Crashworthiness of Composite Structures

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Crashworthiness: Previous Results

- Current FE modeling strategies for composite materials are not predictive
- Modeling strategies require the use of control parameters, some of which cannot be measured experimentally, need to be calibrated by trial and error, and may not have a physical significance
  - **SOFT Parameter**
  - **Stress-Strain curve behavior**
  - **Force-penetration curve**
  - **Contact Formulation**
- The need to produce numerical guidelines is very important to prevent gross mistakes associated with the selection of these parameters

Crushing of square tube

- Trial and error procedure to find the “right” SOFT parameter that matches the experiment
- Softening reduction factor for material strength in crashfront elements.

Figure 12. Example of an unstable crushing of the tubular shape with SOFT=0.64 Buckling starts after 2.446millsec at a displacement of 0.3669 inches.

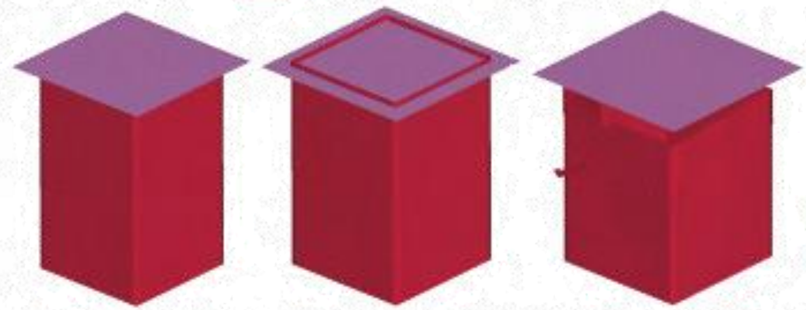


Figure 13. Example of an unstable crushing of the tubular shape with SOFT=0.3. Buckling starts after 3.728millsec at a displacement of 0.5592 inches.

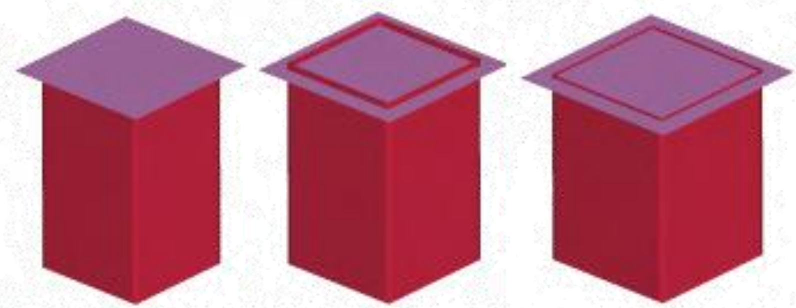
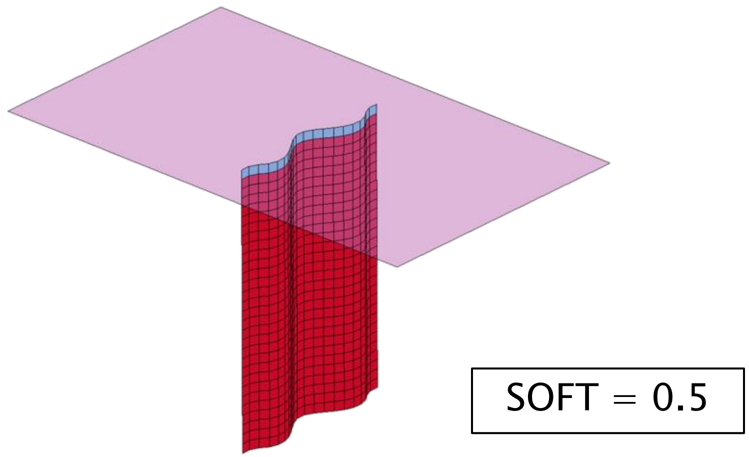
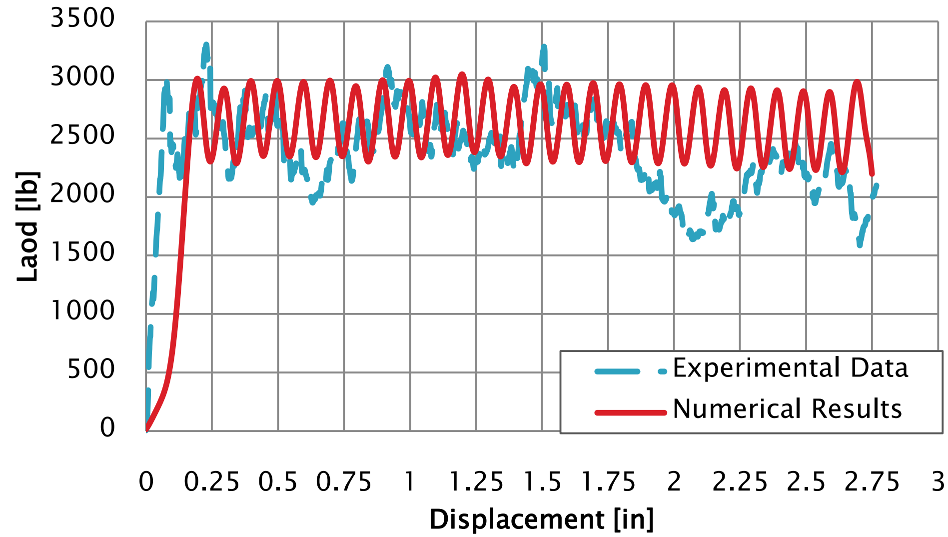
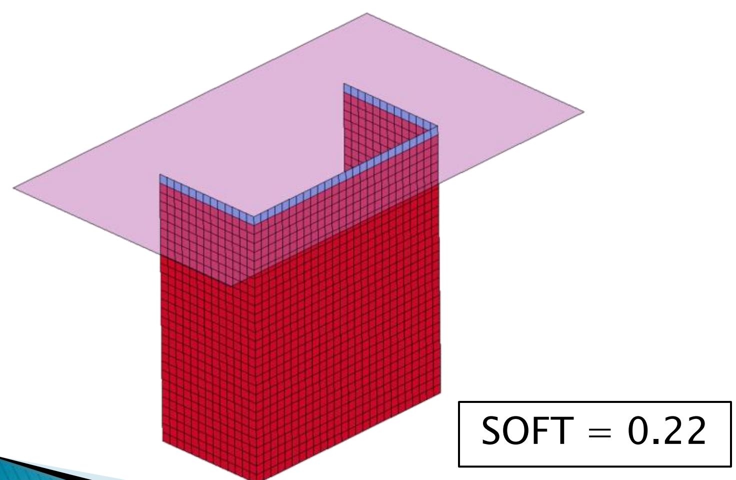


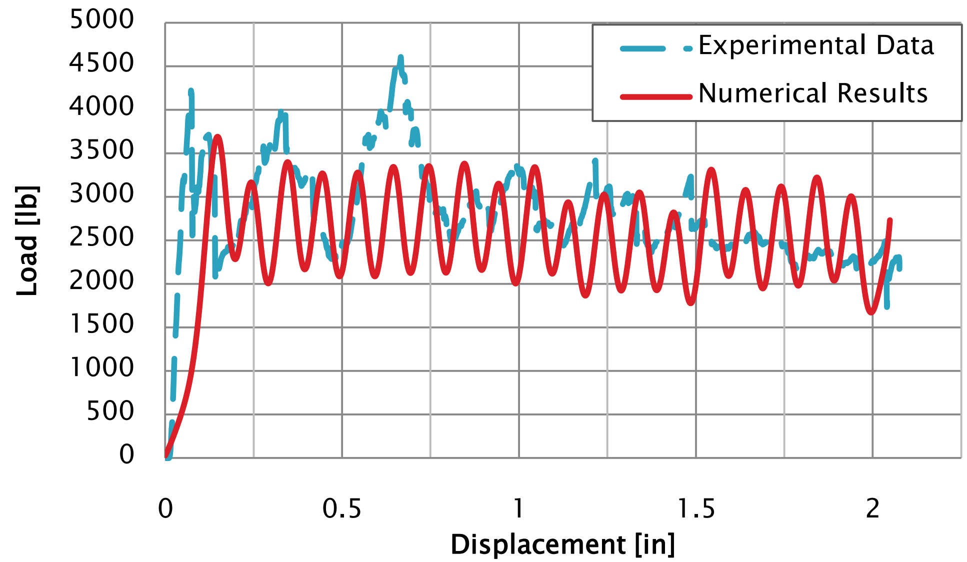
Figure 14. Example of a stable crushing of the tubular shape with SOFT=0.08. No buckling.

Crushing of other geometries



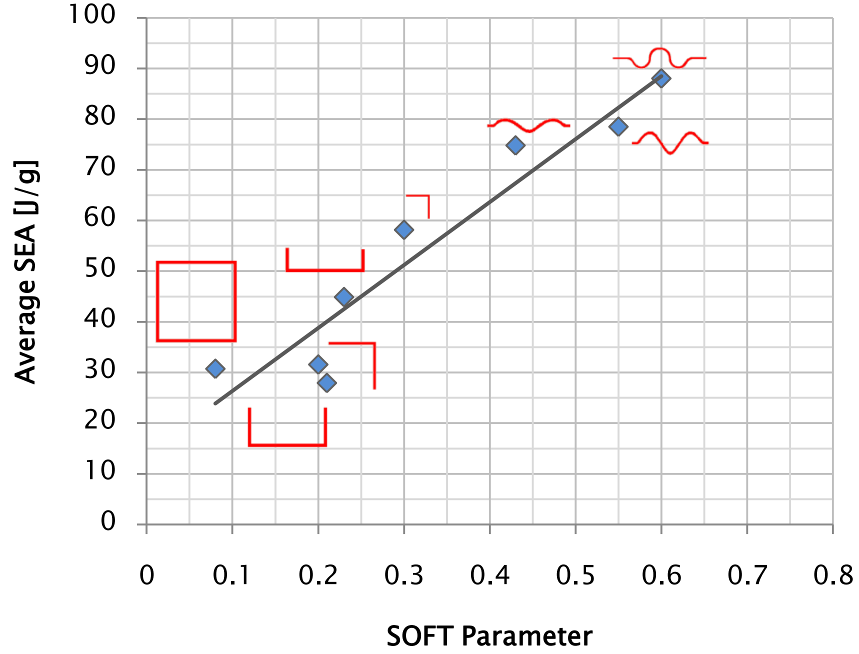






Observations

- For all geometries it is possible to find a suitable value of the SOFT parameter by trial and error
- Each geometry is characterized by a specific value of SOFT that matches the experimental data, while keeping all other parameters unchanged
- The same input deck cannot be used to predict all geometries "as-is"
- Thus the building block approach cannot be used "as-is" to scale from a coupon test to any other geometry
- SOFT parameter is a control parameter

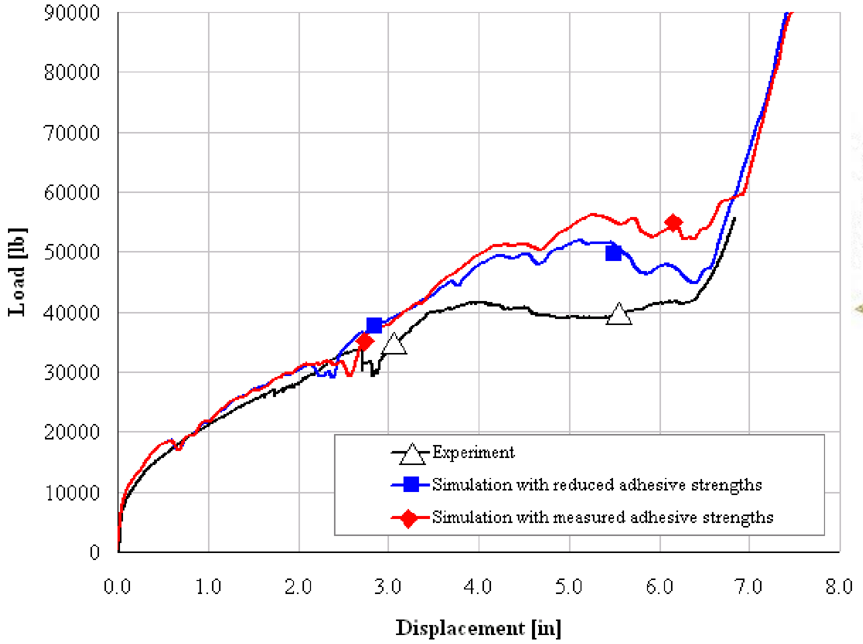


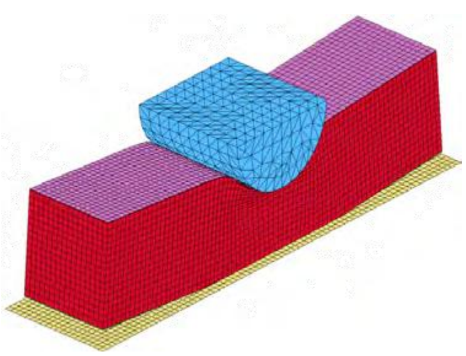
Crashworthiness: Previous Results

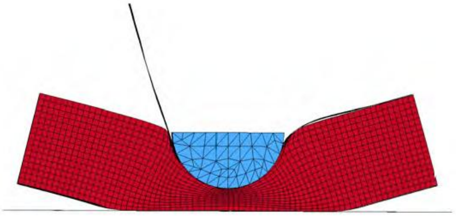
- Progressive Crushing and Penetration of a Deep Sandwich Composite Structure
- Door sill technology demonstrator for certification by analysis for automotive application
- Certification by analysis supported by test evidence
    - Derived from commercial aircraft industry
    - Adapted to automotive needs by Lamborghini
    - Reduces amount of large scale testing by using a mix of testing and analysis

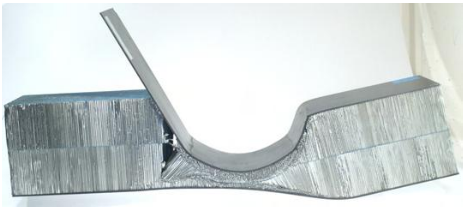
Validation of material model

- Application of the Building Block Approach
- Material models generated by using experimental values
  - MAT 54 for composite facesheets
  - MAT 126 for honeycomb core
- Tie-break contact for adhesive joint
- Material models and contact algorithm calibrated at element level
- Sub-component level: Full scale model assembled and parameters CANNOT be changed to match experiment



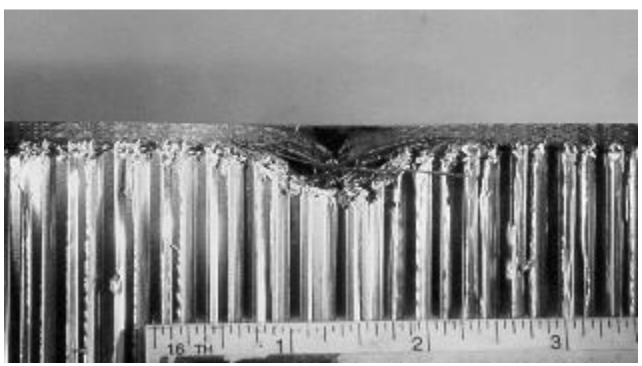


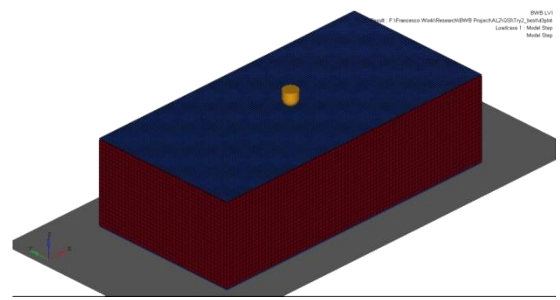


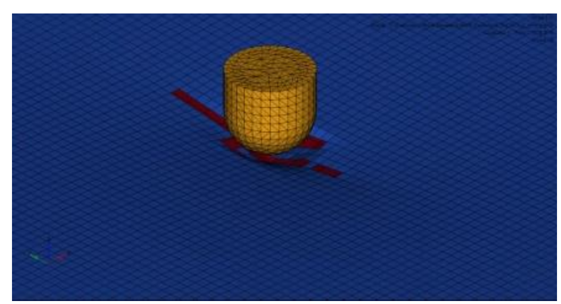


New Case Study

- Simulation of Low Velocity Impact and Quasi Static Indentation of Honeycomb Sandwich Structures with LS-Dyna
- FOD/ Impact Damage Testing of HC Structures
- Knowledge gained from the crashworthiness study of the door sill applied to the study of damage resistance and damage tolerance for LVI







FOD/ Impact Damage Testing

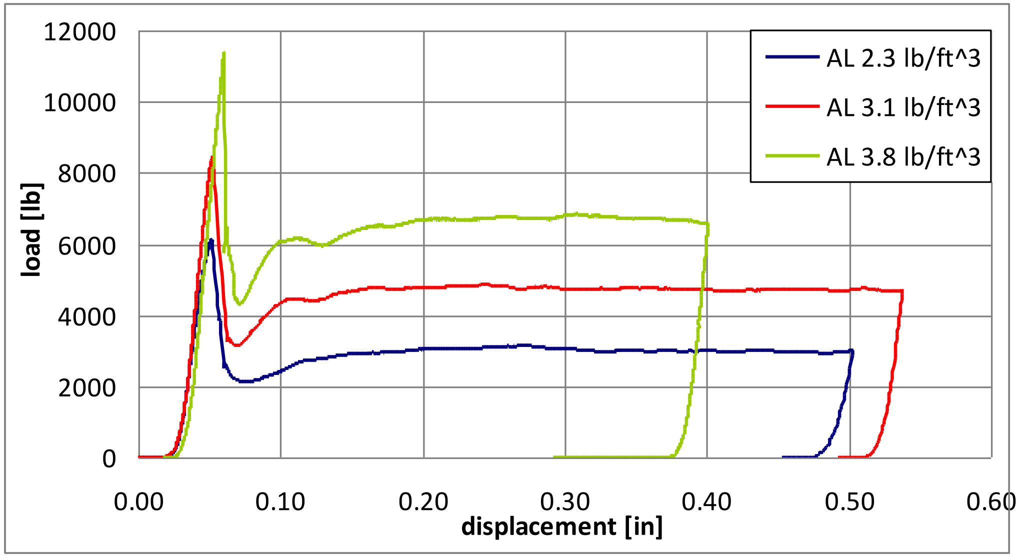
- Purpose: to simulate Quasi-Static Indentation (QSI) and Low Velocity Impact (LVI) tests of very thick sandwich panels, developed as candidate materials for highly loaded fuselage cover panels of possible future aerospace concepts.
- Five different types of specimens: varying in facesheet thickness and core density in order to investigate the influence of the components to material response and damage resistance
- Development of a model which is predictive for all configurations, consisting in varying the energy level, core density and/or facesheet thickness

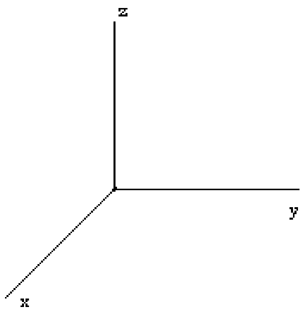
Configuration ID	Facesheet Thickness in. (mm)	Core Density lb/ft^3 (kg/m^3)
AL1	.165 (4.2)	2.3 (36.8)
AL2	.165 (4.2)	3.1 (49.6)
AL3	.165 (4.2)	3.8 (60.9)
AL4	0.22 (5.6)	3.1 (49.6)
AL5	0.11 (2.8)	3.1 (49.6)

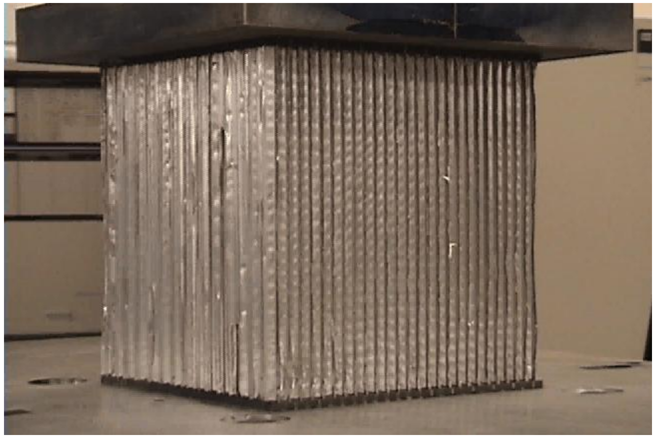
Configuration	LVI ft lb (J)	QSI No. of specimen
AL1	10, 20, 30, 60	1
AL2	20, 30, 50	1
AL3	10, 20, 30	1
AL4	10, 30, 50	1
AL5	10, 20, 30	1

Material model generation

- MAT 126 material model
- Core crushing stress – strain curves are needed for model
- z-direction compression/ crushing experimentally derived.
- x-, y- and shear directions borrowed from literature.







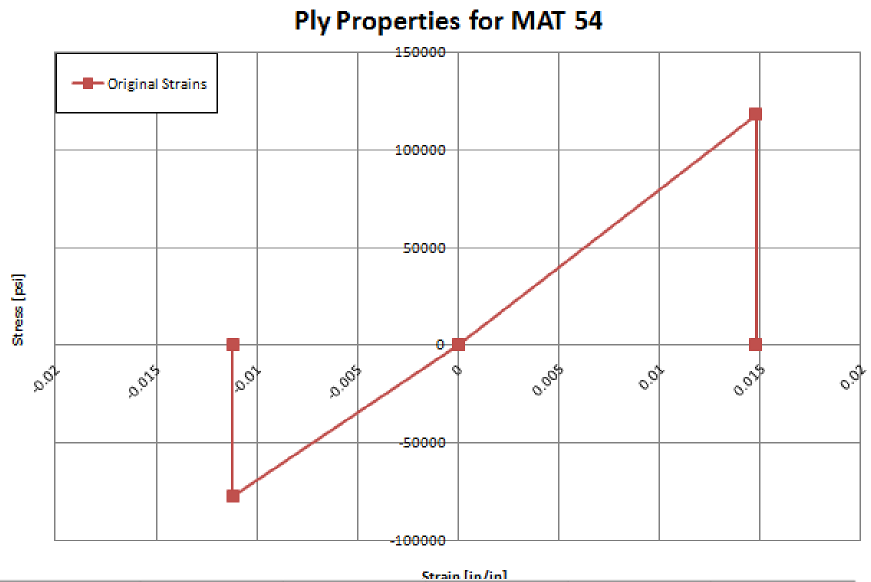
Material model generation

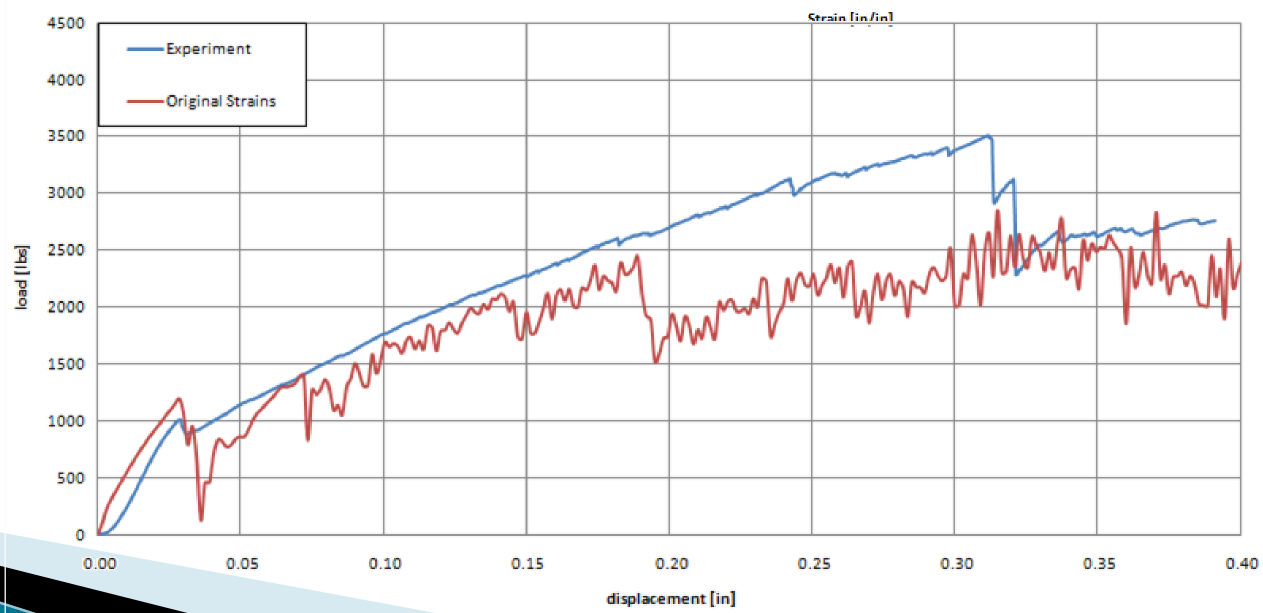
- Mat 54 material model
- Composite facesheets: AS4/3501-6 carbon-epoxy warp-knit preforms.
- Stitching done with 0.125 in step and 0.2 in spacing using Kevlar 29.
- Impregnation by Resin Film Infusion
- Specimens manufactured for ACT Program for NASA Langley

Stacking Sequence	E_x Msi (GPa)	E_y Msi (GPa)	G_{xy} Msi (GPa)	v_{xy}
$[45/-45/0_2/90/0_2/-45/45]_{nT}$	8.89 (57.3)	5.22 (35.9)	2.0 (13.8)	0.459

Material model Generation

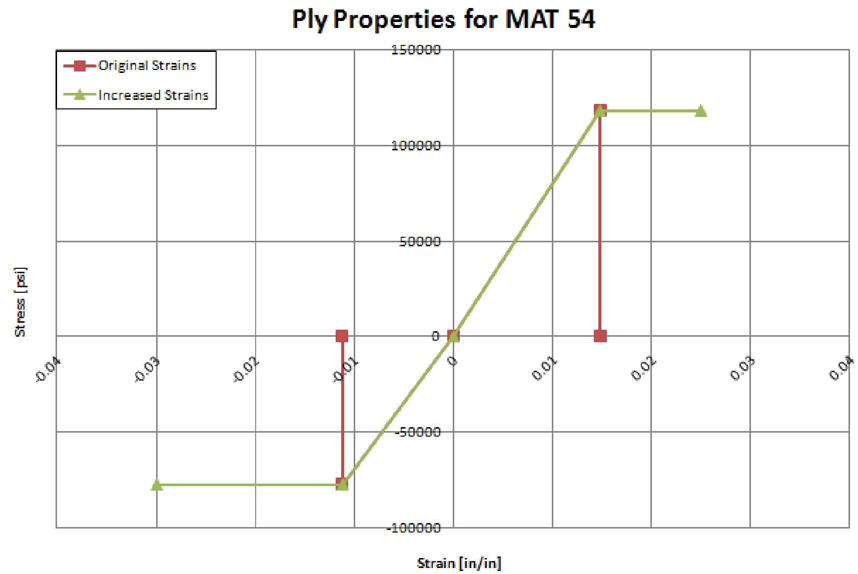
- Experimental strains to failure
- Dfailt: 0.0148 [in/in]
- Dfailc: -0.0112 [in/in]

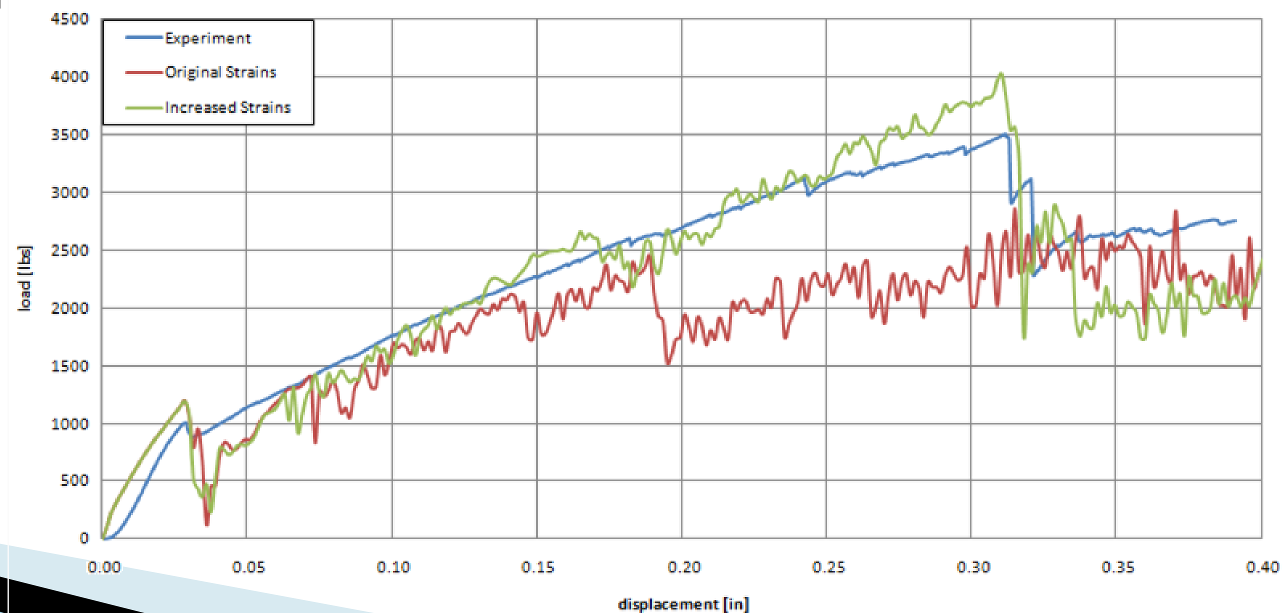




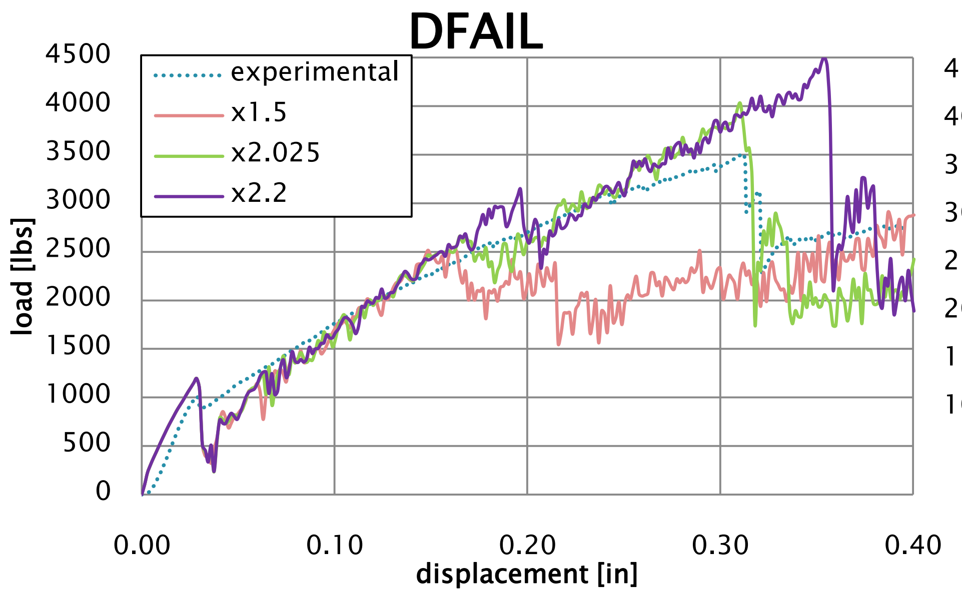
Material model Calibration

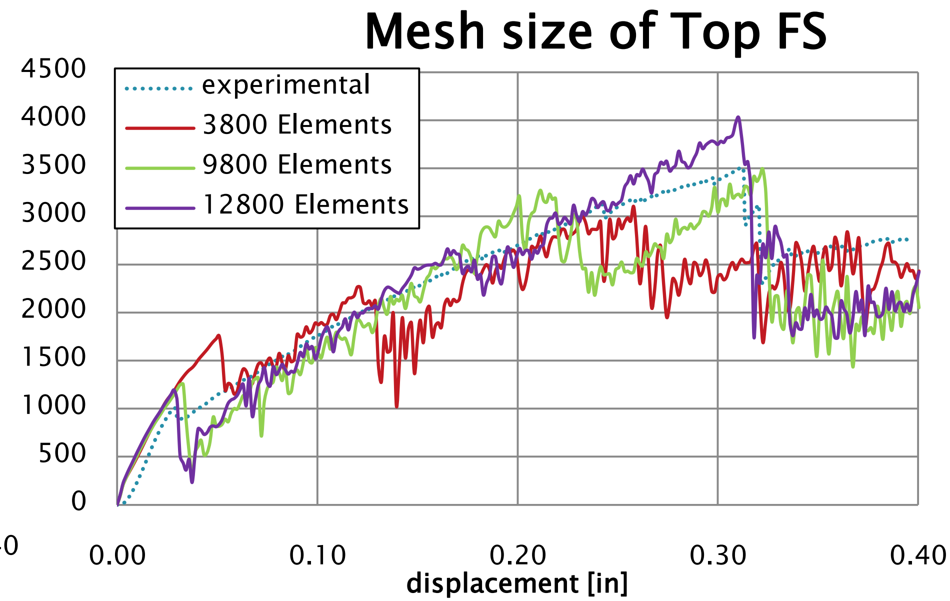
- Maximum tensile and compressive strain
- DFAILT, DFAILC and DFAILM increased to exceed experimental values
- DFAIL used as control parameter is a modeling strategy commonly used with MAT 54

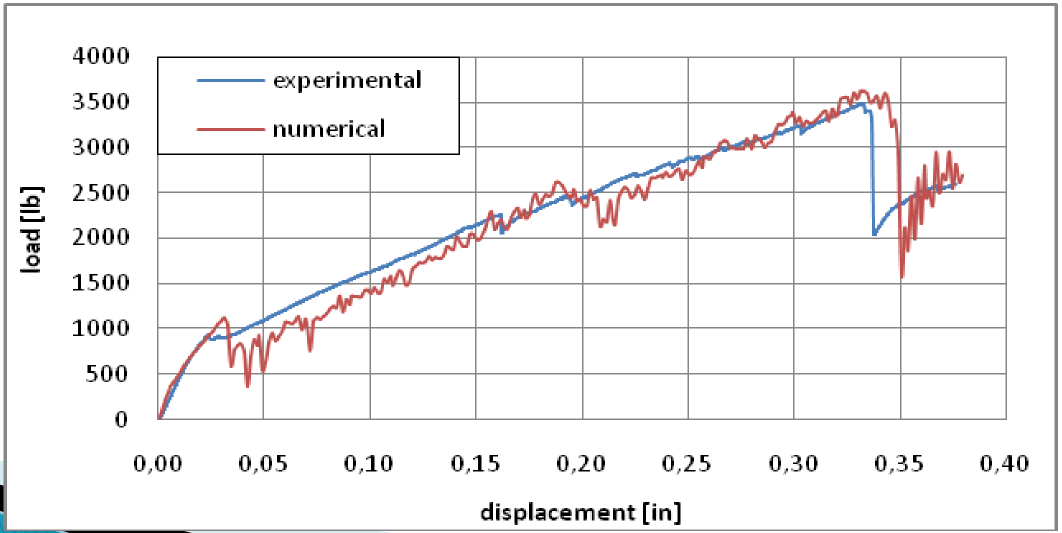




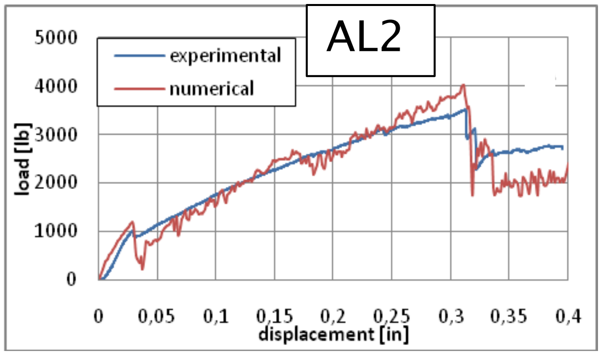
Material Model Calibration

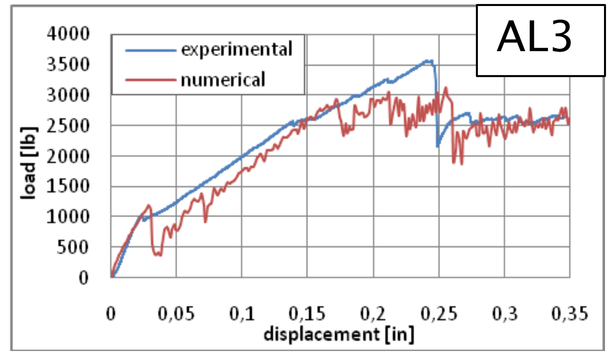


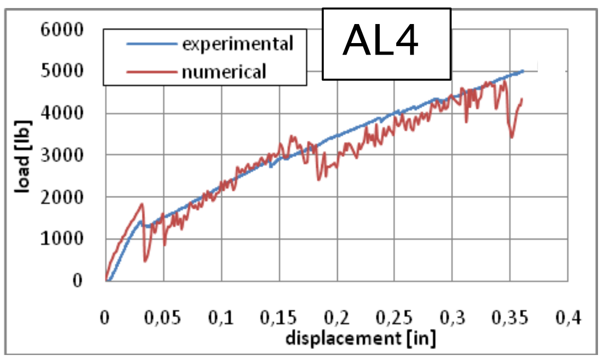


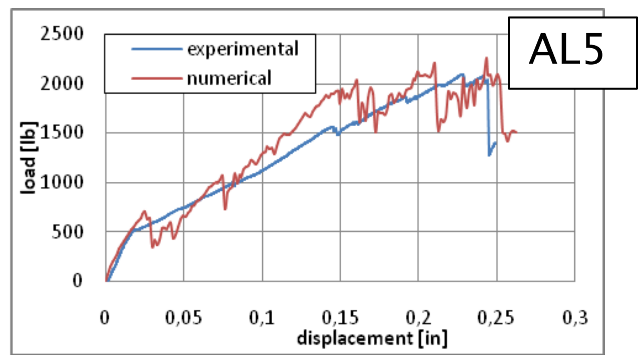


QSI Results







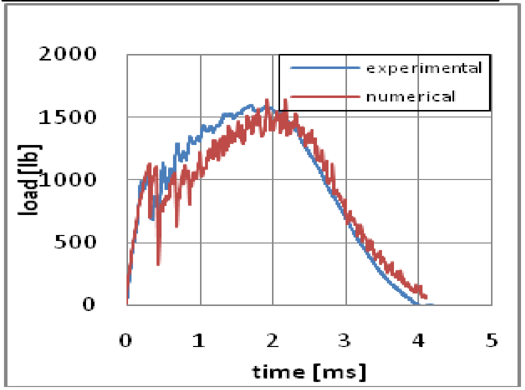


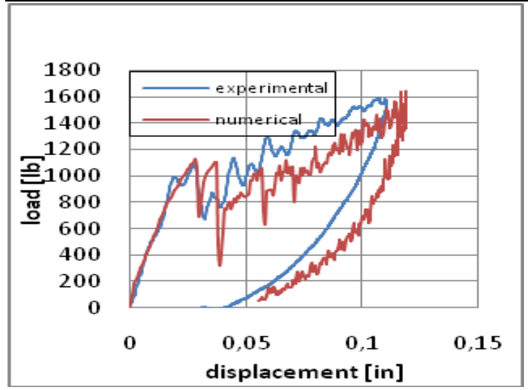
- All material models, contact algorithm, mesh size of all parts and boundary conditions are kept contacts
- Different configuration only varied in FS thickness and HC density
- Load – displ slope, onset of failure and first dimple match well with experimental evidence

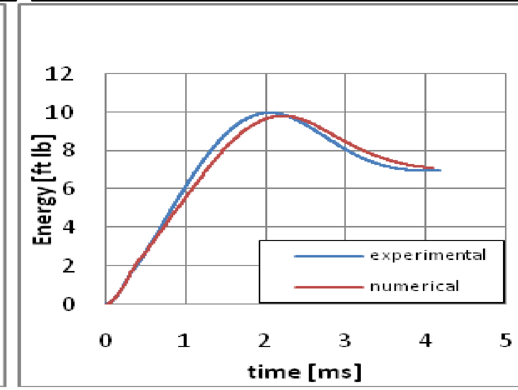
AL1 LVI Results

Load – Time | Load – Displacement | Energy – time

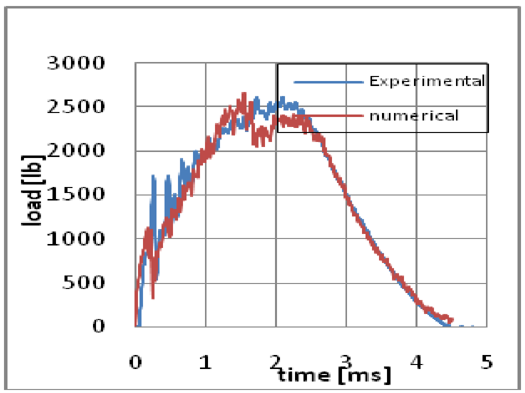
10 ft-lb

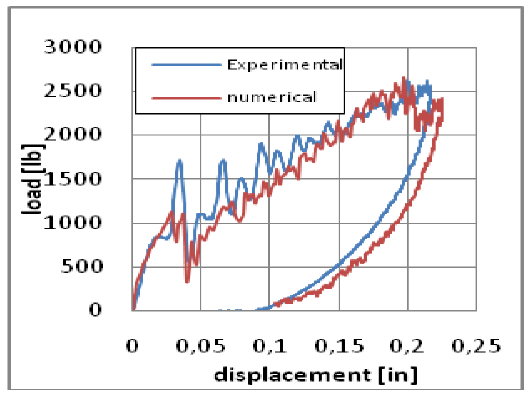


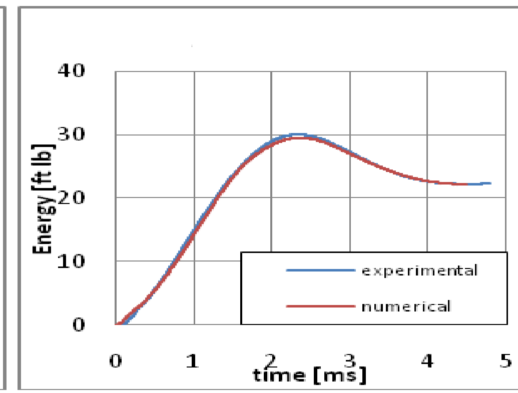




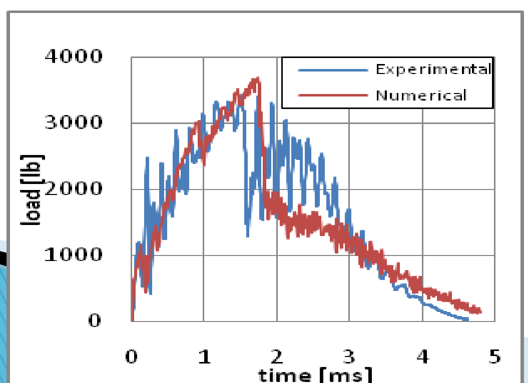
30 ft-lb

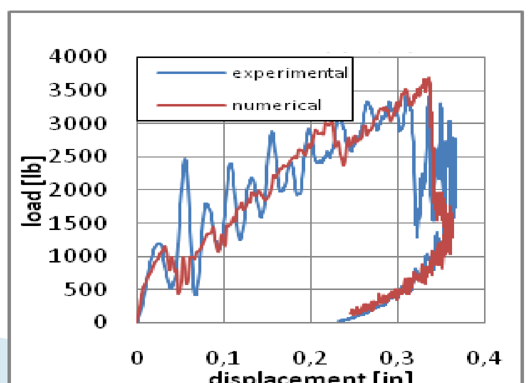


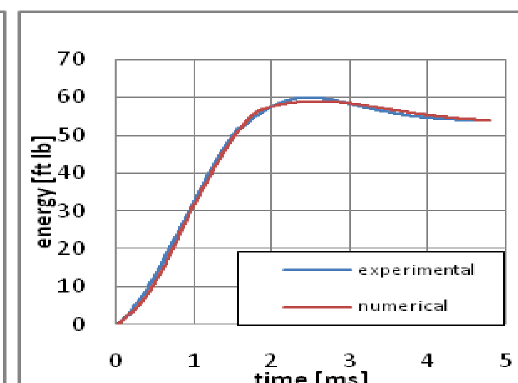




60 ft-lb

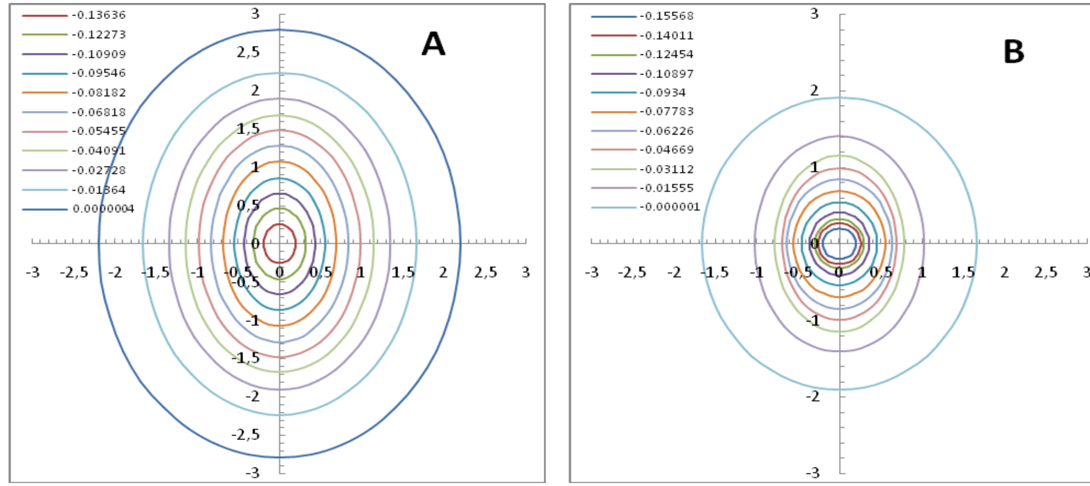




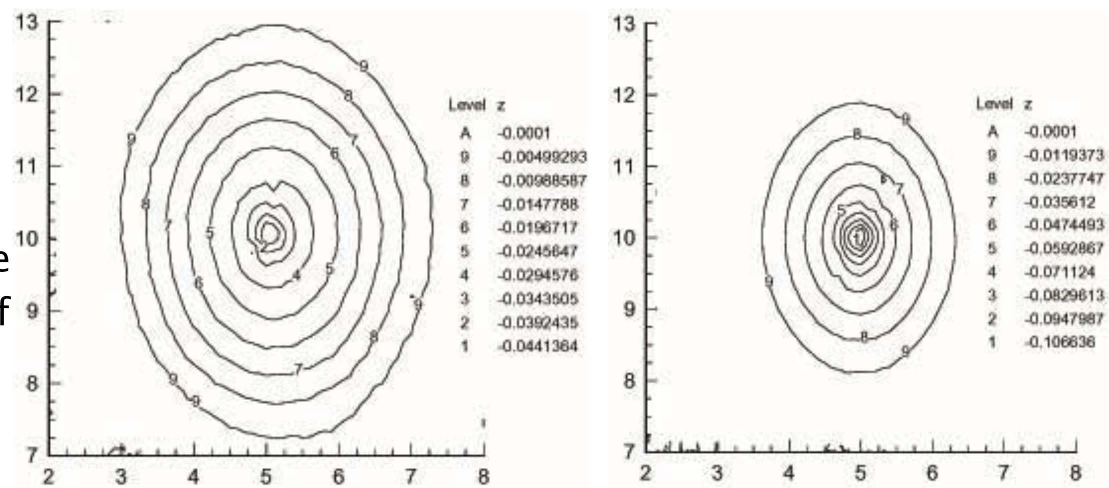


Damage Area

- Nearly circular area of the maximum dent depth at center, larger but shallower area with an elliptical overall shape
- Dent depth for AL5 is deeper and more concentrated, the indented area of AL1 is larger but shallower
- For increasing FS thickness the FS become stiffer and provide a greater resistance to penetration so that the load is distributed to a larger area across the core
- The elliptical shape of the indentation profile is due to the anisotropic elastic properties of the FS



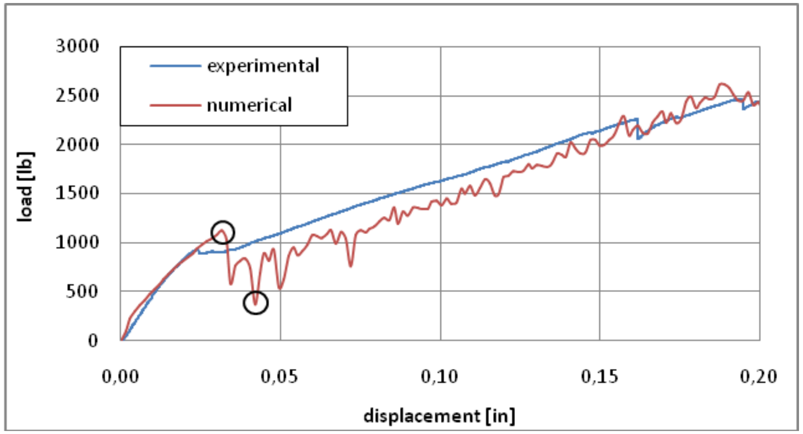
Numerical Indentation depth contour for AL1 (A) and AL5 (B) at 30ft lb

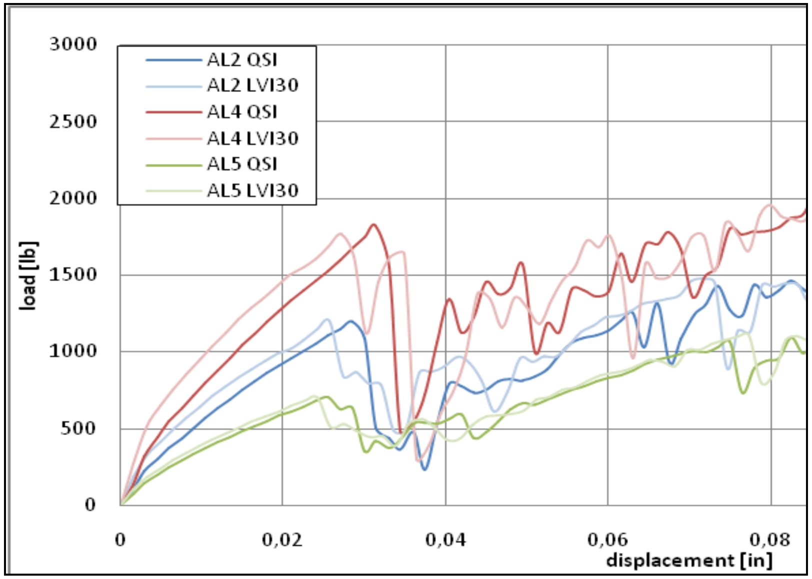


Experimental indentation depth contour for AL1 (A) and AL5 (B) at 30ft lb

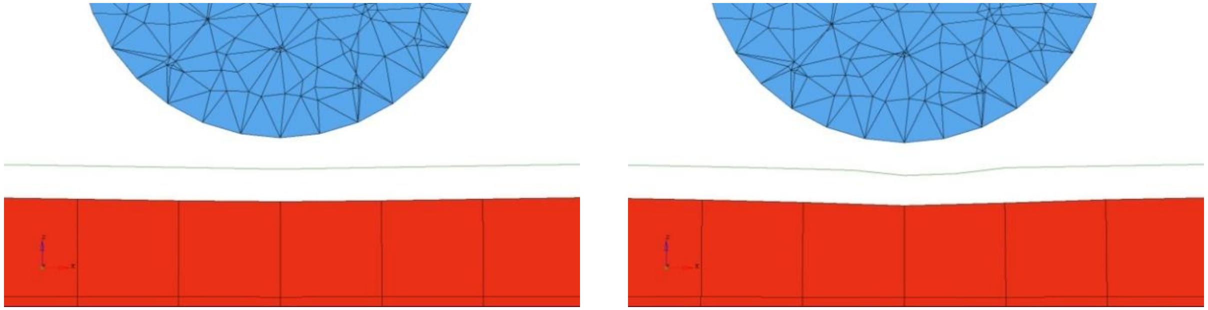
First Dimple Investigation

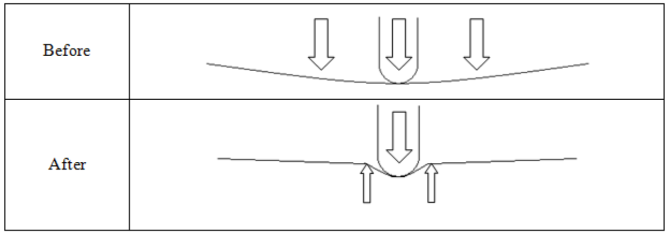
- Dimple is present for <u>all</u> HC sandwich structures and loading conditions, and dictates a significant variation in slope
- During the experimental tests no visible damage or other noticeable incidents can be observed at this point
- The local state of damage in the HC core and facesheet cannot be investigated experimentally
- From experimental LVI curves the presence of the first dimple cannot be seen because they exhibit too much noise
- A well working FEM was used to understand the reason for the presence of the dimple
- A working FEM is an excellent tool to perform parametric studies that cannot be done experimentally and to gain a better understanding of the phenomenon



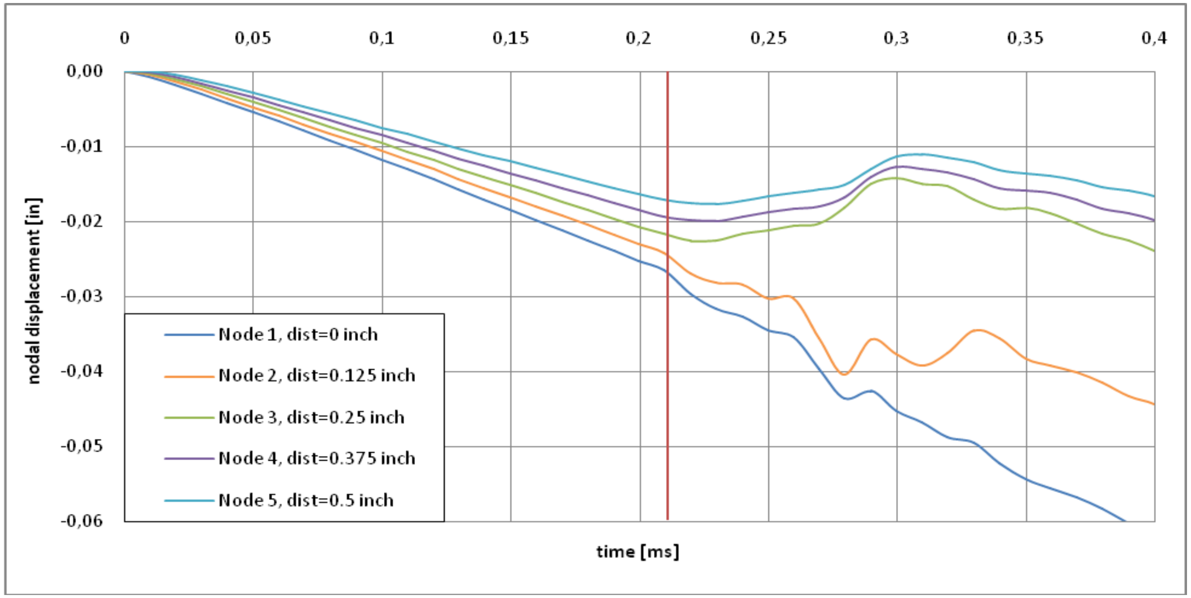


First Dimple Investigation





- At onset of the dimple there is a change in indentation profile associated with core buckling
- As a result the several but not all of the facesheet plies fail



Conclusions

- Learning progression from coupon level calibrations to component level case study and finally to different loading conditions.
- The knowledge gained from the crashworthiness study of the door sill was applied to the damage resistance and the damage tolerance studies of thick HC core sandwich panels
- The calibration was performed on one configuration by matching the QSI experimental results
- After calibration, the same material models and modeling parameters were used for all successive load cases.
- A well working FEM is used to understand the reason for the presence of the dimple and to perform a parametric study