Sandwich Panel with Disbond: Calculation of Crack Front Loading caused by Ground-Air Pressurization Effect

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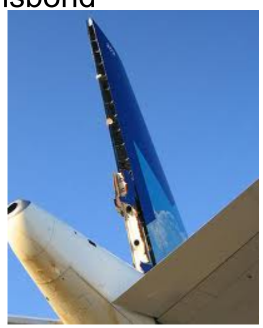
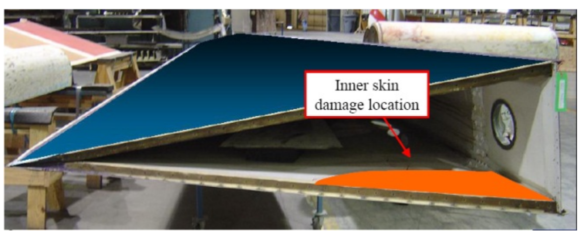
Motivation

Pressure difference between in- and outside honeycomb sandwich structures caused by alternating ambient pressure is a major cause of face sheet peeling loads

Initial disbonds between face sheets and core increase the peeling effect and can decrease the structural reliability significantly

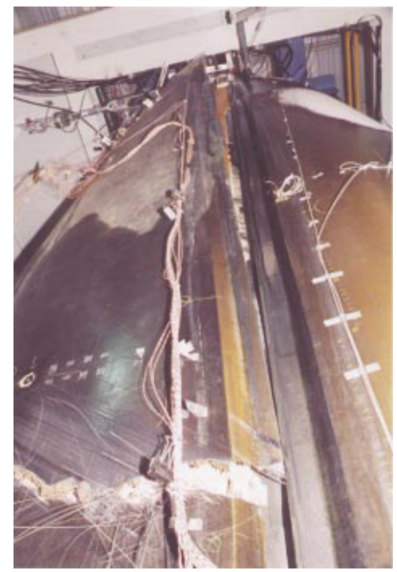
Air-Transit flight 961 (Airbus A310-300):
- Rudder failure due to face sheet disbonding caused by pressure difference and initial disbond





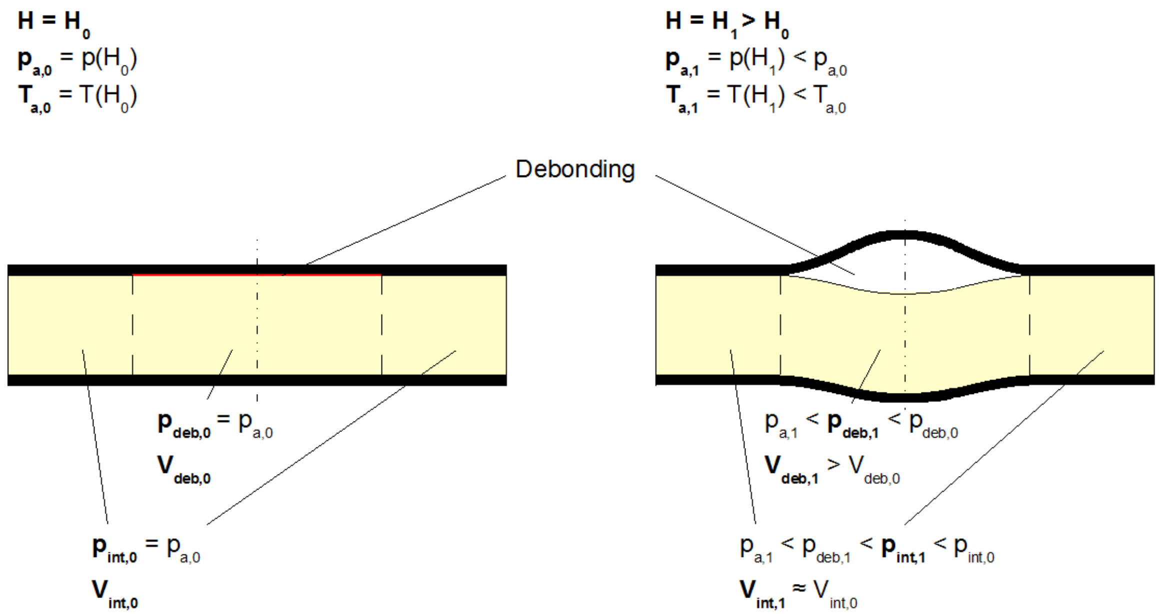
Hilgers R: Substantiation of Damage Growth within Sandwich Structures, In: FAA Workshop for Composite Damage Tolerance & Maintenance, Tokyo, 2009

X-33 technology flight demonstration vehicle:
- Failure of sandwich liquid hydrogen tank due face sheet disbonding caused pressure difference, environmental effects and left teflon strip



Goetz et al: Final Report of the X-33 Liquid Hydrogen Tank Test Investigation Team, NASA George C. Marshall Space Flight Center Huntsville, Alabama 35812, 2000

Motivation



With thin face sheets and large disbonds significant deformations and core volume increase can arise

Following the ideal gas law, volume increase results in pressure decrease

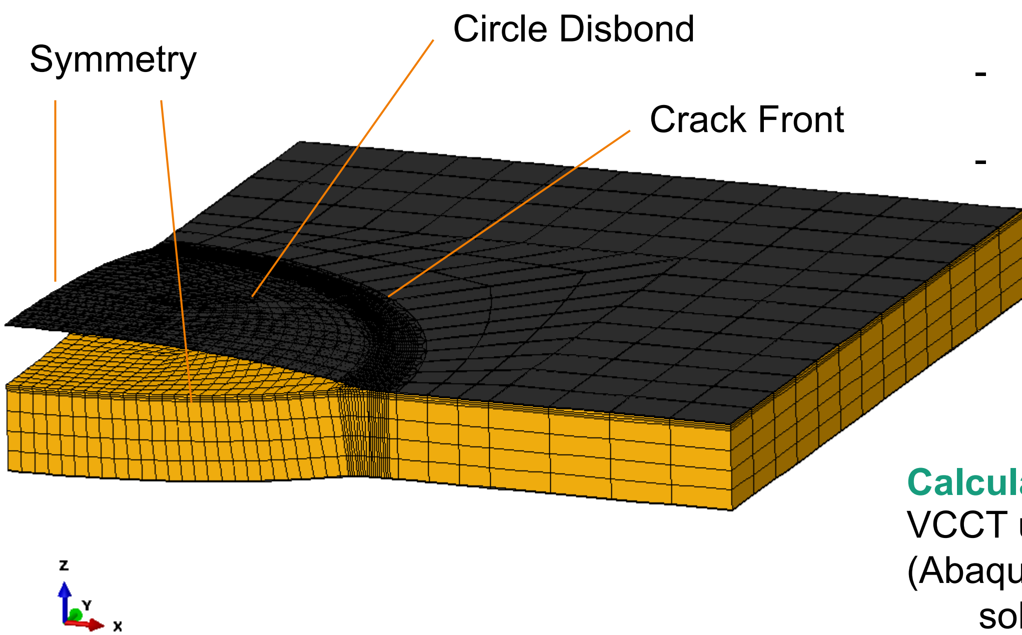
Recursive pressure-deformation coupling needs to be solved for an accurate structural analysis

Presented numerical study is intended to get an idea about the influence of disbond radius, face sheet thickness, core height and core density on the ground-air face sheet disbonding effect

FE model

Geometry:
- Disbond at upper face sheet/core interface
- Variable disbond radius
- Panel length = width = 2 * disbond radius
- Variable face sheet layup
- Variable core thickness
- Variable curvature

Boundary conditions:
- p0 = 0.1201 MPa, T0 = 15 Celsius
- pa = 0.0188 MPa, Ta = -56.5 Celsius



Calculation of panel pressurization:
Surface based Fluid Cavity option in Abaqus
- Definition of two cavities: debonded and intact core
- Border of cavities 3mm (cell size of honeycomb core) in front of crack tip
- Generation of fluid elements and coupling with structural (C3D20) elements

Calculation of crack front loading:
VCCT using *extract* program Ronald Krueger
(Abaqus VCCT not available for higher order solid elements)

FE model

Face sheet layup:

- Cytec 5320-1 plain weave fabric
- i*[45/0/90/-45], i = 1…7
- Face sheet thickness = 0.772 mm (0.03”) … 5.404 mm (0.21”)

Core material:

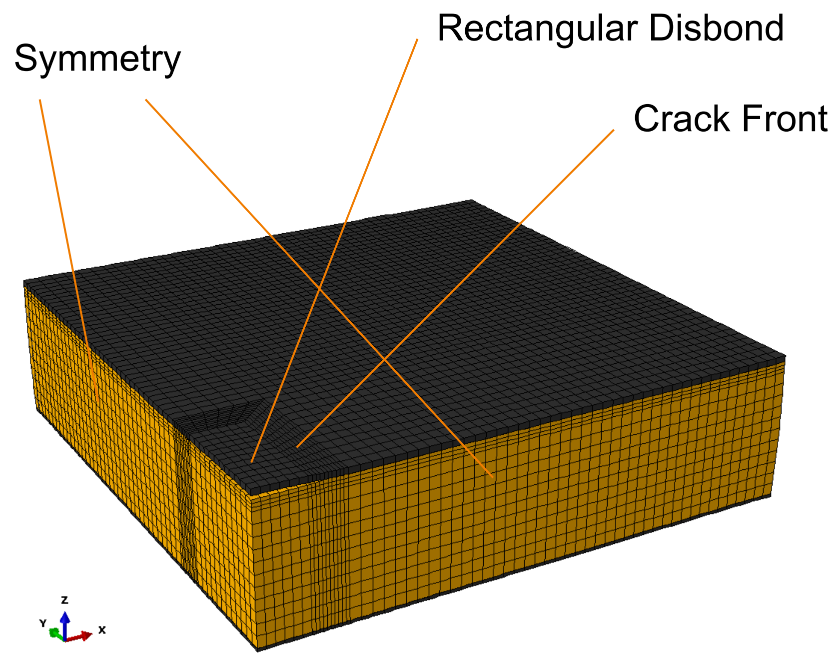
- Hexcel HRH-10, 1/8” cell size
- Density: 29.0 kg/m^3 (1.8 lb/ft^3), 48.0 kg/m^3 (3.0 lb/ft^3)* and 80.0 kg/m^3 (5.0 lb/ft^3)
- Core height: 12.7 mm (0.5”), 25.4 mm (1.0”), 50.8 mm (2.0”) and 76.2 mm (3.0”)

Disbond radius:

- 50.8 mm (2.0”), 101.6 mm (4.0”) and 152.4 mm (6.0”)

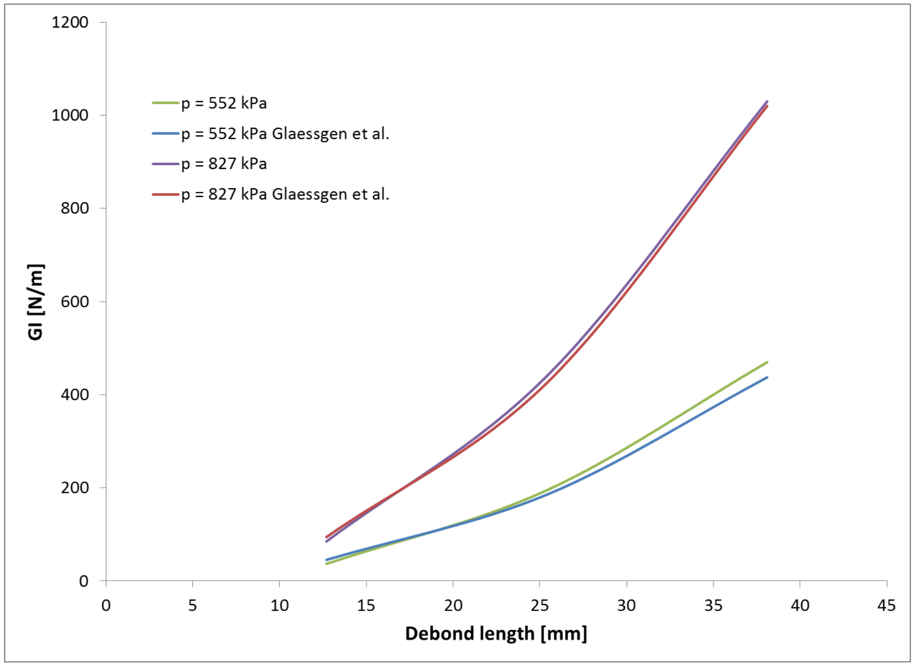
Validation of Modelling Technique

Instance 1: X-33 cryogenic fuel tank - sandwich disbonding investigation at NASA LaRC*



Test panel was pressurized by a compressor …
Defined load, no pressure-deformation coupling

Calculations were performed using surface loads



Good correlation between GI calculated with different models … pressure application with Abaqus fluid elements and VCCT calculation work well

*Glaessgen et al: Debonding Failrue of Sandwich-Composite Cryogenic Fuel Tank with Internal Core Pressure, Journal of Spacecraft and Rockets 2005; 42(4):613-627

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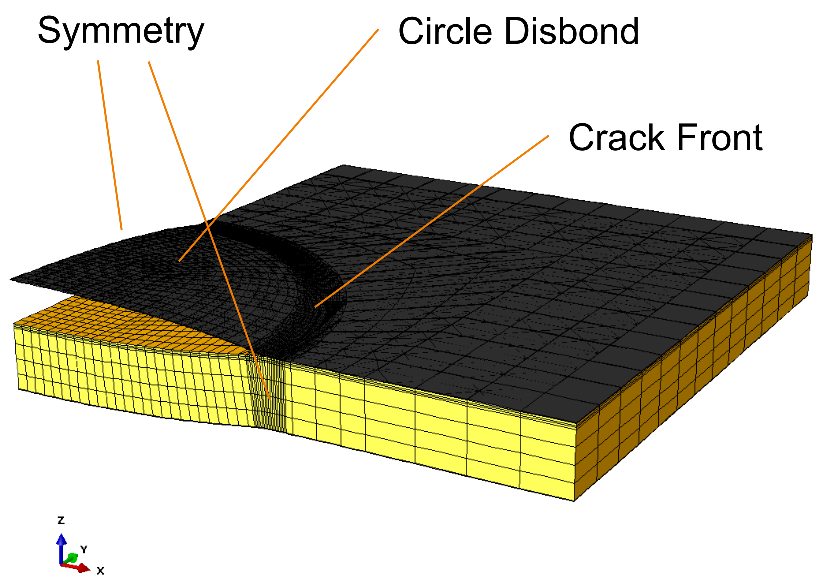
Validation of Modelling Technique

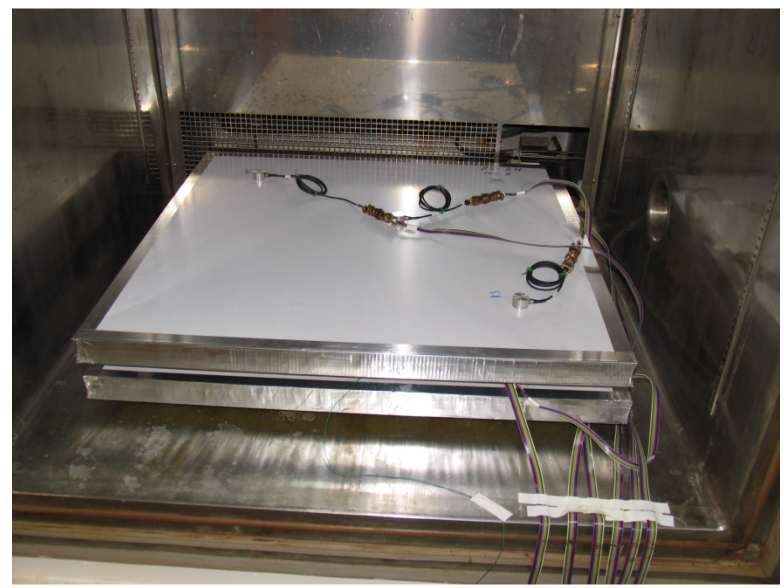
Instance 2: Sandwich panel tested by Airbus in vacuum chamber*



Sandwich panel with 350 mm disbond was tested by airbus in vacuum chamber … pressure-deformation coupling needs to be considered

Pressure in disbonded core section was measured during test

FE analysis was performed calculating pressure-deformation coupling iteratively



*Panel in vacuum chamber**

	Pressure
Airbus Test*	0.0582 MPa
Airbus Analysis*	0.0577 MPa
Abq Fluid Cavity	0.0571 MPa

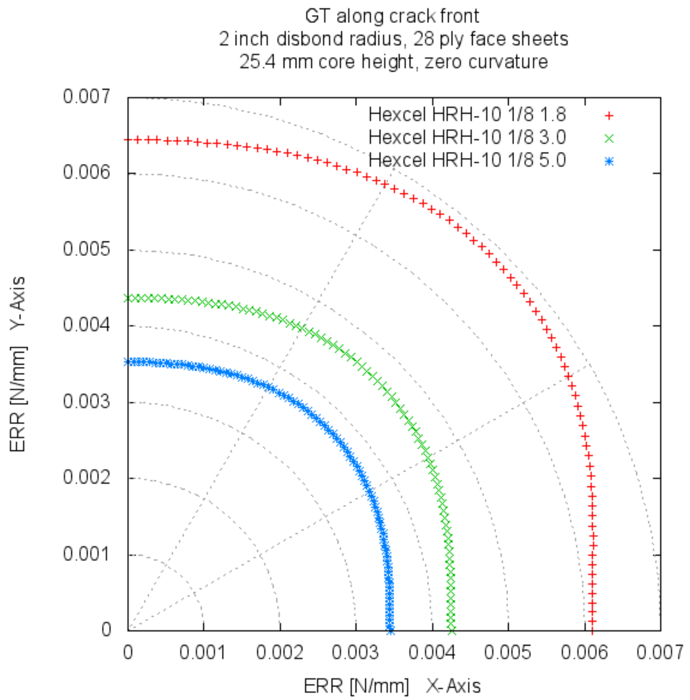
Pressure-deformation coupling is correctly solved via Abaqus Fluid Cavity Simulation

Hilgers R: Substantiation of Damage Growth within Sandwich Structures, In: FAA Workshop for Composite Damage Tolerance & Maintenance, Tokyo, 2009

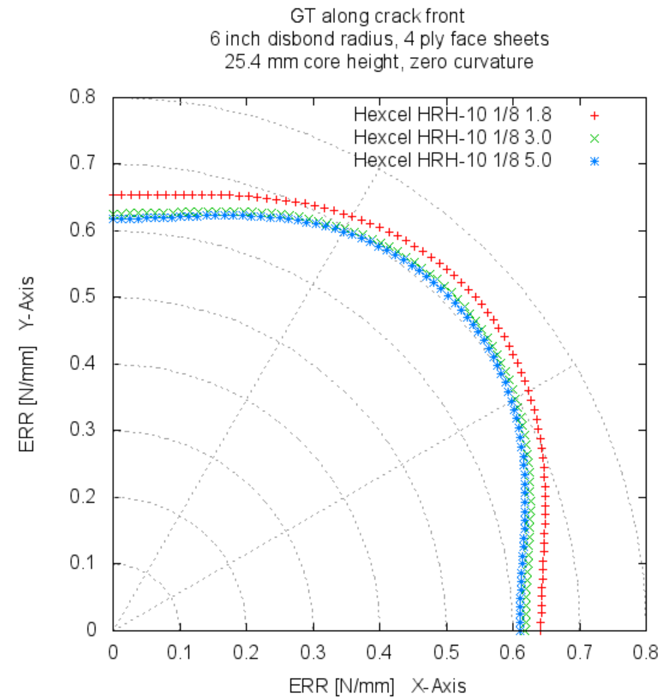
Results

Variation of face sheet ply number, core density and disbond radius
Core height = 25.4 mm (1.0”), zero curvature

Safest case:
Small disbond and thick face sheets



Most critical case:
Large disbond and thin face sheets



- Crack tip loading in the safest case to low for disbond propagation
- Crack tip loading in the most critical case in the range of measured (SCB) fracture toughness values … disbond propagation might be possible

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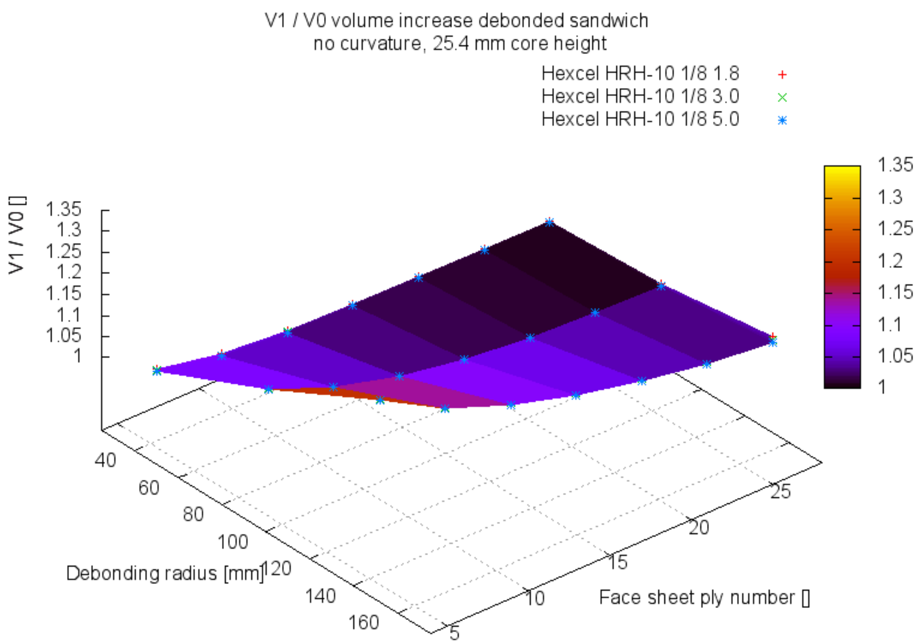
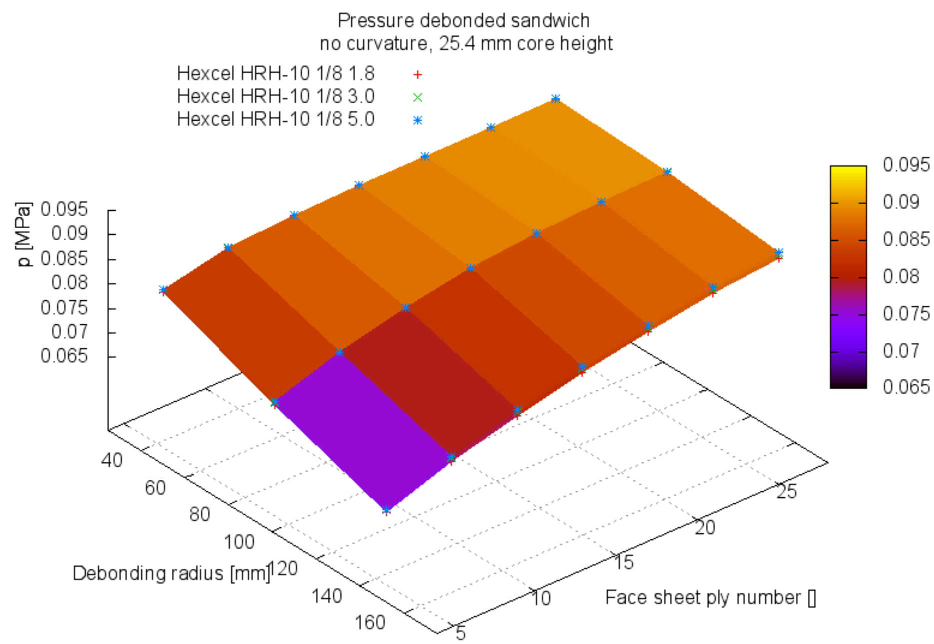
Results

Variation of face sheet ply number, core density and disbond radius
Core height = 25.4 mm (1.0”), zero curvature

Overall results: Pressure-deformation coupling





- Large disbond in combination with thin face sheets result in large deformation and thus volume increase of the disbonded sandwich section (up to factor 1.35)
- Volume increase causes also pressure decrease
- The lowest pressure is in the thin face sheet sandwich with large disbond … the most critical case
- Variation of the core density (from 1.8 lb/ft³ to 5.0 lb/ft³) does not significantly effect the pressure-deformation behaviour

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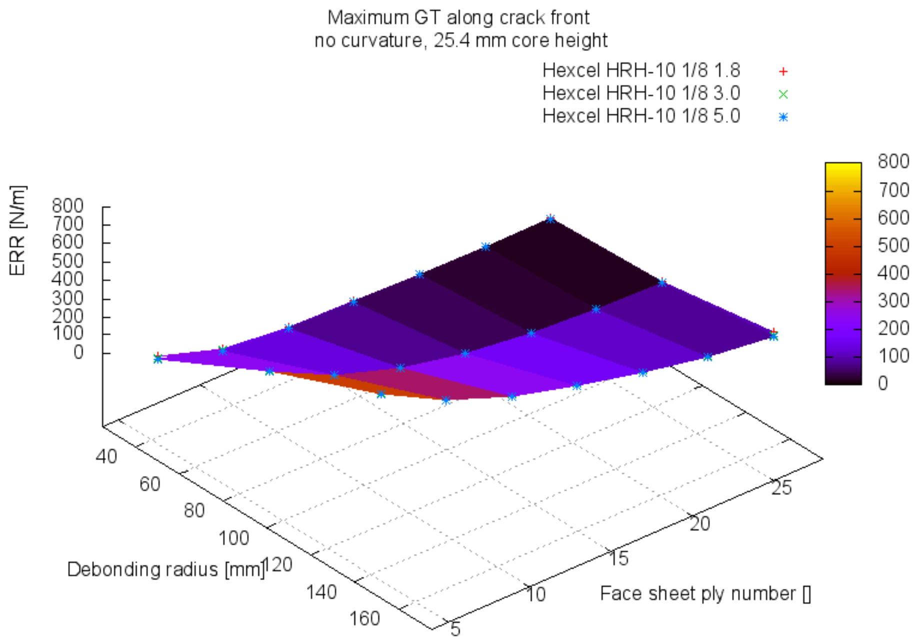
Results

Variation of face sheet ply number, core density and disbond radius
Core height = 25.4 mm (1.0”), zero curvature

Overall results: Maximum GT (mostly at 45° axis between x and y axis)



- Disbond radius below 4.0” probably uncritical
- Face sheets with more than 12 plies probably uncritical
- Variation of the core density (from 1.8 lb/ft³ to 5.0 lb/ft³) does not significantly effect the crack tip loading (but the fracture toughness probably depends on the core density)

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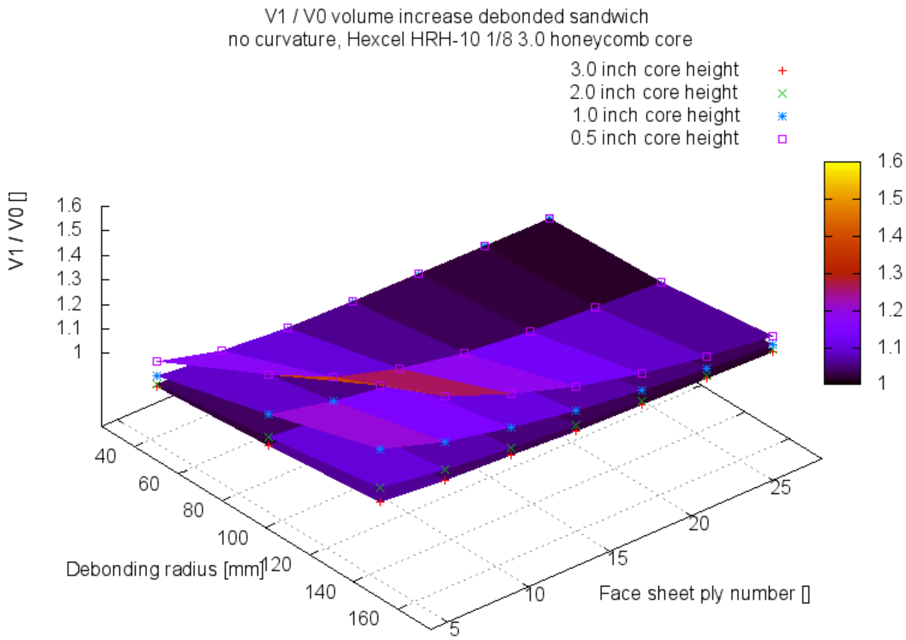
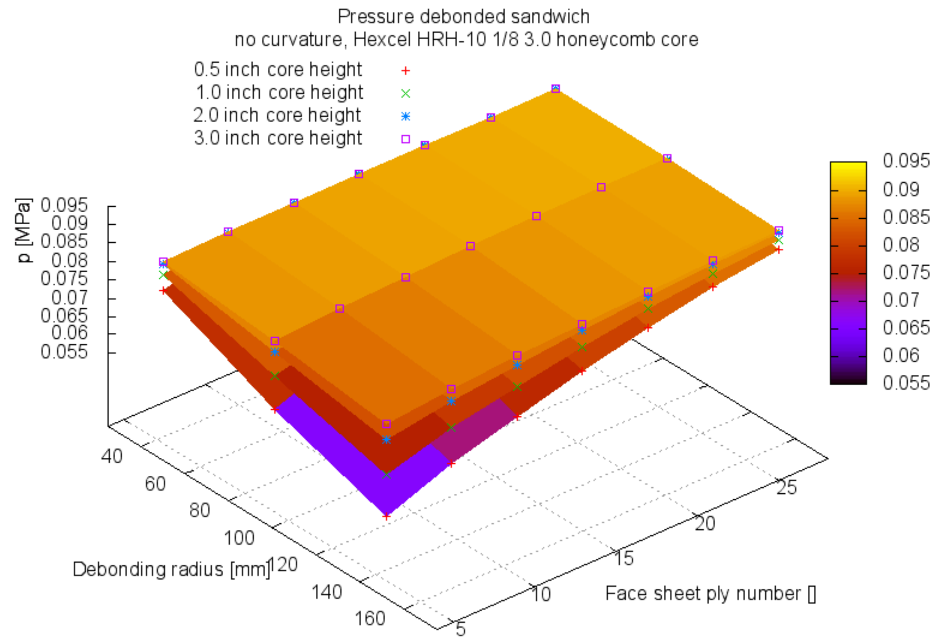
Results

Variation of face sheet ply number, core height and disbond radius
Hexcel HRH-10 1/8 3.0 honeycomb core, zero curvature

Overall results: Pressure-deformation coupling





- Small core height result in higher relative volume increase
- Low relative volume increase means low pressure decrease
- Thus, pressure-deformation coupling is more important for thin cores and thick core sandwich structures are more critical

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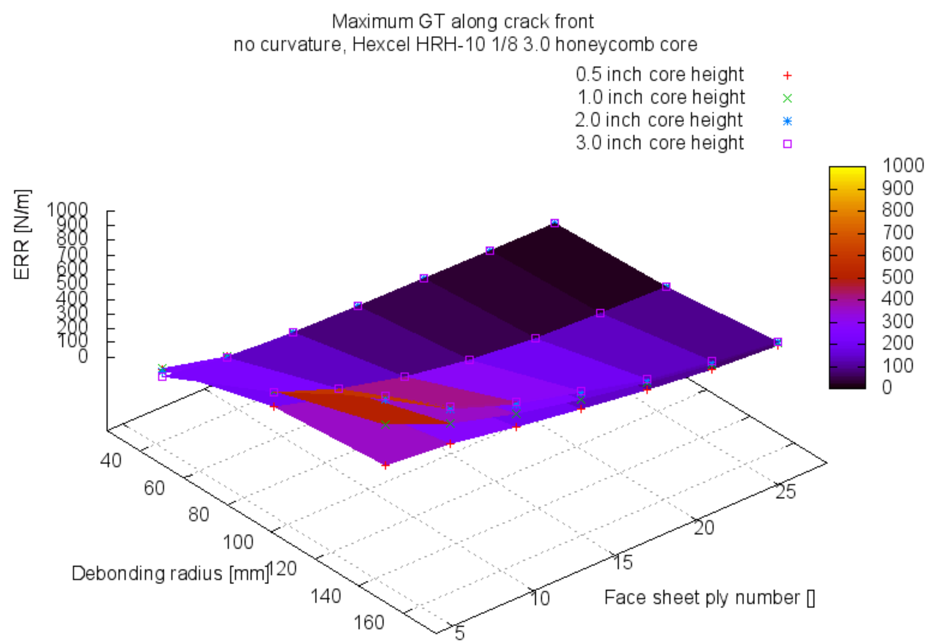
Results

Variation of face sheet ply number, core height and disbond radius
Hexcel HRH-10 1/8 3.0 honeycomb core, zero curvature

Overall results: Maximum GT (mostly at 45° axis between x and y axis)



- Due to the lower pressure decrease the crack tip loading is higher in the thick core sandwich

Does the ERR increase with growing disbonds stop at large disbonds?

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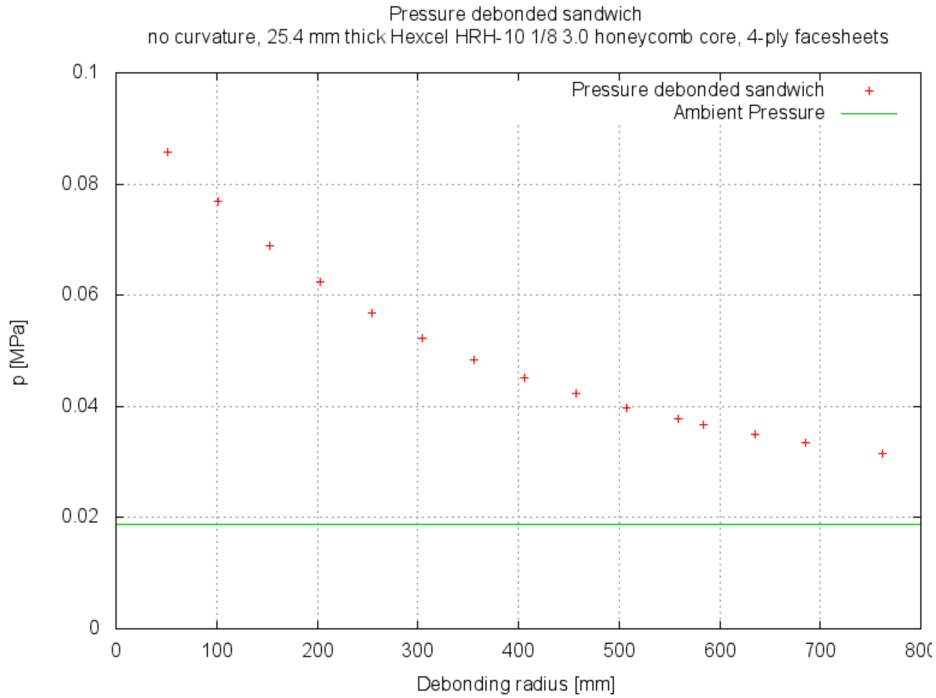
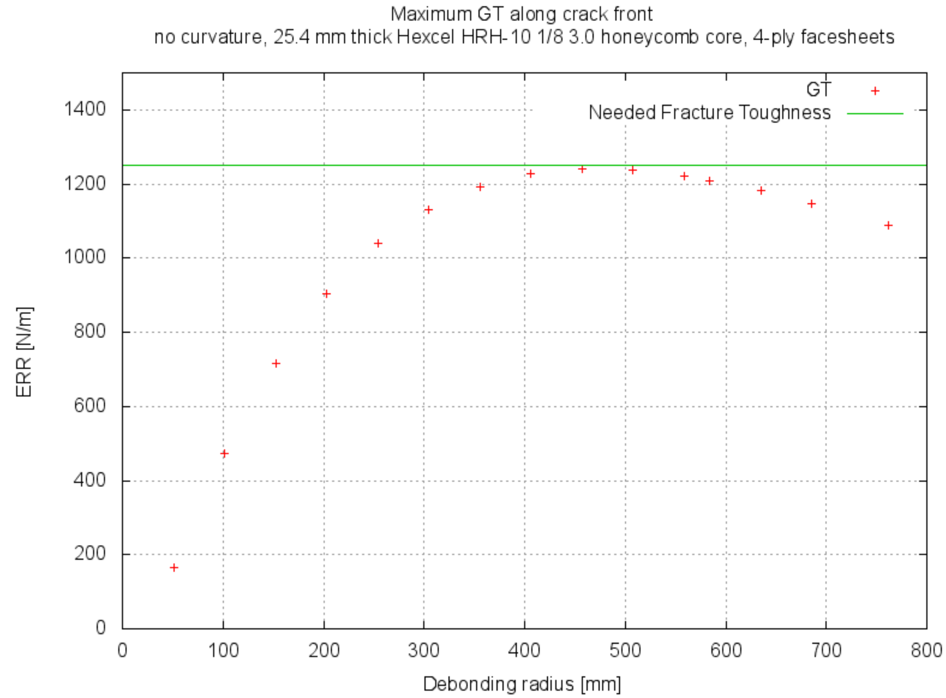
Results

Ground-air pressurization at very large disbonds
25.4 mm thick Hexcel HRH-10 1/8 3.0 honeycomb core, 4-ply face sheets, zero curvature





- With increasing disbond radius, the pressure in the debonded section decreases asymptotically to the ambient pressure
- Crack tip loading reaches a maximum and then decreases
- A minimum needed fracture toughness can be calculated for each sandwich configuration to prevent disbond growth independent of the disbond radius

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Conclusions

- Crack tip loading is for many of the here investigated sandwich configurations less critical than expected
- For thin face sheets and large disbonds, the pressure-deformation coupling following the ideal gas law needs to be considered
- The pressure decrease decreases the crack tip loading at very large disbonds significantly and eventually stops an explosive critical disbond propagation (highly depended on the sandwich configuration)