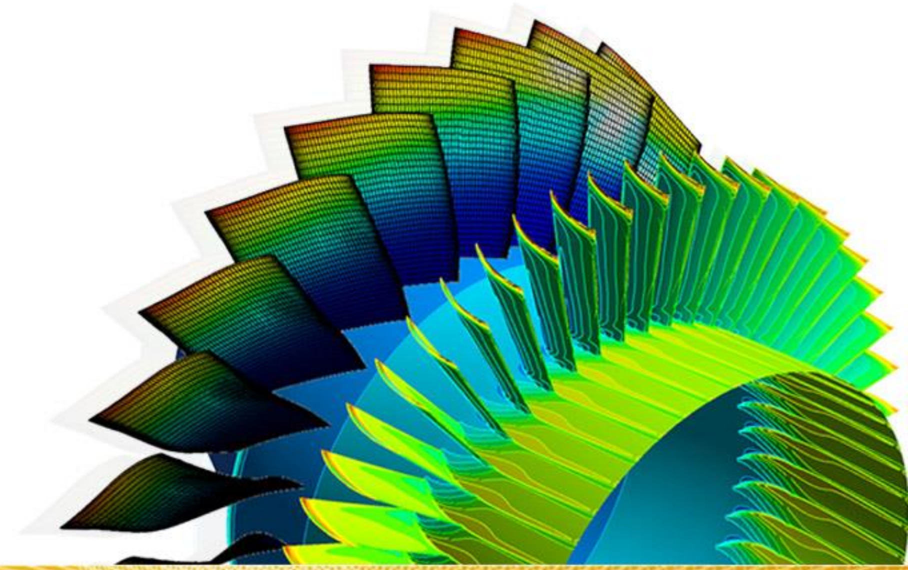
ANSYS Composite PrepPost 19.0

Module 9: Failure Criteria



9. Failure Criteria

- Due to their orthotropic material behavior and multiple possible failure modes failure analyses of composites are significantly more complex than for isotropic materials
- Multiple failure criteria are available to predict different failure modes

Tension Failure Mode

- Failure can occur in fiber direction due to high stresses in fiber direction (Fiber Failure)
- Stress concentration around embedded fibers and tension transverse to the fiber direction can lead to failure (Matrix Failure)

9. Failure Criteria

Compression Failure Mode

- Compression in fiber direction can lead to fiber failure including buckling as well as matrix shear failure. It is therefore difficult to model. Strength depends on fiber and matrix properties as well as on the ability of the matrix to support the fibers. Measurements are difficult and dependent on method and specimens
- Compression transverse to the fiber direction can lead to a crushing of the matrix and/or the fibers. In addition matrix shear failure and debonding are possible

9. Failure Criteria

Shear Failure Mode

- Shear Failure usually occurs due to stress concentrations at the fiber/matrix level

Failure Criteria

- Failure criteria compare loading conditions (stress and/or strain values) with defined strength values for the composite material

9. Failure Criteria

The following failure criteria are currently available in ANSYS Composite PrepPost:

- Max. Strain & Max. Stress
- Tsai-Wu
- Tsai-Hill
- Hashin
- Puck
- LaRC
- Cuntze
- Face Sheet Wrinkling
- Core Failure
- Hoffman

9. Failure Criteria

Maximum Stress Failure Criteria

- Failure will occur when any one of the stress components exceeds the corresponding strength in that direction
- All stresses are independent. Occurring stresses in one direction wont affect the strength of the material in the other directions

Maximum Strain Failure Criteria

- Failure occurs when at least one of the strain components exceeds the ultimate strain

9. Failure Criteria

Tsai-Hill Failure Criteria

- Takes into account interactions between different failure modes
- Based on the von-Mises failure criteria for metals
- The Tsai-Hill failure criteria can not predict different failure modes (Fiber failure, matrix failure, fiber-matrix interface failure, …)

9. Failure Criteria

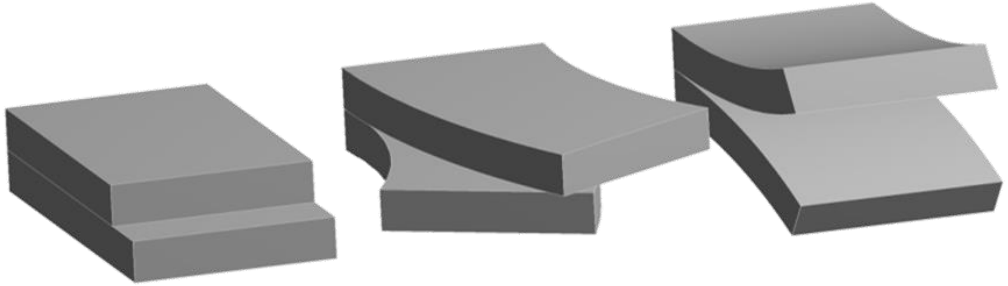
Tsai-Wu Failure Criteria

- Takes into account interactions between different failure modes
- Differences in tensile and compression strengths are considered
- Can not predict different failure modes (Fiber failure, matrix failure, fiber-matrix interface failure, …)
- Requires the definition of interaction parameters *(F_{12}, F_{23}, F_{13}).* The interaction parameters have to be defined by equibiaxial tests which are nearly impossible to perform. Therefore the interaction parameter are either defined by curve fitting or left to the default values of -1.

9. Failure Criteria

Puck and Cuntze Failure Criteria

- Driven by the physics underlying the actual failure modes
- They separate fiber-fracture from the several inter-fiber fracture modes
- Fiber-fracture can be evaluated using the simple stress criteria
- Puck works with action planes in which the composite fails and three inter-fiber fracture modes (Mode A, B and C)



IFF Mode B IFF Mode C IFF Mode A

9. Failure Criteria

LaRC Failure Criteria

- Developed by the NASA Langley Research Center
- Phenomenological criteria
- Based on Hashins and Pucks failure criteria
- Takes into account that a ply has higher transverse tensile and shear strength when it is constrained by plies with different fiber orientations (in-situ effect)

9. Failure Criteria

Failure Criteria Terms

- e = strain   s = stress
- 1 = material 1 direction
- 2 = material 2 direction
- 3 = out-of-plane normal direction
- 12 = in-plane shear
- 13 and 23 = out-of-plane shear terms
- I = principal I direction
- II = principal II direction
- III = principal III direction
- t = tension, c = compression

9. Failure Criteria

Failure Modes

Maximum Strain Failure modes	e1t, e1c, e2t, e2c, e12
Maximum Stress	s1t, s1c, s2t, s2c, s3t, s3c, s12, s23, s13
Tsai-Wu 2D and 3D	tw
Tsai-Hill 2D and 3D	th
Hashin	hf (fiber failure) hm (matrix failure) hd (delamination failure)
Puck (simplified, 2D and 3D)	pf (fiber failure) pmA (matrix tension failure) pmB (matrix compression failure) pmC (matrix shear failure) pd (delamination)

9. Failure Criteria

Failure Modes

LaRC (2D)	lf (fiber failure) lmt (matrix failure tension) lmc (matrix failure compression)
Cuntze 2D and 3D	cft (fiber tension failure) cfc (fiber compression failure) cmA (matrix tension failure) cmB (matrix compression failure) cmC (matrix wedge shape failure)
Sandwich Failure Wrinkling	wb (wrinkling bottom face) wt (wrinkling top face)
Sandwich Failure Core	cf (core failure)

9. Failure Criteria

Reserve Factor

$$RF = \frac{Ultimate\ Strength}{Ultimate\ Load}$$

RF > 1 → Safe

RF < 1 → Failure

Inverse Reserve Factor

$$IRF = \frac{Ultimate\ Load}{Ultimate\ Strength}$$

IRF > 1 → Failure

IRF < 1 → Safe

Margin of Safety

$$MoS = \frac{Material\ Strength}{Design\ Load} - 1$$

MoS < 0 → Failure

MoS > 0 → Margin to Failure

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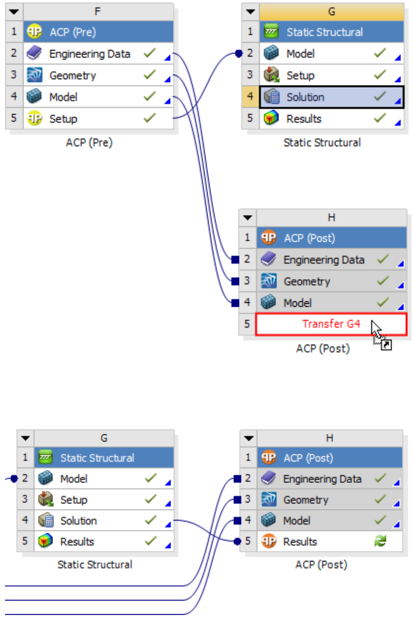
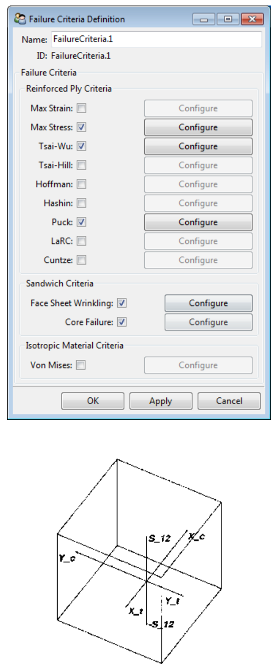
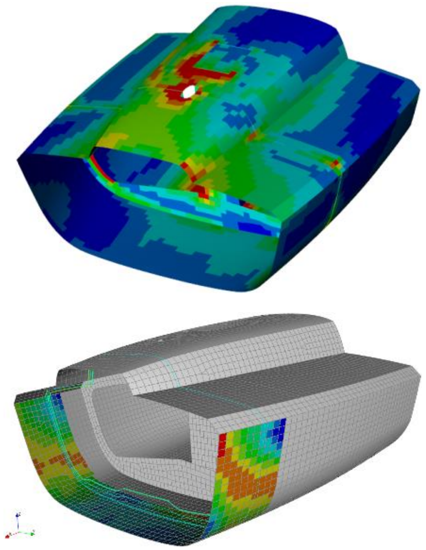
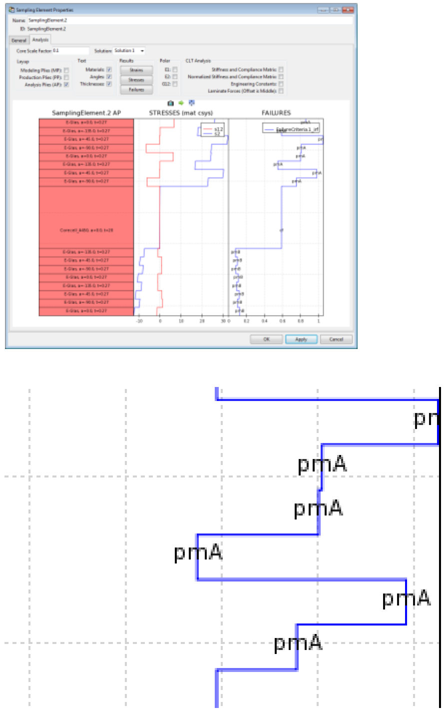
9. Failure Criteria

How to post-process a composite lay-up in ACP?

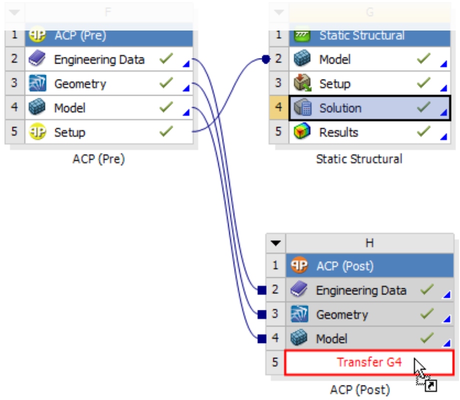
9. Failure Criteria

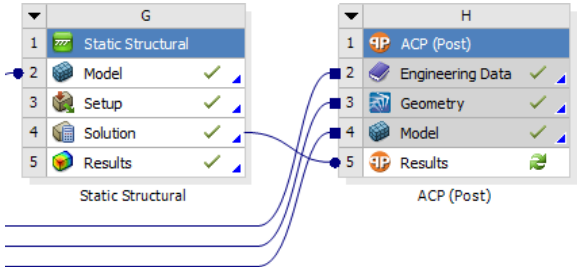
4 Steps Lay-up Post-processing

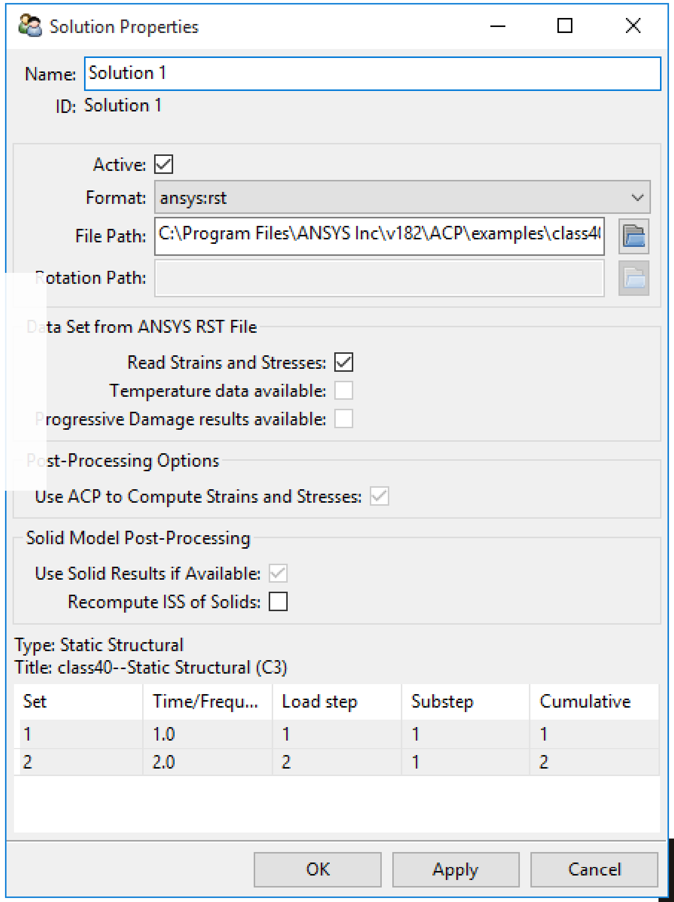
Import Solution from Analysis System	Combined Failure Criteria Definition	Layer-wise Post-processing at a glance	Thru the thickness Analysis
			

9. Failure Criteria

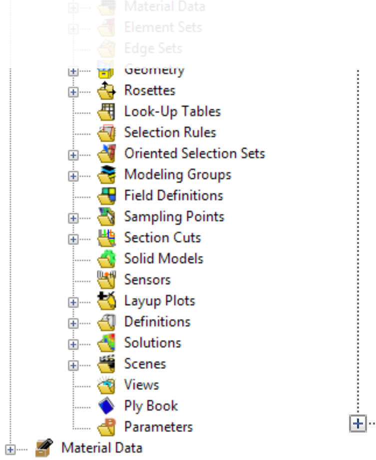
Step 1: Importing a solution in Workbench …

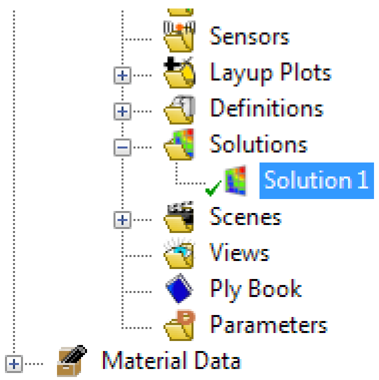






…creates a solution object in the ACP tree





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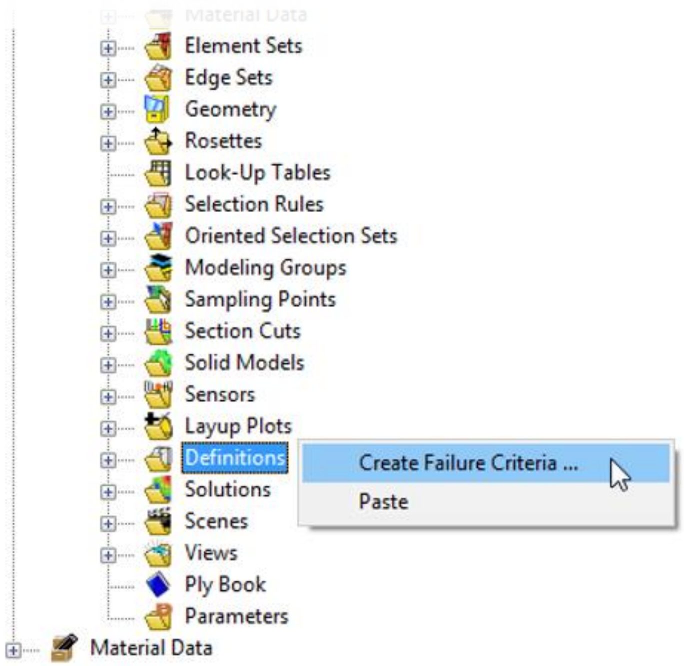
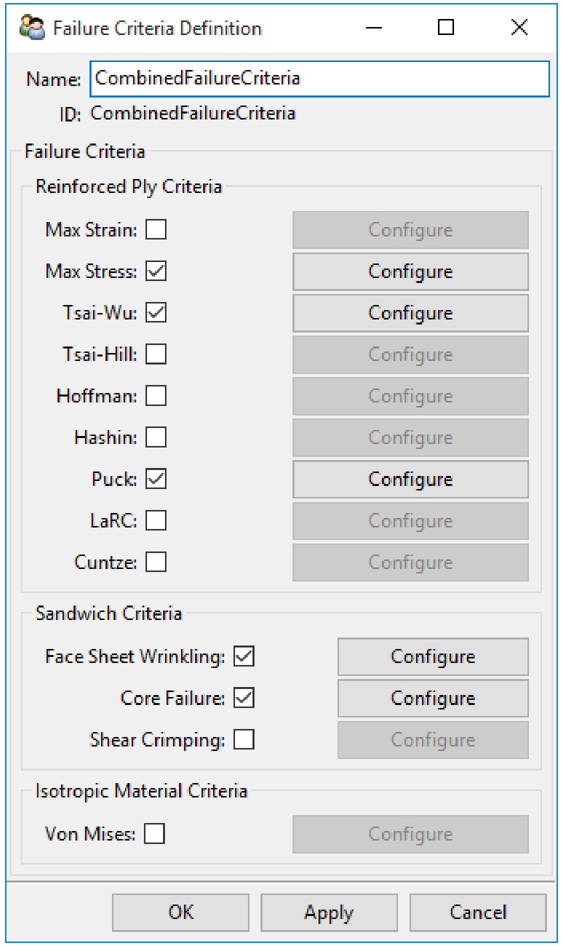
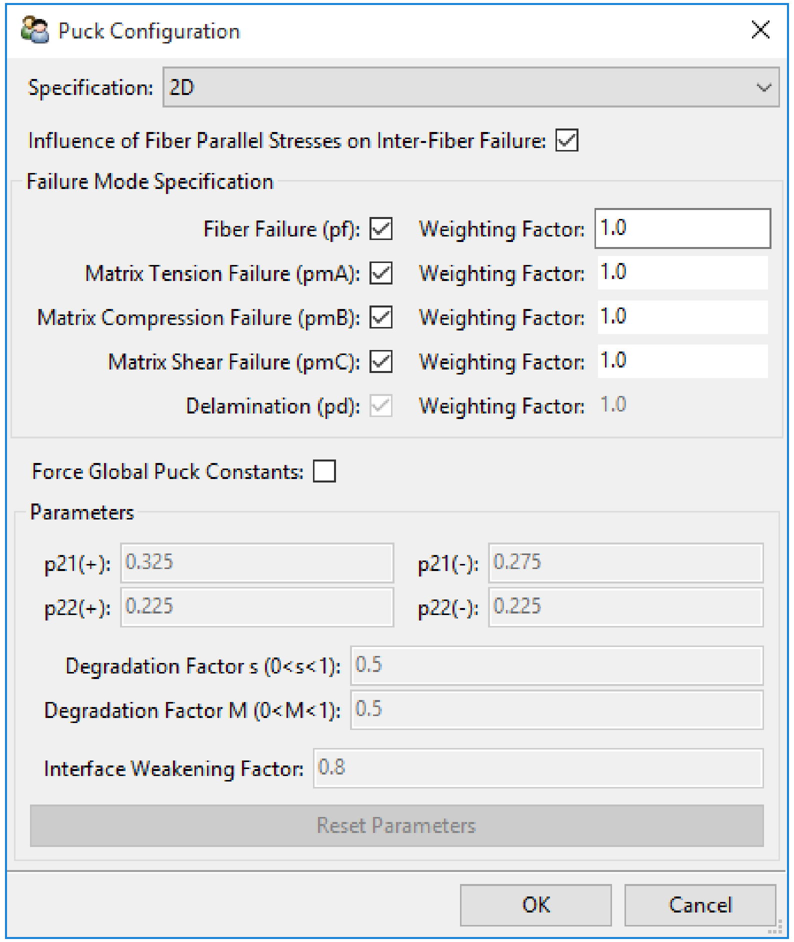
9. Failure Criteria

Step 2: Combined Failure Criteria Definition

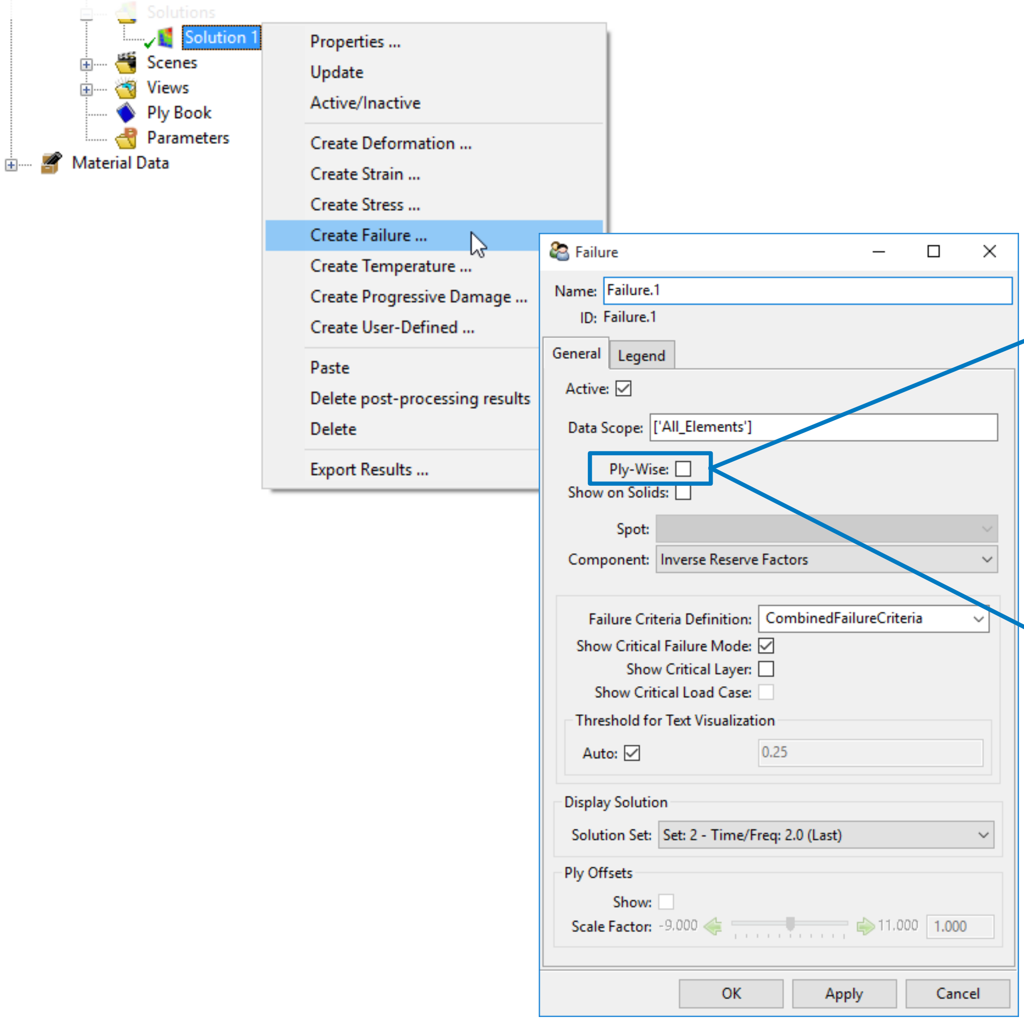






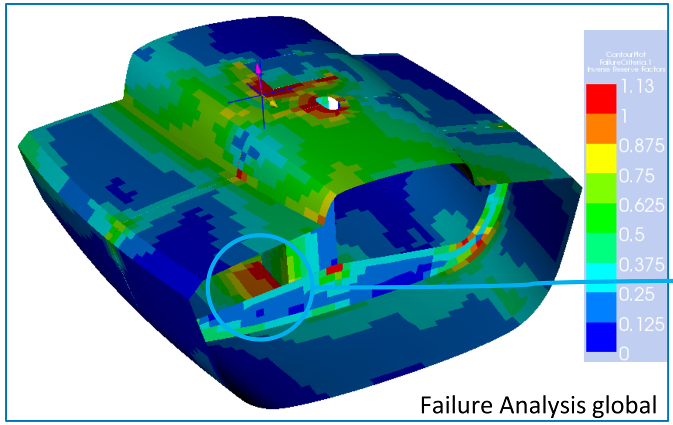
9. Failure Criteria

Step 3: Failure Plots



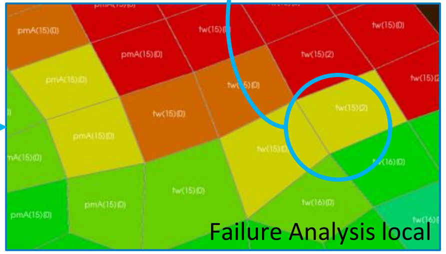
Element-wise Results

Ply-Wise: ☐



Failure Analysis global

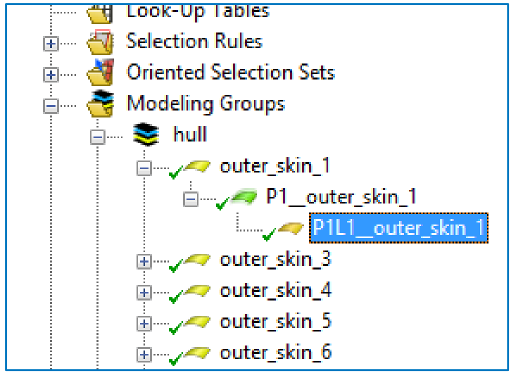
Tw(15)(2):
Tsai-Wu Layer 16,
Loadcase 3

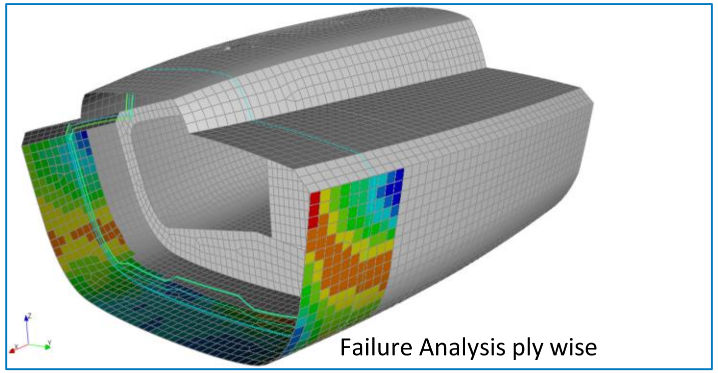

Failure Analysis local

The plot shows an envelope of the critical results through the thickness

Ply-wise Results

Ply-Wise: ☑

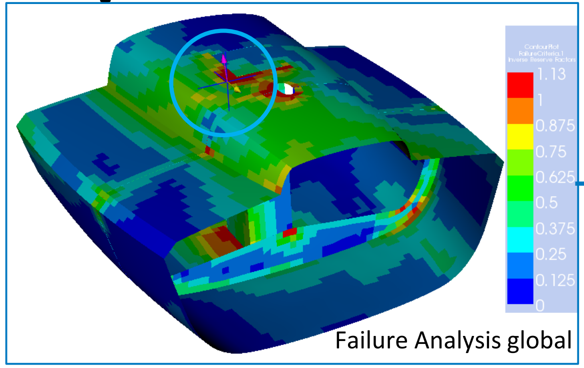



Failure Analysis ply wise

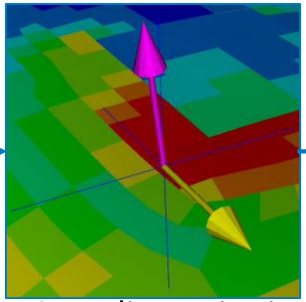
An analysis ply needs to be selected to view results

9. Failure Criteria

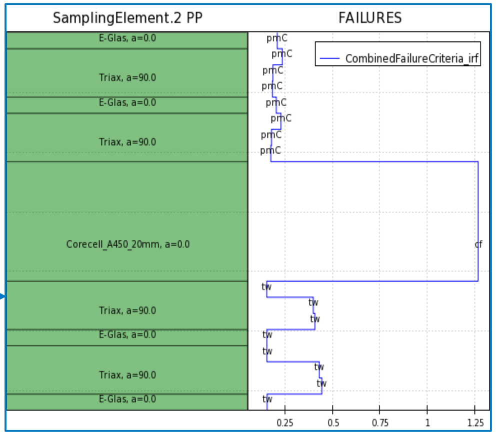
Step 4: Thru Thickness Analysis



Identify a critical region in the global failure plot

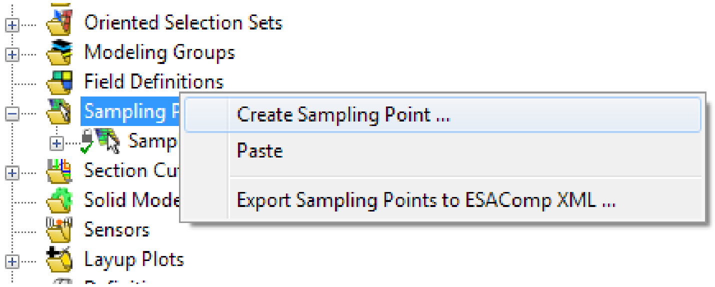


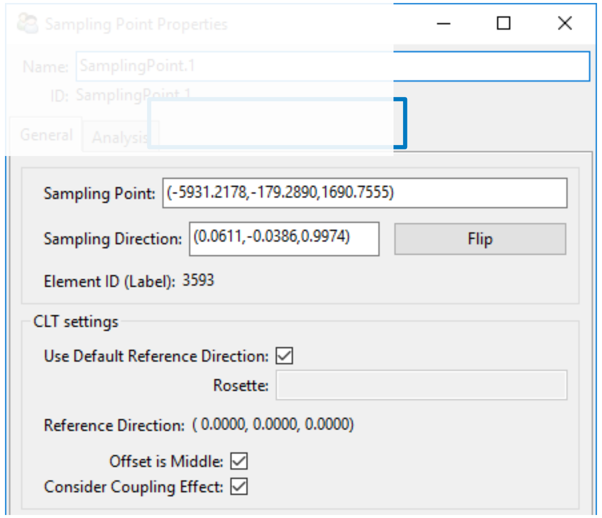
Create a Sampling Point in this location

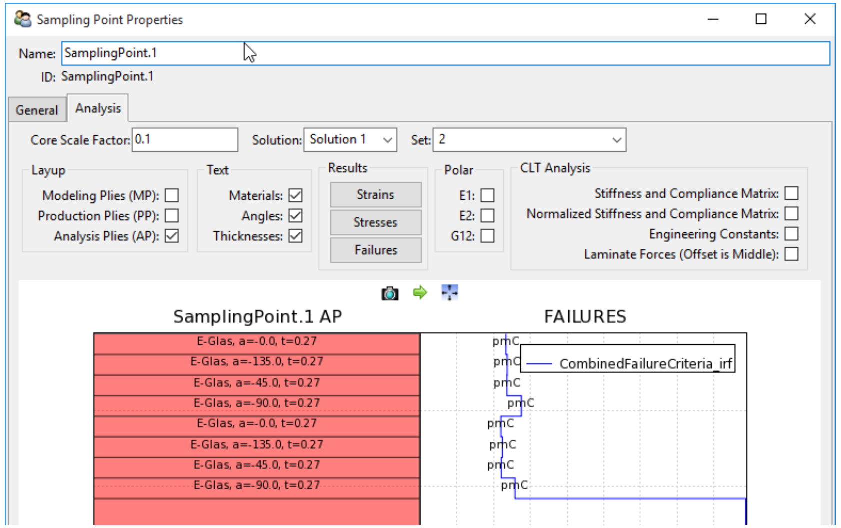


Detailed Failure Analysis through laminate thickness

Creating a Sampling Point







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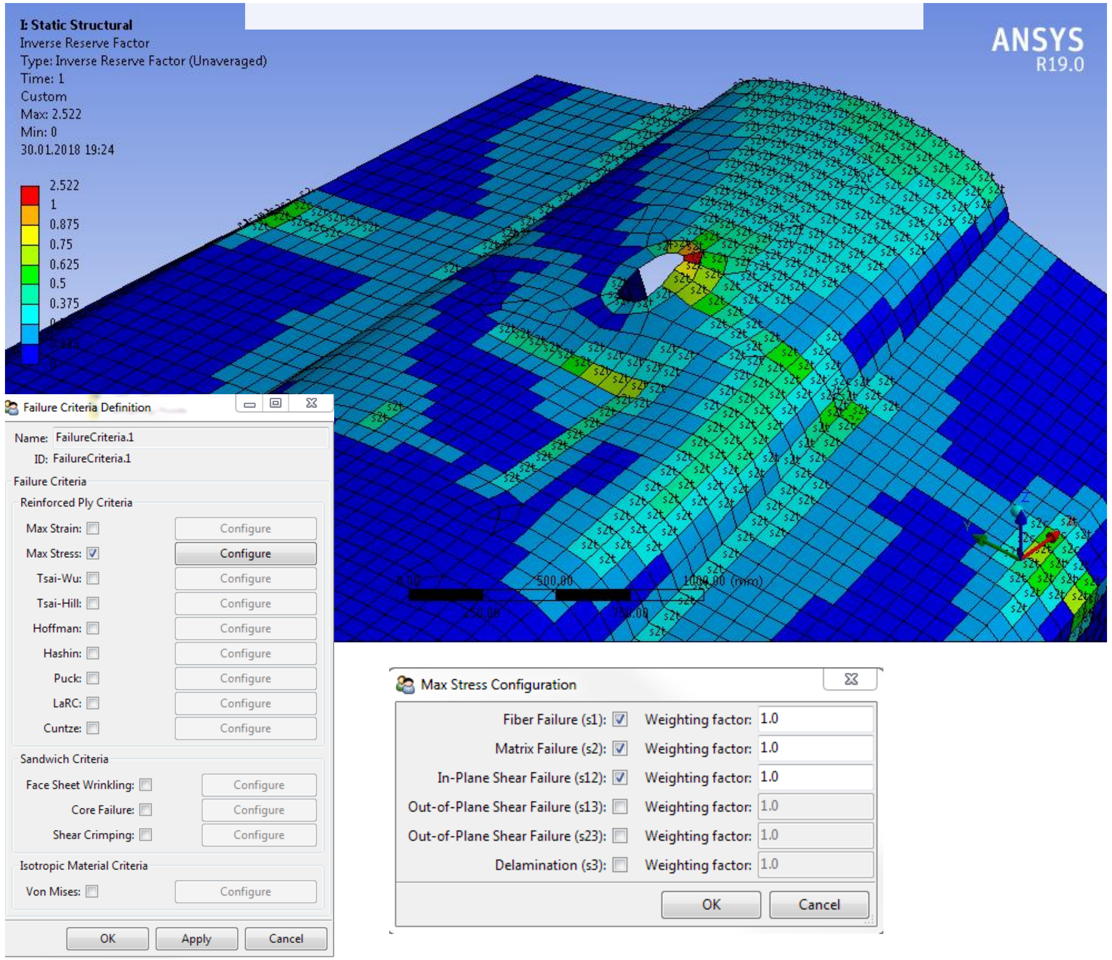
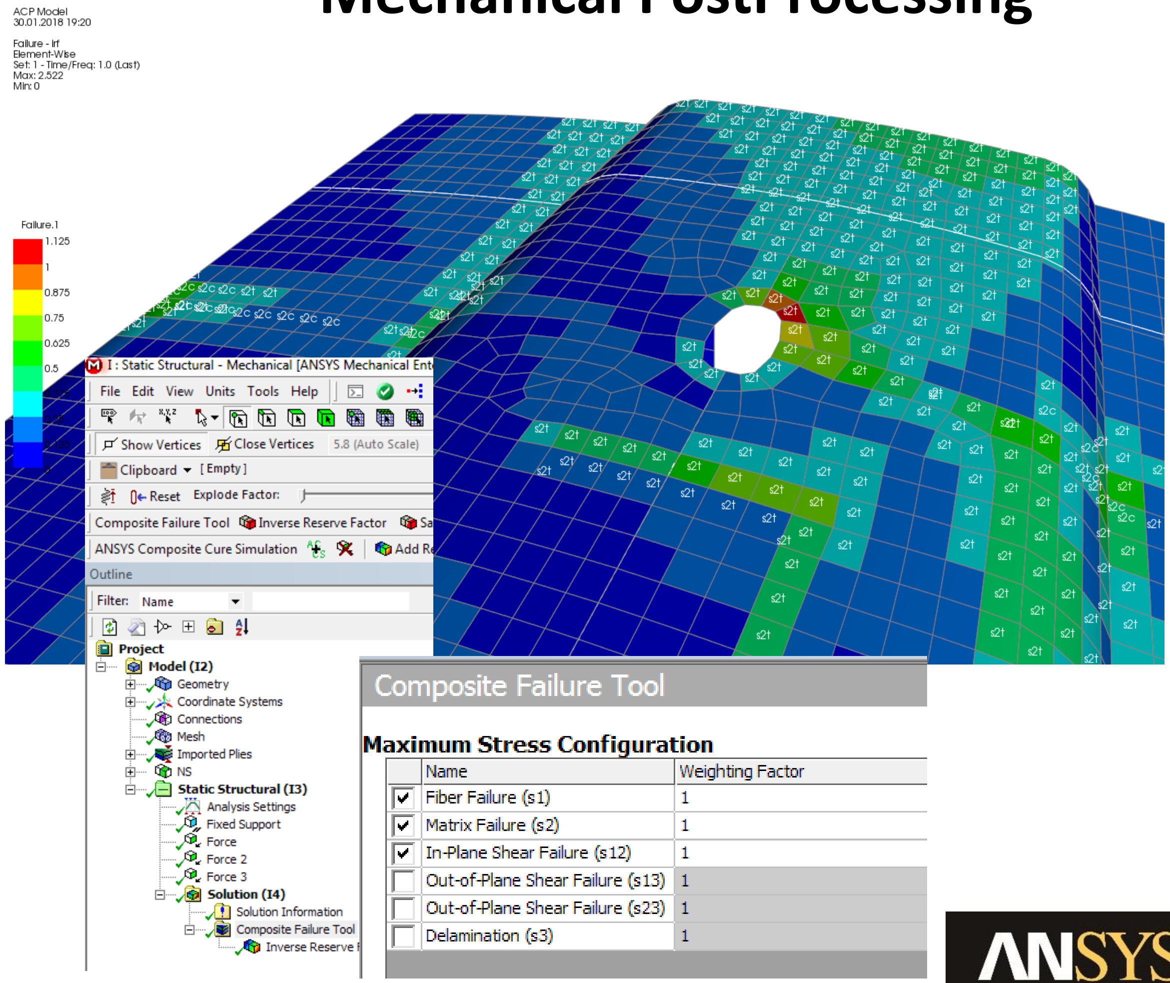
9. Failure Criteria

How to post-process a composite lay-up in Mechanical?

ACP PostProcessing



Mechanical PostProcessing



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