COMP-ECO

WP3: Provision of state of the art training to young researchers

Monday 26.06	Tuesday 27.06
9:00 Motivation	9:00: Systems and functions (TUD)
10:00 – 10:45: *Lightweight engineering I (TUD)* • *History of lightweight* • *Applications in different sectors*	10:00 – 10:45: *Function Integration I (TUD)* • Examples of function integration (sensors, industry 4.0, e.t.c.) • Contradiction between structural integrity and additional functions • Compliant structures
Break	Break
11:15 – 12:00: *Lightweight engineering II (TUD)* • *Isotropic/ anisotropic materials* • *Manufacturing technologies (e.g., braiding, autoclave)*	11:15 – 12:00: *Function Integration II (TUD)* • Design process for function integrative lightweight structures • Spiral developments approach • Design demonstration
Lunch	Lunch
13:00 - 13:45: Composite materials (DELFT) • *Basics of design and calculations*	13:00 - 13:45: Tasks on Application (TUD)
Break	
14:15 – 15:00: Tasks & calculations on design (DELFT)	14:15-15:00: Elevator pitch
Recap	Open discussion and application on their topics

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COMPOSITE MATERIALS

BASICS OF DESIGN AND CALCULATIONS

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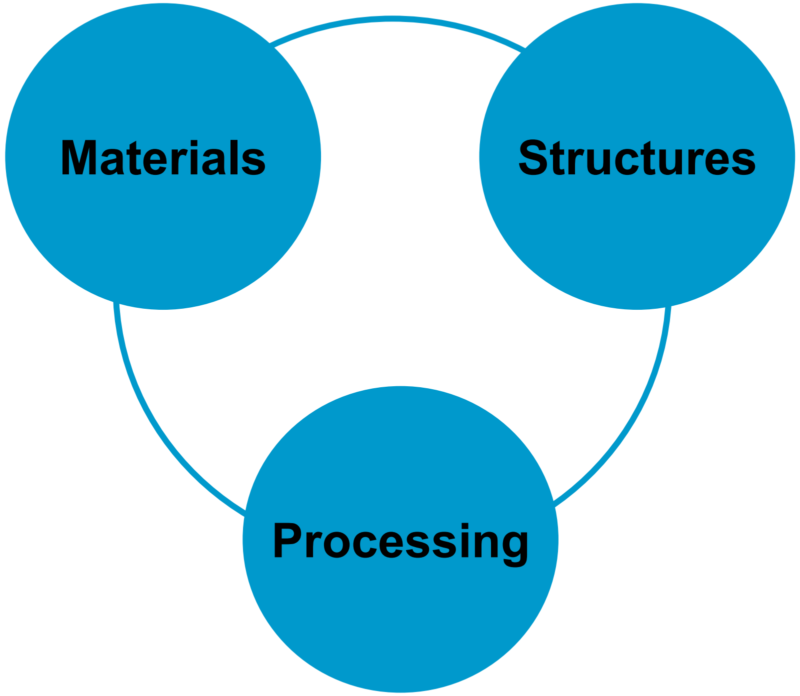
LIGHTNESS



COMPOSITE MATERIALS

Lightness

high specific properties (minimum mass)

shortest load path

all material equally loaded

process fits structure and material: a strategy for design

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TECHNOLOGY PARTNERS

TUDelft

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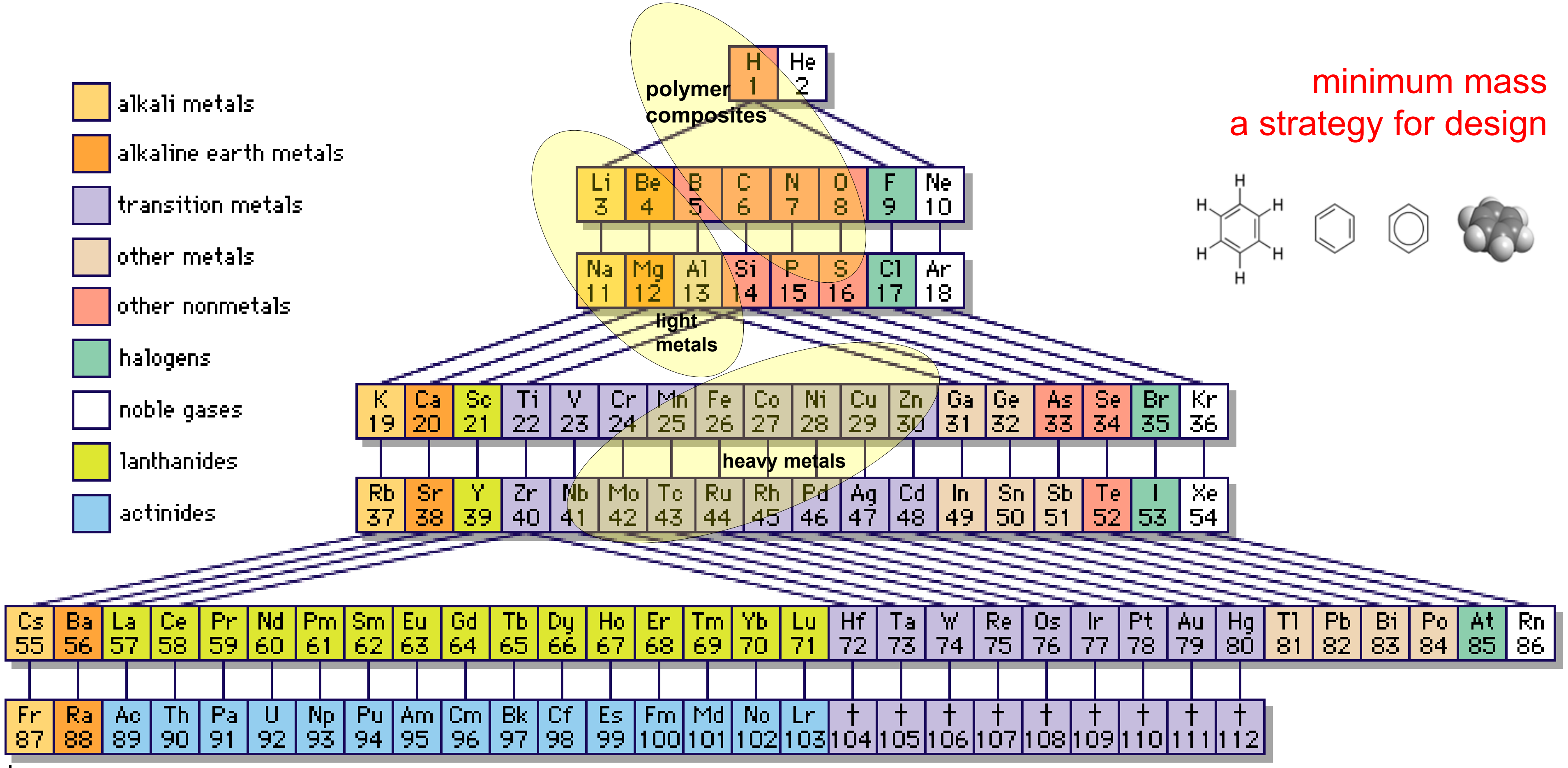
PERIODIC SYSTEM OF ELEMENTS



† For the names of elements 104-112, see Table 27.

minimum mass
a strategy for design

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Slide created by A.Beukers

fried
air

LIGHTNESS

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COMPOSITE MATERIALS

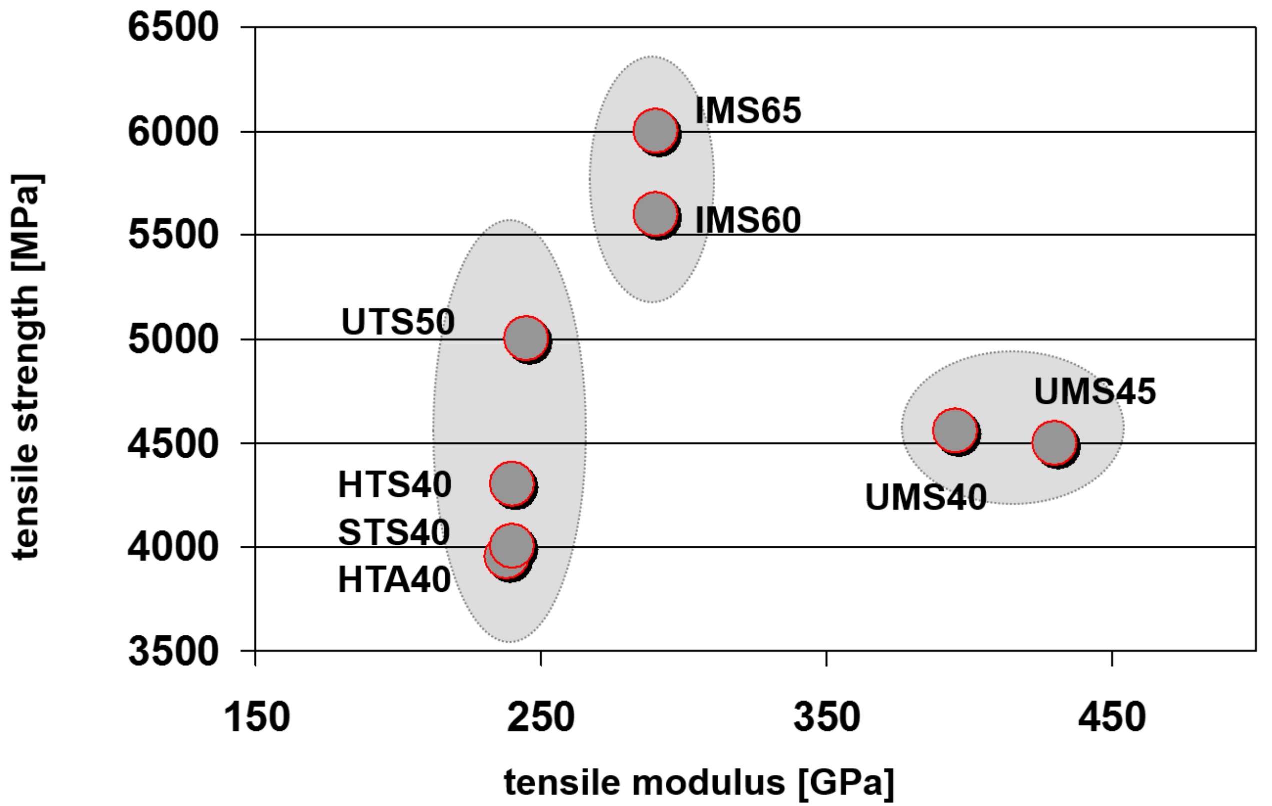
COMPOSITION

- Composites
  - reinforcement material
    - carbon
    - glass
    - aramid
    - other.....
  - reinforcement shape
    - fibres (1D)
    - platelets (2D)
    - hollow spheres (3D)
    - (dis)continuous
  - fibre architecture
    - prepreg
    - UD
    - weave
    - tape
    - braid
    - tow
  - matrix material
    - thermoset
    - thermoplastic
    - metals

TEIJIN

Toho Tenax

Tenax® Product Programme



Toho Tenax Europe GmbH

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FIBRE ARCHITECTURE

Fibre Appearance:

Short – Long – Continuous

Tow

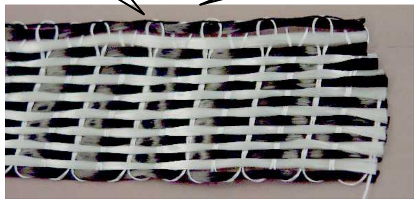
Mechanical properties:

The longer the better

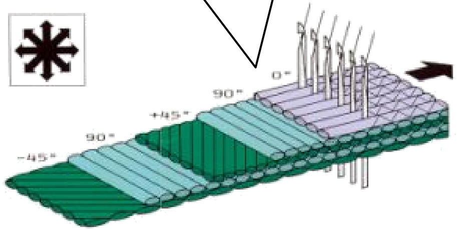
Continuous: Textile Morphology

UD

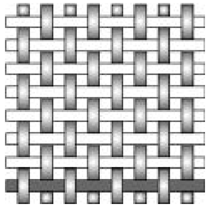
Tape



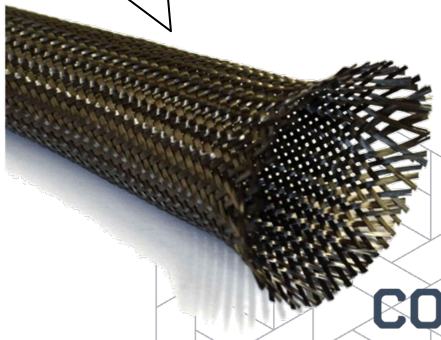
Non woven



Weave

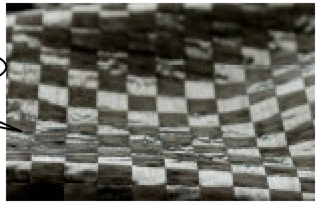


Braid



The Flatter The Better

Textreme®



Matrix	Essential feature
Epoxy (EP)	• Thermoset, common resin system for CFRP • *Polyaddition* between resin and curing agent
Unsaturated Polyester / Vinylester	• Unsaturated Polyester are commonly used with glass fibre • Vinylester for wind energy and marine application • Low moisture pickup • Cheaper than EP • *Peroxidic polymerisation*, already at room temperature • Accelerator for quick curing (accelerator and curing agent may explode) • Styrene as reactive diluent

Matrix	Essential feature
Phenol-Formaldehyde	• *Polycondensation* • Airplane interior – FST (fire, smoke, toxicity)
Benzoxazine	• Relativly new resin system, based on phenol, formaldehyd and amine • *Polyaddition* reaction • Long storage time, even at room temperature • Mechanical properties similar to EP • Good FST properties

Matrix	Essential feature
High Performance Thermoplastics (PEEK, PEKK, PAEK, PPS)	• High energy release, high impact- and fracture toughness • Long storage time • HSE (Health Safety Environment) properties are optimal • High processing temperatures • Unwanted yielding and creeping
Miscellaneous	• Bismaleimides BMI, Polyimide PI (good temperature stability for space applications) • Technical thermoplastics, acrylate, cyanate ester, ceramic (Developing products and/ or other applications than mechanical reinforcement)

MATRIX MATERIALS (POLYMERS)

Documentation	Essential feature
Technical data sheet **Product data sheet**	• Provide mechanical data • Provide processing data •………..
Safety data sheet (MSDS)	• Provide composition of ingredients • Provide first aid measures • Provide fire fighting aspects •…….

Before design you want to have the technical data sheet,
but also the safety data sheet, as that can influence your processing.

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MATRIX MATERIALS (POLYMERS)

Example safety wording: (scotch-weld 9323 B/A structural adhesive)

Health and Safety Information	**PART A** contains: 2,4,6 - Tris (Dimethylaminomethyl) phenol, polymeric diamine. **PART B** contains: Epoxy Resin. **Precautions:** Irritating to skin. Risk of serious damage to eyes. May cause sensitisation by skin contact. May be harmful if swallowed. Avoid contact with skin and eyes. Wear suitable gloves and eye/face protection.	**First Aid:** **Eye Contact:** Immediately flush eyes with copious amounts of water for at least 15 minutes, holding eyes open. Call a physician. **Skin Contact:** Wash immediately with plenty of soap and water. **Ingestion:** Drink two glasses of water and call a physician immediately. Do not induce vomiting.	For further Health & Safety information, please contact our Toxicology Department on Bracknell (0344) 858000.

PROCESSING

Combine reinforcements and matrix

- Process!
- There are many, many processes, they all lead to some final material.

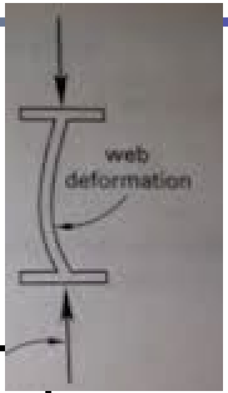
So:

Values for properties you dare (are allowed) to use when designing something depend on processing

Five material tensile strength test results:

300 MPa ; 308 MPa; 320 MPa; 303 MPa; 287 MPa

Which value should we use???................ALLOWABLES.



ALLOWABLES

Property/failure mode	Dominant constituent	Factors affecting Properties
Stiffness		
Elastic constants	Fibre	**Temperature**
Buckling	Fibre	**Fibre alignment**
Crippling	Fibre	**Element geometry**

ALLOWABLES

Property/failure mode	Dominant constituent	Factors affecting Properties
In-plane strength		
Tension	Fibre	**Low temperatures**
Compression	Fibre Matrix/interface	**Moisture/elevated temperature**
Shear	Fibre Matrix/interface	**Moisture/elevated temperature**
Pin bearing	Matrix/interface	**Element geometry**
Bearing/bypass	Matrix/interface	**…**

ALLOWABLES

Property/failure mode	Dominant constituent	Factors affecting Properties
Out-of-plane strength		
Interlaminar shear	Matrix	**Elevated temperatures**
Interlaminar tension	Matrix	**Moisture content**
Free-edge failure	Matrix	**Chemical exposure**

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ALLOWABLES

Property/failure mode	Dominant constituent	Factors affecting Properties
Durability/damage tolerance		
Notched tension and compression	Interface	**Elevated temperatures**
Compression after impact	Matrix/interface	**Moisture content**
Fatigue	Matrix	**Load history**
Creep	Matrix	**Elevated temperatures**

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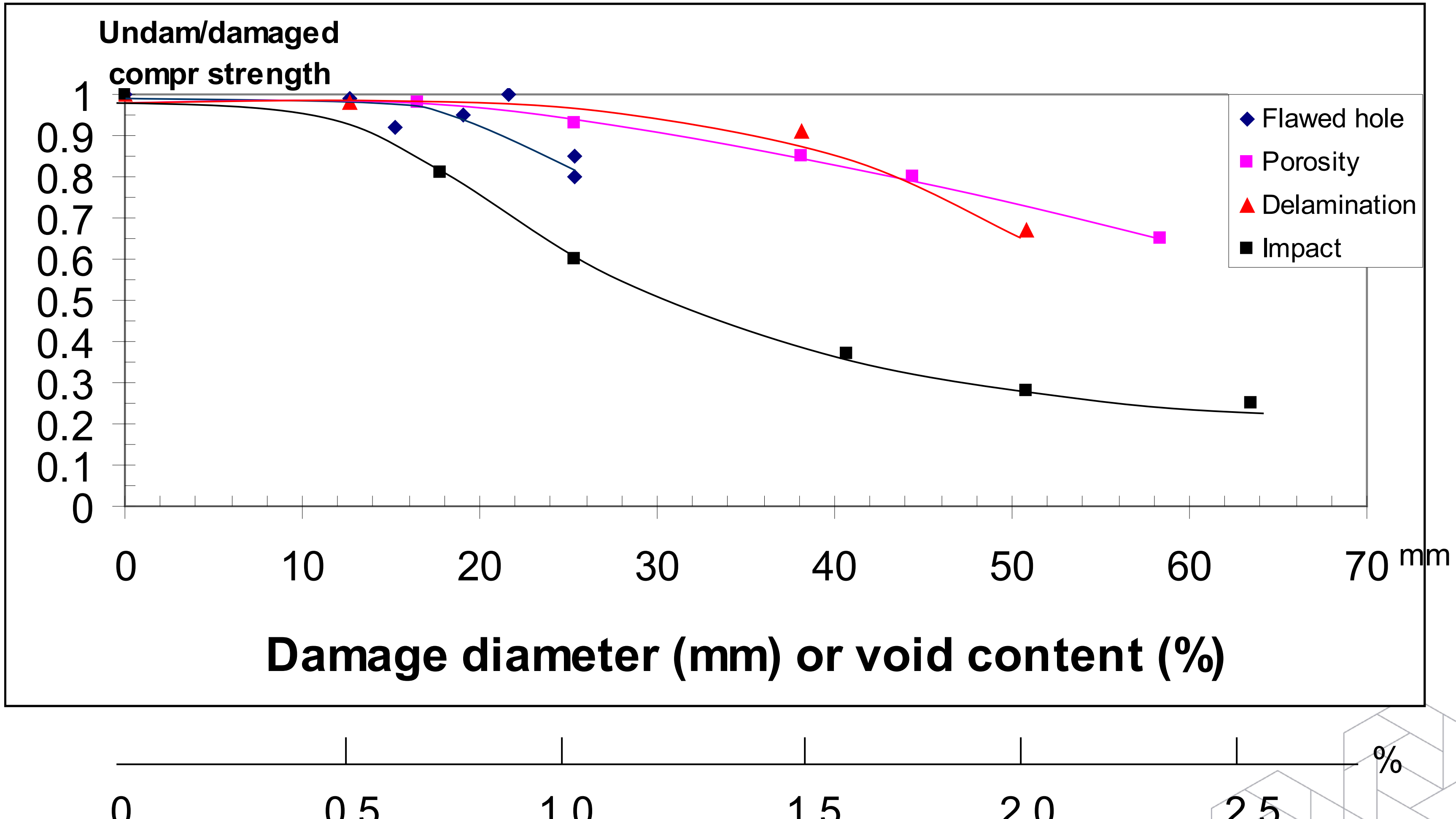
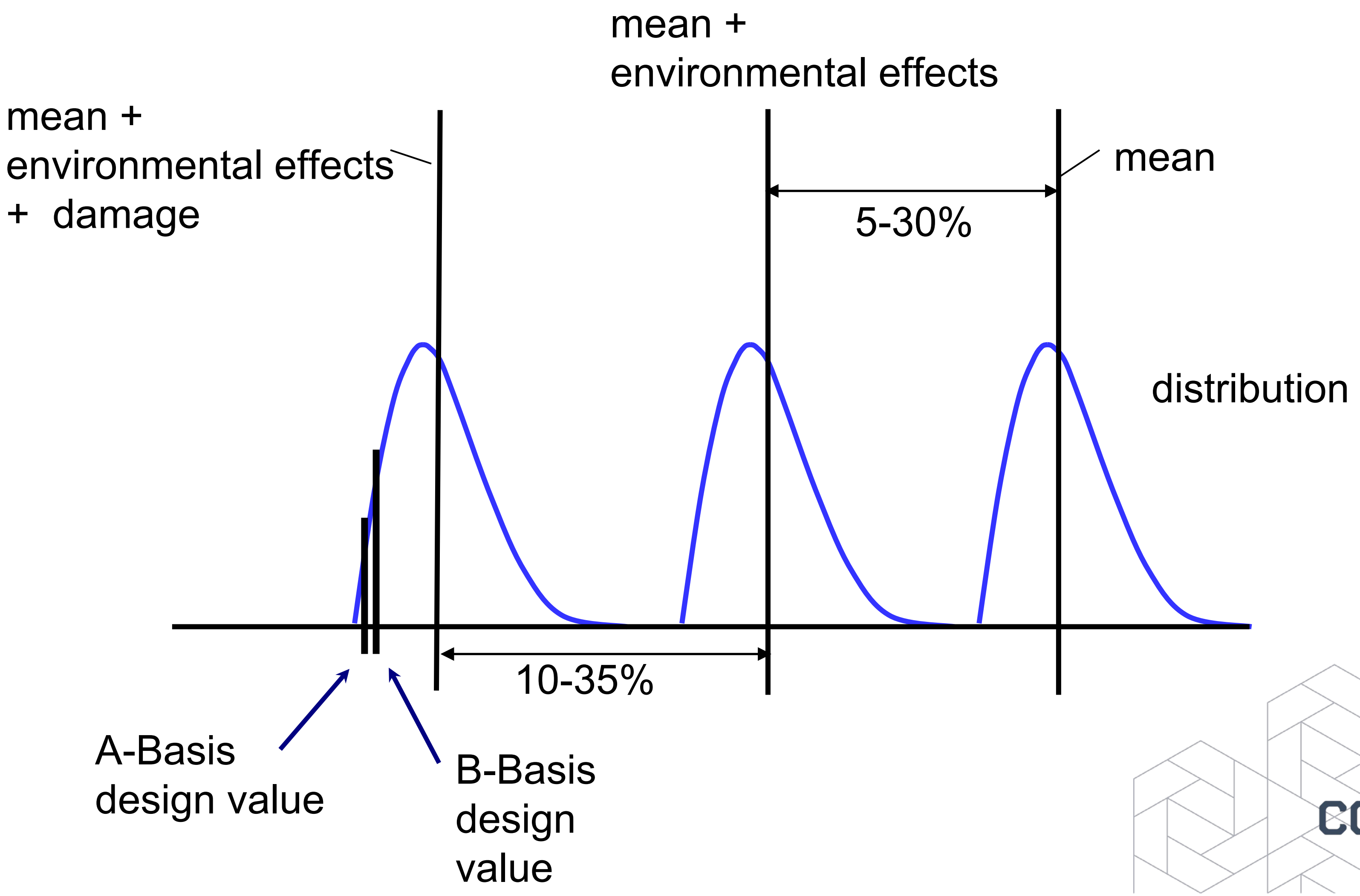
Compression loading[1]



(1) Whitehead, R.S., "Lessons Learned for Composite Structures", Proc First NASA Advanced Composites Technology Conference, Seattle WA, 1990, pp 399-415

DESIGN VALUES



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Limit strains (or stresses)

Combine effects for material scatter, environment, and damage

Mean undamaged failure strain (compression) 1.1 % strain

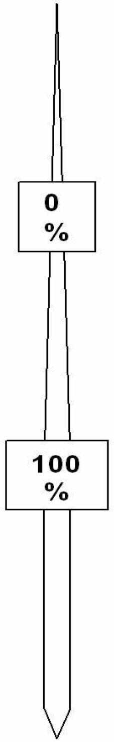
Knockdown source	Knockdown fraction
Environment	0.8
Damage (BVID)	0.65
Material scatter	0.8

Limit strain = 1.1 x 0.8 x 0.65 x 0.8 =0.45 % strain

Traditional safe design strain is 0.3 %

FIBRES & RESINS:

VOLUME, ARCHITECTURE AND HANDLING

fibre content	orientation control	fibre length	manufacturing processes	applications
Vf [%]		L [mm]	thermo sets / thermo plastics	
25%		$L_{crit} < L < 10$	injection moulding pressing	**small detailed parts** (housings and brackets)
		$10 < L < 100$	thermo sets: injection moulding, RTM; thermo plastics: SRIM; pressing: BMC/SMC, GMT	**beams and shell structures** (car body parts)
40%		$L \rightarrow \infty$	laminating, tapelaying, filament winding, RTM (vari), pressing, diaphragm forming	**large plate and shell structures** (aerospace) (packaging / pressure vessels) (ship building / civil engineering); **small plate and shell structures** (aerospace)
70%		$L \rightarrow \infty$	pultrusions	**profiled beams** (civil engineering)

RTM: Resin Transfer Moulding
BMC: Bulk Moulding Compound
VARI: Vacuum Assisted Resin Infusion
SMC: Sheet Moulding Compound
SRIM: Structural Reaction Injection Moulding
GMT: Glass Mat reinforced Thermoplastic

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TASKS & CALCULATIONS ON DESIGN

Mechanical behaviour of composites

Composites are anisotropic inhomogeneous materials. The morphologies may vary to a large extent due to variation of matrix, fibres, fibre length….Consequently, mechanical behaviour is more complex than for other materials.

The mechanical behaviour of composites is described in many books. The focus is different per book.

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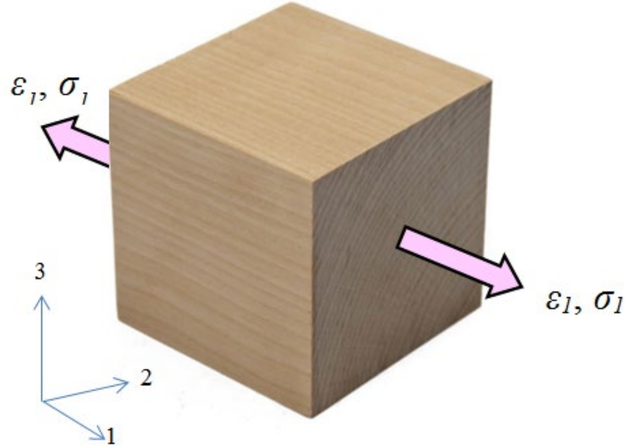
ISOTROPIC VERSUS ANISOTROPIC

- <u>Isotropic materials</u>: identical(mechanical) properties in all directions

  - Same stiffness constant for all loading directions
  - $\sigma = E\,\varepsilon$, E [N/m^2 or MPa] is modulus of elasticity

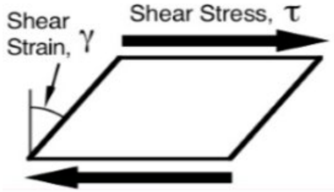
- <u>Anisotropic materials</u>: direction dependent stiffness



  - $\sigma_1 = E_{11}\,\varepsilon_1$ if loaded in 1 direction
  - In general:

$$\sigma_1 = C_{11}\varepsilon_1 + C_{12}\varepsilon_2 + C_{13}\varepsilon_3 + C_{14}\varepsilon_4 + C_{15}\varepsilon_5 + C_{16}\varepsilon_6$$

  - ε_4 ε_5 and ε_6 are the <u>shear</u> strains ($\varepsilon_4 = \gamma_{23}$, $\varepsilon_5 = \gamma_{31}$, $\varepsilon_6 = \gamma_{12}$)



<u>NB</u>: sometimes ε_{ij} is used instead of γ_{ij}

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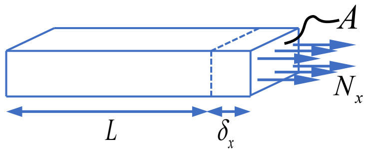
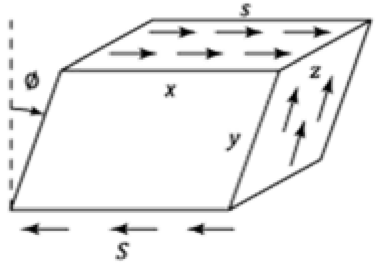
THE LOADS ON ISOTROPIC BEAMS

$$N_x = \frac{AE}{L}\delta_x = AE\varepsilon_x \quad per\ width: \frac{N_x}{width} = N'_x = \frac{AE}{width}\varepsilon_x = tE\varepsilon_x$$



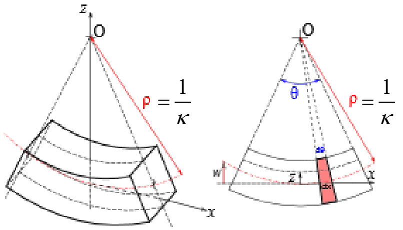
$$N_y = \frac{AE}{L}\delta_y = AE\varepsilon_y \quad per\ width: \frac{N_y}{width} = N'_y = \frac{AE}{width}\varepsilon_y = tE\varepsilon_y$$

$$N_{xy} = A\tau_{xy} = AG\gamma_{xy} \quad per\ width: \frac{N_{xy}}{width} = N'_{xy} = \frac{AG}{width}\gamma_{xy} = tG\gamma_{xy}$$

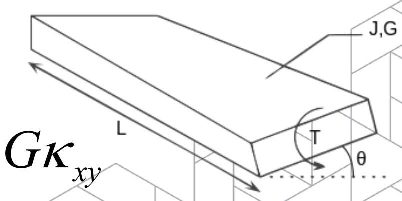


$$M_x = EI\frac{1}{\rho_x} = EI\kappa_x \quad per\ width: \frac{M_x}{width} = M'_x = \frac{EI}{width}\kappa_x = \frac{1}{12}t^3E\kappa_x$$

$$M_y = EI\frac{1}{\rho_y} = EI\kappa_y \quad per\ width: \frac{M_y}{width} = M'_y = \frac{EI}{width}\kappa_y = \frac{1}{12}t^3E\kappa_y$$



$$M_{xy} = \frac{GJ}{L}\theta_{xy} = GJ\kappa_{xy} \quad per\ width: \frac{M_{xy}}{width} = M'_{xy} = \frac{GJ}{width}\kappa_{xy} = \sqrt{2}t^3G\kappa_{xy}$$



THE LOADS ON ISOTROPIC PLATES

$$\sigma_x = \frac{E}{1-\upsilon^2}\varepsilon_x + \frac{\upsilon E}{1-\upsilon^2}\varepsilon_y$$

$$\sigma_y = \frac{E}{1-\upsilon^2}\varepsilon_y + \frac{\upsilon E}{1-\upsilon^2}\varepsilon_x$$

$$\tau_{xy} = G\gamma_{xy} = \frac{E}{2(1+\upsilon)}\gamma_{xy}$$

$$N_x^{'} = \sigma_x t = t\frac{E}{1-\upsilon^2}\varepsilon_x + t\frac{\upsilon E}{1-\upsilon^2}\varepsilon_y = C_{xx}^{normal} tE\varepsilon_x + C_{xy}^{normal} tE\varepsilon_y$$

$$Plate: \; N_x^{'} = C_{xx}^{normal} tE\varepsilon_x + C_{xy}^{normal} tE\varepsilon_y$$

$$Beam: \; N_x^{'} = tE\varepsilon_x$$

$$For\ moments\ it\ is\ similar: \quad M_x^{'} = C_{xx}^{bending} t^3 E\kappa_x + C_{xy}^{bending} t^3 E\kappa_y$$

THE LOADS ON ISOTROPIC PLATES

$$N_x^{'} = C_{xx}^{normal} tE\varepsilon_x + C_{xy}^{normal} tE\varepsilon_y$$

$$N_y^{'} = C_{yy}^{normal} tE\varepsilon_y + C_{yx}^{normal} tE\varepsilon_x$$

$$N_{xy}^{'} = C_{xy}^{shear} tG\gamma_{xy}$$

$$M_x^{'} = C_{xx}^{bending} t^3 E\kappa_x + C_{xy}^{bending} t^3 E\kappa_y$$

$$M_y^{'} = C_{yy}^{bending} t^3 E\kappa_y + C_{yx}^{bending} t^3 E\kappa_x$$

$$M_{xy}^{'} = C_{xy}^{torsion} t^3 G\kappa_{xy}$$

THE LOADS ON ISOTROPIC PLATES IN MATRIX NOTATION

$$\begin{pmatrix} N'_x \\ N'_y \\ N'_{xy} \\ M'_x \\ M'_y \\ M'_{xy} \end{pmatrix} = \begin{pmatrix} C_{xx}^{normal} tE & C_{xy}^{normal} tE & 0 & 0 & 0 & 0 \\ C_{yx}^{normal} tE & C_{yy}^{normal} tE & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{xy}^{shear} tG & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{xx}^{bending} t^3 E & C_{xy}^{bending} t^3 E & 0 \\ 0 & 0 & 0 & C_{yx}^{bending} t^3 E & C_{yy}^{bending} t^3 E & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{xy}^{torsion} t^3 G \end{pmatrix} \begin{pmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \\ \kappa_x \\ \kappa_y \\ \kappa_{xy} \end{pmatrix}$$

How does this look like for **anisotropic** plates?

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THE ABD MATRIX FROM CLT

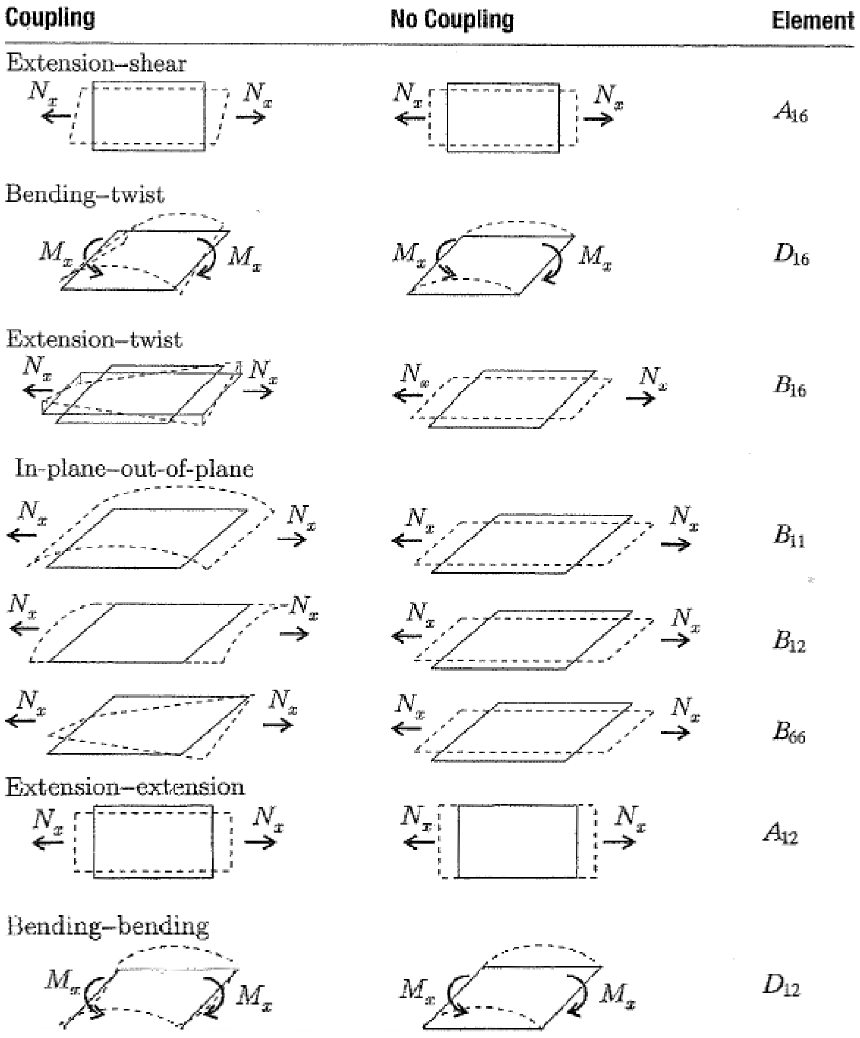
Response of a laminate under loading

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ \chi_x \\ \chi_y \\ \chi_{xy} \end{Bmatrix}$$

$$[A] = \int_{h_b}^{h_t} [\overline{Q}]\, dz \Rightarrow A_{ij} = \sum_{k=1}^{K} (\overline{Q}_{ij})_k (z_k - z_{k-1})$$

$$[B] = \int_{h_b}^{h_t} z [\overline{Q}]\, dz \Rightarrow B_{ij} = \frac{1}{2} \sum_{k=1}^{K} (\overline{Q}_{ij})_k (z_k^2 - z_{k-1}^2)$$

$$[D] = \int_{h_b}^{h_t} z^2 [\overline{Q}]\, dz \Rightarrow D_{ij} = \frac{1}{3} \sum_{k=1}^{K} (\overline{Q}_{ij})_k (z_k^3 - z_{k-1}^3)$$



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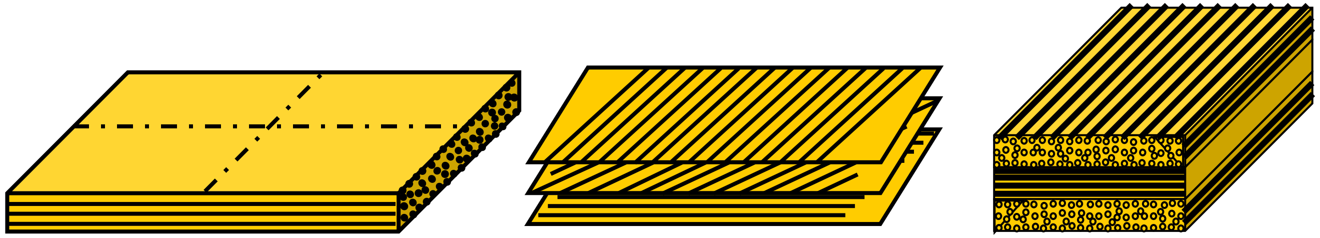
COMPOSITE LAMINATES

- Composite plates are usually made by stacking a series of oriented unidirectional layers (plies)



- These plies are about 0.1 – 0.2 mm thick
  - A stack of 10 layers (a laminate) is still very thin!
- Plies are very stiff along their fiber direction
  - Perfect opportunity to design properties of our laminate plate

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LAMINATE STACKING EFFECTS ON ABD

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ \chi_x \\ \chi_y \\ \chi_{xy} \end{Bmatrix}$$

- Symmetric $[23,23]_s$ (Off axis)
  - A_{16} & A_{26} are not zero, in-plane normal and shear coupling
  - D_{16} & D_{26} are not zero, bending torsion coupling
  - B matrix is zero, no in-plane out-of-plane coupling
- Balanced [23,-23,44,-23,23,-44]
  - A_{16} & A_{26} are zero, no in-plane normal and shear coupling
  - D_{16} & D_{26} are not zero, coupling bending torsion
  - B matrix is not zero, in-plane out-of-plane coupling
- Symmetric & balanced (symmetric angleply) $[90,0,-45,+45]_s$
  - A_{16} & A_{26} are zero, no in-plane normal and shear coupling
  - D_{16} & D_{26} are not zero, coupling bending torsion
  - B matrix is zero

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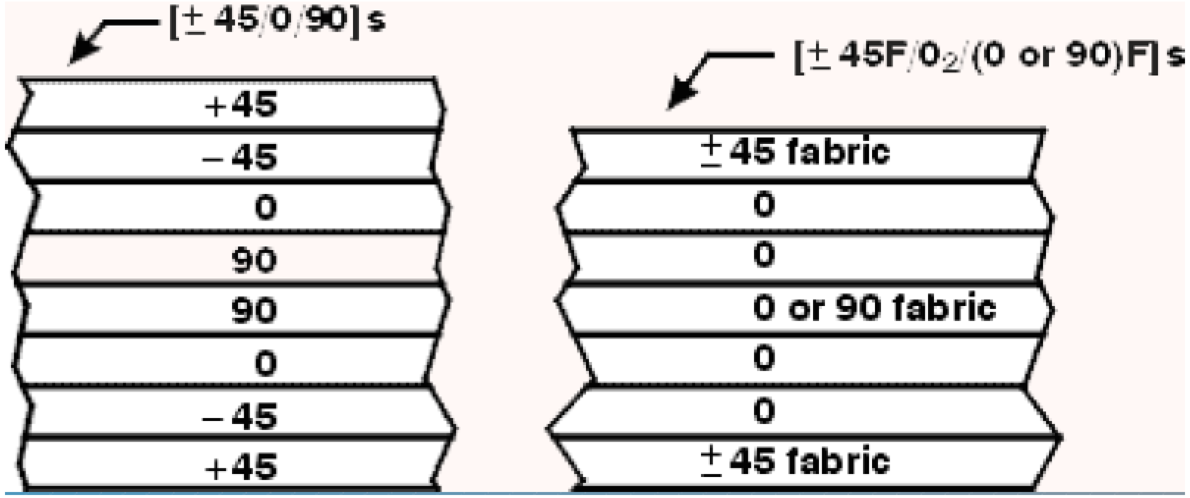
LAMINATE STACKING EFFECTS ON ABD

$$\begin{Bmatrix} N_x \\ N_y \\ N_{xy} \\ M_x \\ M_y \\ M_{xy} \end{Bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} & B_{11} & B_{12} & B_{16} \\ A_{12} & A_{22} & A_{26} & B_{12} & B_{22} & B_{26} \\ A_{16} & A_{26} & A_{66} & B_{16} & B_{26} & B_{66} \\ B_{11} & B_{12} & B_{16} & D_{11} & D_{12} & D_{16} \\ B_{12} & B_{22} & B_{26} & D_{12} & D_{22} & D_{26} \\ B_{16} & B_{26} & B_{66} & D_{16} & D_{26} & D_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_x^0 \\ \varepsilon_y^0 \\ \gamma_{xy}^0 \\ \chi_x \\ \chi_y \\ \chi_{xy} \end{Bmatrix}$$

- Anti symmetric (anti symmetric angleply) [23,-23,44,-44,23,-23]
  - A_{16} & A_{26} are zero
  - D_{16} & D_{26} are zero,
  - B matrix is not zero
- Special Balanced [+44,-44,90,-44,+44, -44,+44,90,+44,-44]
  (antisymmetric with a symmetric & balanced top half and symmetric & balanced bottom half)
- Symmetric & balanced & crossply [0,90,90,0] ([0,90,0_n,90,0])
  - A_{16} & A_{26} are zero
  - D_{16} & D_{26} are zero
  - B matrix is zero

LAMINATE STACK CODING



- Brackets [] with angles separated by '/'
- Always start at bottom (mould side)
- Subscript "S" for mirror symmetry: [0/90/90/0] = $[0/90]_S$
- N-repeated layers with subsript "N": $[0/0/45/-45]_S=[0_2/\pm45]_S$
- ±45 means 45/-45, ∓ 30 is -30/30
- "F" is used for Fabric layer: $[\pm45F/0_2/90F]_S$

The warp direction of the fabric is the 0 direction.
The fact that a fabric has a top and bottom side is not reflected!

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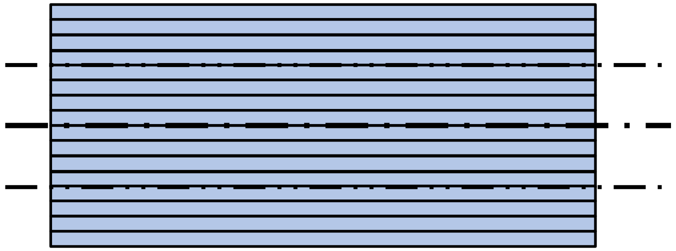
LAMINATE GUIDELINES

- Anti symmetric & Special balanced
  - A_{16} & A_{26} & D_{16} & D_{26} & B are zero
  - Example [0,+45,-45,90,-45,+45,0,-45,+45,90,+45,-45,0]



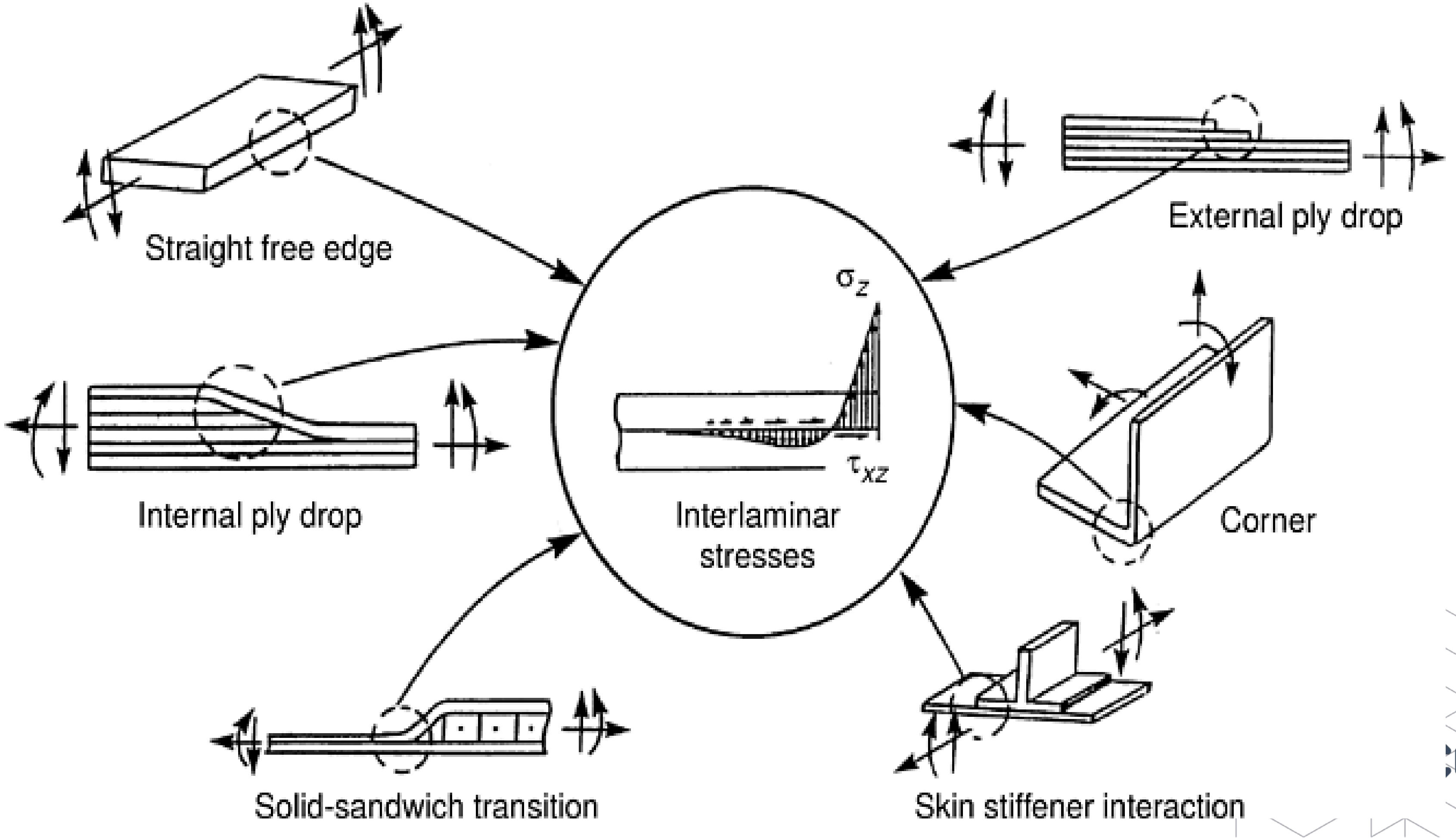
- Anti symmetric & Special balanced
  - General [$[..]_{BS}$,$[..]_{BS}$ $]_{AS}$ BS=Balanced & symmetrical AS = Anti Symmetrical
  - [+18,-18,-18,+18, -18,+18,+18,-18]
  - You need many layers.
  - [0,-60,+60,+60,-60,0] is quasi isotropic (A matrix (=in-plane), not D matrix).
  - [0,-60,+60,+60,-60,0, 0,+60,-60,-60,+60,0] is quasi isotropic (A and D matrix).

DIFFERENCE WITH METALLIC STRUCTURES

- Which loads are not wanted in metallic structures?
  - Often alternating loads as they lead to fatigue cracks

- Which loads are not wanted in composite structures?
  - Loads leading to stresses in the matrix material
  - Interlaminar stresses
  - Peel stresses
  - Lead to delaminations (the weak matrix material)

DELAMINATION SOURCES AT GEOMETRIC AND MATERIAL DISCONTINUITIES



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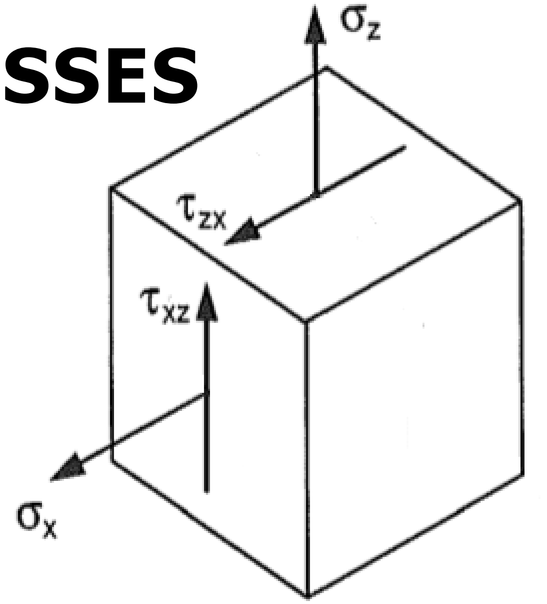
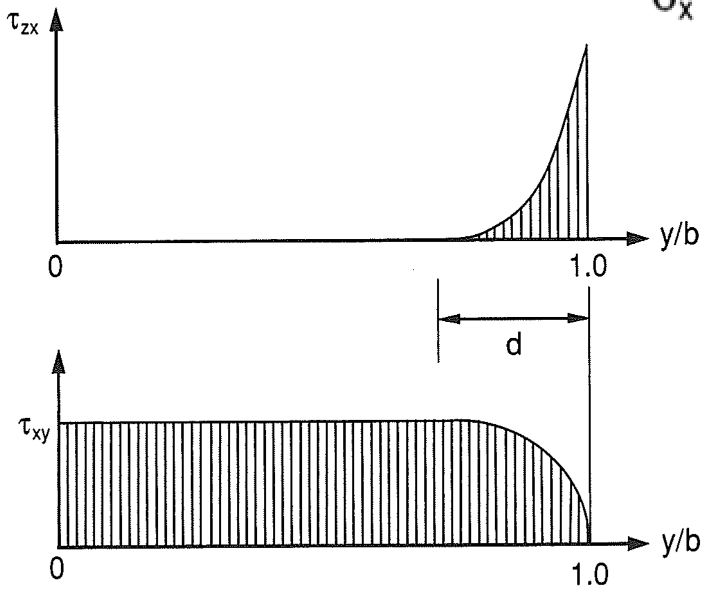
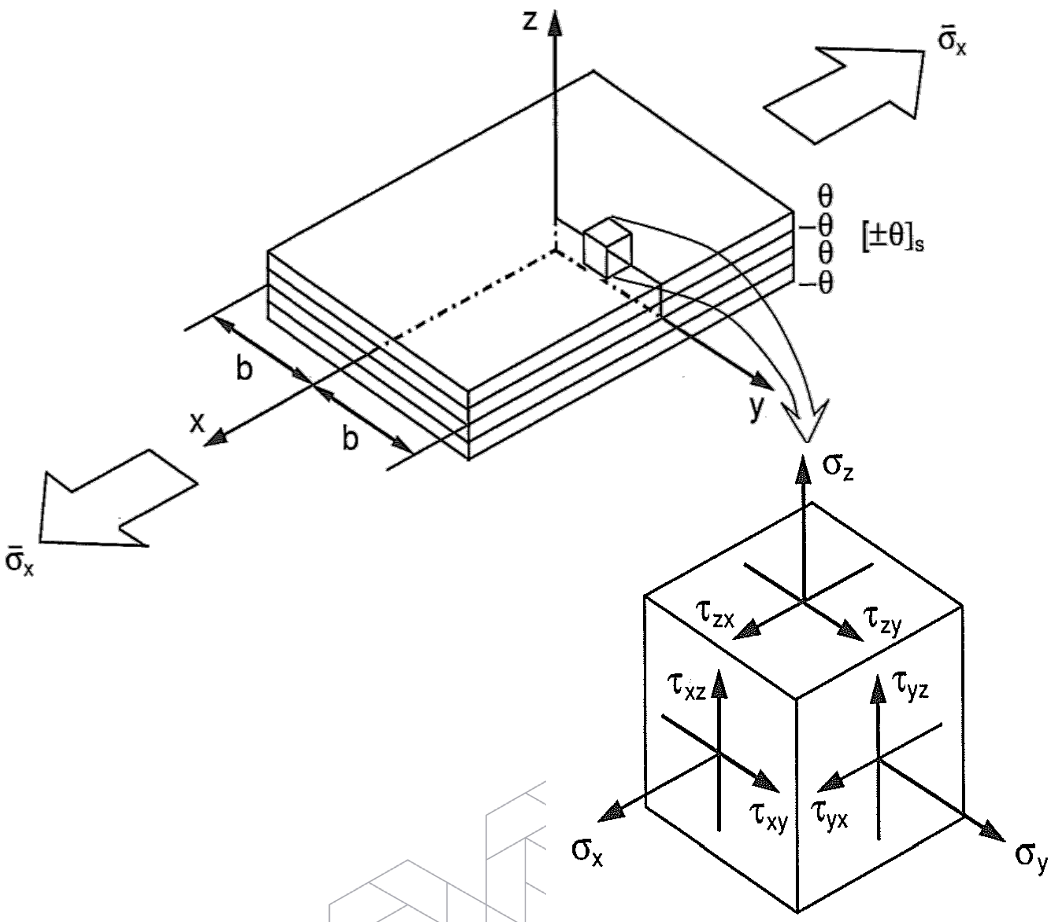
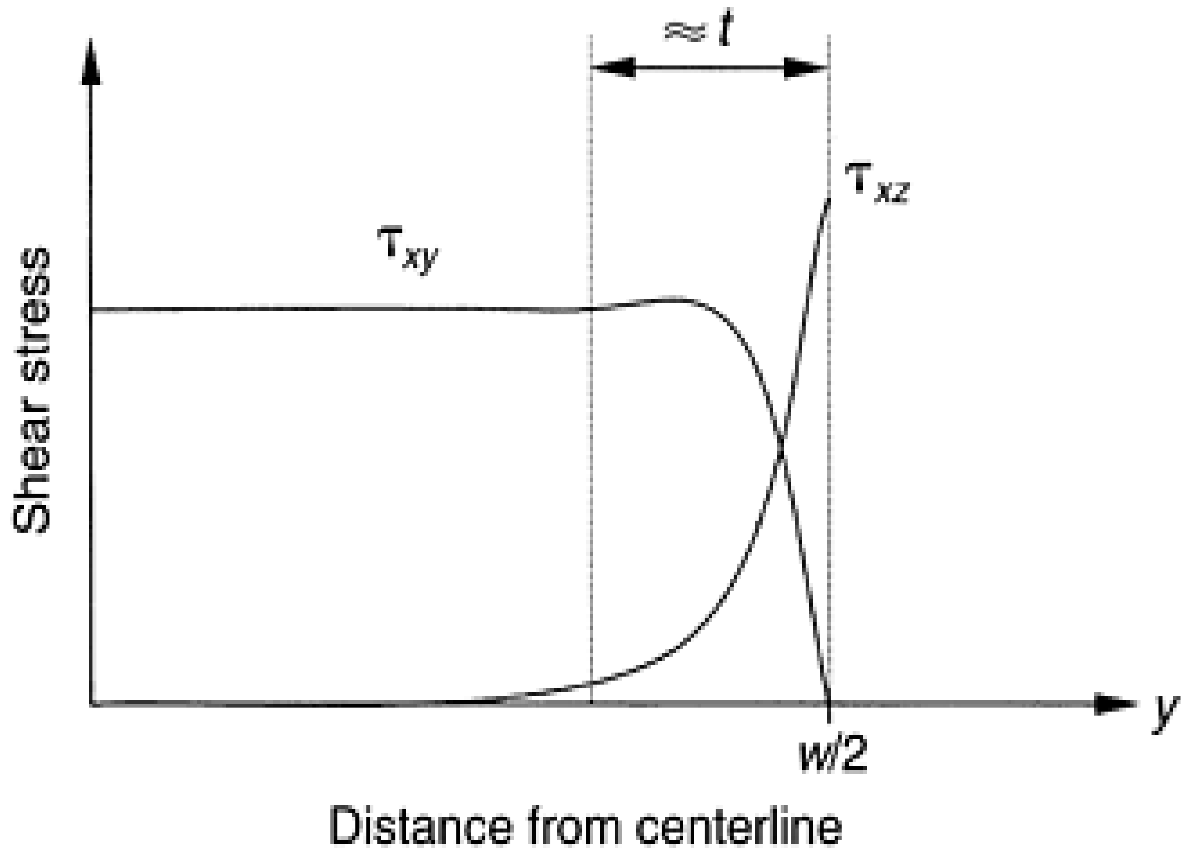
FREE EDGE STRESSES







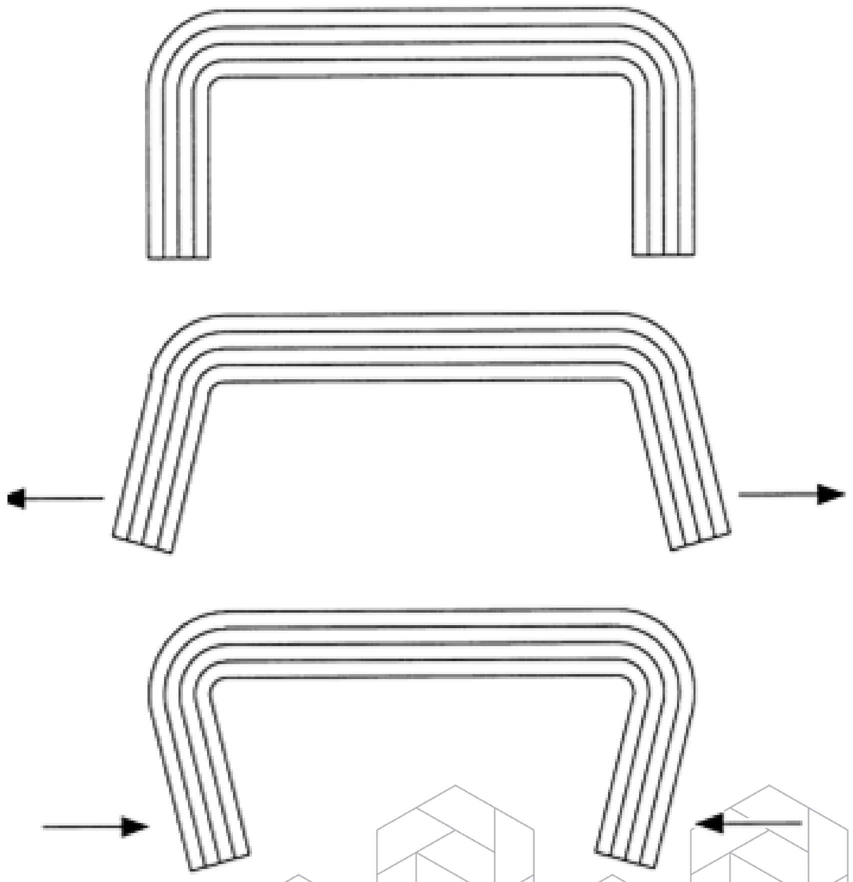
Distribution of shear stresses across the width of a laminate. Free-edge stress distribution is limited to a region approximately one laminate thickness wide.



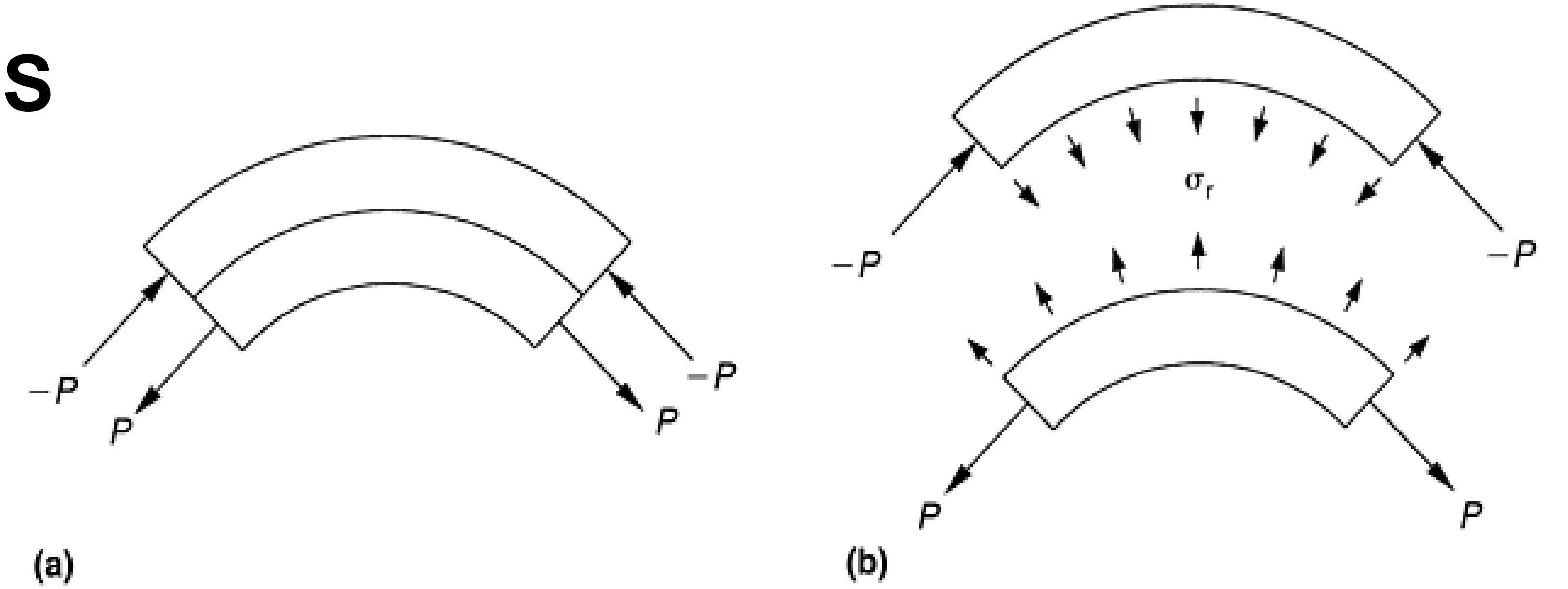
STRESSES

A curved laminate "C" channel in various loading conditions.

- Radii open under tensile load.
- Radii close under compressive load



PEEL STRESS

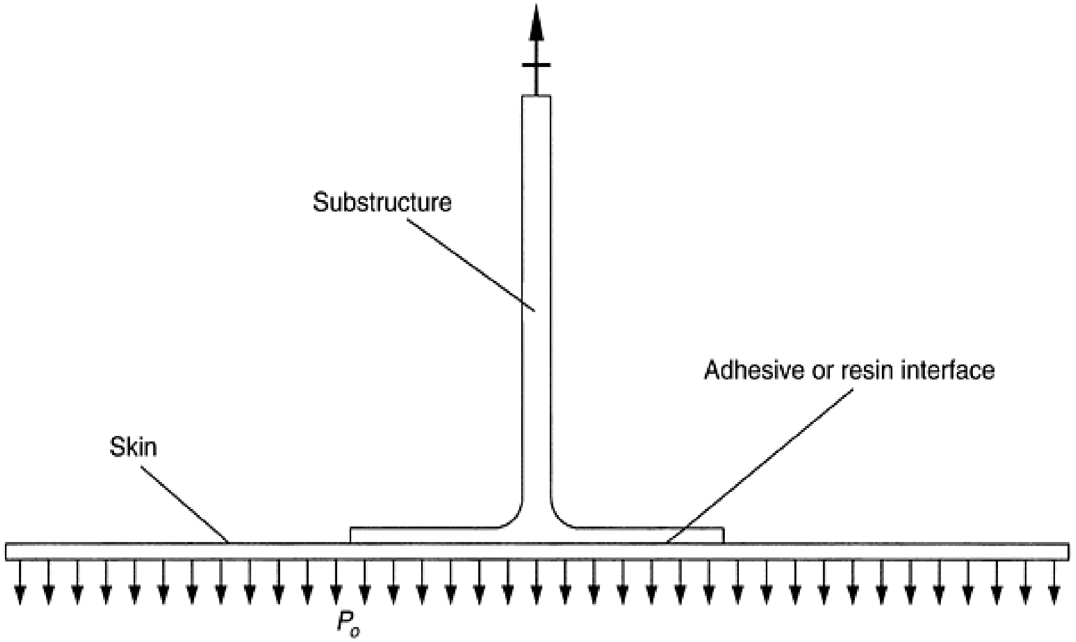


Development of radial stresses in a curved laminate.

- (a) The force couples (−*P*, +*P*) act on the curved laminate.
- (b) The radial stresses (σ_r) must balance the vertical components of these loads.

PEEL STRESS

- Transfer of pressure loads on the skin through the substructure



Van Tooren
- Extra 400 how?

LAMINATE GUIDELINES

10% Rule

- **most engineering laminates do not qualify as "specially orthotropic"**
- **Similar behaviour when:**
  - There are at least 3 ply orientations (no matrix dominated direction)
  - The angles between the fibers are at least 15 degrees
  - The number of plies in each fiber direction is at least 10% of the total number of plies
- **For unsymmetrical lay-ups: Define reduced bending stiffness as:**

$$\tilde{D} = D - B^T A^{-1} B$$

- N.B. Good for bending, but for buckling has to be used with caution

LAMINATE GUIDELINES

- Homogeneous with a preferred increased performance direction
- Small orientation difference between adjacent layers
- Do not group identical layers
- Prefer orthotropy ($A_{16}=A_{26}=0$)
- Avoid free edges
- Reduce interlaminar shear stresses by proper angular differences
- Thick laminates: outer layer: 90° w.r.t. the main tension direction
- Always assess individual layer strains and stresses

LAMINATE GUIDELINES

- Thin layers are better than thick layers
- Build laminate in such a way that out of plane edge stresses are compressive
- Be careful with bearing stresses (metal bus insert)
- Avoid plydrops on the outside
- Drop plies near the middle, if possible in a symmetric way
- Limit to dropped thickness to 0.5 mm in on step
- Keep the minimal distance for the next plydrop ten times the drop thickness.

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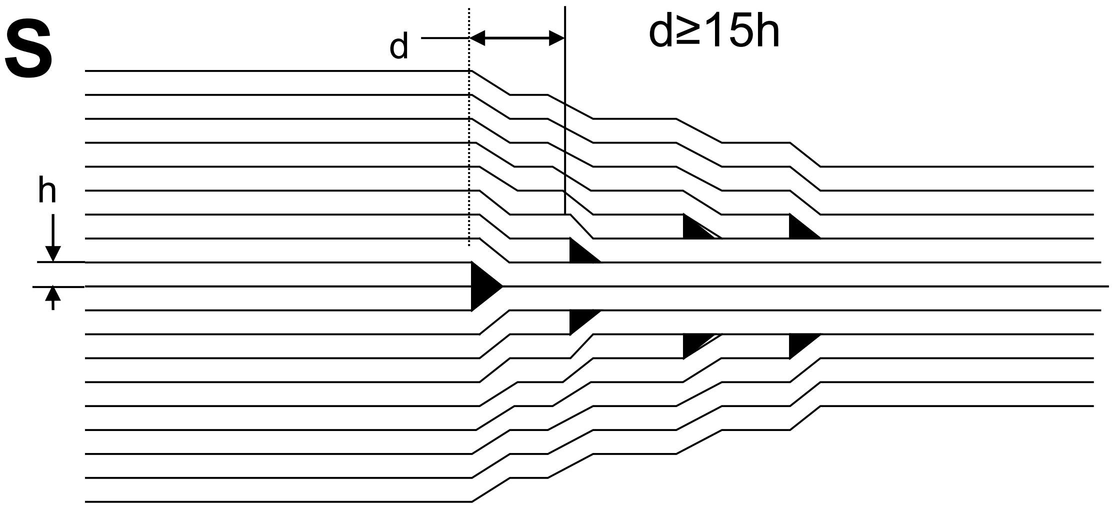
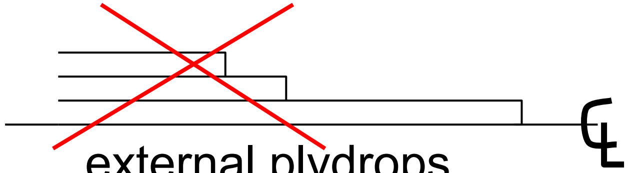
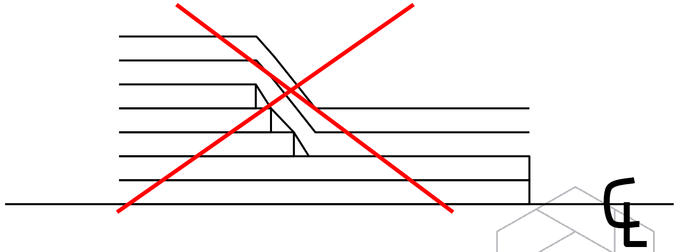
PLYDROP RULES



Good design



external plydrops



adjacent plydrops too close to each other

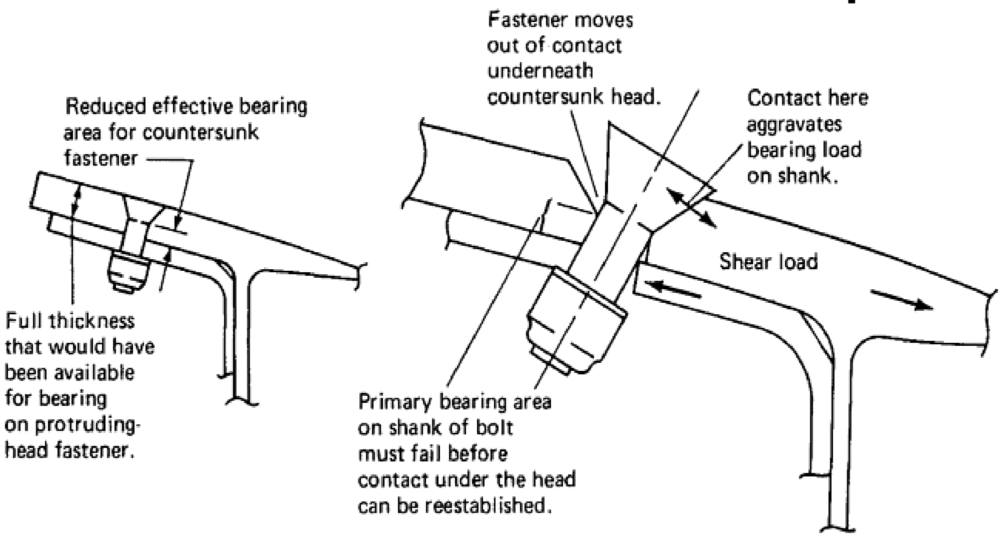
too many plydrops at same location

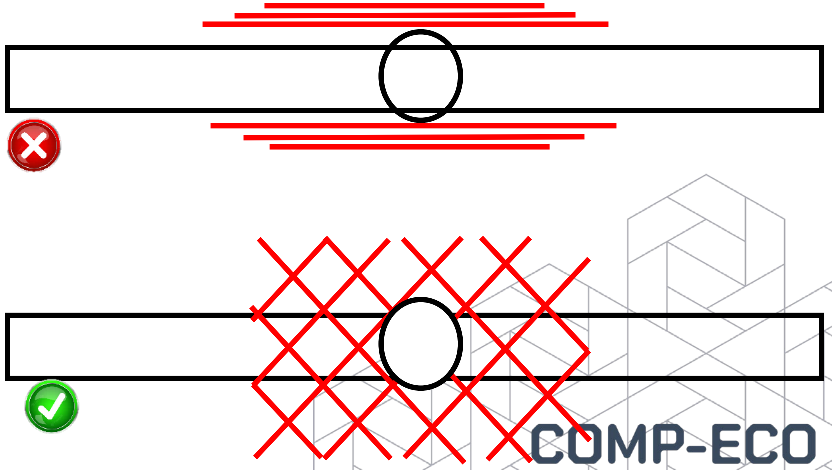
LOCAL REINFORCEMENT NEAR HOLES

Orientation

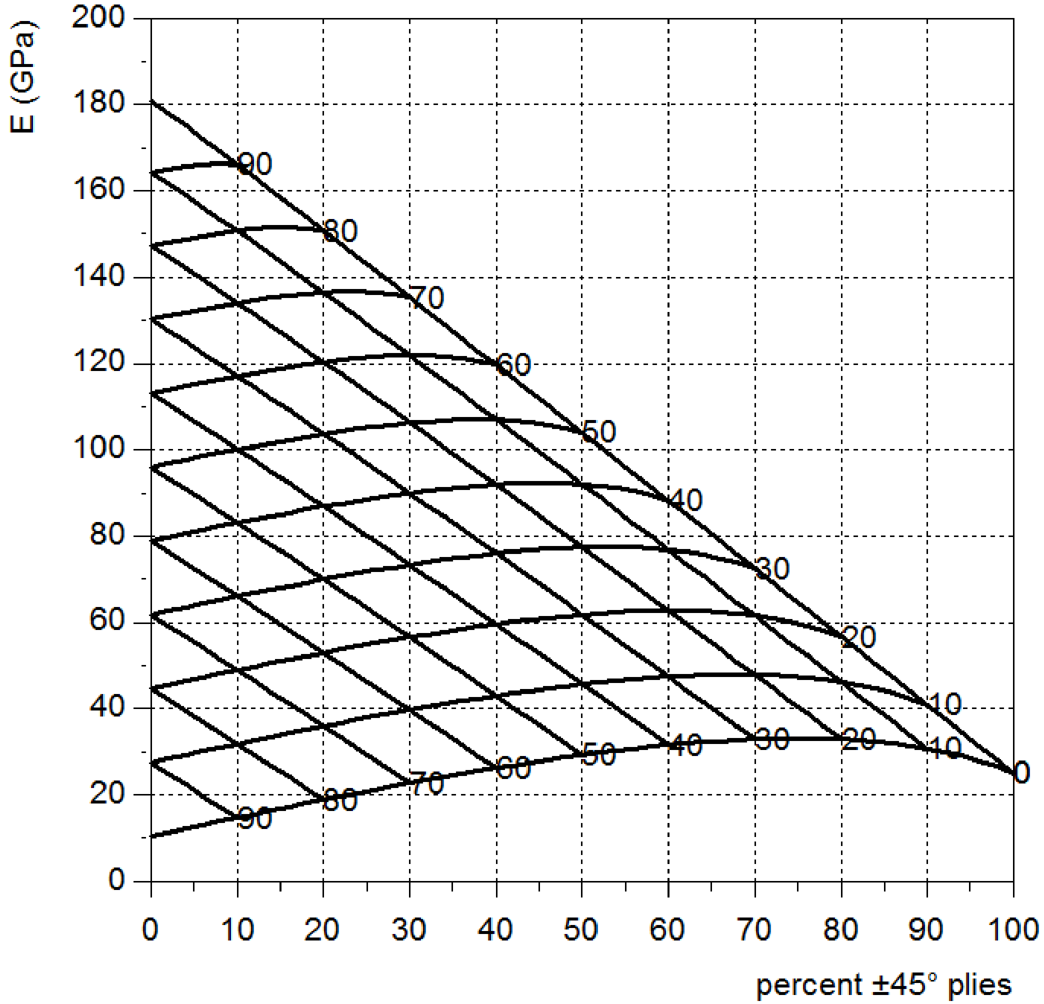
- ± 45° layers to spread load over more material
- tangential reinforcement
- no extra UD: attracts stresses

- Limit countersunk depth to 1/3 of laminate thickness





EXAMPLE LAMINATE DESIGN SPACE



10% rule ?

Design space includes a variety of variables, including lay-up, thickness, temperature, and other design or environmental effects.

L.J. HART-SMITH, THE BOEING COMPANY; R.B. HESLEHURST, AUSTRALIAN DEFENCE FORCE ACADEMY

Some technical and managerial lessons learned include

the following:

- Don't design for primary loads being transferred by interlaminar shear; also, avoid secondary induced interlaminar loads.
- Do plan the tooling and manufacturing approach during the preliminary design phase to ensure that all three are compatible. Don't complete the design in isolation and then worry afterward about how to build it at a specified production rate.
  (Part of what we call the trinity principle)

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CONTINUED

- Don't begin the formal design drawings until after the first part has been completed. Do the drawings last to ensure that they are in conformity with the part.
- Don't trust computer strength analysis or optimization programs that advocate the use of highly orthotropic fiber patterns.
- Don't design the basic structure first and the joints last—design the joints first, to maximize the structural efficiency, and fill in the gaps in between afterward.
- Do not adhere blindly to original plans when difficulties arise. If three cure cycles are needed to manufacture a design that was supposed to be made in one shot, it is time to change to a different optimal design for two- stage manufacture.

CONTINUED

- Do understand the reasons behind historical precedents before following them in the future. What is optimal for one set of circumstances is often quite unsuitable for others.
- Don't be a slave to fashion. Understand the merits and limitations of past design and manufacturing techniques thoroughly before deciding on an approach for some given application.
- Don't treat repairability and damage tolerance as afterthoughts once the static ultimate- strength design has been accomplished. All conditions need to be treated simultaneously.

CONTINUED

- Don't complicate designs by seeking the last ounce of weight saving. Doing so will add unreasonably to the design and manufacturing costs.
- Don't ever design an adhesive bond to be the weak link in a structure. The bonds should always be stronger than the members being joined.
- Do be wary of induced peel stresses, both in adhesive layers and in the composite laminates.
- Do remember to allow for expansion and contraction of the tools and composite material at different times during the cure cycle.
- and many more

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PRODUCT COSTS

Cost build up is a trade secret of companies, so not shared

- Material cost is often a small part of the product cost
  - Prepreg is more expensive than reinforcement and resin.
  - Weaves are more expensive than UD material.
  - Carbon is more expensive than glass.
  - Composite material is more expensive than metal (bulk cost)
- Production cost:
  - Equipment cost
  - Manufacturing time (Man hours)
    - Cutting of reinforcement
    - Lay up actions of reinforcement (Kg/min)
  - Finishing operations
- Lead time of process is relative long.

IS YOUR DESIGN STIFFNESS OF STRENGTH BASED?

- Design for stiffness versus design for strength

Think about what happens if the structure becomes overloaded

Does it crack and fail? ……..Strength design

Does it stop functioning, too large deflections? ……..Stiffness design

What is preferred?

Stiffness design, as it gives a change to recover……

HOW TO IMPLEMENT THIS KNOWLEDGE?

- Take a problem/challenge where you might want to apply composites
- Make clear which requirements there are with respect to loads.
- Make clear which other requirements there are.
- Sketch a design solution and show the points of attention, especially the ones discussed in this workshop

- Extra: think about repairability and how that might influence your design solution?

COMP-ECO