

NEiNastran

Finite Element Analysis of Composites

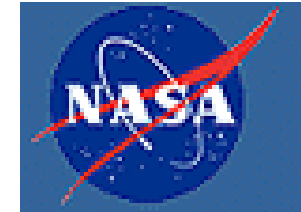
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Customer Driven Solutions

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Some Composites-Focused Customers



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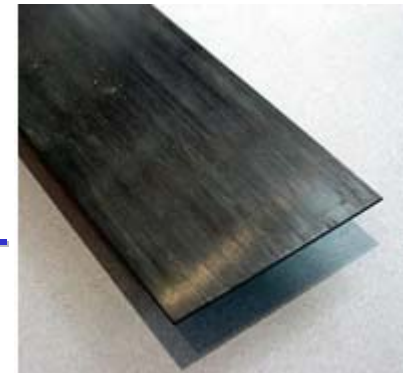
Material Definitions

ISOTROPIC - the same material properties in all directions, steel is a typical example.



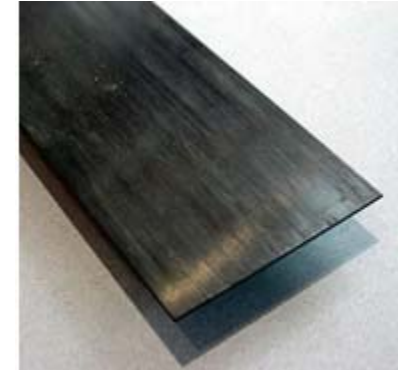
ANISOTROPIC - different material properties in all directions, a chunk of volcanic rock is an example.

ORTHOTROPIC – special case of anisotropic , clear material directionality in 3 directions – represents a carbon fiber/resin matrix for example, where the along axis, transverse axis and through thickness axis are different.



Material Definitions

2D ORTHOTROPIC, A further simplification is where we ignore the through thickness variation. This is the usual starting point for what we call **Classical laminate Theory**, the foundation of most FE solutions.



(a) Plane strain - Thick bodies

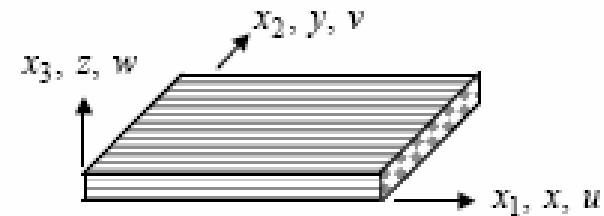
$$\epsilon_z = \gamma_{xz} = \gamma_{yz} = 0$$

$$\therefore \tau_{xz} = \tau_{yz} = 0$$

(b) Plane Stress - Thin bodies

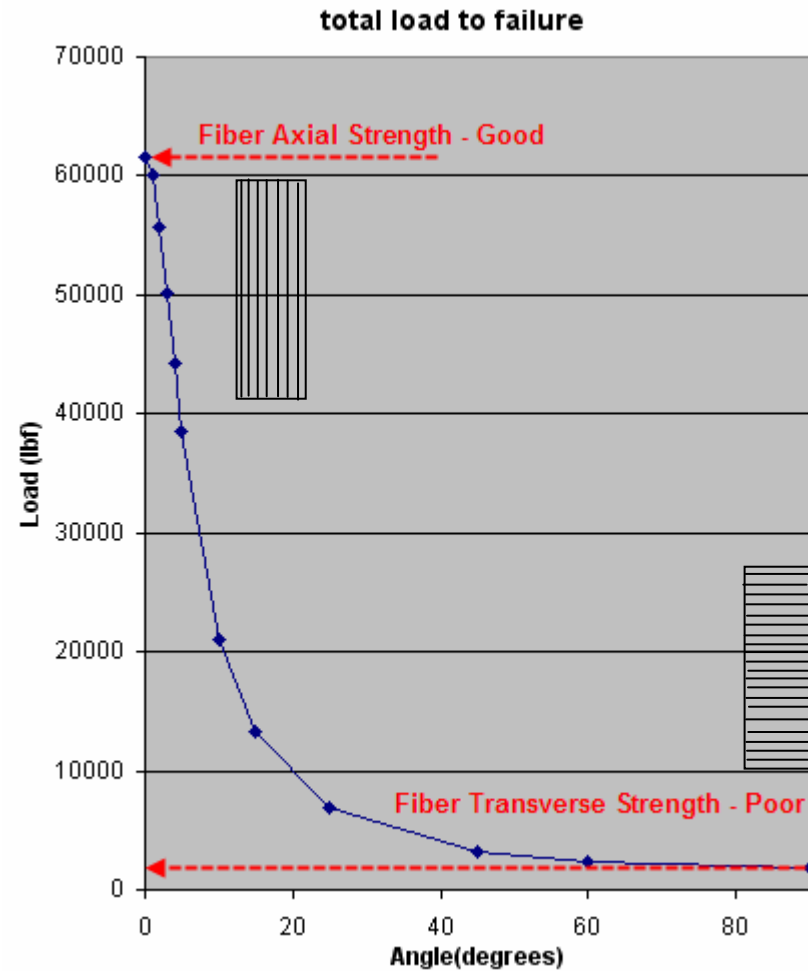
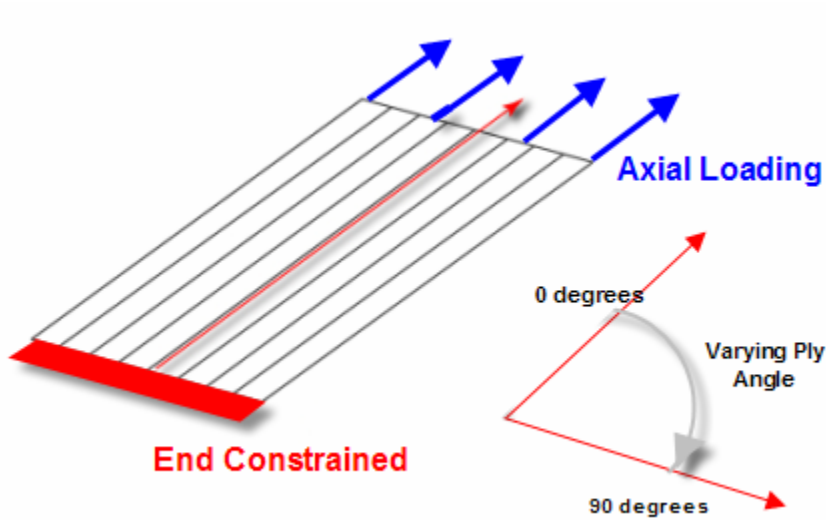
$$\sigma_z = \tau_{xz} = \tau_{yz} = 0$$

$$\therefore \epsilon_z = \gamma_{xz} = \gamma_{yz} = 0$$

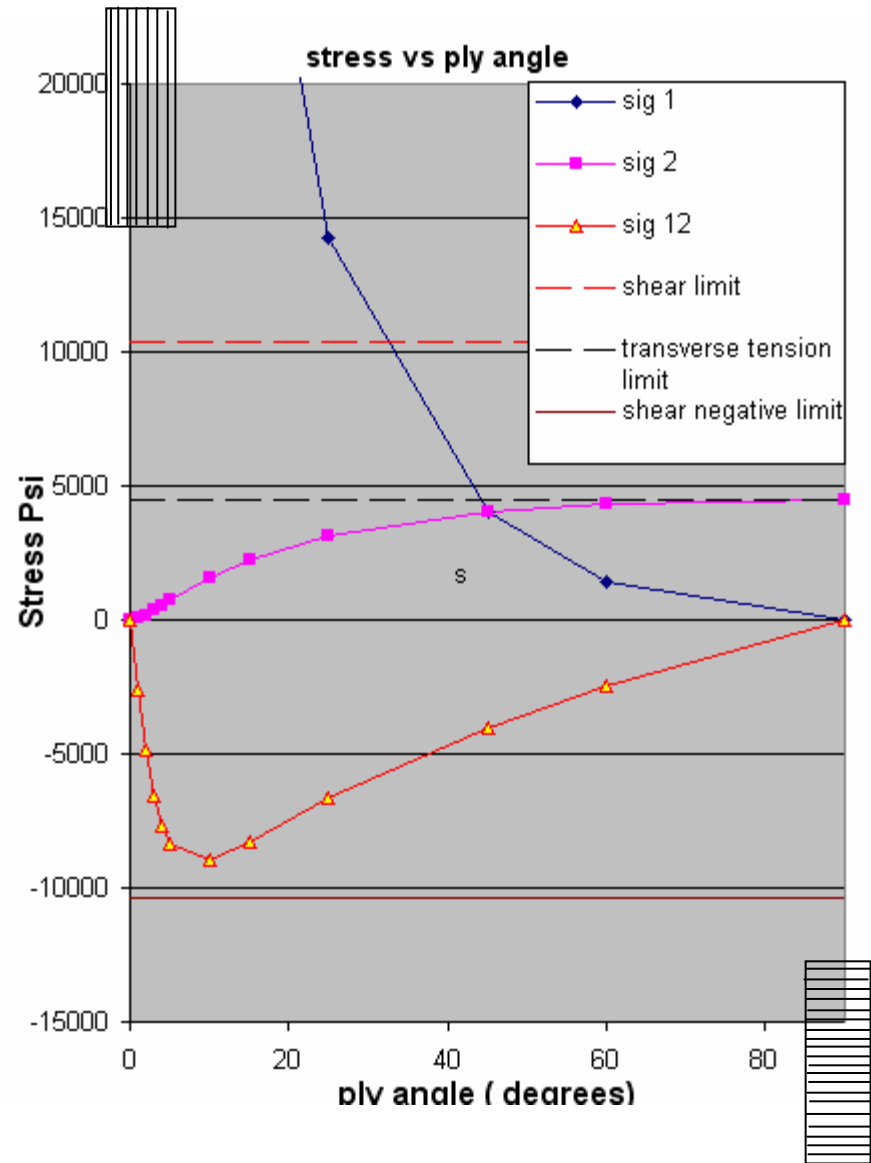
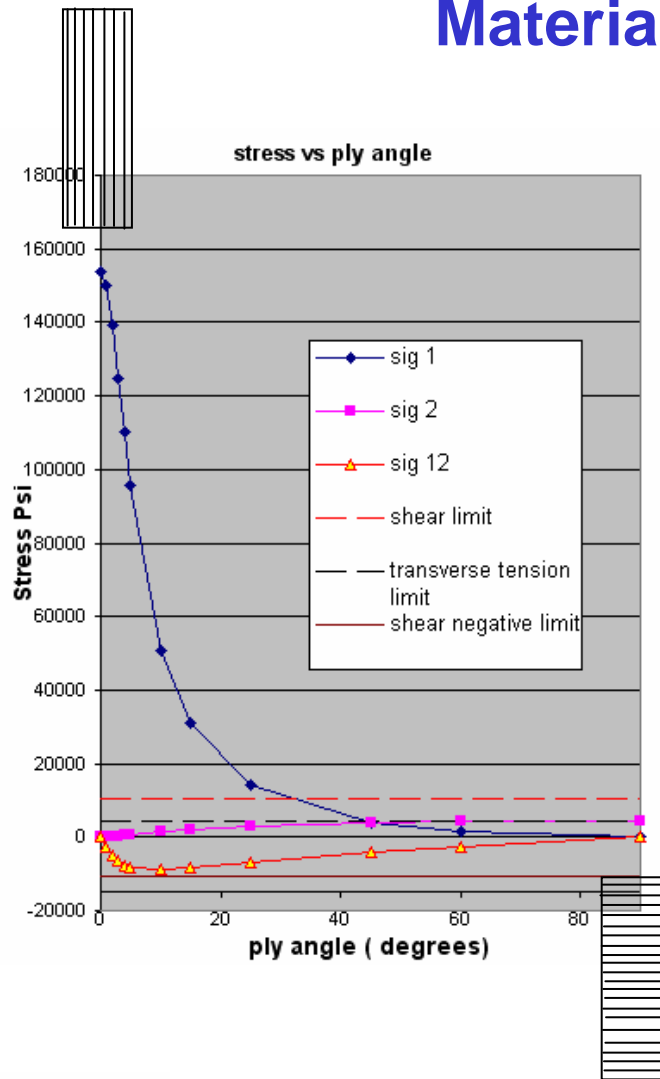


Material Behaviour

Single Ply



Material Behaviour



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Material Behaviour

0 degrees

- full allowable axial stress is obtained, 154,000 psi
- fibers are carrying the load in the most favorable, axial direction.
- resin is acting to stabilize the fibers, and not carrying any significant load.
- transverse stress that will tend to pull the fibers apart is zero
- shear stress is zero

90 degrees

- transverse properties of the material resisting the load.
- transverse tension allowable is only 4,500 PSI , based mainly on resin strength.

0 -> degrees

- even a few degrees from zero strength drops off rapidly.
- At 10 degrees the stress at failure is down to just over 40,000 psi
- fibers are now subjected to transverse stresses,
- fibers and the resin have to balance the applied stress state.
- weaker transverse strength of the resin reduces the strength.
- longitudinal, transverse and shear stresses present
- A **failure theory** analogous to Von Mises stresses for Isotropic materials is used to predict failure.



Failure Theories

Tsai-Wu typical model

$$\left(\frac{1}{X_t} - \frac{1}{X_c}\right)\sigma_1 + \left(\frac{1}{Y_t} - \frac{1}{Y_c}\right)\sigma_2 + \frac{\sigma_1^2}{X_t X_c} + \frac{\sigma_2^2}{Y_t Y_c} + \frac{\tau_{12}^2}{S^2} + 2F_{12}\sigma_1\sigma_2 = F.I.$$

X_t tension limit, along fiber

X_c compression limit, along fiber

Y_t tension limit, transverse fiber

Y_c compression limit, transverse fiber

S shear limit

F₁₂ interaction term

Failure Index > 1.0 is bad news



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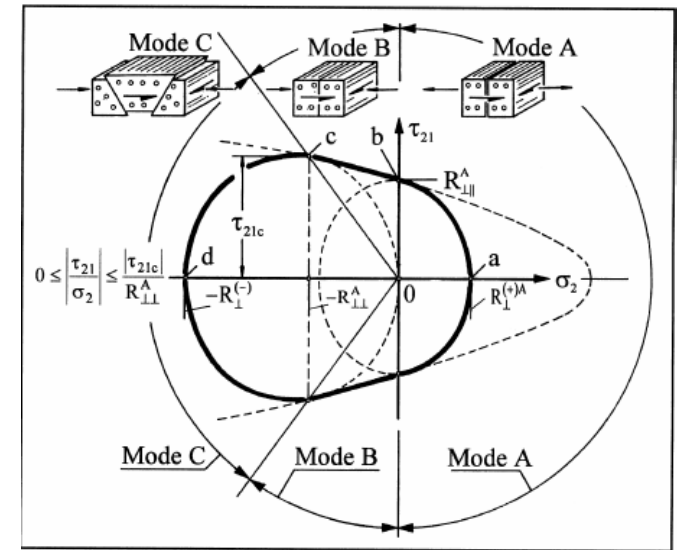
Available Failure Theories

Theory	Failure Index	Remarks
Hill	$\frac{\sigma_1^2}{X^2} - \frac{\sigma_1\sigma_2}{X^2} + \frac{\sigma_2^2}{Y^2} + \frac{\tau_{12}^2}{S^2} = F.I.$	Orthotropic materials with equal strengths in tension and compression.
Hoffman	$\left(\frac{1}{X_t} - \frac{1}{X_c}\right)\sigma_1 + \left(\frac{1}{Y_t} - \frac{1}{Y_c}\right)\sigma_2 + \frac{\sigma_1^2}{X_t X_c} + \frac{\sigma_2^2}{Y_t Y_c} + \frac{\tau_{12}^2}{S^2} - \frac{\sigma_1\sigma_2}{X_t X_c} = F.I.$	Orthotropic materials under a general state of plane stress with unequal tensile and compressive strengths.
Tsai-Wu	$\left(\frac{1}{X_t} - \frac{1}{X_c}\right)\sigma_1 + \left(\frac{1}{Y_t} - \frac{1}{Y_c}\right)\sigma_2 + \frac{\sigma_1^2}{X_t X_c} + \frac{\sigma_2^2}{Y_t Y_c} + \frac{\tau_{12}^2}{S^2} + 2F_{12}\sigma_1\sigma_2 = F.I.$	Orthotropic materials under a general state of plane stress with unequal tensile and compressive strengths.
LaRC02	<i>Dávila, C.G., Jaunky, N., and Goswami, S., Failure Criteria for FRP Laminates in Plane Stress, , 2003</i>	Unidirectional materials in a general state of plane stress with unequal tensile and compressive strengths
Max Stress	$\text{Max} \left[\left(\frac{\sigma_1}{X_t} \right), \left(\frac{\sigma_2}{Y_t} \right), \left(\frac{ \tau_{12} }{S} \right) \right]$	None
Max Strain	$\text{Max} \left[\left(\frac{\epsilon_1}{X_t} \right), \left(\frac{\epsilon_2}{Y_t} \right), \left(\frac{ \gamma_{12} }{S} \right) \right]$	None
Puck	<i>A. Puck and H. Schürmann: "Failure analysis of FRP laminates by means of physically based phenomenological models", 1998</i>	Unidirectional materials in a general state of plane stress with unequal tensile and compressive strengths

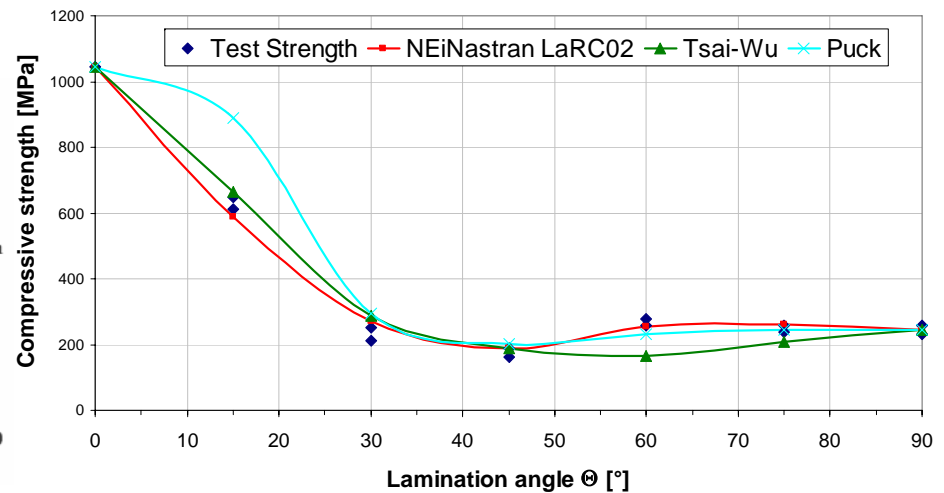
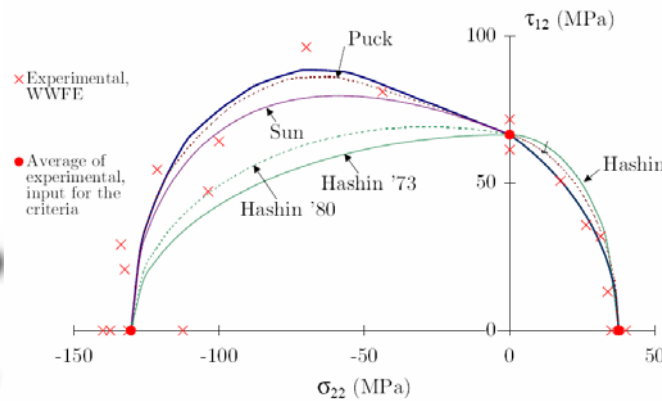


Advanced Failure Criteria for Composites

- Puck PCP Set of Criteria
 - Officially recommended by VDI
 - First-ply-failure
 - Phenomenological / Physically based
 - Action plane approach
 - Failure mode taken into account
 - Extensive validation (WWFE)
 - Very accurate is material characterization is available



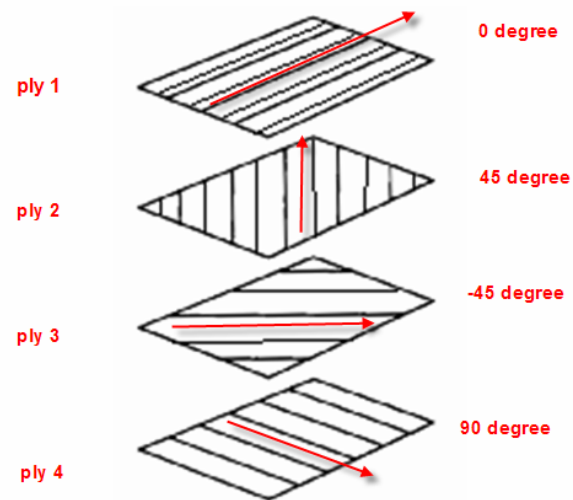
Compressive Strength of [+/-θ]s Laminates



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Ply Layups

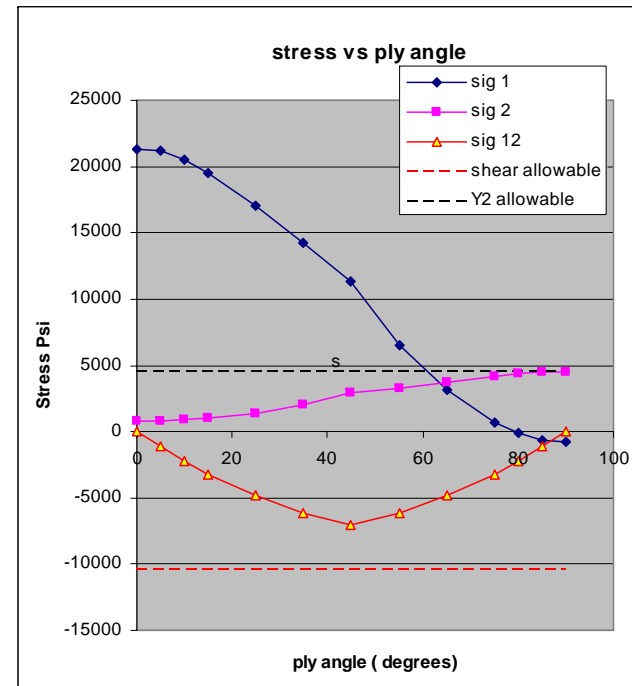
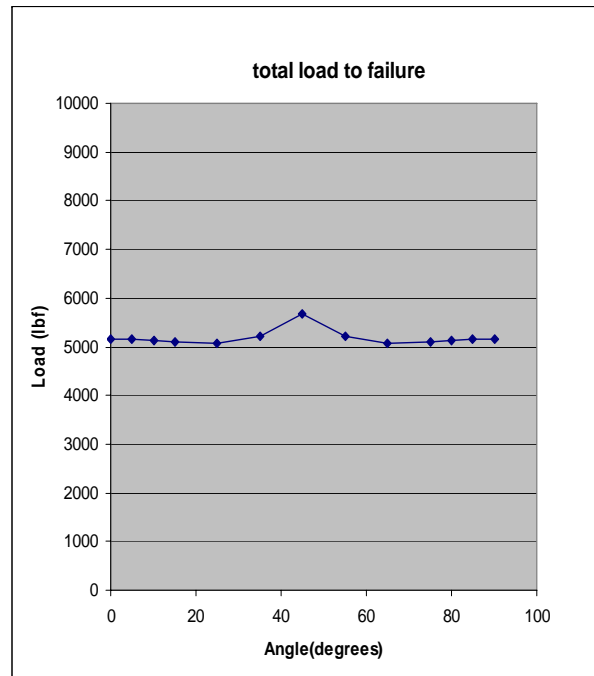
- Single Ply directions exposes weakness
- Ply layups used of multiple orientation



A laminate made up of 4 plies

- Shorthand 0/45/-45/90
- Tuning the layup orientation, thickness and stacking order is key to optimum design

Ply Layups

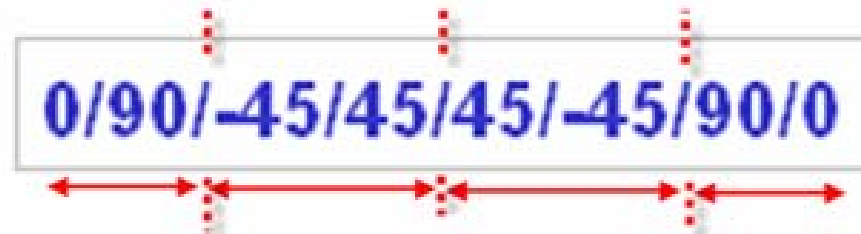


- ❑ Previous Single Ply replaced by 0/90/-45/45/45/-45/90/0
- ❑ Maximum Strength is reduced, but now very predictable
- ❑ No Optimization! Sometimes called 'black' isotropic material

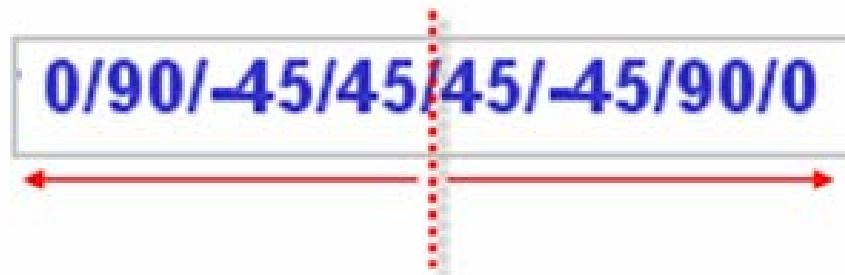


Ply Layups

- why 0/90/-45/45/45/-45/90/0 choice?

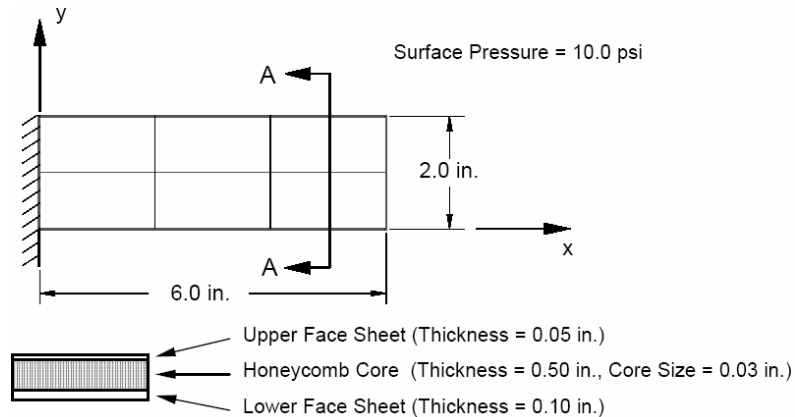


BALANCED pairs - No Inplane Direct and Shear Coupling



SYMMETRIC plies - No Inplane and Out of Plane Coupling

Advanced Failure Criteria for Sandwich Structures



Honeycomb Sandwich Results Output

STABILITY INDEXES FOR COMPOSITE QUAD ELEMENTS ON SURFACE 0									
ELEMENT ID	DOF ID	STRESS LIMITS			STABILITY INDEXES			CRITICAL INDEX	FAILURE MODE
		WRINKLING	BEMLING	CRIMPING	WRINKLING	BEMLING	CRIMPING		
1	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	STRESS
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING
2	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	CRIMPING
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING
3	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	STRESS
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING
4	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	STRESS
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING
5	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	CRIMPING
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING
6	1	9.00718E+08	2.49890E+09	1.86919E+08	9.07901E-09	1.27020E-08	2.89992E-08	9.53932E-08	STRESS
	3	2.89907E+08	6.28449E+07	1.86919E+08	2.71388E-04	4.28228E-07	9.84178E-04	9.84178E-04	CRIMPING



Theory based on *Facesheet Wrinkling in Sandwich Structures*, NASA-CR-1999-208994, 1999

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FEA Process for Composite Structure Analysis

Some modelling strategies:

Global Model

- Thin shell 2d orthotropic elements model lay-ups and/or honeycomb face skins and core
- Solid isotropic model honeycomb core
- Solid 3D orthotropic elements model thick or tapering layups, orthotropic cores

Local Model

- 2D plane strain orthotropic elements
- Solid 3D orthotropic elements – ply by ply



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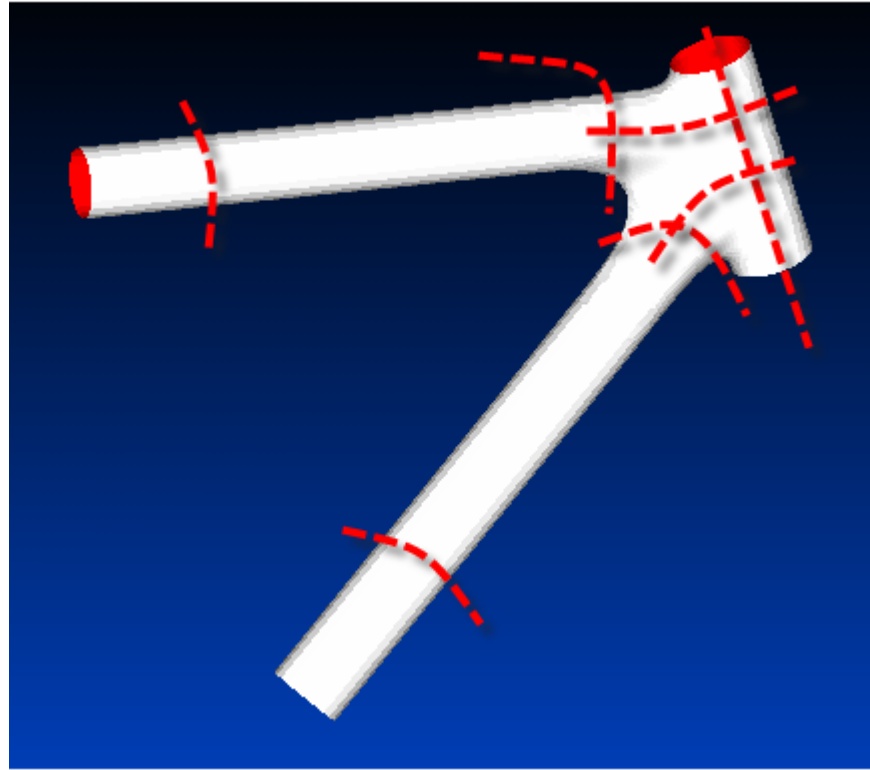
FEA Process for Composite Structure Analysis

**Composite Material
Library Available**

**Easy Input for Strength and
Stiffness Terms**

- **Create or Load 2D orthotropic and/or 3D Orthotropic materials**

FEA Process for Composite Structure Analysis



- Choose regions of common orientation and stackup

FEA Process for Composite Structure Analysis

Define Property - LAMINATE Element Type

ID: 2 Title: Laminate Material: [Dropdown]
Color: 24 Palette... Layer: 1 Elem/Property Type...

Layer Property Values

Material	Thickness	Angle	Material	Thickness	Angle
1	0.01	0.	10		
2	0.01	90.	11		
3	0.01	45.	12		
4	0.01	-45.	13		
5	0.01	90.	14		
6	0.125	0	15		
7			16		
8			17		
9			18		

Bottom Surface: 0.
N.S. Mass/Area: 0.
BondShr Allow: 210
Ref Temp: 0.
Damping: 0.

Failure Theory:
 None
 Hill
 Hoffman
 Tsai-Wu
 Max Strain

Symmetric Layers At Layer 6

Buttons: << Prev, Next >>, Insert, Delete, Load..., Save..., Copy..., OK, Cancel

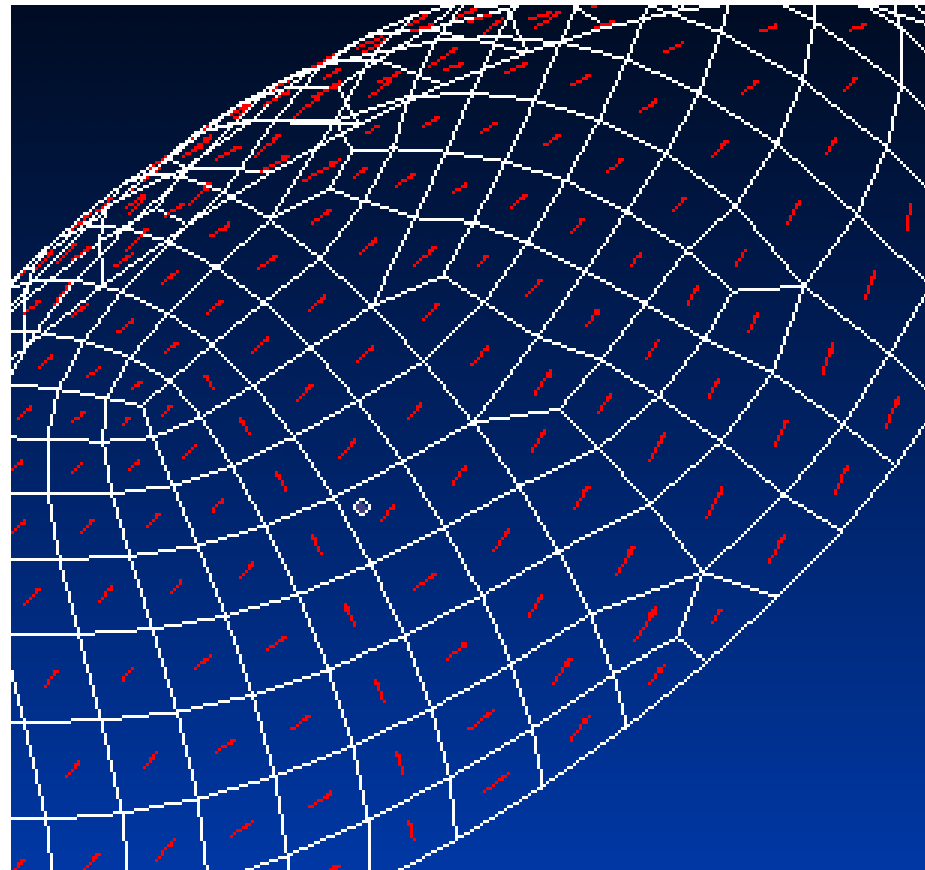
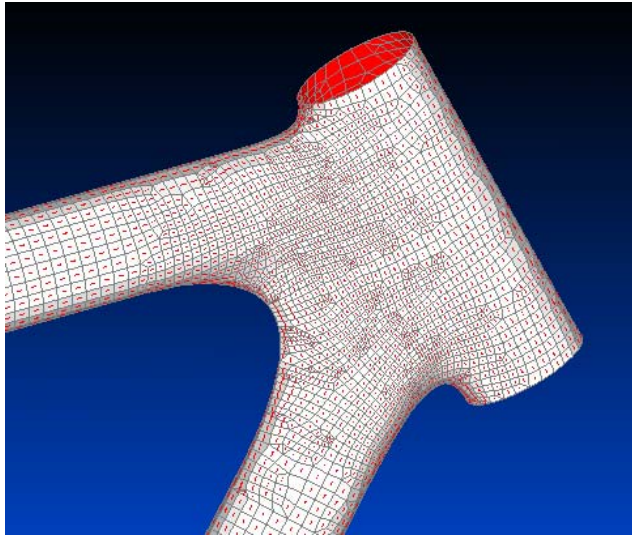
6 plies
Symmetry
6 plies

Symmetry switched on for ease of layup definition

Choice of Failure Criterion

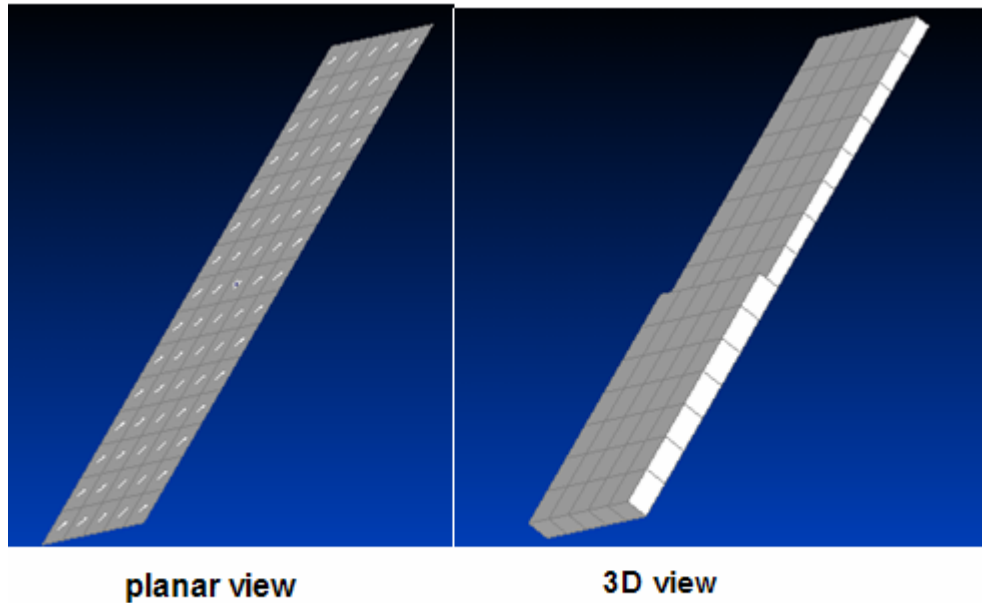
- Create schedule of stackups

FEA Process for Composite Structure Analysis



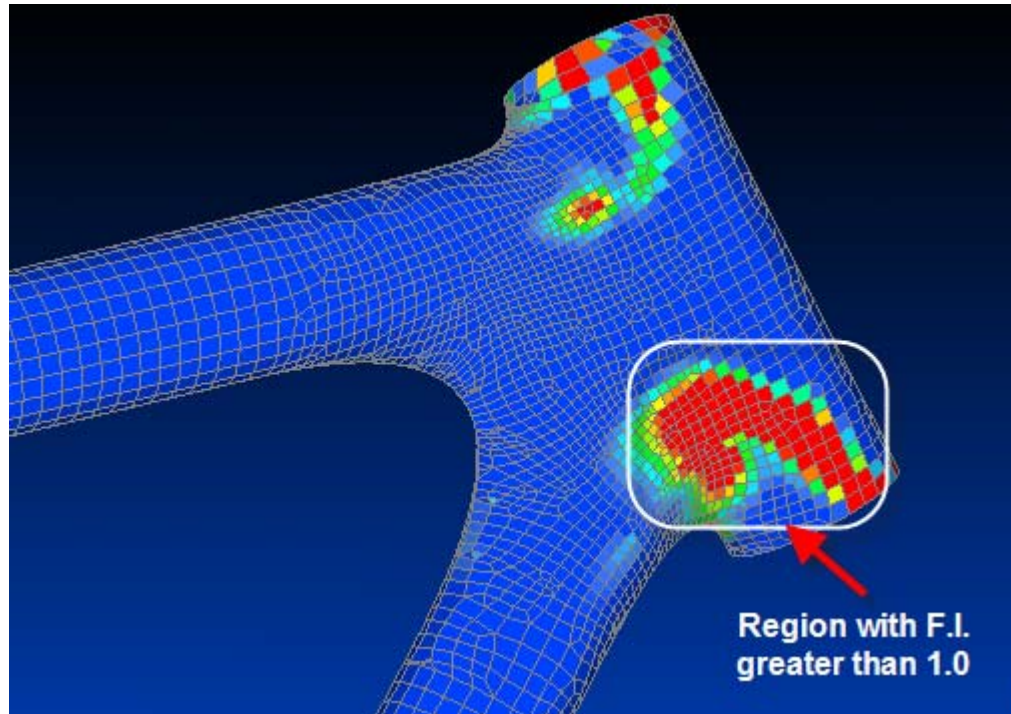
- Map datum ply orientations

FEA Process for Composite Structure Analysis



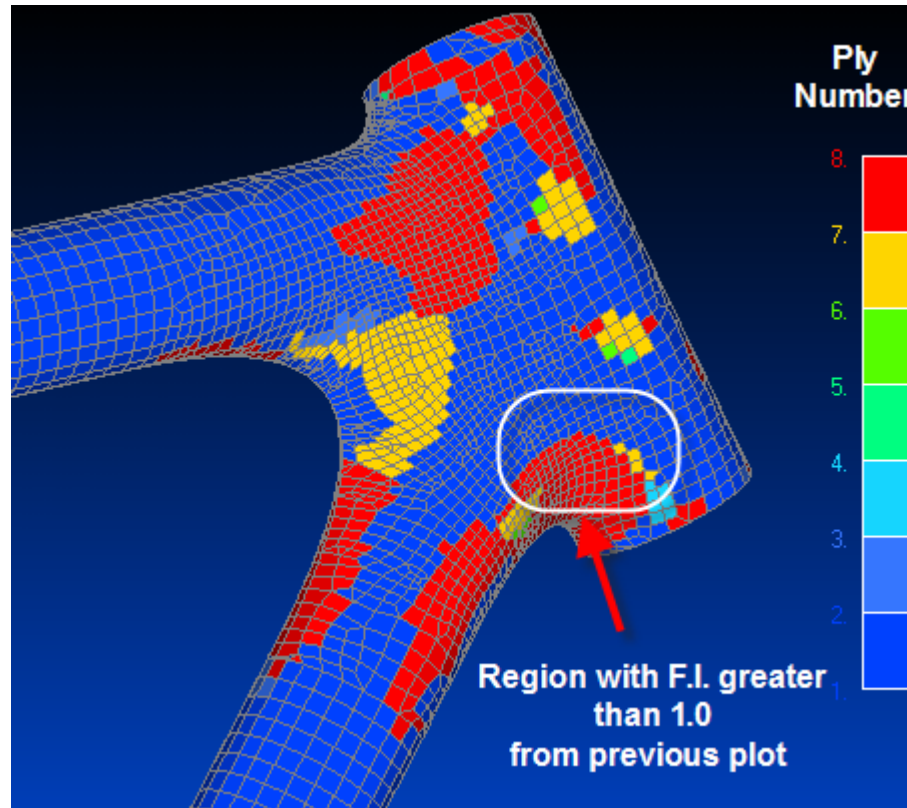
- Account for Outer/Inner Mold Line continuity

FEA Process for Composite Structure Analysis



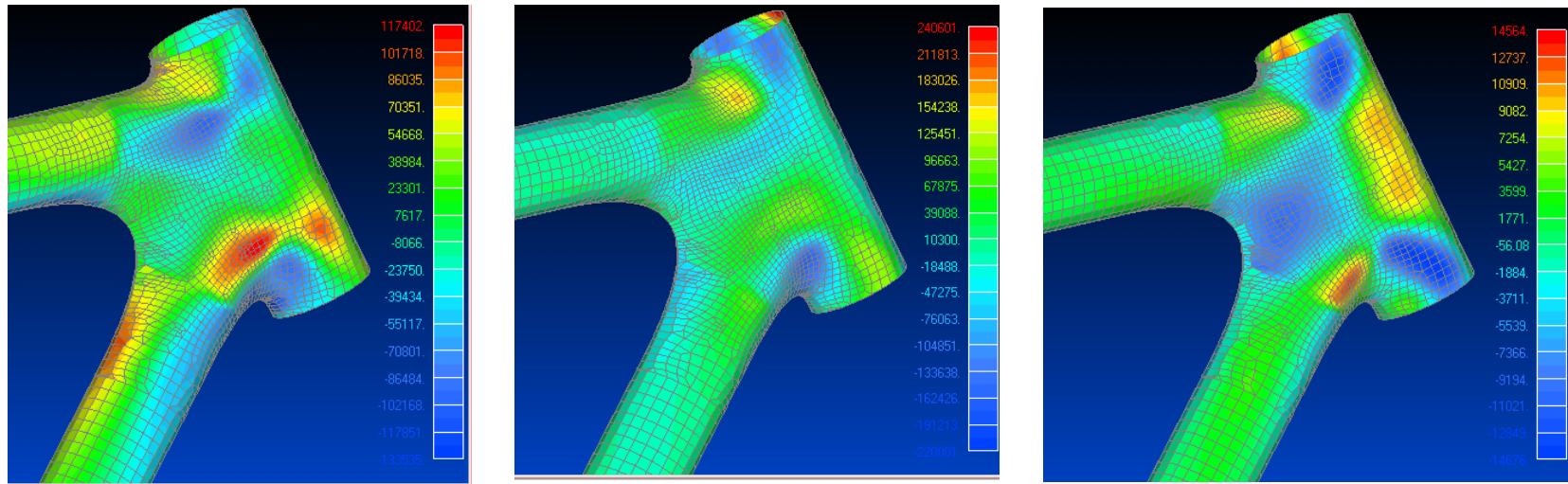
- Identify regions where F.I. shows failure in the layup

FEA Process for Composite Structure Analysis



- Identify which plies are failing in the layup in that region

FEA Process for Composite Structure Analysis



- Review Direct X, Direct Y and Shear XY ply stresses in the individual ply
- Assess major mode of failure
- Assess coupling through plies
- Redesign if required

FEA Analysis of Composite Structures

Final Thoughts

- Actual material strength and stiffnesses are subject to many factors
- Fatigue, environmental degradation or abuse loads may dominate
- Published data – or generic test data, can only be a guide
- 'As Built' versus 'As Designed' in Composites can be significant
- FEA is not exact

Conclusions

- Aim for robust design (maximum xx microstrains everywhere)
- Keep engineering judgment in the picture
- Ignore progressive failure and fancy theories in initial design margins
- Test, analyze, 'correlate', etc. but test should be the final decider

