Parameter Identification for the Simulation of Debonding in Honeycomb Sandwich using LS-DYNA

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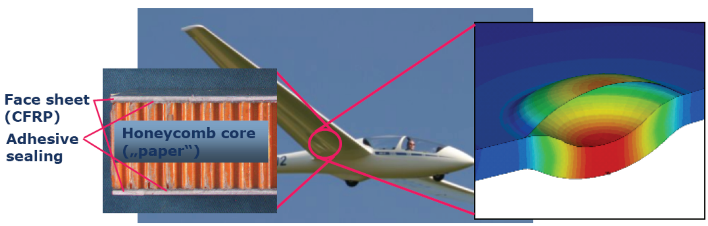
Problem Description

sandwich structures show outstanding performance concerning ratio of bending stiffness/weight



At what load level debonding occurs / becomes progressive?

Problem: Parts / Loadings are not applicable to test during flights! ("rupture level")

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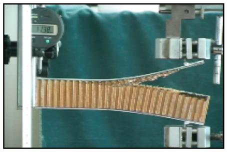
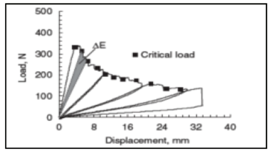
Problem Description

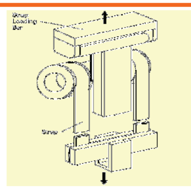
A characteristic value of the toughness of the adhesive sealing is determined by standardised tests ➔ G_c-value (Fracture energy release rate)

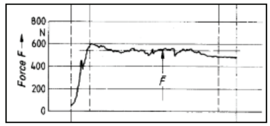
1. **Double Cantilever Beam-Test (DCB)**





2. **Drum Peel Test**





Challenging task: How to simulate the fracture tests with FEA?

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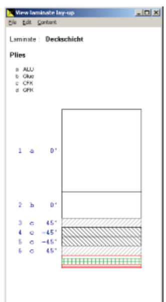
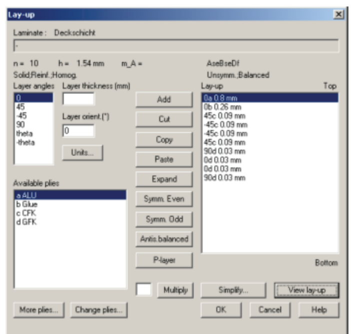
Modeling and Characteristics

New Feature in LS-DYNA971:

Different types of materials can be used for thickness integration points of shell

Calculation of displacements for a cantilever beam 220x50 [mm] made of face sheet and comparison with results of ESAComp





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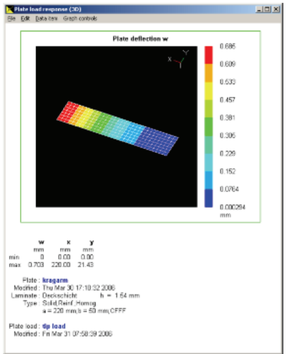
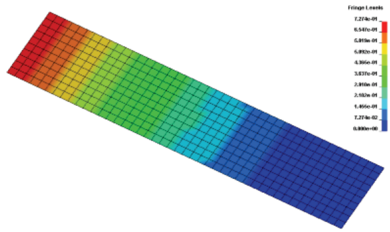
Modeling and Characteristics

ESAComp



Componeering,
distribution by CADFEM

LS-DYNA



Displacement of cantilever tip:

ESAComp → 0,70 mm (FSDT)

LS-DYNA → 0,71 mm (Reissner-Mindlin)

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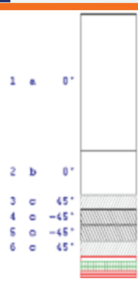
Modeling and Characteristics



variants

	#1	#2	#3	#4	#5	#6
Alu	2 IP halved	2 IP halved	1 IP mid	3 IP uniform	4 IP uniform	3 IP uniform
Glue	2 IP halved	2 IP halved	1 IP mid	3 IP uniform	4 IP uniform	1 IP uniform
CFRP	each 1 IP mid	each 2 IP halved	each 1 IP mid	each 1 IP mid	each 1 IP mid	each 1 IP mid
GFRP	each 1 IP mid	each 2 IP halved	each 1 IP mid	each 1 IP mid	each 1 IP mid	each 1 IP mid
displacement	0,7630	0,7627	1,045	0,7271	0,714	0,7274

→ Variant #5 is best in terms of displacement solution but expensive in terms of computation time (#IP=16)

→ Variant #6 is better than variant #1 although same number of integration points is used (#IP=12)

→ User-defined integration method needs more integration points in order to calculate bending dominant stiff layers correctly; one integration point per layer is not sufficient; no Gauss integration method is used anymore

→ In view of accuracy and computation time variant #6 is used

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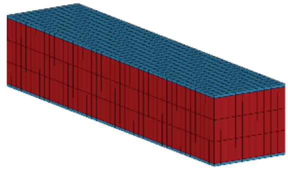
Modeling and Characteristics



Geometry [mm]:

Length = 220; width = 50; height core = 40; thickness face sheet = 1,54

Used element types:

Solid → one-point integration hexahedron (Typ1)

Shell → S/R integrated four-noded shell element (type 16) shells offset by half the shell thickness

Elemente sizes:

in plane of DCB → 5,0 mm

along thickness of core → 13,33 mm

Used material models:

Core → *MAT_ORTHOTROPIC_ELASTIC

CFK → *MAT_ENHANCED_COMPOSITE_DAMAGE GFK → * MAT_ENHANCED_COMPOSITE_DAMAGE

Glue → *MAT_ELASTIC Alu → *MAT_ELASTIC

Boundary prescribed motion:

Imposed velocity in z-direction for nodes of shells in a distance of 25 mm from leading edge of DCB; on both top side and bottom side applied

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Modeling and Characteristics

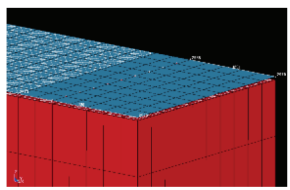
Bonding face layer with core – Modeling

*CONTACT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK

New contact option in LS-DYNA971 with input of failure stresses normal and tangential (nfls, sfls) as well with maximum crack opening displacement (ccrit) for which no stresses are transmitted anymore (cohesive zone model

Top face layer unbonded with a length of 35 mm from leading edge of DCB specimen; otherwise fully bonded

Bottom face layer fully bonded



Bonding face layer with core – Contact card

```
*CONTACT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK_ID
$#     cid                                                                title
         1upper layer with core
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         1         3         0         0         0         0         1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
  0.100000     0.000     0.000     0.000 10.000000         0     0.0001.0000E+20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
 10.000000 10.000000     0.000     0.000  1.000000  1.000000  1.000000  1.000000
$#  option      nfls      sfls     ccrit
         8&nfls     &sfls     &ccrit
```

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Modeling and Characteristics

***PART_COMPOSITE: new feature in LS-DYNA 971**

```
*PART_COMPOSITE
$# title
Deckschicht positiv z-richtung
$#     pid    elform      shrf      nloc     marea      hgid    adpopt
         2        16     0.833         0         0         2         0
$ 4 Layers GFRP [90/0/0/90] each 0.03mm thick
$      mid     thick      beta                 mid     thick      beta
         3      0.03      90.0                   3      0.03       0.0
$      mid     thick      beta                 mid     thick      beta
         3      0.03       0.0                   3      0.03      90.0
$ 4 Layers CFRP [45/-45/-45/45] each 0.09mm thick
$      mid     thick      beta                 mid     thick      beta
         2      0.09      45.0                   2      0.09     -45.0
$      mid     thick      beta                 mid     thick      beta
         2      0.09     -45.0                   2      0.09      45.0
$ 1 Integrationpoint for Gluing Layer 0.26mm thick
$      mid     thick      beta                 mid     thick      beta
         4      0.26       0.0
$ 3 Integrationpoints for Aluminum Doubler 0.8mm thick
$      mid     thick      beta                 mid     thick      beta
         5      0.27       0.0                   5      0.27       0.0
$      mid     thick      beta                 mid     thick      beta
         5      0.26       0.0
```

Laminate setup (from core side to outer face):

Material/Orient	GFK [90/0/0/90]	CFK [45/-45/-45/45]	Glue [isotropic]	Alu [isotropic]
Thickness	4x0,03	4x0,09	1x0,26	1x0,80
Material-ID	3	2	4	5

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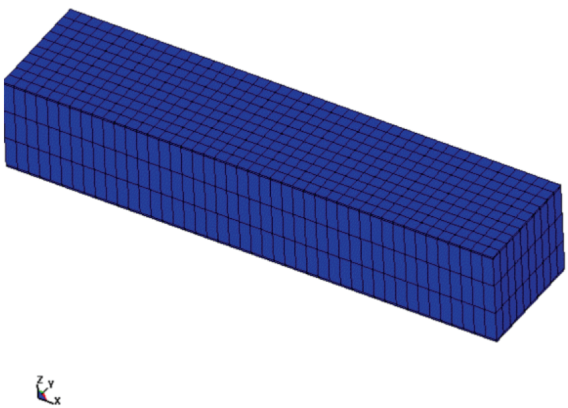
Resultant Displacement

DCB-TEST, QUASISTATIC SIMULATION, MHOE



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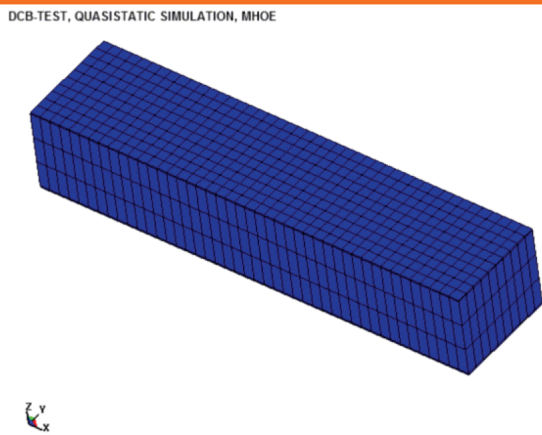
Resultant M_x-Moment



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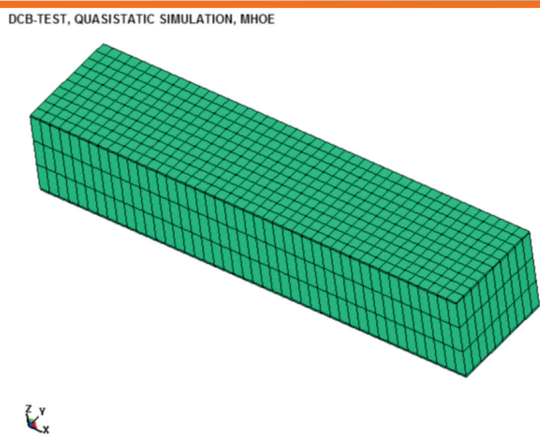
Resultant N_x-Force



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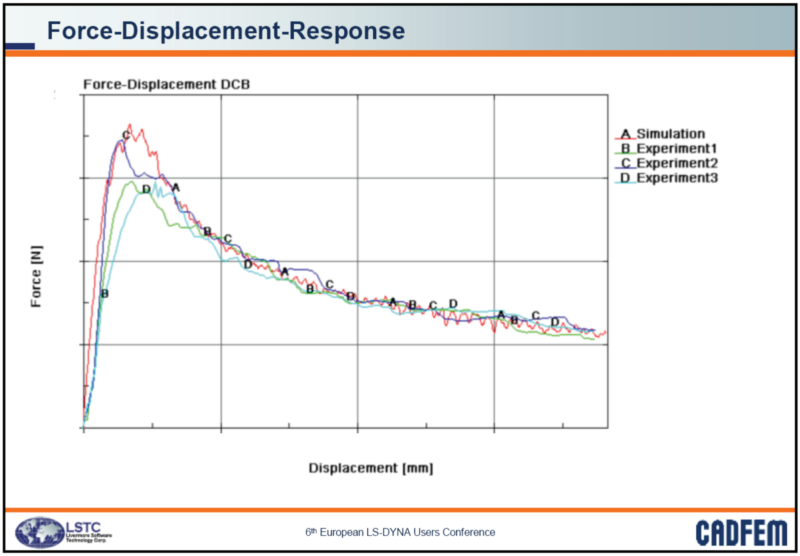
Force-Displacement-Response
Force-Displacement DCB
Force [N]
Displacement [mm]
A Simulation
B Experiment1
C Experiment2
D Experiment3
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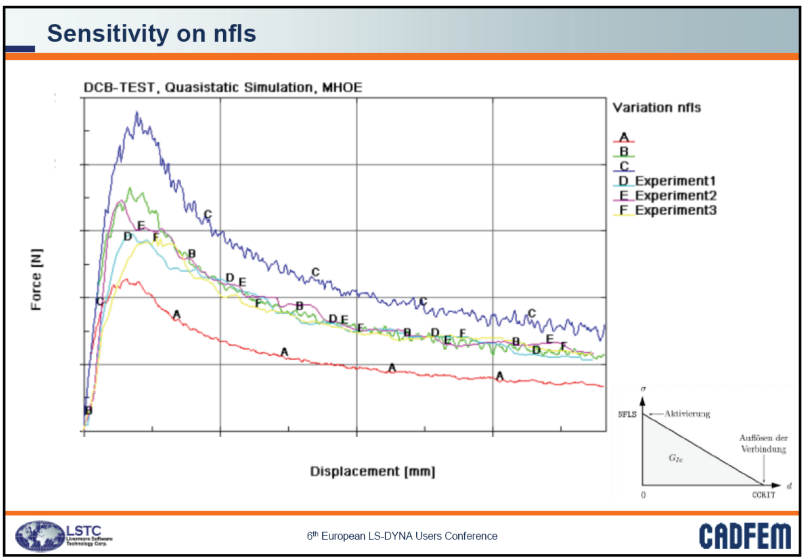
Sensitivity on nfls
DCB-TEST, Quasistatic Simulation, MHOE
Force [N]
Displacement [mm]
Variation nfls
A
B
C
D Experiment1
E Experiment2
F Experiment3
NFLS
Aktivierung
Auflösen der Verbindung
CCRIT
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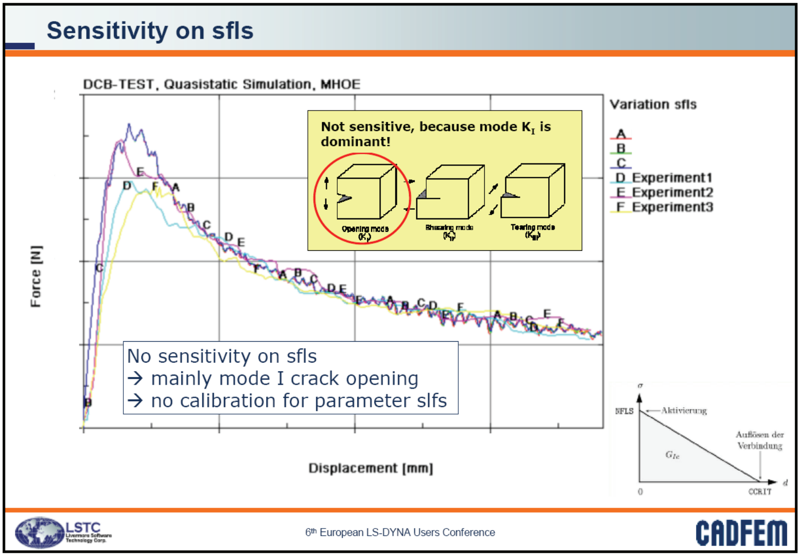
Sensitivity on sfls
DCB-TEST, Quasistatic Simulation, MHOE
Force [N]
Displacement [mm]
Variation sfls
A
B
C
D Experiment1
E Experiment2
F Experiment3
Not sensitive, because mode K_I is dominant!
Opening mode (K_I)
Shearing mode (K_{II})
Tearing mode (K_{III})
No sensitivity on sfls
→ mainly mode I crack opening
→ no calibration for parameter slfs
σ
NFLS
Aktivierung
Auflösen der Verbindung
G_{Ic}
0
CCRIT
d
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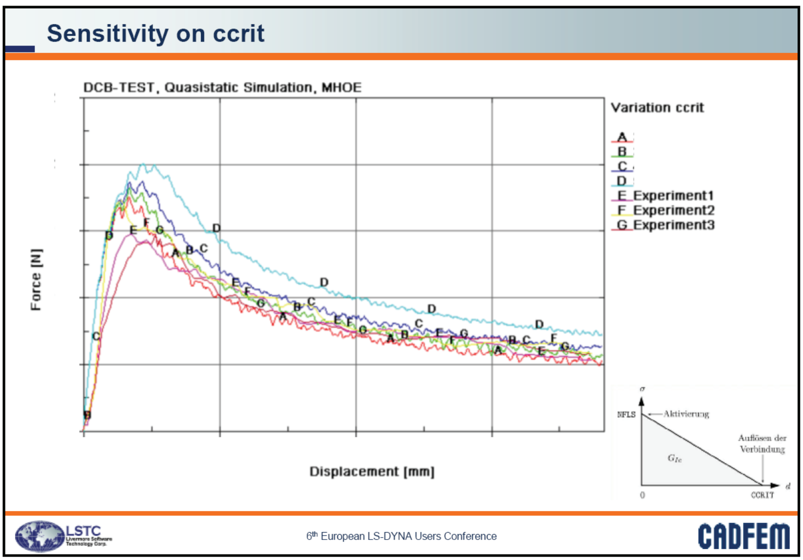
Sensitivity on ccrit
DCB-TEST, Quasistatic Simulation, MHOE
Force [N]
Displacement [mm]
Variation ccrit
A
B
C
D
E Experiment1
F Experiment2
G Experiment3
σ
NFLS
Aktivierung
Auflösen der Verbindung
G_{Ic}
0
CCRIT
d
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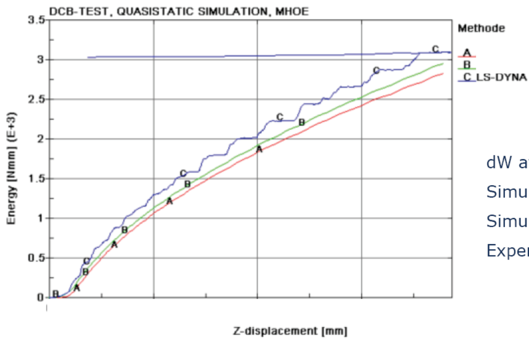
Energy vs. Crack Opening



dW at U_{Zmax}

Simulation=2.96 J, method B

Simulation=2.83 J, method A

Experiment= 3.22 J; 3.03 J; 3.03 J

LS-DYNA

Energy before unloading = 3.10 J

Energy after unloading = 3.04 J

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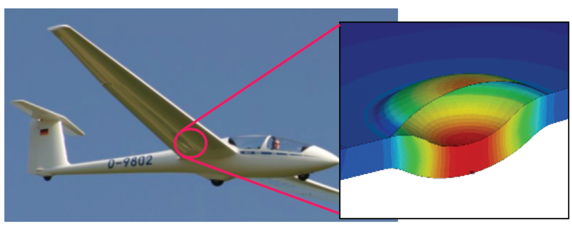
Application – Prediction of Debonding Start Level



At what load level delamination occurs / becomes progressive?

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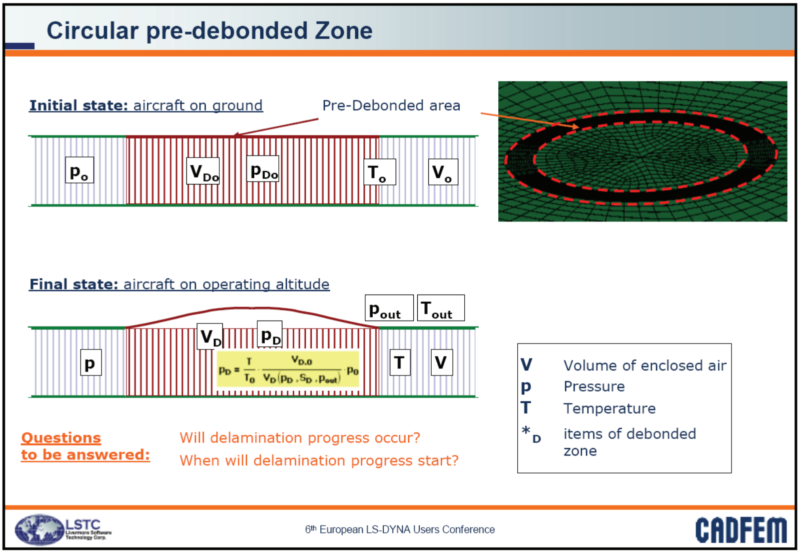
Circular pre-debonded Zone
Initial state: aircraft on ground
Pre-Debonded area
p_o
V_Do
p_Do
T_o
V_o
Final state: aircraft on operating altitude
p_out
T_out
V_D
p_D
p
T
V
p_D = T/T_0 · V_D,0 / V_D(p_D, S_D, p_out) · p_0
V Volume of enclosed air
p Pressure
T Temperature
*_D items of debonded zone
Questions to be answered:
Will delamination progress occur?
When will delamination progress start?
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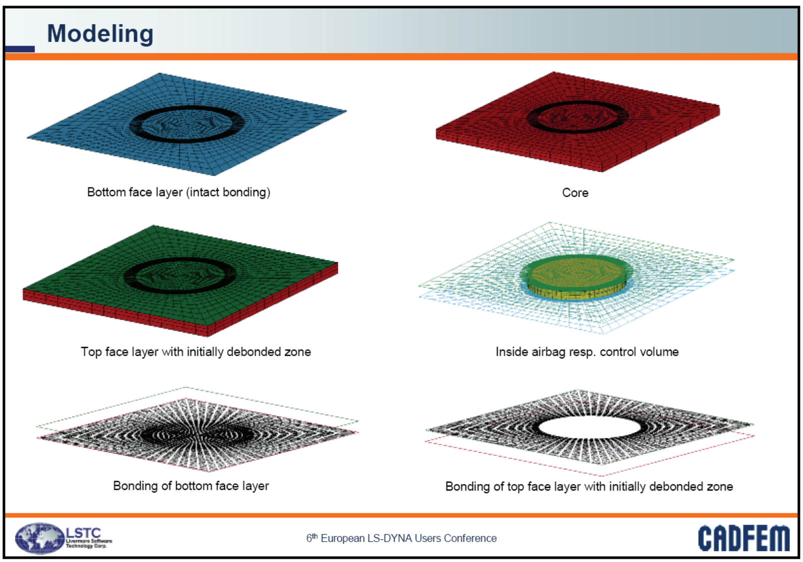
Modeling
Bottom face layer (intact bonding)
Core
Top face layer with initially debonded zone
Inside airbag resp. control volume
Bonding of bottom face layer
Bonding of top face layer with initially debonded zone
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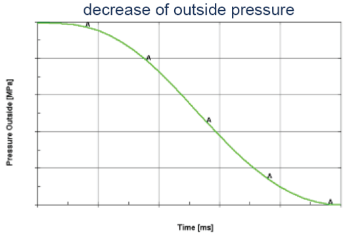
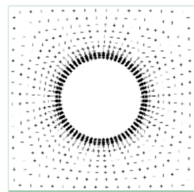
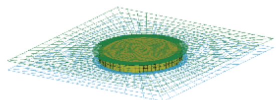
Modeling

decrease of outside pressure



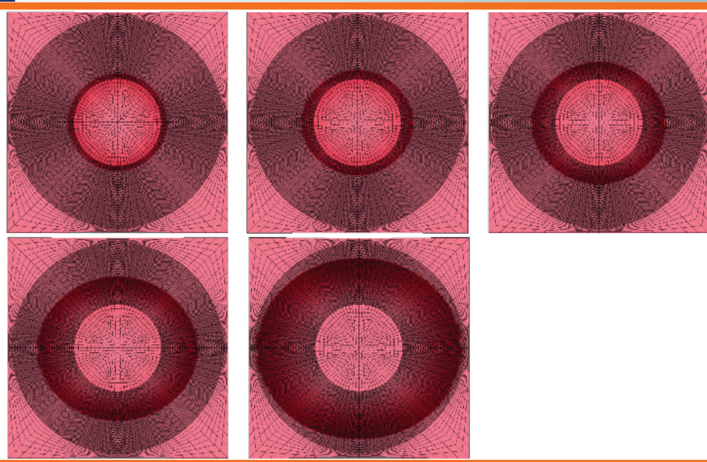
outside pressure on entire surface



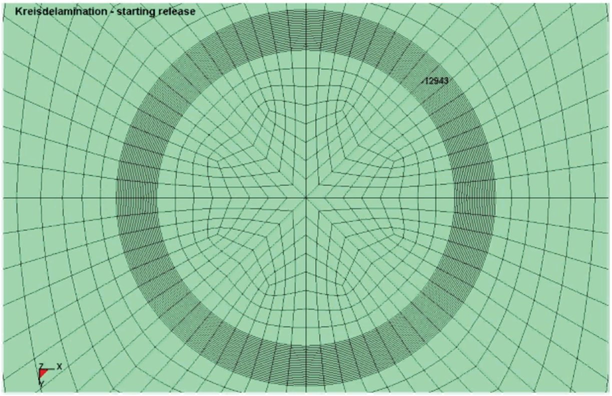


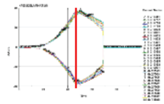
constant inside pressure on undebonded area as well as on circumferential surface of airbag

Debonding Progress



Debonding – Starting Release





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Experiences & Summary

- Number of integration points per physical layer can influence stiffness and displacement response of structure if stiff and bending dominant layers are present
  → pre-check for integration rule is useful and recommended
- Calibration of failure relevant parameters (nfls, ccrit) with DCB specimen possible; no calibration of parameter sfls
  → needs to be finally checked with ENF specimen (mode II)
  → drawback: only one ccrit is introduced, must fit both loading cases
- Good correlation with experimental result of DCB specimen
- Energy calculated from sliding interface energy fits well with experimentally observed fracture energy in DCB specimen
- Debonding onset and progress can be predicted in circular pre-debonded plate
- Debonding remains in interface between face layers and honeycomb core
  → DCB test shows failure of core at larger crack openings

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