass Fiber Roving

1. Composite Introduction

Carbon Fibers

- Orthotropic properties
- Many different types available
- Expensive to extremely expensive
- Low density
- Low ductility in impact
- Coefficient of thermal expansion nearly zero
- Electrically conductive



Carbon Fiber Sandwich

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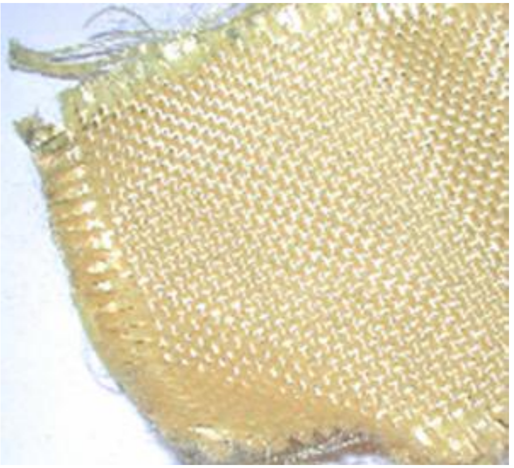
Carbon Fibers

- PAN (polyacrylnitrile)-fiber
  - Low stiffness
  - Very high tensile & compressive strength (HT-, HS-, HM-fibers)
- Pitch-fiber
  - High to ultra high stiffness (HM-, UHM-fiber)
  - High tensile and low compressive strength
  - Large scatter in material properties

1. Composite Introduction

Aramid Fibers (also known as Kevlar, Twaron)

- Orthotropic properties
- Lowest density of all fibers
- Higher stiffness compared to glass fiber
- High tensile strength
- Low compressive strength
- Highly ductile in impact
- Negative coefficient of thermal expansion
- Moisture absorption → decreases material properties
- Available with low stiffness (life vests, robes, etc.)
- Moderately expensive



Woven Aramid

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Other Fiber Materials

- For special application, e.g. embedded in ceramic or metal matrix
  - Boron
  - Silicon Carbide (SiC)
  - Silicon Oxide (SiO_2)
  - Aluminum Oxide (Al_2O_3)
  - others

1. Composite Introduction

Thermosets as Matrix Material

- Isotropic properties
- Polyester (unsaturated)
  - Most common resin
  - Good resistance against chemicals and UV-light
  - Catalytic reaction, short curing time, emits styrene
  - Large shrinkage during curing
  - Inexpensive

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Thermosets as Matrix Material

- Epoxy
  - Most often used resin for high quality composite materials
  - Very good strength properties, good gluing properties
  - Curing with hardener through polyaddition is critical in view of health
  - Low shrinkage
  - Expensive

Epoxy Resin and Hardener

1. Composite Introduction

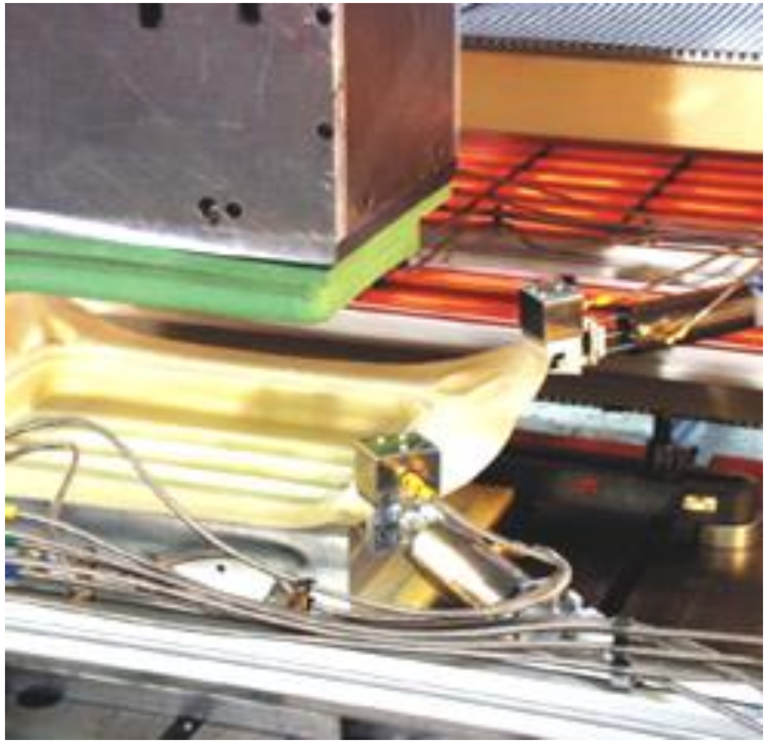
Thermosets as Matrix Material

- Vinyl ester
  - Properties in between Polyester and Epoxy
  - Very good chemical resistance
  - Low shrinkage
  - Moderate price

1. Composite Introduction

Thermoplastics as Matrix Material

- Different production process necessary (valid for mass production)
- Needs heat to be formed and solidified
- Creeps at larger temperatures
- Larger ductility then thermosetting



Press for Thermoplastics, University Kaiserslautern

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1. Composite Introduction

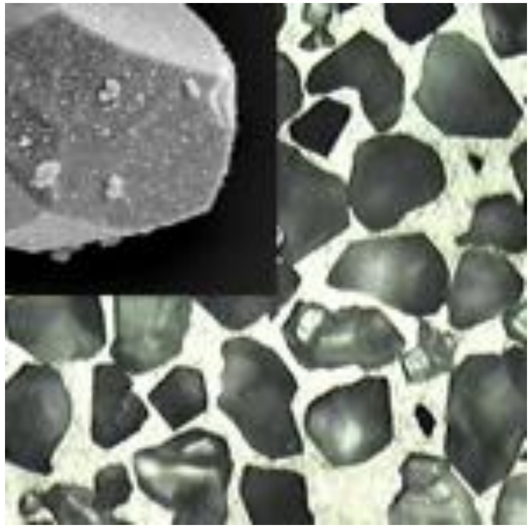
Thermoplastics as Matrix Material

- PP (Polypropylene), PE (Polyethylene), PA (Polyamide), PEEK (Polyether ether ketone)
  - High ductile resistance
  - Good mechanical properties
  - Temperature resistance (up to max. 250 °C)
  - Expensive
- Polyamide
  - Less thermal resistance but less expensive
- PTFE (Teflon)
  - Temperature resistant

1. Composite Introduction

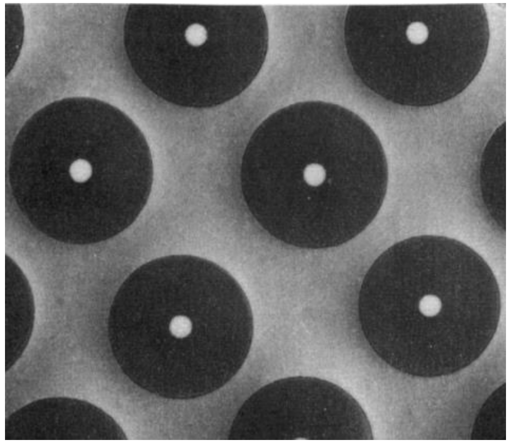
Non-Polymer Matrix Materials

- Metal-Matrix-Composites (MMC)
  - Aluminum
  - Titanium
  - Copper
  - Magnesium
- Ceramics-Matrix-Composites (CMC)
  - Aluminum oxide
  - Mullite
  - Carbon
  - Silicon carbide
- Concrete



Ceramic Particles in Aluminum

Steel Fiber Reinforced Concrete

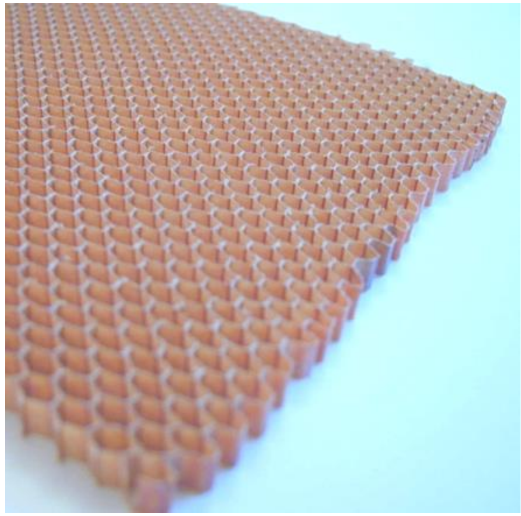


Boron Fibers in Aluminum

1. Composite Introduction

Core Materials

- Foam
  - Polyurethane PU
  - Polyvinylchloride PVC
  - Polystyrene PS
- Honeycombs
  - Aluminum
  - Plastic (Nomex)
  - Glass / Penol
  - Paper
- Wood
  - Balsa
  - Prestressed wooden cores



Nomex Honeycomb

Foam

Balsa