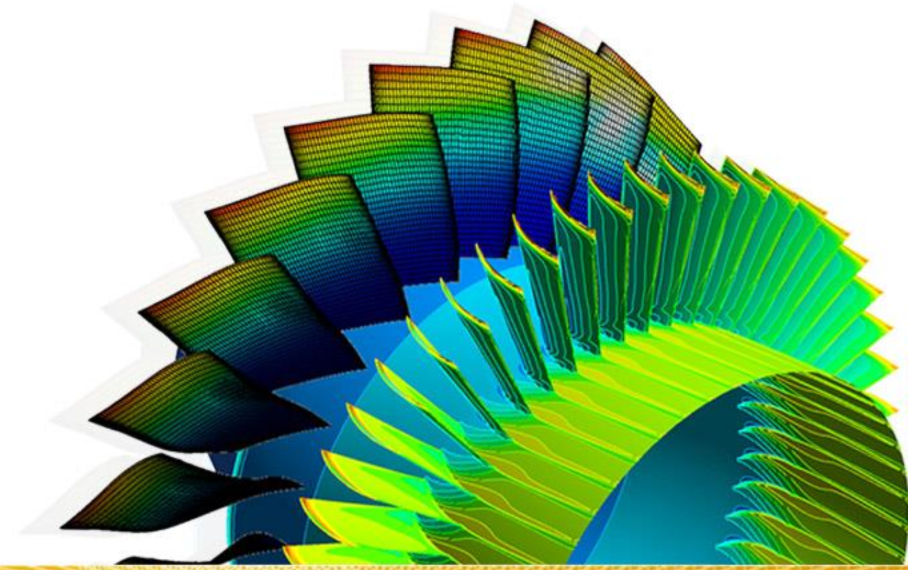
ANSYS Composite PrepPost 19.0

Module 1: Composite Introduction



1. Composite Introduction

Agenda

- General Introduction of 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

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1. Composite Introduction

- Composite materials are made of multiple layers of different materials

- They typically are light weight and high in strength but also other very specific properties can be engineered into them (e.g. good fatigue behavior, second order effects…)

1. Composite Introduction

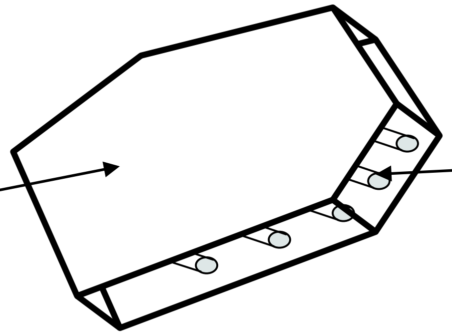
Application Areas

- Aerospace
- Wind Energy
- Sports & Recreation
- Motorsport
- Construction
- Automotive
- Marine
- Defense
- … and more

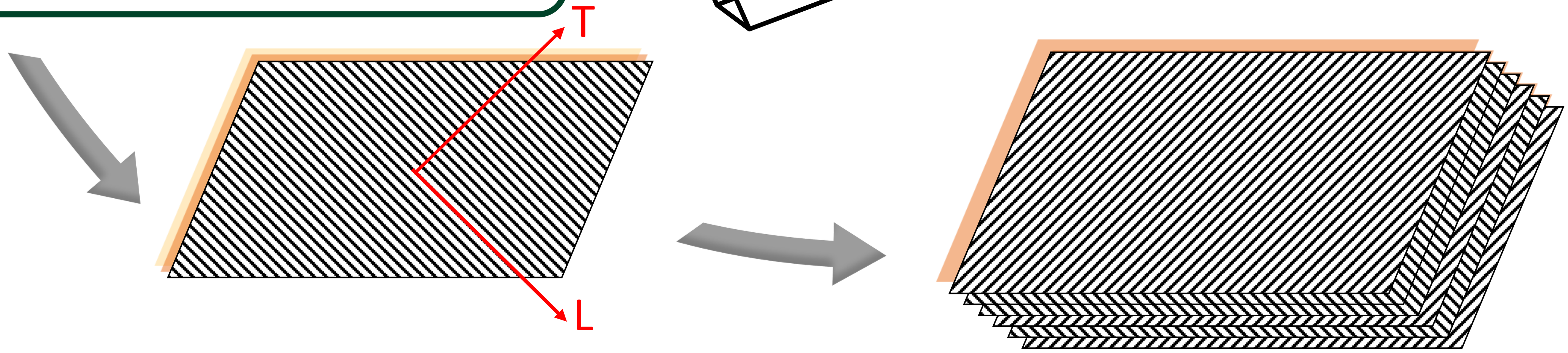
1. Composite Introduction

Terms:

Matrix- A homogeneous base material that forms the bulk of a composite material layer.



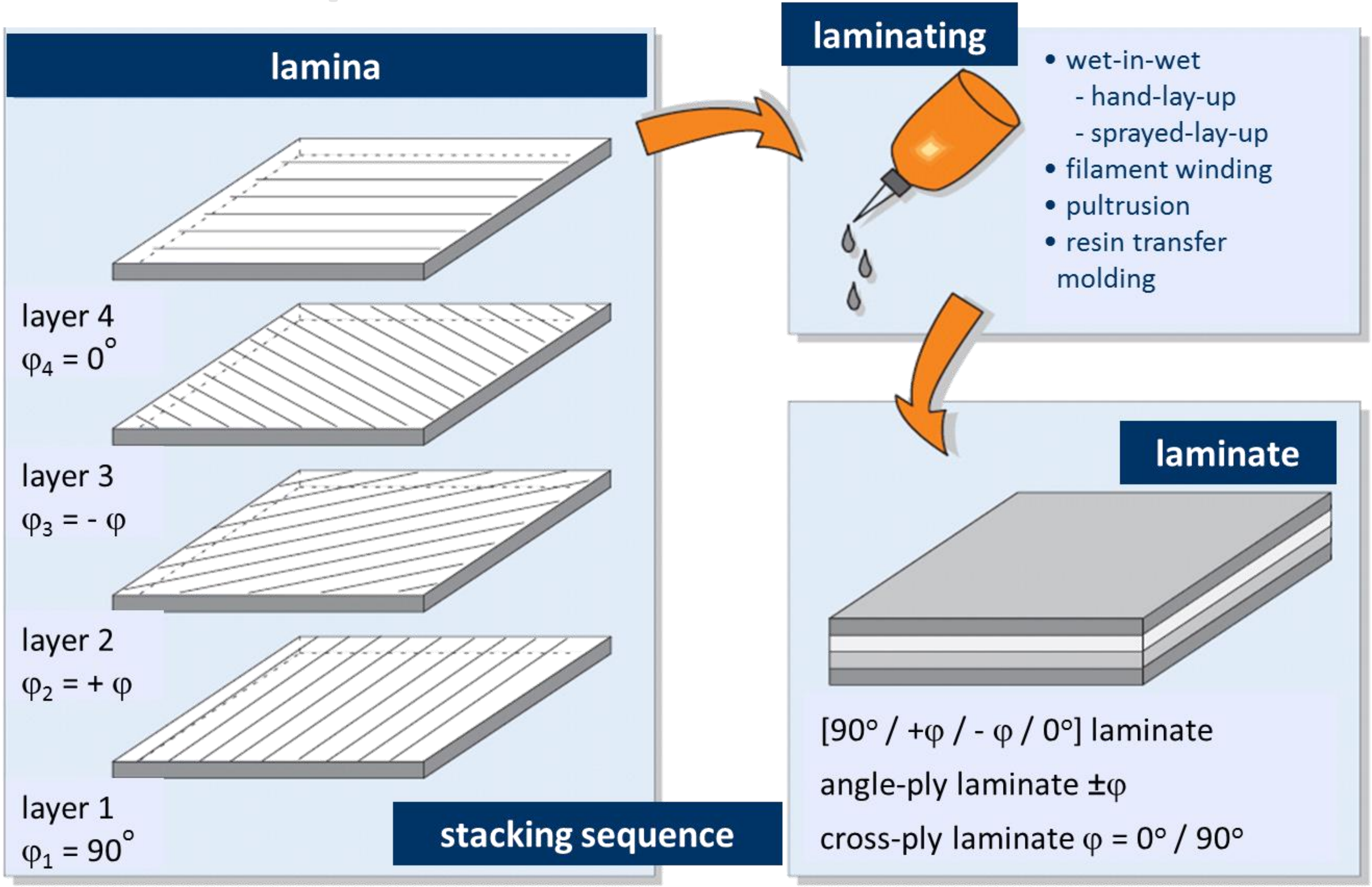
Fibers- Bonded or embedded reinforcing fibers that are usually responsible for the anisotropy of the composite.



Lamina- A composite material in sheet form usually referred to as a **layer** or **ply**. The material properties of a layer is usually determined through an equivalent homogenization (smearing) process.

Laminate- A stack of lamina joined together in arbitrary directions, referred to as a composite **lay-up** or **stacking-sequence**.

1. Composite Introduction



1. Composite Introduction

Typical Positive Features of Composite Designs (1/2)

- Oriented stiffness and strength properties
- Material properties adjustable by engineers (material design)
- Parameters to modify e.g. type of fibers and matrix, fiber volume fraction, fiber orientation, stacking sequence, layer thickness, fabrication method
- Significant reduced weight compared to metals
- High stiffness and strength properties with respect to weight
- High fatigue resistance (e.g. for Carbon Fiber)

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Typical Positive Features of Composite Designs (2/2)

- Specific material characteristics possible (e.g. thermal stability due to negative coefficient of thermal expansion of carbon fibers)
- Reduced corrosion tendency
- Low moisture absorption
- Damping of vibrations
- Less sensitive for imperfections (geometrical and physical)
- Electrical conductivity or non-conductivity (depending on the materials used)

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Typical Negative Features of Composite Designs (1/2)

- Low stiffness and strength perpendicular to fiber direction
- Anisotropic thermal strain behavior
- Low interlaminar shear stiffness and strength
- Long time durability (especially concerning environmental influence, e.g. heat, moisture, chemical, UV, aging …)
- Heat resistance (e.g. fire resistance of matrix material)
- Undesirable brittle failure behavior (safety concepts)

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Negative Features of Composite Designs

- Open questions concerning recycling
- Difficulties in damage detection (x-rays, ultra sonic, thermo graphic, non-destructive methods)
- Open questions concerning reparability
- Relatively high material costs
- Problems with conventional joints (bolts, rivet, adhesive)
- Sensitive with respect to the fabrication process (flaws, bubbles, dust)

1. Composite Introduction

Classification of Composites Based on Reinforcement

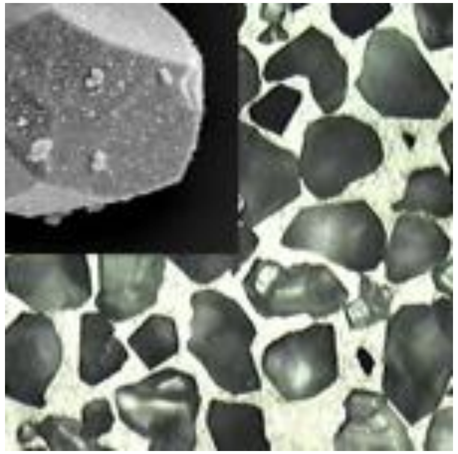
Composite Materials can be classified by the type of reinforcements used for the matrix material.

A. Particle Reinforced Composites
B. Fiber Reinforced Composites
   - Short Fiber Reinforced (<2mm)
   - Long Fiber Reinforced (2-30mm)
   - Endless Fiber (>30mm)

1. Composite Introduction

A. Particle Reinforced Composites

- Particle reinforced composites consist of particles of one material dispersed in a matrix of a second material. Particles may have any shape or size, but are generally spherical, ellipsoidal, polyhedral, or irregular in shape.



Ceramic - Aluminum

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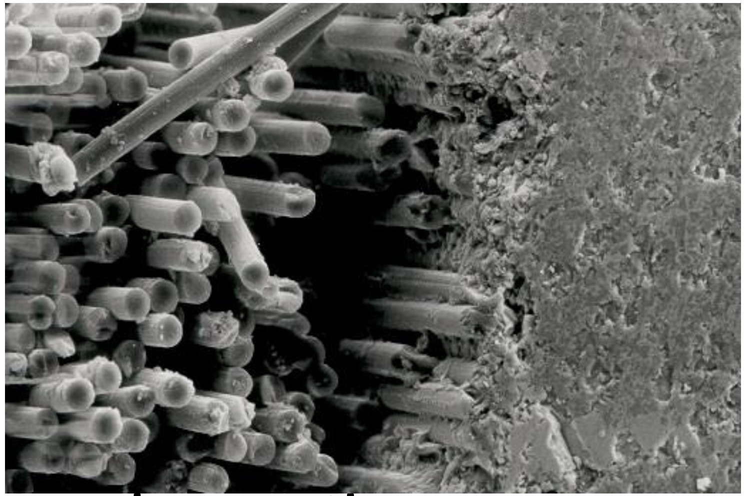
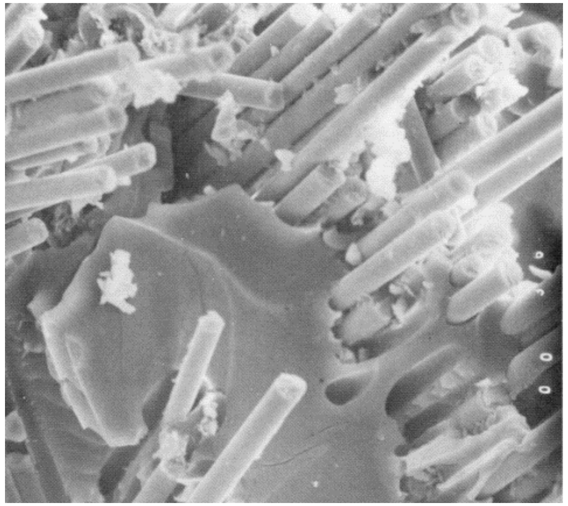
B. Fiber Reinforced Composites

- Fiber reinforced composites (FRC) are composites where one material component (fiber) is used as a reinforcing material for the matrix.



Carbon Fiber - Epoxy



Glass Fiber - Epoxy

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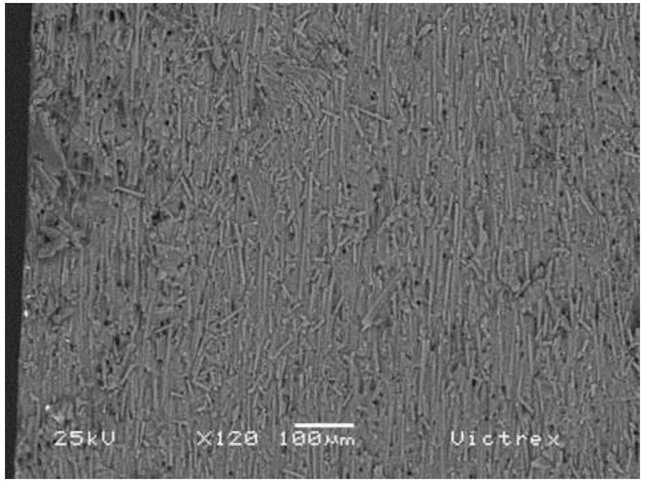
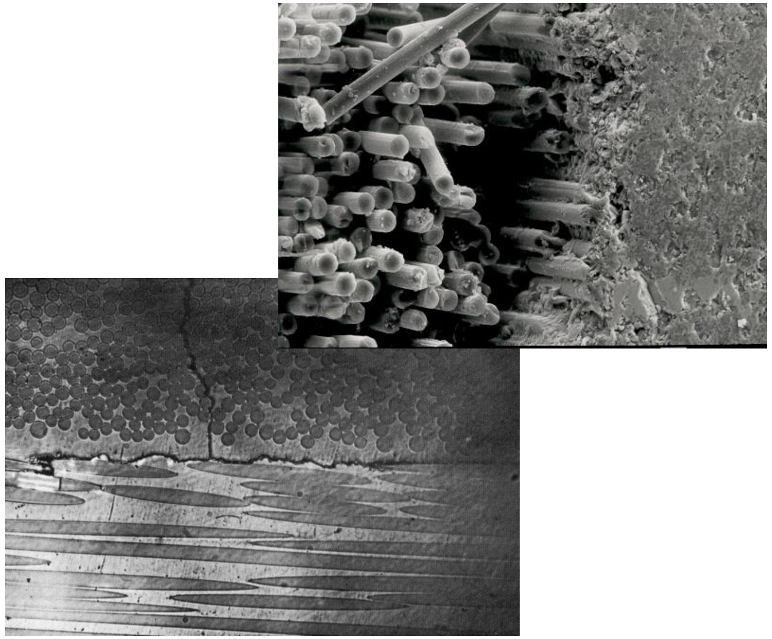
B. Fiber Reinforced Composites

Short Fiber Reinforced



Long Fiber Reinforced

Endless Fiber Reinforced



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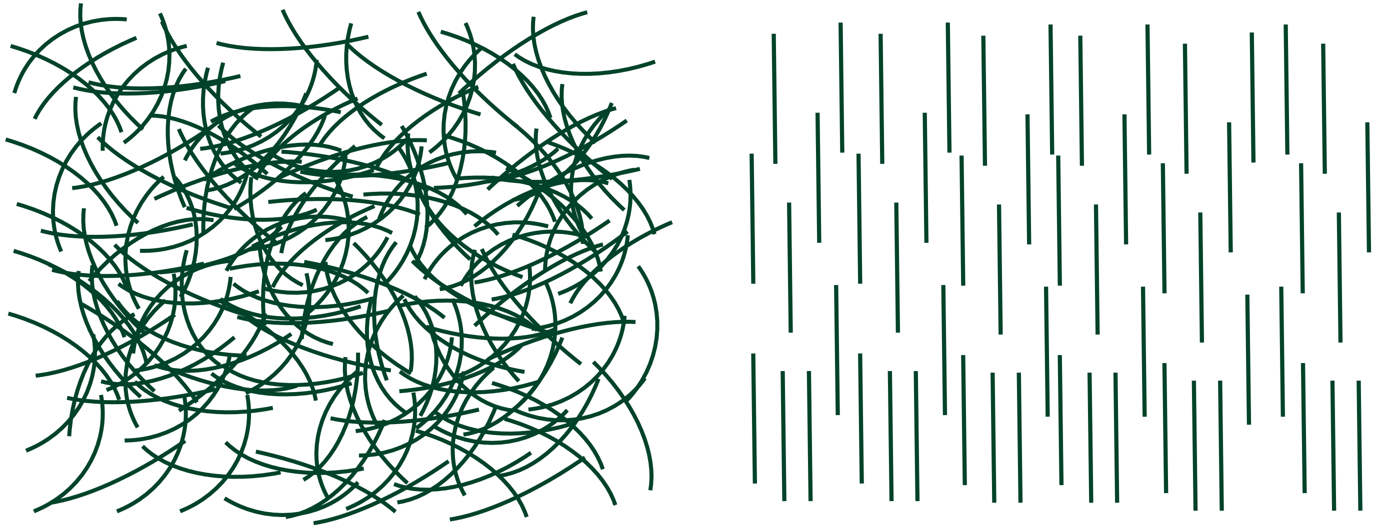
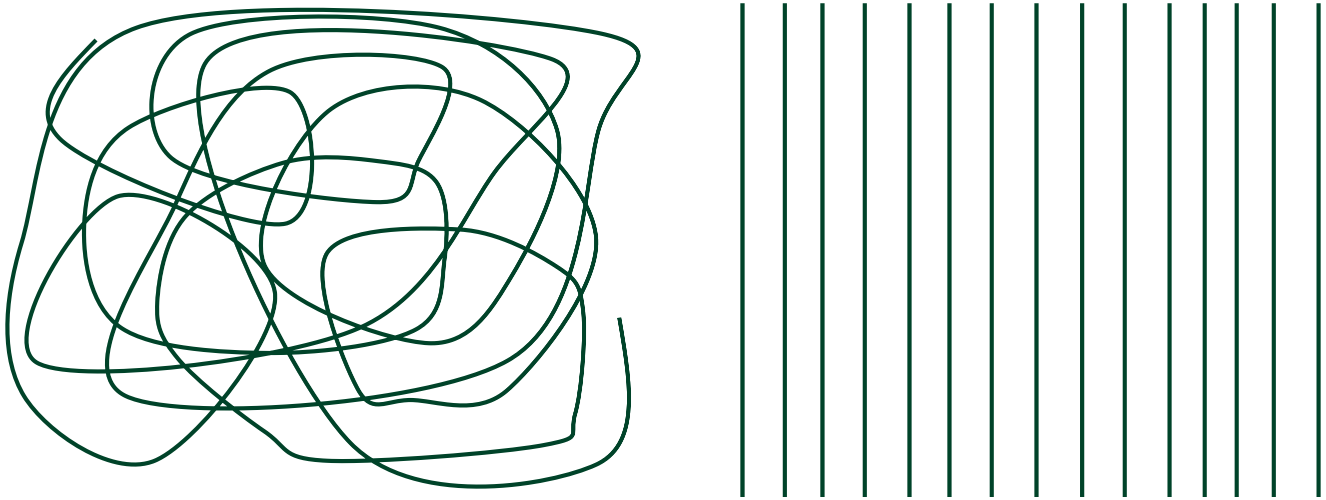


Random and oriented short/long fiber reinforced composites



Random and oriented long/endless fiber reinforced composites

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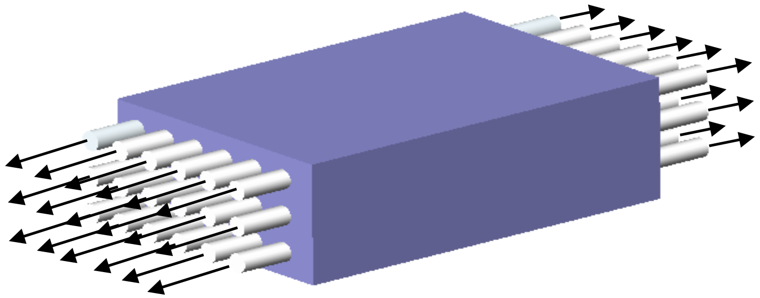

Materials

- **Matrix Materials**
  - Thermosets
  - Thermoplastics
  - Metals
  - Ceramics
- **Fiber Materials**
  - Glass
  - Carbon
  - Aramid (Kevlar)
  - Boron
  - Ceramics
  - Hemp/Flax

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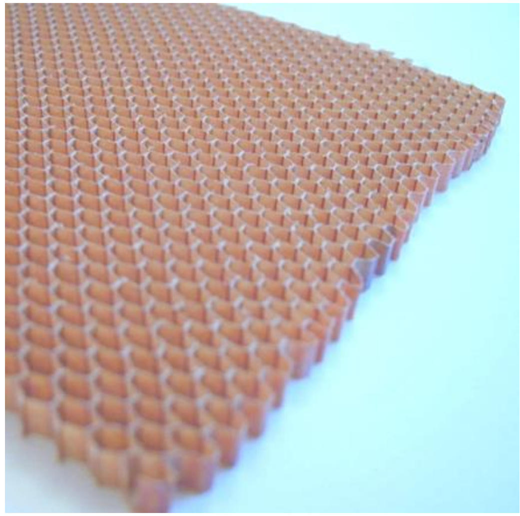
Gel Coats

Gel coats are specialized resins formulated to provide a cosmetic outer surface on a composite product. They provide the high quality finish for composite products and increase the durability and resistance of the outer surface.

1. Composite Introduction

Core Materials

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



Nomex Honeycomb

Foam

Balsa

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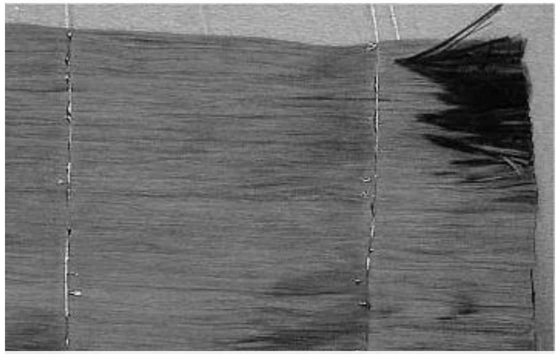
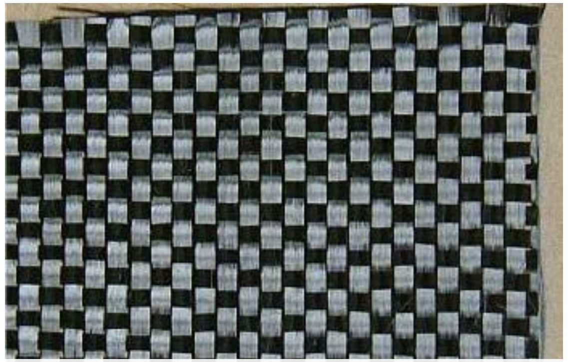
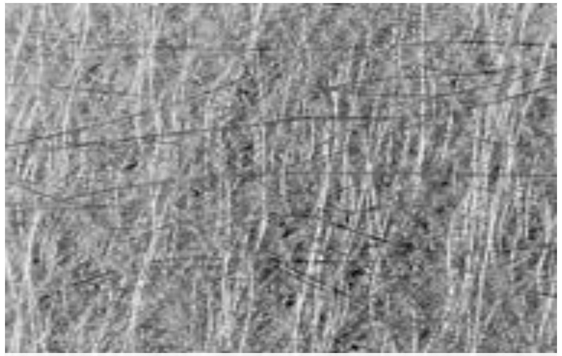
Reinforcement Forms



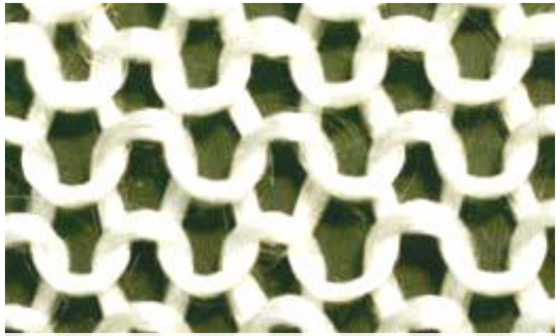
Unidirectional



Woven

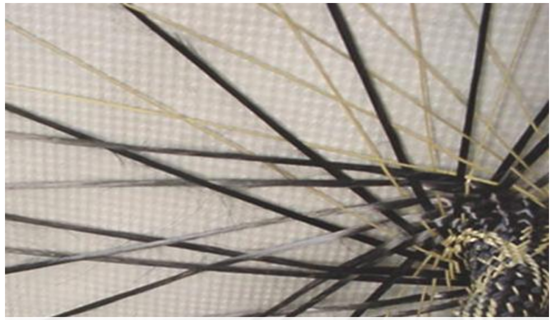


Mat



Knits

Stitched



Braiding

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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**

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Manufacturing Methods

- **Often Open Molding Process is applied in context with**
  - Hand Lay-Up
  - Spray-up
  - Filament Winding

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Manufacturing Methods

- **Typical Closed Molding Proccesses**
  - Vacuum Bag Molding
  - Vacuum Infusion Processing
  - Compression molding
  - Pultrusion
  - Resin Transfer Molding (RTM)
  - Centrifugal Casting
  - Continuous Lamination

1. Composite Introduction

	Hand Layup	Prepreg	Winding / Braiding	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%
Typical Mechanical Properties	Middle	High	Middle	Middle
Typical Quality	Moderate	Very good	Middle	Good
Reproducibility	Moderate	Very good	Good	Good
Tooling Costs	Moderate	Moderate	Moderate	Very High

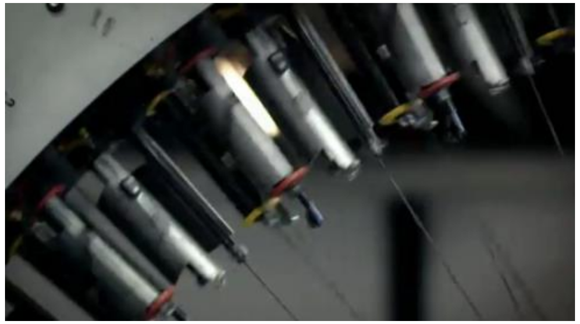
According to Ermanni, ETH Zürich

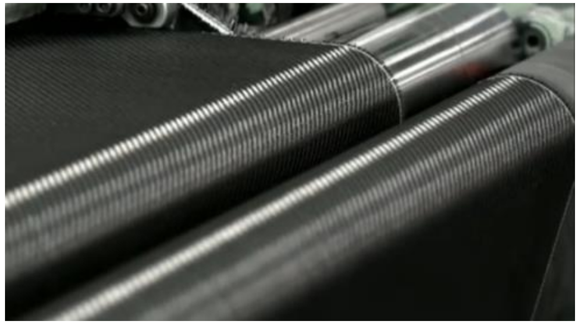
[1] *only one side*

[2] *both sides*

1. Composite Introduction

From Fibers to Finished Composite Components



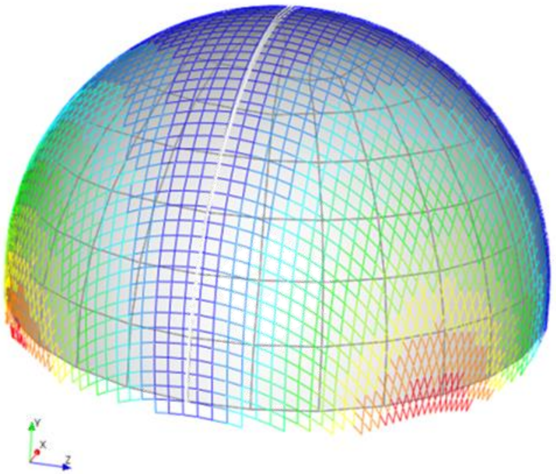


By SGL Group
The Carbon Company

1. Composite Introduction

Draping

- The ability to drape describes the formability of textile preforms and how they adapt themselves to the contour of 3D surfaces
- Draping is simulated to avoid wrinkles or other undesired effects and to consider changes of the fiber orientation



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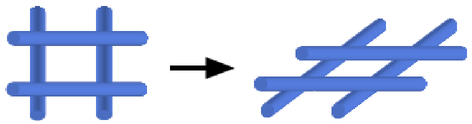
Draping of a Ply

Inside a Ply

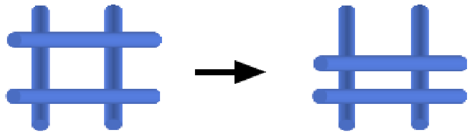
“Trellis”-Effect:
change of angle between fiber directions due to shearing



Fiber Stretching:
curvature of woven fibers changes due to tensile loading

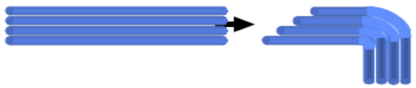
Fiber Straining:
due to elasticity of fibers

Fiber Translation:
due to slipping, especially at edges and corners



In a Laminate

Translation:
translation of plies with respect to each other



According to Ermanni, ETH Zürich

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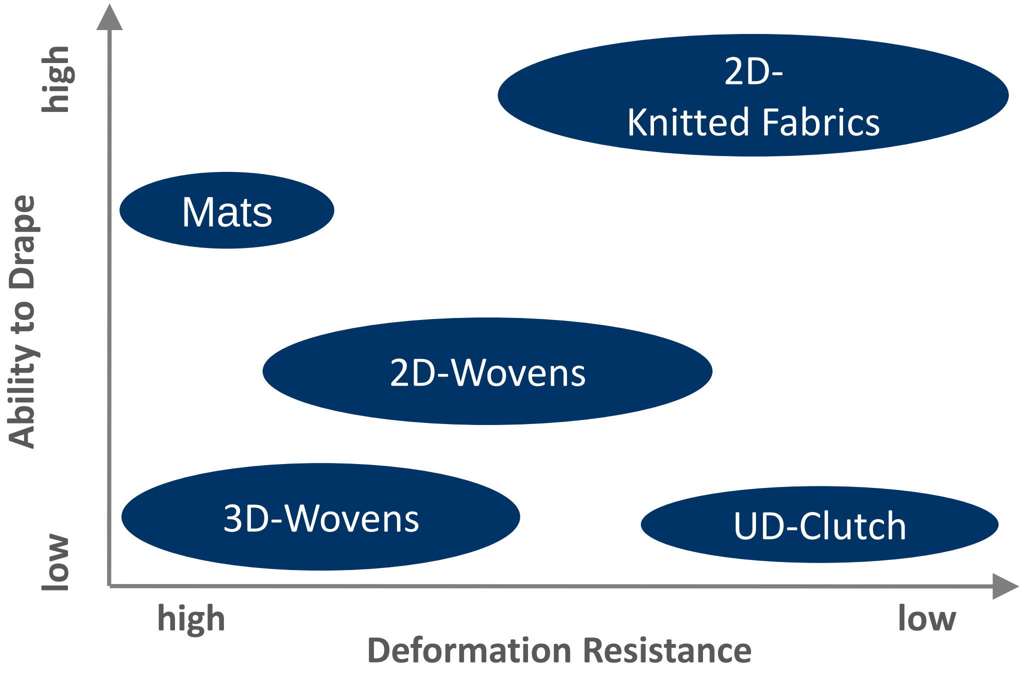
Draping

- High ability to drape and low deformation resistance allow draping of complex geometries



Plank, Wiesbaden 1992

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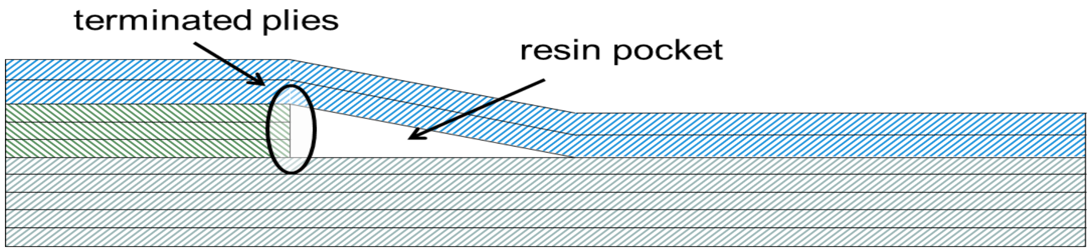
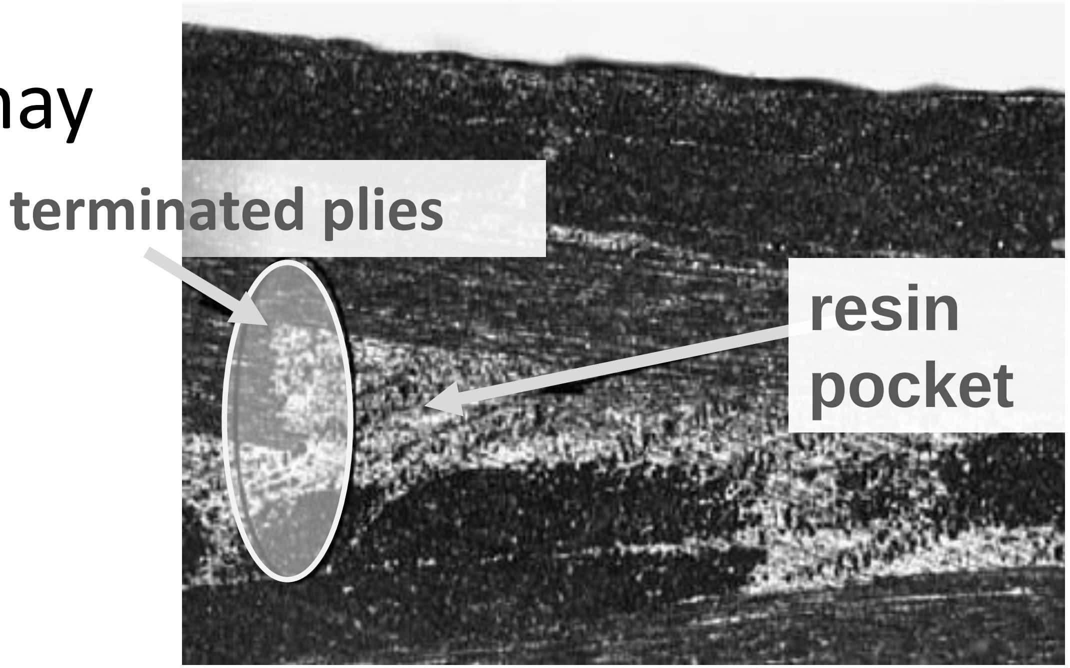
Ply Drop Offs

- Achieve gradual thickness changes and tapering in composite laminates
- Introduces resin pockets, which may lead to delamination failure





1. Composite Introduction

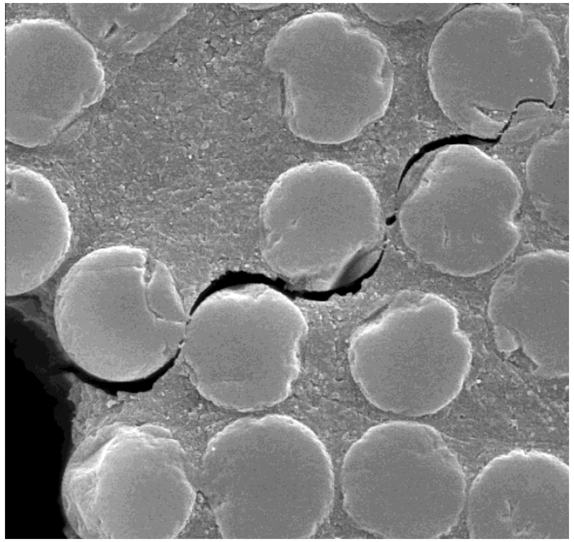
Numerical Approaches

Rotor Diameter 82m
Hub Height up to 100m

(Figure Coutesy by REpower Systems SE)

5.000.000 : 1

Scale relation geometry to fiber diameter



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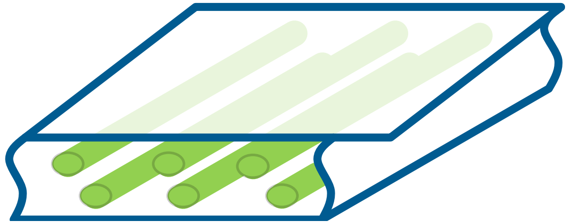
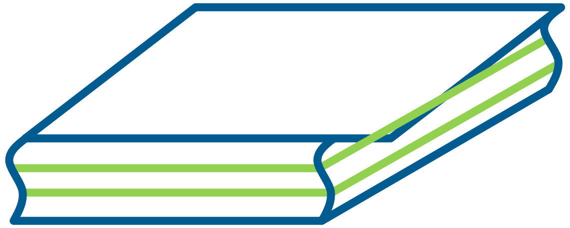
Numerical Approaches

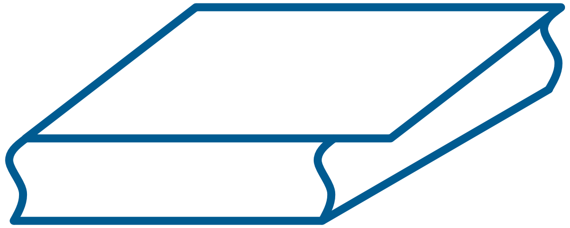
- Micro-Scale Approach
  (Fiber Level)



- Meso-Scale Approach
  (Ply Level)



- Macro-Scale Approach
  (Laminate Level)



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Numerical Approaches

- The most detailed approach describes the micro-structure of the composite. This includes fiber shape, fiber location and material properties of reinforcement and matrix.
- If only displacements, buckling loads, or vibration frequencies and modes are required, the laminate can be analyzed as a homogeneous shell using a macro-scale approach. In this case the stress distribution can not be obtained.

1. Composite Introduction

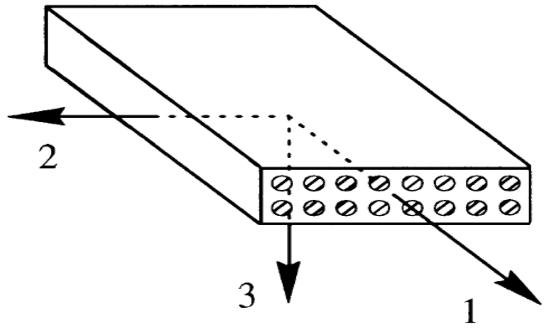
Numerical Approaches

- Analyzing strains, stresses and failure criteria of the composite laminate requires to model the single layers a composite design is built up by. This method is called meso-scale approach. It requires material properties and thicknesses for each layer of the design.
- ANSYS Composite PrepPost is mainly used to prepare and evaluate composite specific results of a design using the meso-scale approach.

1. Composite Introduction

Single Plies

- The Ply Coordinate System
  - 1-Direction: Parallel to fiber direction
    (also II-direction, L-direction or x-direction)
  - 2-Direction: Perpendicular to fiber direction
    (also ⊥ direction, T-direction or y-direction)
  - 3-Direction: Normal to ply
    (also “out of plane” or z-direction)



1. Composite Introduction

Unidirectional Plies

- Fiber Volume Fraction

$$\varphi_F = \frac{Fiber\ Volume}{Total\ Volume} = \frac{V_F}{V_{tot}} = \frac{A_F}{A_F + A_M}$$

- Fiber Weight Fraction

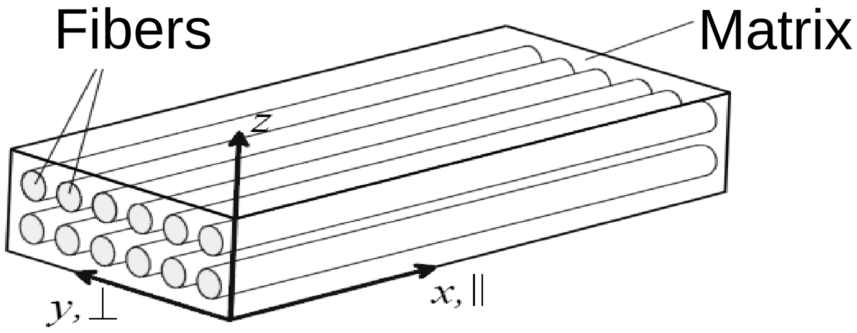
$$\psi_F = \frac{Fiber\ Weight}{Total\ Weight} = \frac{G_F}{G_{tot}} = \frac{A_F \rho_F}{A_F \rho_F + A_M \rho_M}$$

- Matrix Weight Fraction

$$\psi_M = \frac{Matrix\ Weight}{Total\ Weight} = \frac{G_M}{G_{tot}} = \frac{A_M \rho_M}{A_F \rho_F + A_M \rho_M}$$

- Conversion

$$\varphi_F = \frac{1}{1 + \frac{\rho_F}{\rho_M}\left(\frac{1}{\psi_M} - 1\right)}$$



1. Composite Introduction

Unidirectional Plies

- Fiber volume fraction, fiber mass and the ply thickness are dependent values
- **Wovens and Fabrics:**
    - Fiber volume fraction for specific ply thickness
    - Ply thickness for a specific fiber volume fraction

$$\varphi_F = \frac{M_F}{\rho_F t_{target}} \qquad M_F \left(\frac{kg}{m^2} \right)$$

$$t_{target} = \frac{M_F}{\rho_F \varphi_F}$$

1. Composite Introduction

Rules of Mixture

- Rules of mixture are used to estimate material properties (Young's modulus in the 1 and 2 direction) of a composite based on the fiber and matrix material properties
- Multiple different rules of mixture exist in literature, all of them are an estimation
- Using the rules of mixture we simplify the mechanics of the composites layers

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Rules of Mixture, Jones

$$E_1 = \varphi \cdot E_{F1} + (1-\varphi) \cdot E_M$$

$$E_2 = \frac{E_M \cdot E_{F2}}{\varphi \cdot E_M + (1-\varphi) \cdot E_{F2}}$$

$$G_{12} = \frac{G_M \cdot G_{F12}}{\varphi \cdot G_M + (1-\varphi) \cdot G_{F12}}$$

$$\nu_{12} = \varphi \cdot \nu_{F12} + (1-\varphi) \cdot \nu_M$$

$$\nu_{21} = \nu_{12} \frac{E_2}{E_1}$$

1. Composite Introduction

Rules of Mixture, Puck

- Empirical modification with respect to experimental values using a nonlinear approach according to Puck

$$E_1 = \varphi \cdot E_{F1} + (1-\varphi) \cdot E_M$$

$$E_2 = \frac{E_M{}^* \cdot (1+0.85\varphi^2)}{\varphi \cdot \frac{E_M{}^*}{E_{F2}} + (1-\varphi)^{1.25}}$$

$$E_M{}^* = \frac{E_M}{1-\nu_M^2}$$

$$G_{12} = \frac{G_M (1+0.6\ \varphi^{0.5)}}{\varphi \cdot \frac{G_M}{G_{F12}} + (1-\varphi)^{1.25}}$$

$$\nu_{12} = \varphi \cdot \nu_{F12} + (1-\varphi) \cdot \nu_M$$

$$\nu_{21} = \nu_{12} \frac{E_2}{E_1}$$

1. Composite Introduction

Rules of Mixture, Halpin-Tsai Equations

- The Halpin-Tsai equations are a set of semi-empirical relationships that enable the property of a composite material to be expressed in terms of the properties of the matrix and reinforcing phases together with their proportions and geometry.

- Halpin and Tsai showed that the property of a composite P_c could be expressed in terms of reinforcement volume fraction f and the corresponding properties of matrix P_m and reinforcing phase P_f using the following relationships:

$$P_c = \frac{1+\zeta\eta f}{1-\eta f} P_M$$

$$\eta = \frac{\frac{P_F}{P_M} - 1}{\frac{P_F}{P_M} + \zeta}$$

ζ is the contiguity factor defined empirically by curve fitting and it is used to describe the influence of geometry of the reinforcing phase on a particular property. This factor is different for different properties in the same composite. The table in the next slide summarizes this factor for many typical geometries.

D. Hull and T.W. Clyne, 1996, An Introduction to composite Materials, second edition, Cambridge University Press, Cambridge

1. Composite Introduction

Rules of Mixture, Halpin-Tsai Equations

Geometry	E_1	E_2	V_{12}	G_{12}
Aligned continuous fibres	$fE_f + (1-f)E_m$	$\dfrac{E_f E_m}{fE_m + (1-f)E_f}$ or $\zeta = 2 + 40f^{10}$	$f\nu_f + (1-f)\nu_m$	$\zeta = 1 + 40f^{10}$ or $G_m\left(\dfrac{G_f(1+f) + G_m(1-f)}{G_m(1+f) + G_f(1-f)}\right)$
Spherical particles	$\zeta = 2 + 40f^{10}$	$\zeta = 2 + 40f^{10}$	$f\nu_f + (1-f)\nu_m$	$\zeta = 1 + 40f^{10}$
Oriented short fibres	$l < l_c \quad E_m\left(1 - f\left(1 - \dfrac{l}{2d}\right)\right)$ $l \geq l_c \quad fE_f\left(1 - \dfrac{l_c}{2l}\right) + (1-f)E_m$	$\zeta = 2 + 40f^{10}$	$f\nu_f + (1-f)\nu_m$	$\zeta = 1 + 40f^{10}$
Oriented plates	$\zeta = 2\left(\dfrac{l}{t}\right) + 40f^{10}$	$\zeta = 2\left(\dfrac{w}{t}\right) + 40f^{10}$	$f\nu_f + (1-f)\nu_m$	$\zeta = \left(\dfrac{l+w}{2t}\right)^{1.73} + 40f^{10}$
Oriented whiskers	$\zeta = 2\left(\dfrac{l}{d}\right) + 40f^{10}$	$\zeta = 2 + 40f^{10}$	$f\nu_f + (1-f)\nu_m$	$\zeta = \left(\dfrac{l}{d}\right)^{1.73} + 40f^{10}$

D. Hull and T.W. Clyne, 1996, An Introduction to composite Materials, second edition, Cambridge University Press, Cambridge

In all composite systems the equations are not valid above f=0.9 since these volume fractions of fibers are impossible geometrically.

1. Composite Introduction

Homogeneous and Heterogeneous Materials

- Heterogeneous materials have varying properties at different locations within the material
- In contrast, properties for homogeneous materials (e.g steel) are the same at every location within the material
- Composite laminate material is considered predominantly as a homogenous material for simulations on a laminate level

1. Composite Introduction

Isotropic Material

- Most common materials of industrial use are isotropic (aluminum, steel, etc.)
- Isotropic materials have an infinite number of planes of symmetry, meaning that the properties are independent of the orientation
- Two constants (Young modulus and Poisson's Ratio) are necessary to represent the elastic properties of isotropic material

1. Composite Introduction

Anisotropic Material

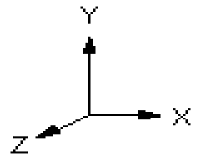
- Isotropic material (e.g. steel) has the same properties in any direction
- Anisotropic material has properties (mechanical, etc.) that vary with the orientation
- The stiffness of an isotropic material is described by two properties, the modulus of elasticity E and Poisson's ratio ν, whereas anisotropic material requires up to 21 properties

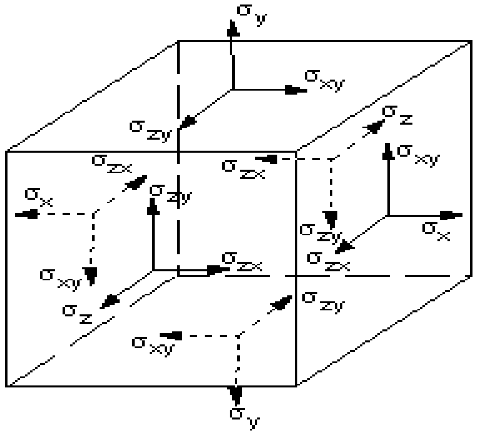
1. Composite Introduction

Anisotropic Material

- Material definition requires the full 6×6 elastic coefficient matrix [D]

$$
\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{bmatrix}
=
\begin{bmatrix}
D_{11} & & & & & \\
D_{21} & D_{22} & & & symmetry & \\
D_{31} & D_{32} & D_{33} & & & \\
D_{41} & D_{42} & D_{43} & D_{44} & & \\
D_{51} & D_{52} & D_{53} & D_{54} & D_{55} & \\
D_{61} & D_{62} & D_{63} & D_{64} & D_{65} & D_{66}
\end{bmatrix}
\cdot
\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xy} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \end{bmatrix}
$$



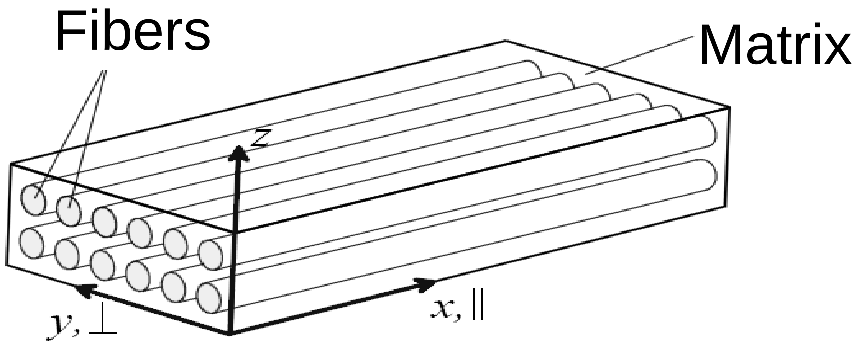


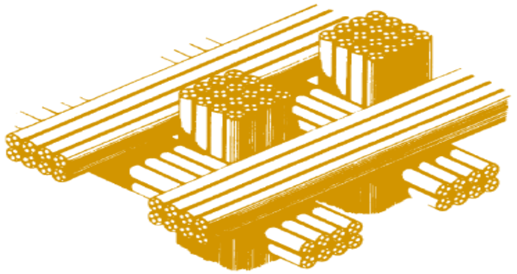
$$\{\sigma\} = [D] \cdot \{\varepsilon\}$$

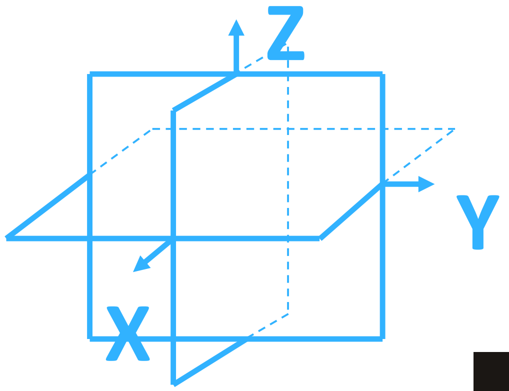
1. Composite Introduction

Orthotropic Material

- An orthotropic material has three planes of material symmetry
- A unidirectional fiber-reinforced composite may be considered to be orthotropic
- One plane of symmetry is perpendicular to the fiber direction, and the other two can be any pair of plane orthogonal to the fiber direction

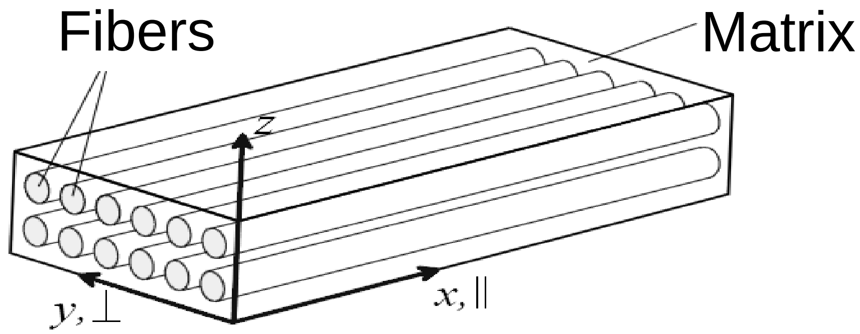






1. Composite Introduction

Orthotropic Material



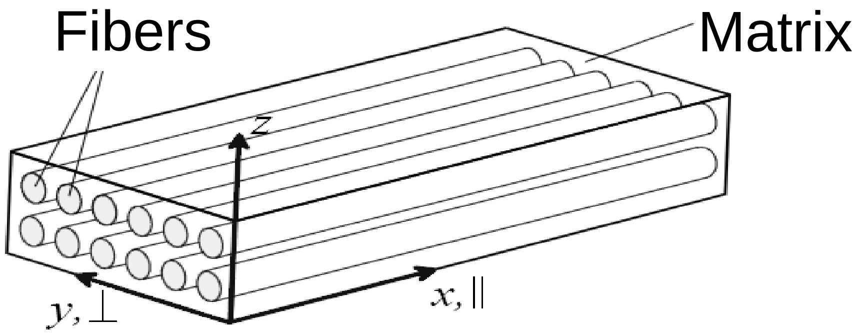
$$E_x, E_y, E_z, \nu_{xy}, \nu_{yz}, \nu_{xz}, G_{xy}, G_{yz}, G_{xz}$$

- Nine constants are required to describe an orthotropic material

$$\begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} & D_{13} & & & \\ D_{21} & D_{22} & D_{23} & & & \\ D_{31} & D_{32} & D_{33} & & & \\ & & & D_{44} & & \\ & & & & D_{55} & \\ & & & & & D_{66} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xy} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \end{bmatrix}$$

1. Composite Introduction

Orthotropic Material



- The compliance matrix $\{\varepsilon\} = [S]\cdot\{\sigma\}$ $\left([S] = [D]^{-1}\right)$ is defined as

$$\begin{bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xy} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \end{bmatrix} = \begin{bmatrix} \frac{1}{E_x} & -\frac{\nu_{yx}}{E_y} & -\frac{\nu_{zx}}{E_z} & & & \\ -\frac{\nu_{xy}}{E_x} & \frac{1}{E_y} & -\frac{\nu_{zy}}{E_z} & & & \\ -\frac{\nu_{xz}}{E_x} & -\frac{\nu_{yz}}{E_y} & \frac{1}{E_z} & & & \\ & & & \frac{1}{G_{xy}} & & \\ & & & & \frac{1}{G_{yz}} & \\ & & & & & \frac{1}{G_{xz}} \end{bmatrix} \cdot \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{yz} \\ \sigma_{xz} \end{bmatrix}$$

1. Composite Introduction

Transversal Isotropic Material

- Transversal isotropic materials are orthotropic materials characterized by isotropic material behavior in one material symmetry plane
- A unidirectional layer has transversal isotropic material behavior with the fiber direction as symmetry axis
- A woven fabric has transversal isotropic material behavior with the out of plane normal direction as symmetry axis
- The number of constants to define is reduced to 5

1. Composite Introduction

Transversal Isotropic Material

- Unidirectional Layer

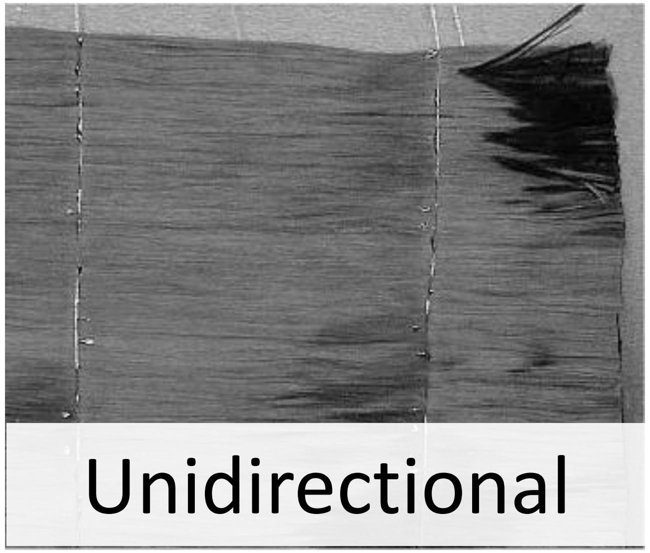
$$E_y = E_z \qquad \nu_{xy} = \nu_{xz}$$

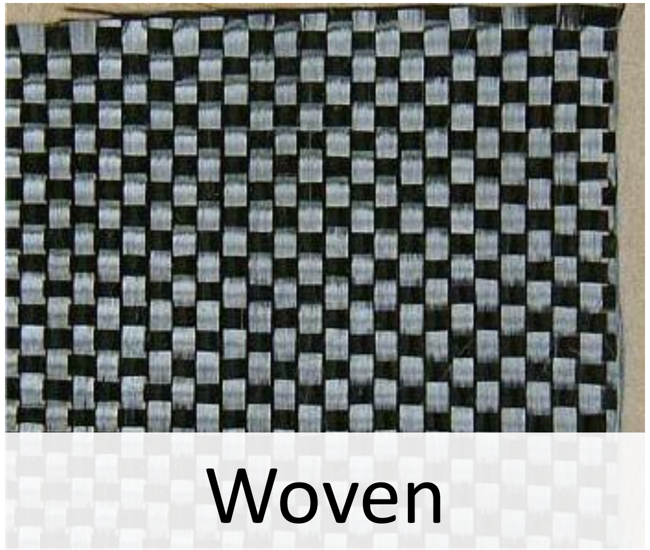
$$G_{xy} = G_{xz} \qquad G_{yz} = \frac{E_y}{2 \cdot (1 + \nu_{yz})}$$

- Woven Fabrics

$$E_x = E_y \qquad \nu_{yz} = \nu_{xz}$$

$$G_{yz} = G_{xz} \qquad G_{xy} = \frac{E_x}{2 \cdot (1 + \nu_{xy})}$$

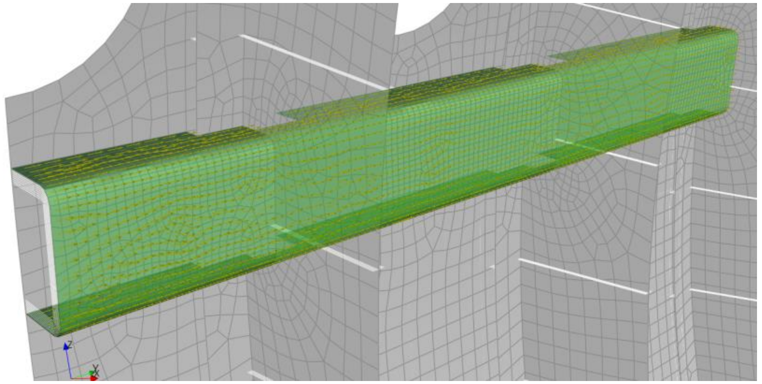




1. Composite Introduction

From Three Dimensional to Plane Stress State

- Composite materials are often used in form of plates and shells, which have two dimensions (length and width) much larger than the third dimension (thickness). When the thickness of a plate is small compared to the other dimension, it is reasonable to assume that the transverse stress is zero ($\sigma_Z=\sigma_3=0$).



1. Composite Introduction

From Three Dimensional to Plane Stress State

$$\sigma_{zz}=0,\quad \sigma_{yz}=0,\quad \sigma_{xz}=0$$

$$\begin{bmatrix} \boxed{\begin{matrix}\varepsilon_{xx}\\ \varepsilon_{yy}\end{matrix}} \\ \varepsilon_{zz} \\ \boxed{\varepsilon_{xy}} \\ \varepsilon_{yz} \\ \varepsilon_{xz} \end{bmatrix} = \begin{bmatrix} \boxed{\begin{matrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{matrix}} & \begin{matrix} S_{13} \\ S_{23} \end{matrix} & & & \\ S_{31} \quad S_{32} & S_{33} & & & \\ & & \boxed{S_{44}} & & \\ & & & S_{55} & \\ & & & & S_{66} \end{bmatrix} \cdot \begin{bmatrix} \boxed{\begin{matrix}\sigma_{xx}\\ \sigma_{yy}\end{matrix}} \\ \sigma_{zz} \\ \boxed{\sigma_{xy}} \\ \sigma_{yz} \\ \sigma_{xz} \end{bmatrix}$$

Compliance Matrix $\{\varepsilon\}=[S]\cdot\{\sigma\}$

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \\ S_{12} & S_{22} & \\ & & S_{44} \end{bmatrix} \cdot \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix}$$

$$S_{11}=\frac{1}{E_1},\quad S_{22}=\frac{1}{E_2},\quad S_{44}=\frac{1}{G_{12}}$$

$$S_{12}=S_{21}=-\frac{\nu_{12}}{E_1}$$

Stiffness Matrix $\{\sigma\}=[D]\cdot\{\varepsilon\}$

$$\begin{Bmatrix} \sigma_x \\ \sigma_y \\ \sigma_{xy} \end{Bmatrix} = \begin{bmatrix} D_{11} & D_{12} & \\ D_{12} & D_{22} & \\ & & D_{44} \end{bmatrix} \cdot \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_{xy} \end{Bmatrix}$$

$$D_{11}=\frac{E_1}{\Delta},\quad D_{22}=\frac{E_2}{\Delta},\quad D_{44}=G_{12}$$

$$S_{12}=S_{21}=-\frac{\nu_{12}\cdot E_2}{\Delta}$$

$$\Delta=1-\frac{E_2}{E_1}\nu_{12}^{\ 2}$$

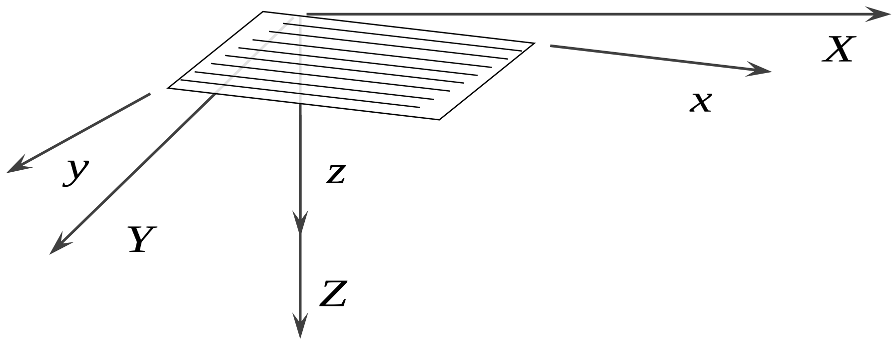
1. Composite Introduction

Transformation to the Global Coordinate System

- Layers are defined with different specific fiber angles
- In order to build a stiffness matrix for the complete layup the stiffness matrixes for each layer are transformed from the layers x,y,z or 1,2,3 coordinate system into the global coordinate system using a transformation matrix

$$[T]=\begin{bmatrix} \cos^2\theta & \sin^2\theta & 2\sin\theta\cos\theta \\ \sin^2\theta & \cos^2\theta & -2\sin\theta\cos\theta \\ -\sin\theta\cos\theta & \sin\theta\cos\theta & \cos^2\theta-\sin^2\theta \end{bmatrix}$$

$$[T]^{-1}=\begin{bmatrix} \cos^2\theta & \sin^2\theta & -2\sin\theta\cos\theta \\ \sin^2\theta & \cos^2\theta & 2\sin\theta\cos\theta \\ \sin\theta\cos\theta & -\sin\theta\cos\theta & \cos^2\theta-\sin^2\theta \end{bmatrix}$$

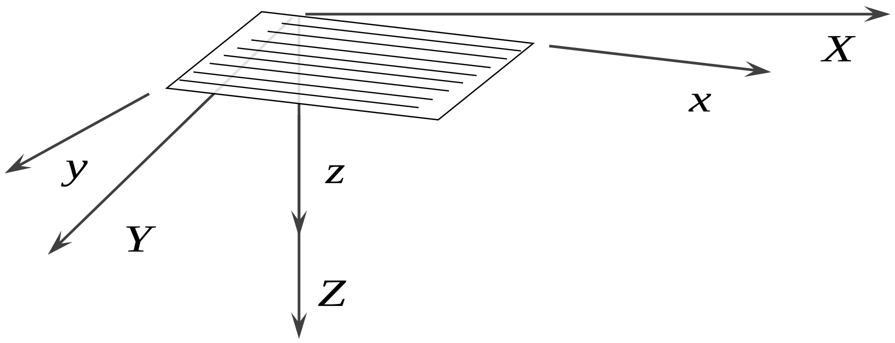


1. Composite Introduction

Transformation to the Global Coordinate System

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_{xy}\end{Bmatrix}=[T]\cdot\begin{Bmatrix}\sigma_X\\ \sigma_Y\\ \sigma_{XY}\end{Bmatrix}\qquad\begin{Bmatrix}\sigma_X\\ \sigma_Y\\ \sigma_{XY}\end{Bmatrix}=[T]^{-1}\cdot\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \sigma_{xy}\end{Bmatrix}$$

$$\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_{xy}\end{Bmatrix}=[T]\cdot\begin{Bmatrix}\varepsilon_X\\ \varepsilon_Y\\ \varepsilon_{XY}\end{Bmatrix}\qquad\begin{Bmatrix}\varepsilon_X\\ \varepsilon_Y\\ \varepsilon_{XY}\end{Bmatrix}=[T]^{-1}\cdot\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \varepsilon_{xy}\end{Bmatrix}$$



Compliance Matrix:

$$\begin{Bmatrix}\varepsilon_X\\ \varepsilon_Y\\ \varepsilon_{XY}\end{Bmatrix}=\begin{bmatrix}\overline{S}_{11} & \overline{S}_{12} & \\ \overline{S}_{12} & \overline{S}_{22} & \\ & & \overline{S}_{44}\end{bmatrix}\cdot\begin{Bmatrix}\sigma_X\\ \sigma_Y\\ \sigma_{XY}\end{Bmatrix}$$

$$[\overline{S}] = [T]^{-1}\,[S]\,[T]$$

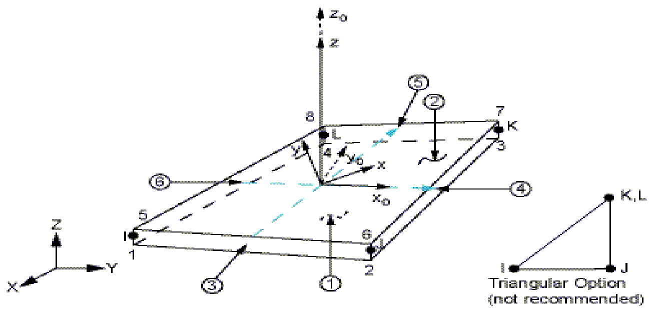
Stiffness Matrix:

$$\begin{Bmatrix}\sigma_X\\ \sigma_Y\\ \sigma_{XY}\end{Bmatrix}=\begin{bmatrix}\overline{D}_{11} & \overline{D}_{12} & \\ \overline{D}_{12} & \overline{D}_{22} & \\ & & \overline{D}_{44}\end{bmatrix}\cdot\begin{Bmatrix}\varepsilon_X\\ \varepsilon_Y\\ \varepsilon_{XY}\end{Bmatrix}$$

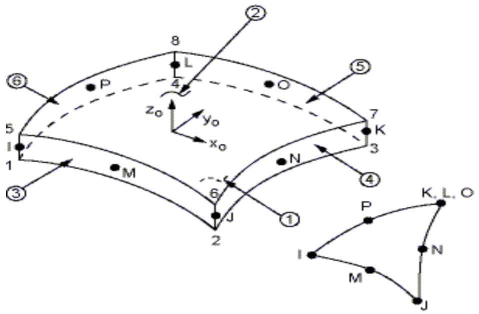
$$[\overline{D}] = [T]^{-1}\,[D]\,[T]$$

1. Composite Introduction

Layered Shell-Elements in ANSYS



4-Node Structural Shell



8-Node Structural Shell

- Structural shell elements require the definition of the following mechanical material properties per layer
  - Young's Modulus in X, Y and Z direction
  - Shear Modulus in the XY, YZ and XZ plane
  - Poisson's Ratio in the XY, YZ and XZ plane

1. Composite Introduction

Element Technology in ANSYS

- A layup can also be defined for solid elements (SOLID185, SOLID186) and solid like shell elements (SOLSH190) in ANSYS
- Furthermore discrete reinforcements (REINF264) are possible for shell and solid elements
- Please see the ANSYS Theory Reference in the ANSYS Help (// Theory Reference) for more information on element technology in ANSYS

1. Composite Introduction

Measuring Ply Properties

- Mechanical properties of composite materials depend on the production process and the specific material properties of the basic materials used as well as on the manufacturing process of the composite design
- General material databases are available (ESAComp has a comprehensive material database) but the data provided are standard material data
- For individual material data ask your material manufacturer about data, recommended tests and/or recommended test laboratories
- Contact test laboratories offering standard test (ISO or ASTM) and non standard tests

1. Composite Introduction

Measuring Ply Properties

- International Organization for Standardization

International Organization for Standardization

"The International Organization for Standardization is an international standard-setting body composed of representatives from various national standards organizations."

Examples:

- ISO 14125:1998 fiber-reinforced plastic composites -- Determination of flexural properties
- ISO 527-5:2009 Plastics -- Determination of tensile properties -- Part 5: Test conditions for unidirectional fiber-reinforced plastic composites

ANSYS

1. Composite Introduction

Measuring Ply Properties

- American Society for Testing and Materials (ASTM)

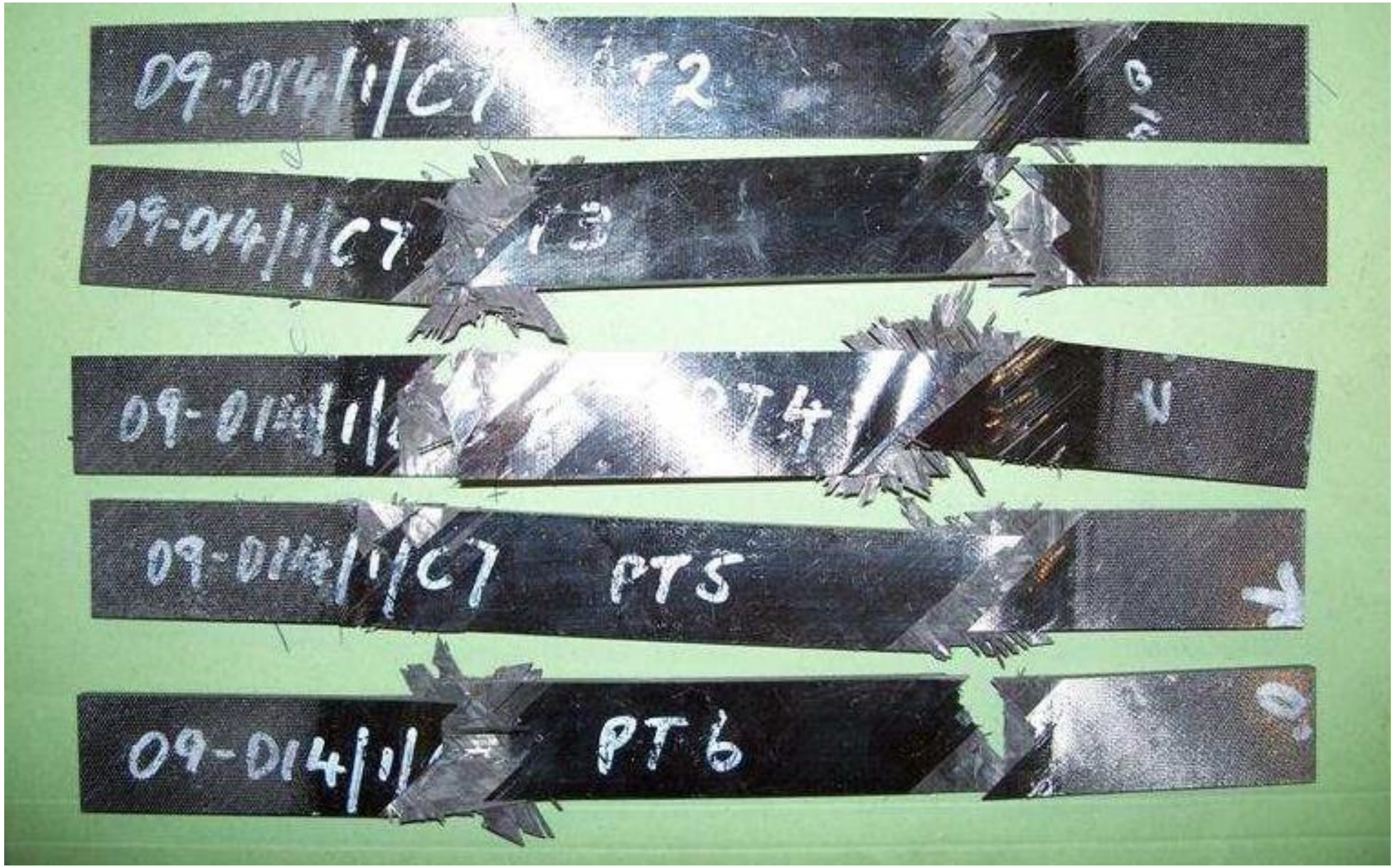
"ASTM International is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services."

Examples:

- Committee D30 on Composite Materials
- ASTM D7205 / D7205M - 06 Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
- ASTM D7617 / D7617M - 11 Standard Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars

1. Composite Introduction

Tension Tests and Failure Mode

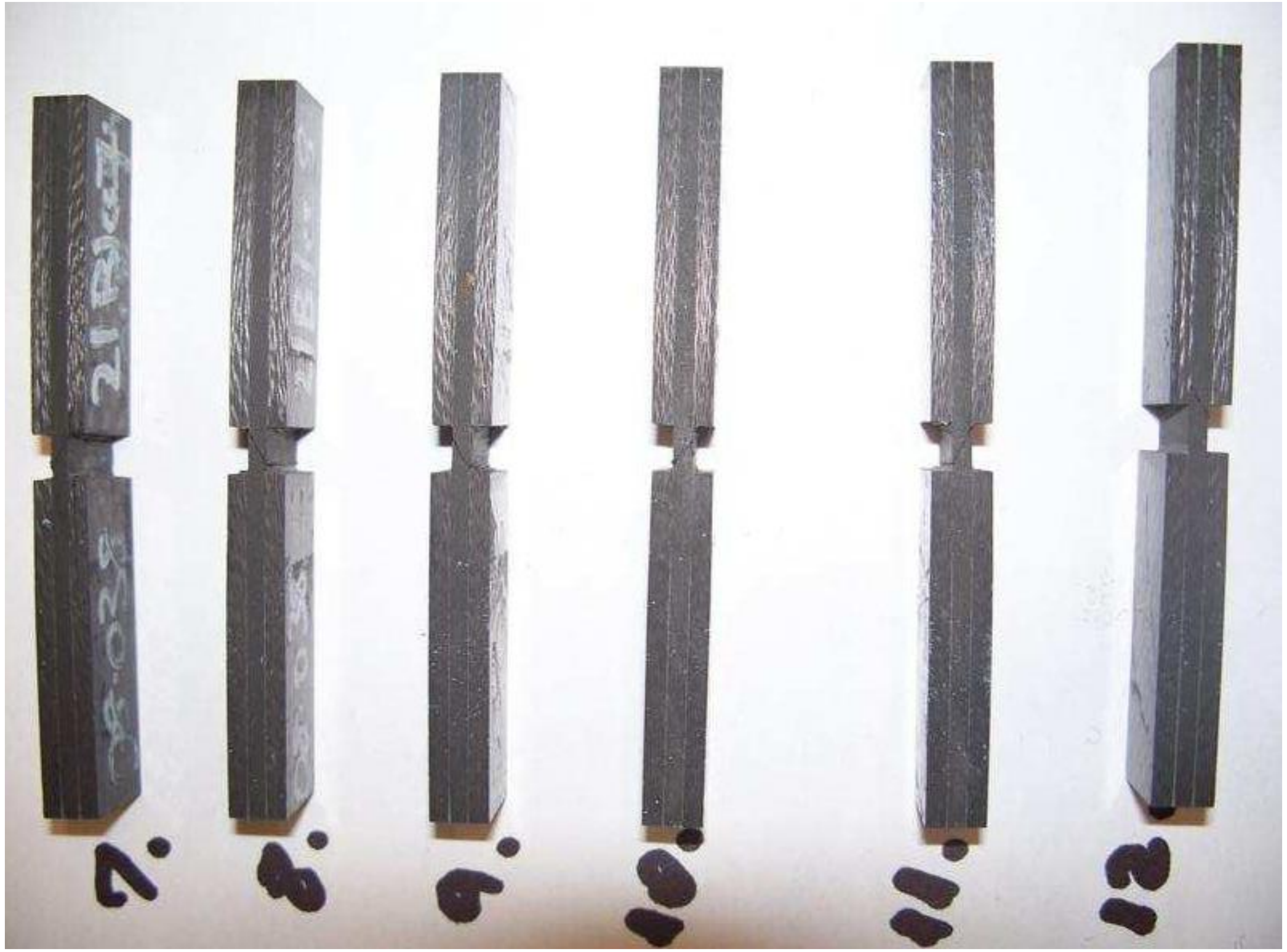


Unidirectional Composite Tensile Test

Carbon Fiber Tensile Test

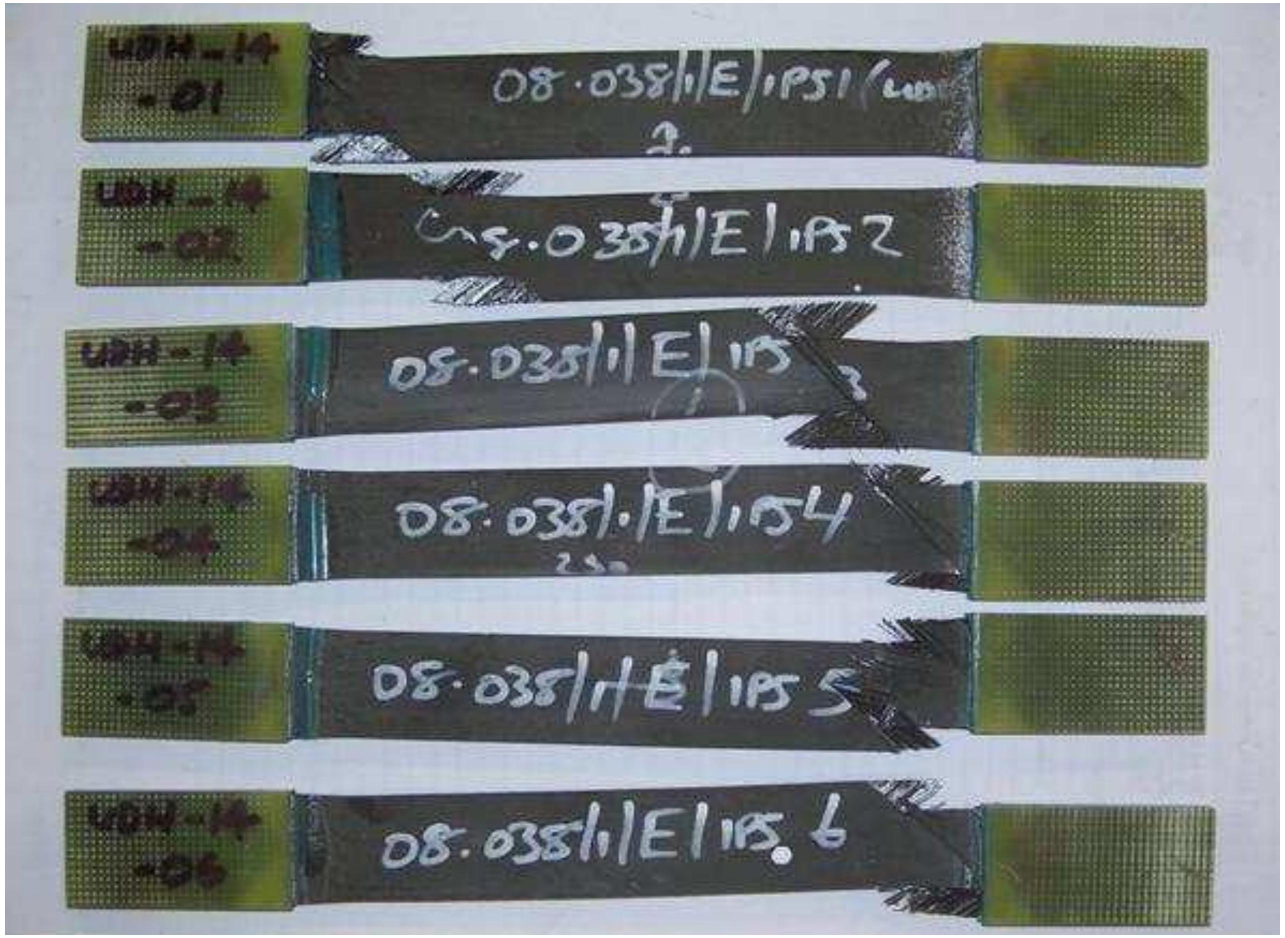
1. Composite Introduction

Compression Tests and Failure Mode



1. Composite Introduction

In-Plane Shear Tests and Failure Modes



1. Composite Introduction

Failure Indicator

FPF – First-Ply-Failure Indicator

- Mathematical equations indicating first failure of any ply
- Indicates the occurring failure mode: fiber tension, fiber compression, matrix tension, matrix compression
- Determines reserve factor, inverse reserve factor, margin of safety
- Typical criteria: Max. Stress, Max. Strain, Tsai-Wu, Tsai-Hill, Hashin, Puck2D, Puck3D, Cuntze

1. Composite Introduction

Failure Indicator

LPF – Last-Ply-Failure (Progressive Damage)

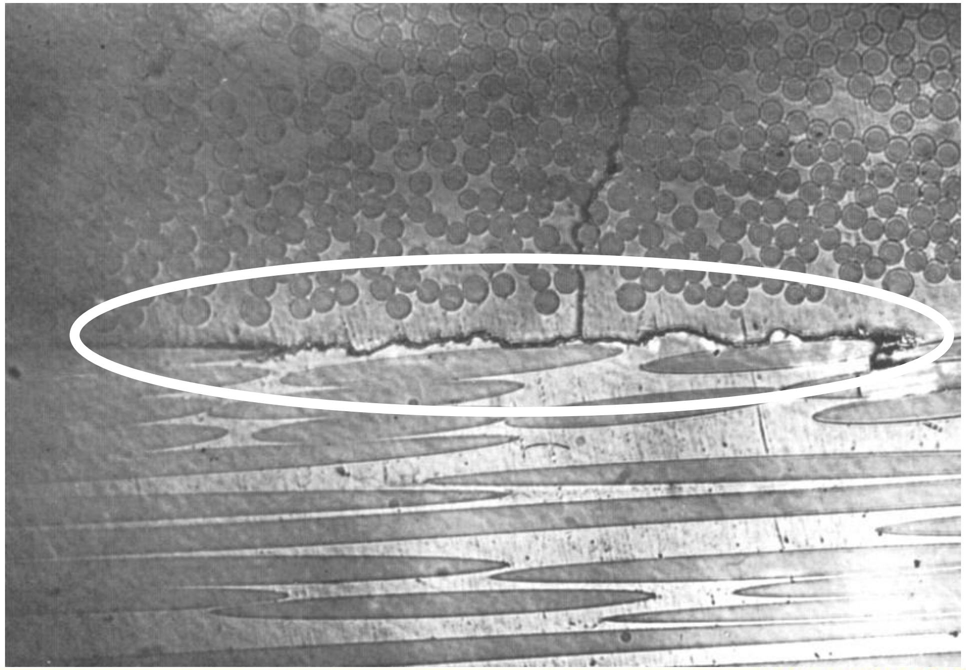
- Further loading beyond FPF until ultimate failure of laminate.
- Post-failure formulations needed (ply-discount method)
- May also include energy dissipating methods

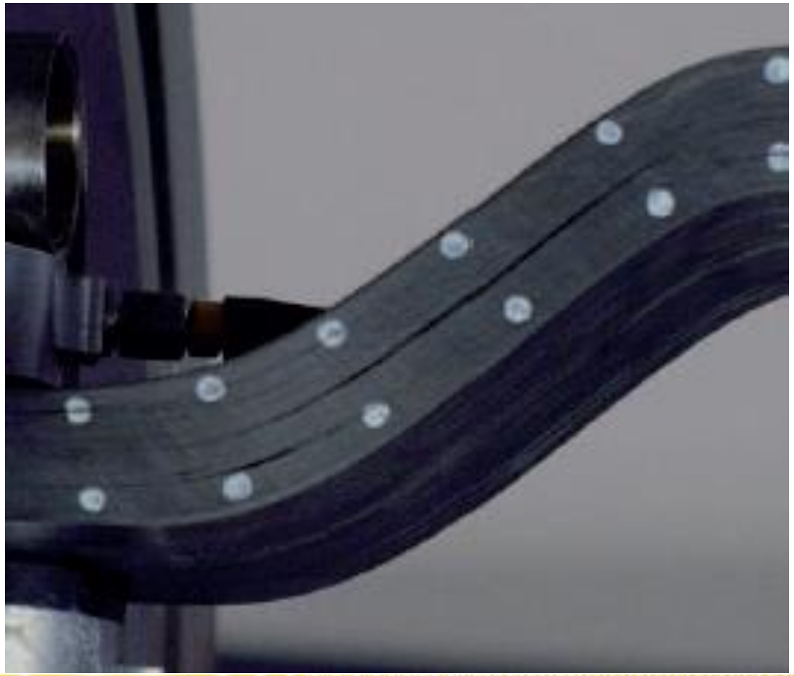
1. Composite Introduction

Delamination

- Interface failure between two plies in normal direction

  → Interlaminar Failure
- Driven by normal stress in thickness direction

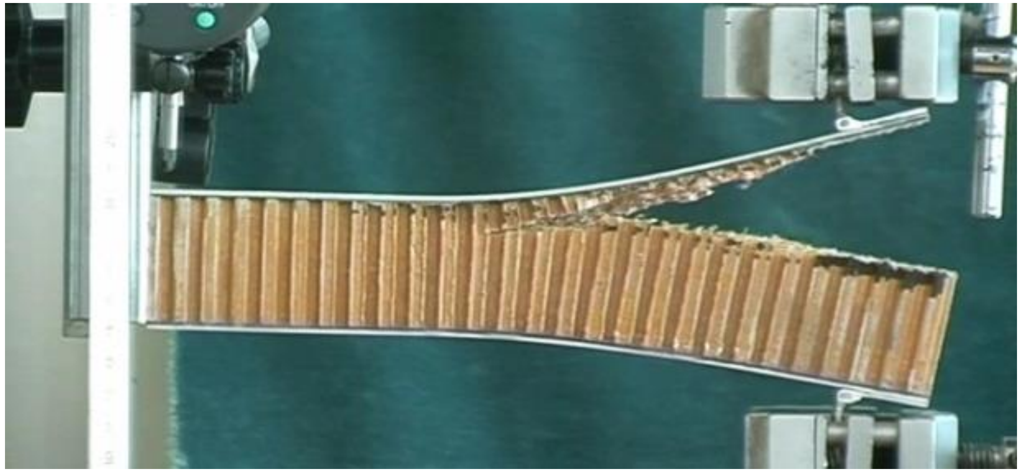




1. Composite Introduction

Debonding

- Interface failure between face sheet and core of sandwich structures.
- Only predictable when core and sheet are separately modeled.



YouTube

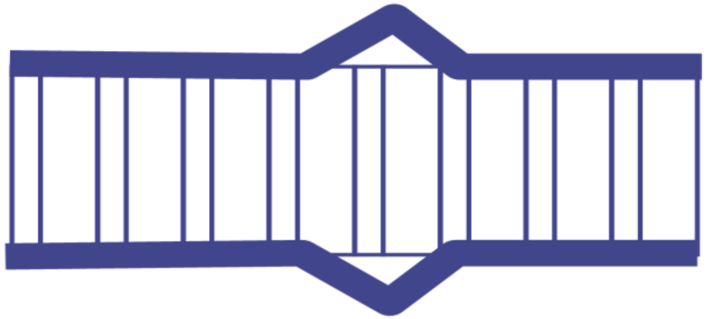
Compression Test

ANSYS

1. Composite Introduction

Wrinkling

- Local buckling of a face sheet under compression
- Failure indicator available using shell modeling of sandwich



Core Failure

- Local failure of core in shear or tensile loading
- Failure indicator available using shell modeling of sandwich