GREAT DESIGNS IN STEEL

Presentations will be available for download on SMDI’s website on Wednesday, May 22

GREAT DESIGNS IN STEEL

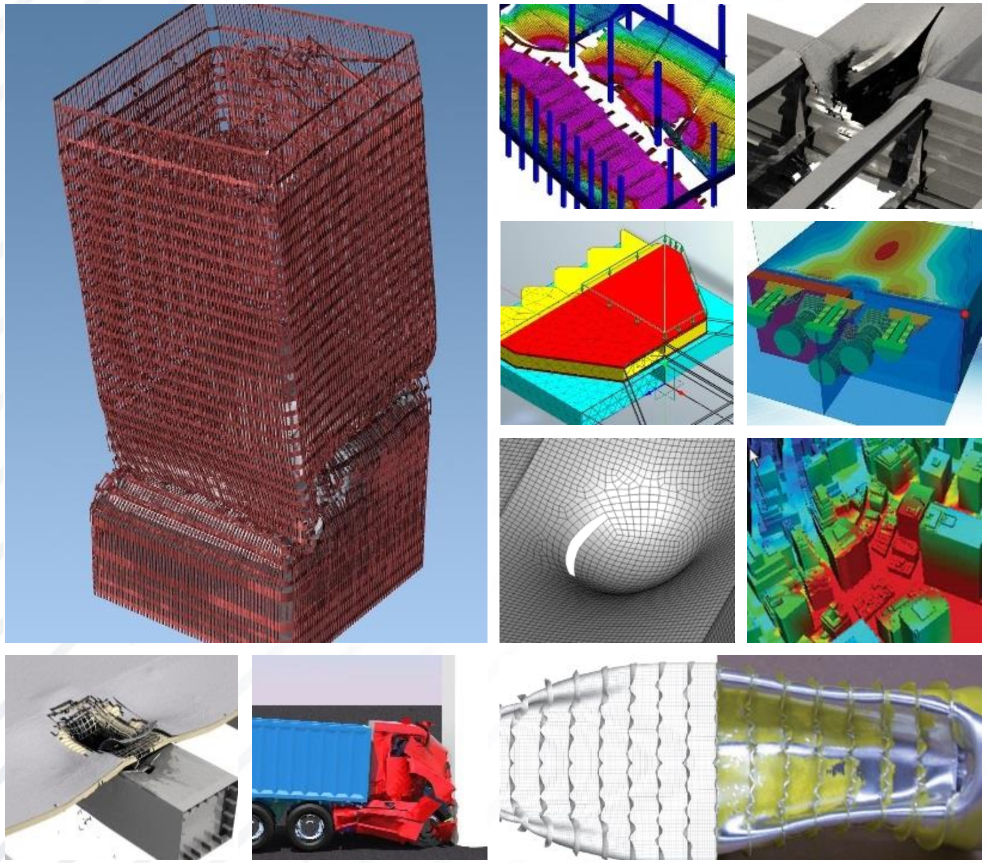
ON THE DIFFERENCES ON FRACTURE PREDICTION OF PLANE STRAIN BENDING AND TENSION OF THIN SHEETS

Mostafa Mobasher

Thornton Tomasetti | Applied Science Practice

Thornton Tomasetti VistaMat

ABOUT US – THORNTON TOMASETTI



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VistaMat Suite

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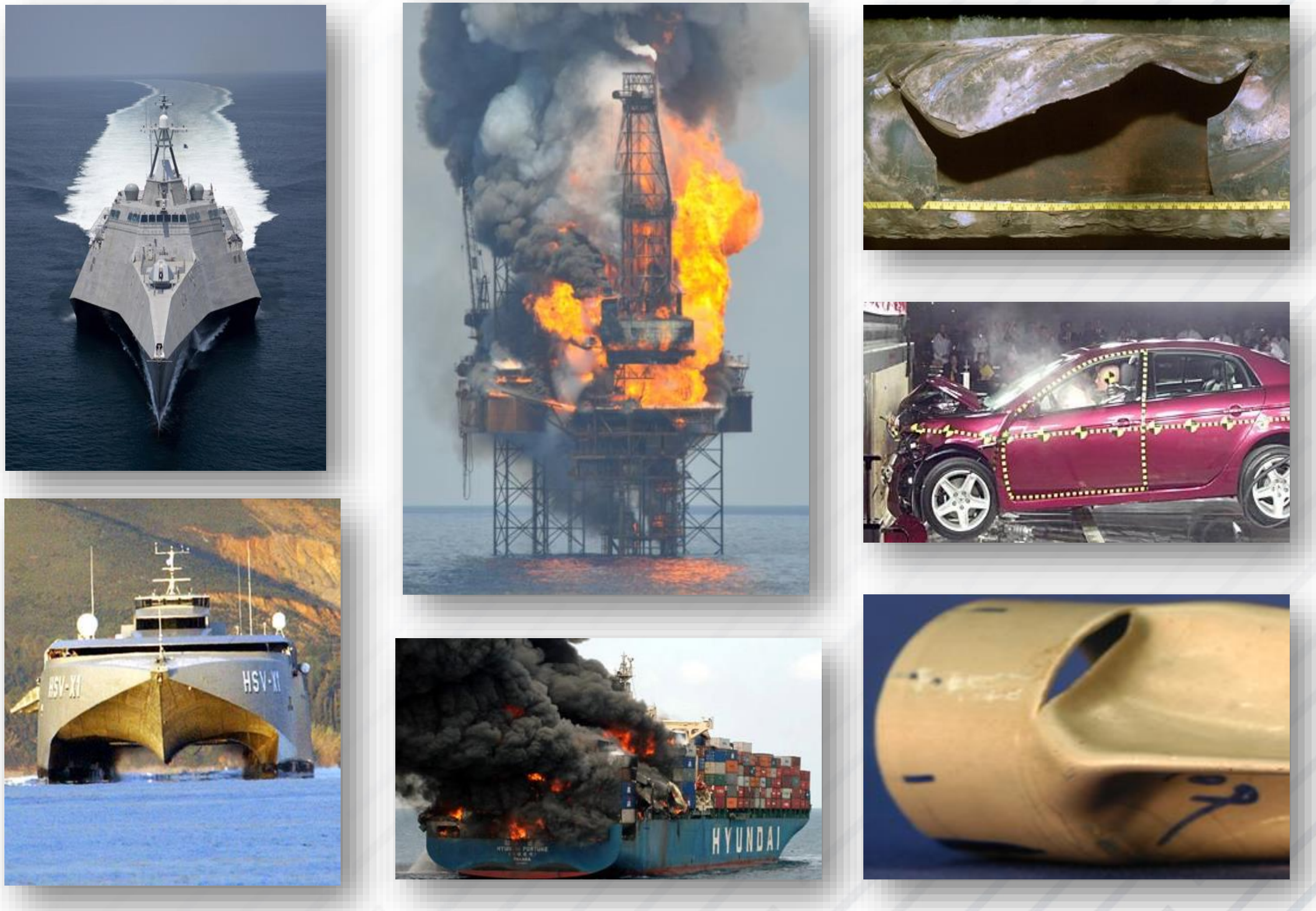
VistaMat Suite is a high fidelity material modeling tool that aids the simulation of ductile fracture of metal sheets subject to mechanical and thermal loading.

VistaMat Suite provides a solution to calibrate material models with minimal amount of experimental data.



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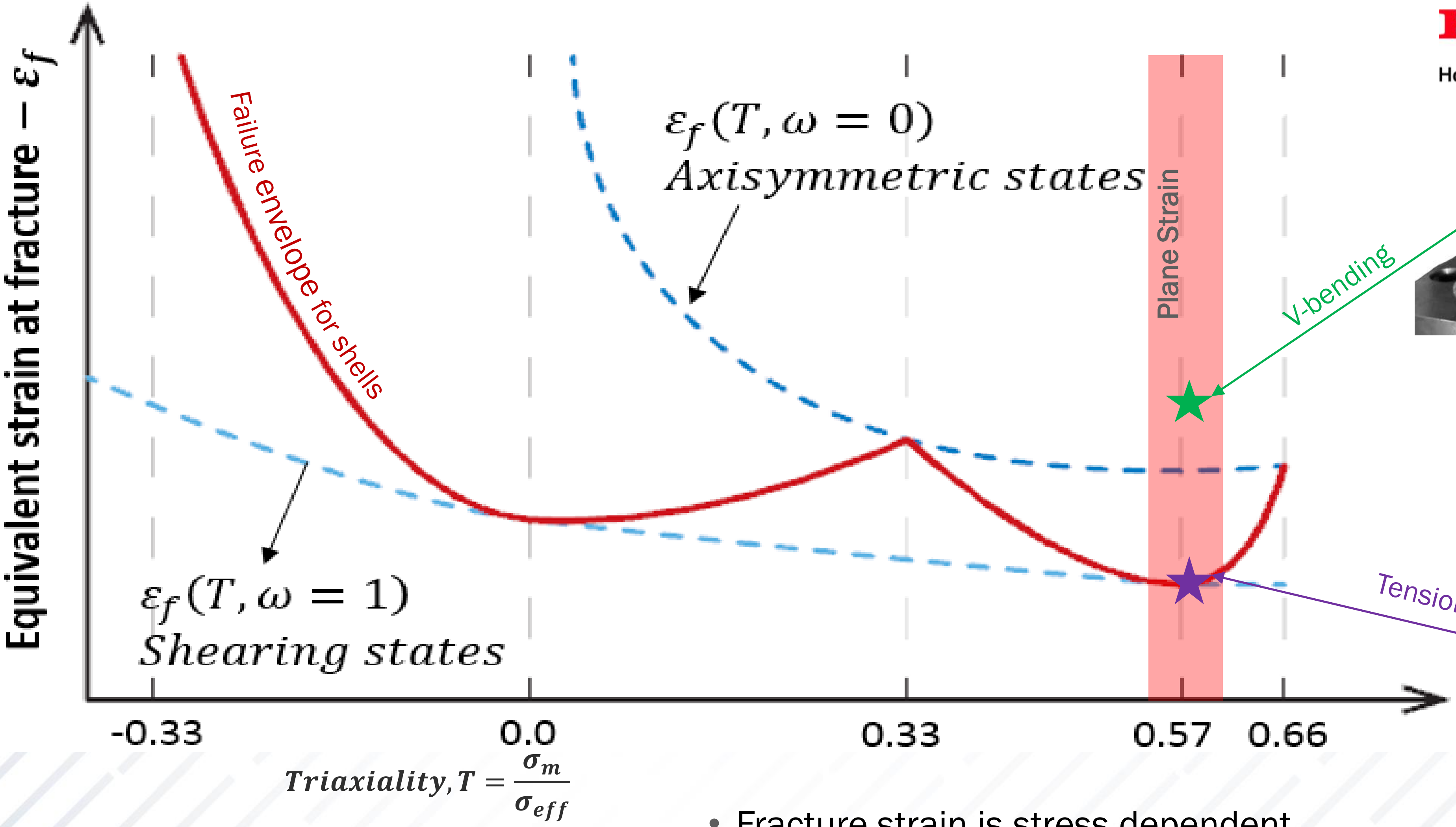
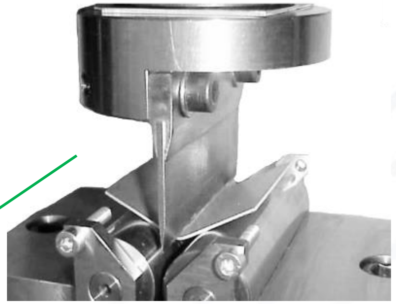
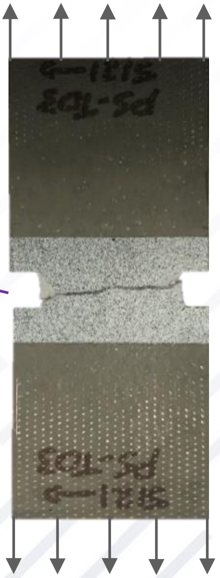
PLANE STRAIN FRACTURE: BENDING VS. IN-PLANE



HONDA

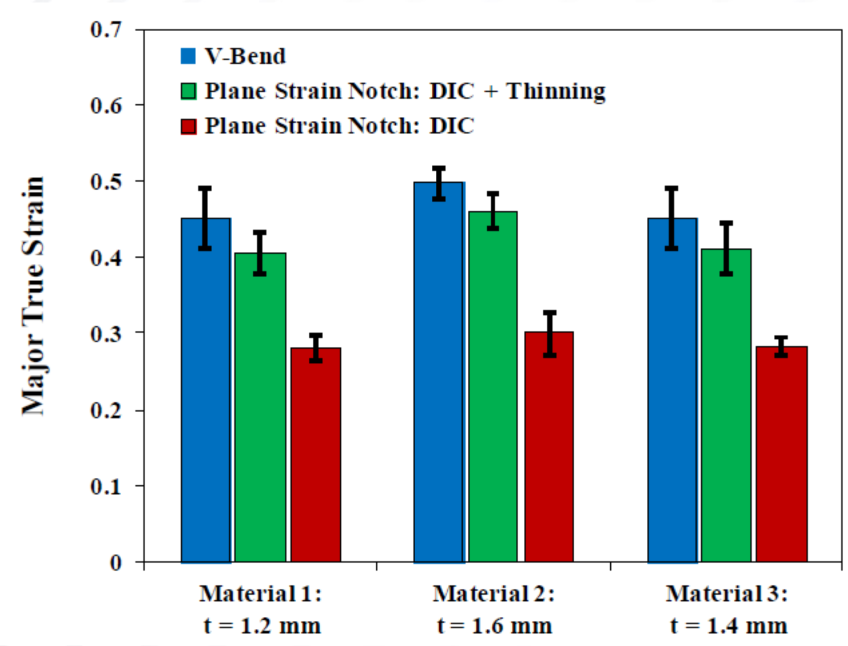
Honda R&D Americas, Inc.



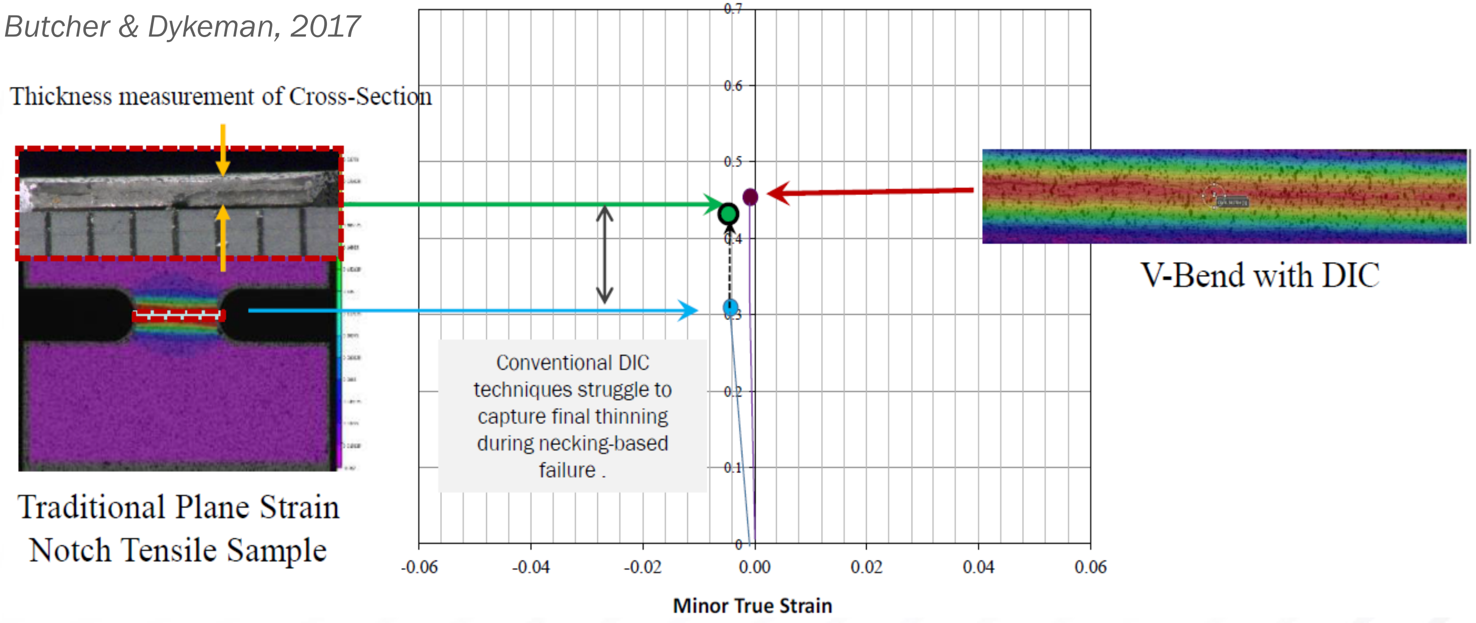


- Fracture strain is stress dependent
- Two nominally similar *plane strain* tests
- How can we predict both results (simulations)?

PLANE STRAIN FRACTURE: BENDING VS. IN-PLANE



Butcher & Dykeman, 2017

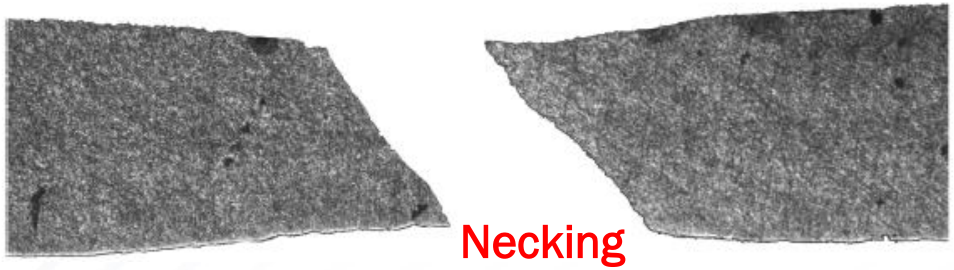


Conventional DIC techniques struggle to capture final thinning during necking-based failure .

- Observation:
  - In-plane coupons vs. VDA bending → ε_f discrepancy
- Challenge:
  - Understanding the causes of discrepancy
  - Predicting actual failure scenario in local (fracture scale) and global (component scale) models

PLANE STRAIN FRACTURE: BASIC OBSERVATIONS

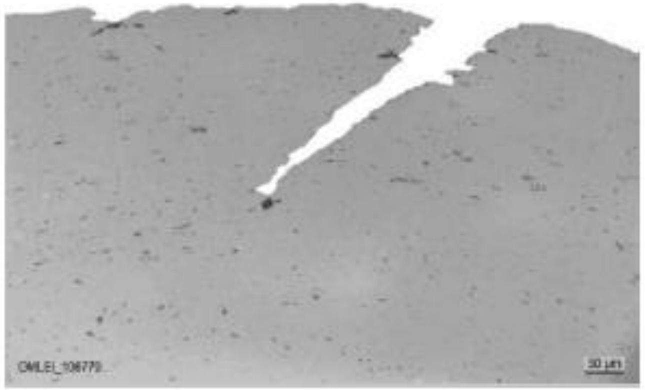
In-Plane:



Necking

Bending:

No Necking

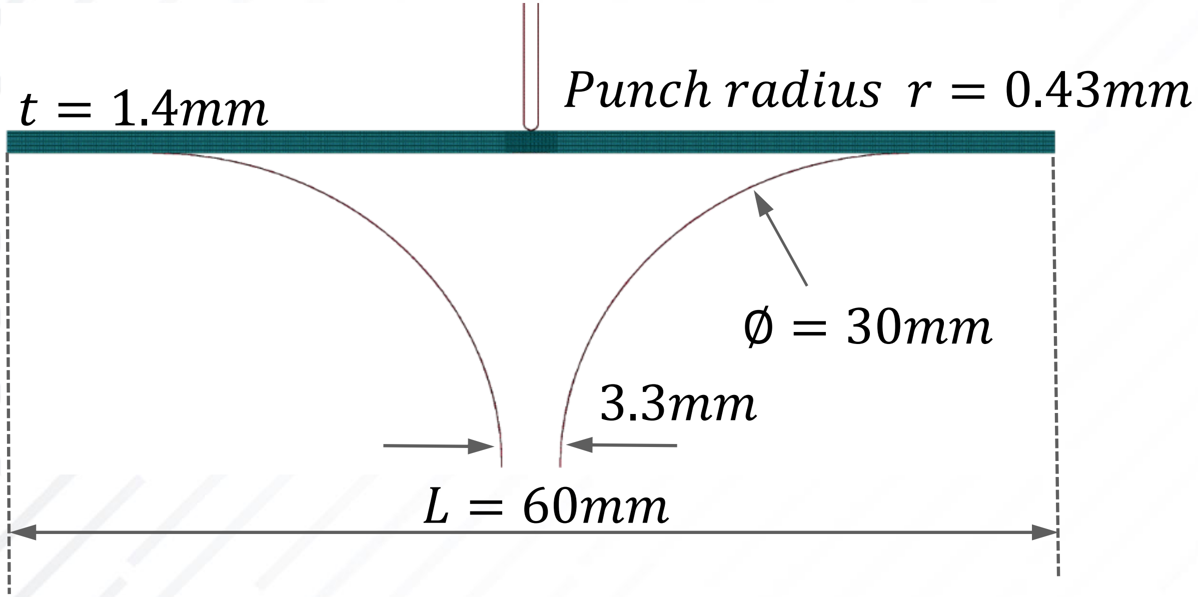


[Bandpay, 2015]

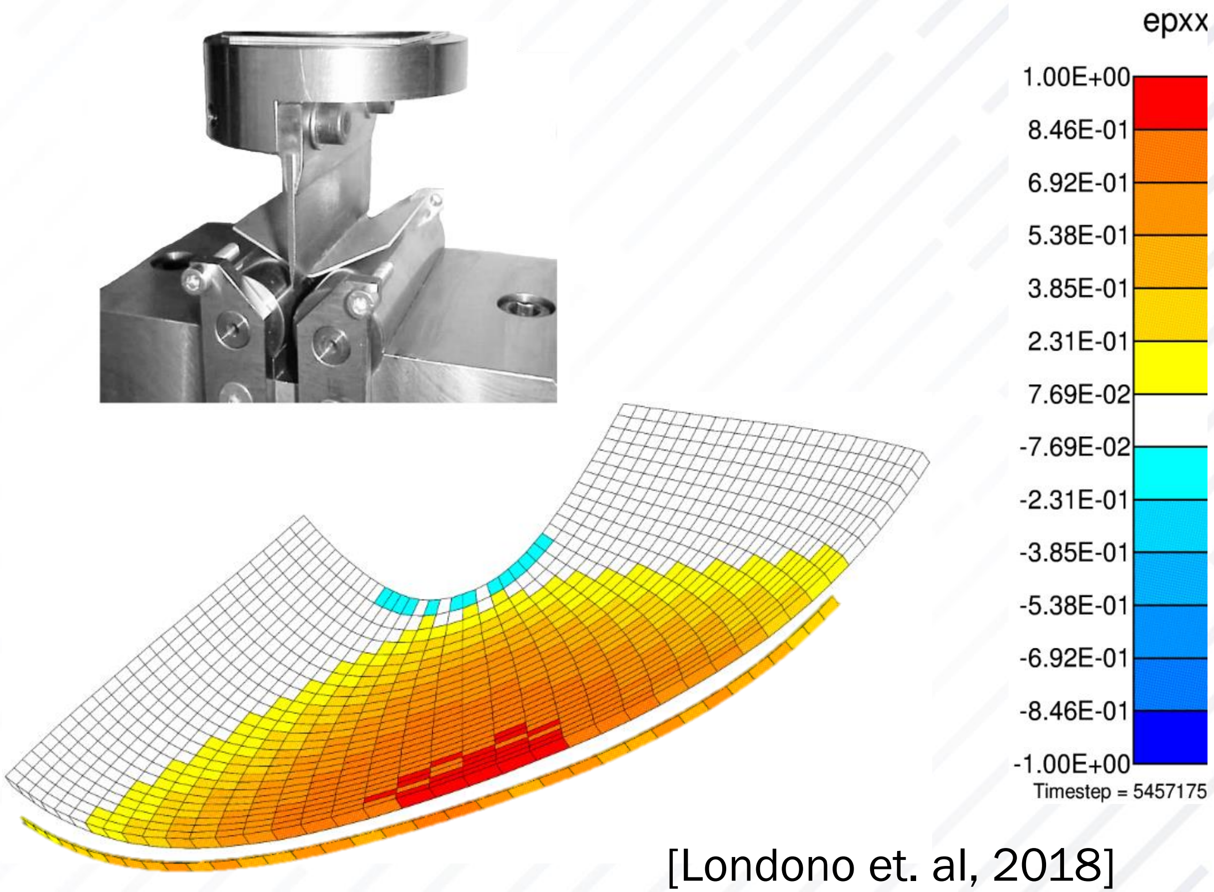
Basic observations:

- Progressive crack propagation in bending – stress and strain change through thickness
- Extensive vs. no necking

VDA BEND – PRELIMINARY SIMULATIONS (MBW1500)

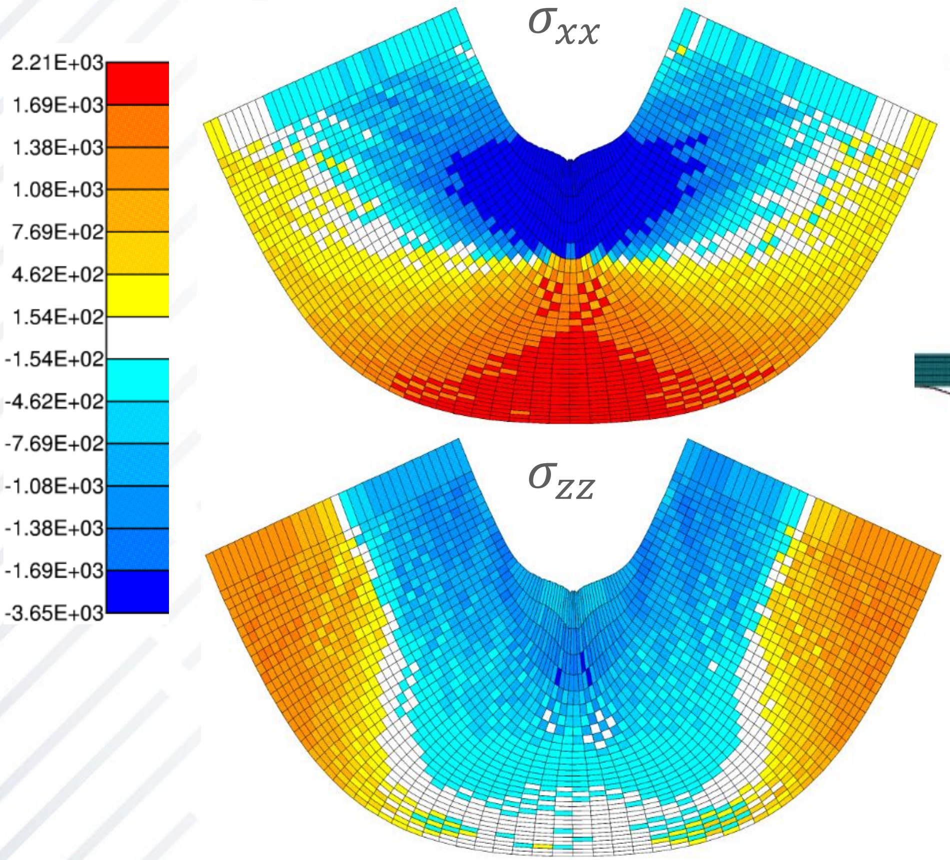


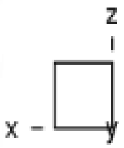
- 0.04mm element size
- Solid elements throughout
- Thin (0.001mm) layer of soft membrane elements: $\mathrm{E} = 200MPa$ (DIC membrane)
- Calibration with no failure – stress analysis only



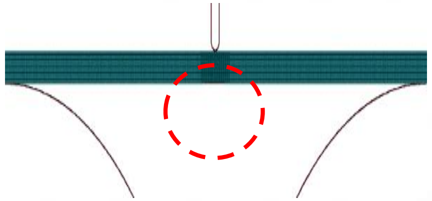
[Londono et. al, 2018]

VDA BEND – STRESS STATE

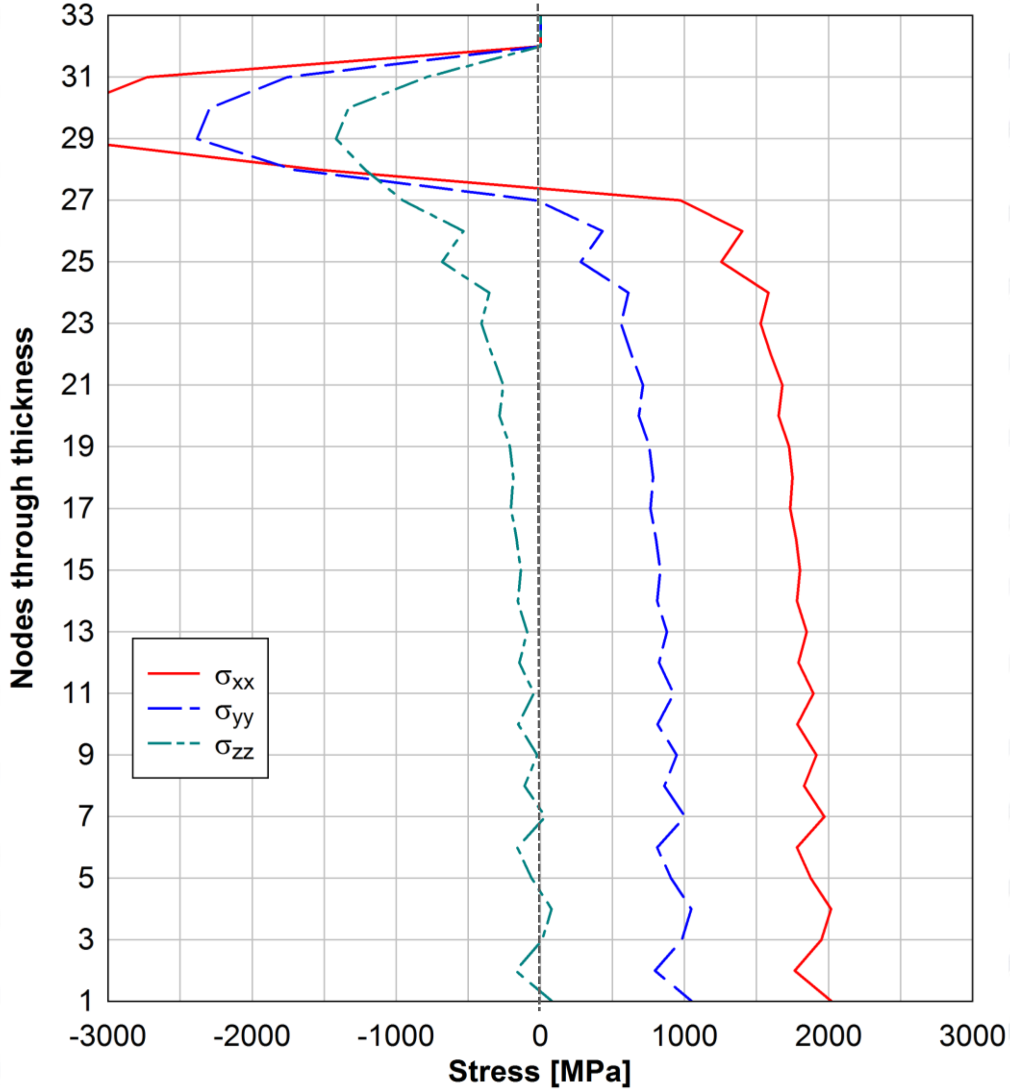




$$\sigma_{xx} > \sigma_{yy} \gg \sigma_{zz}$$

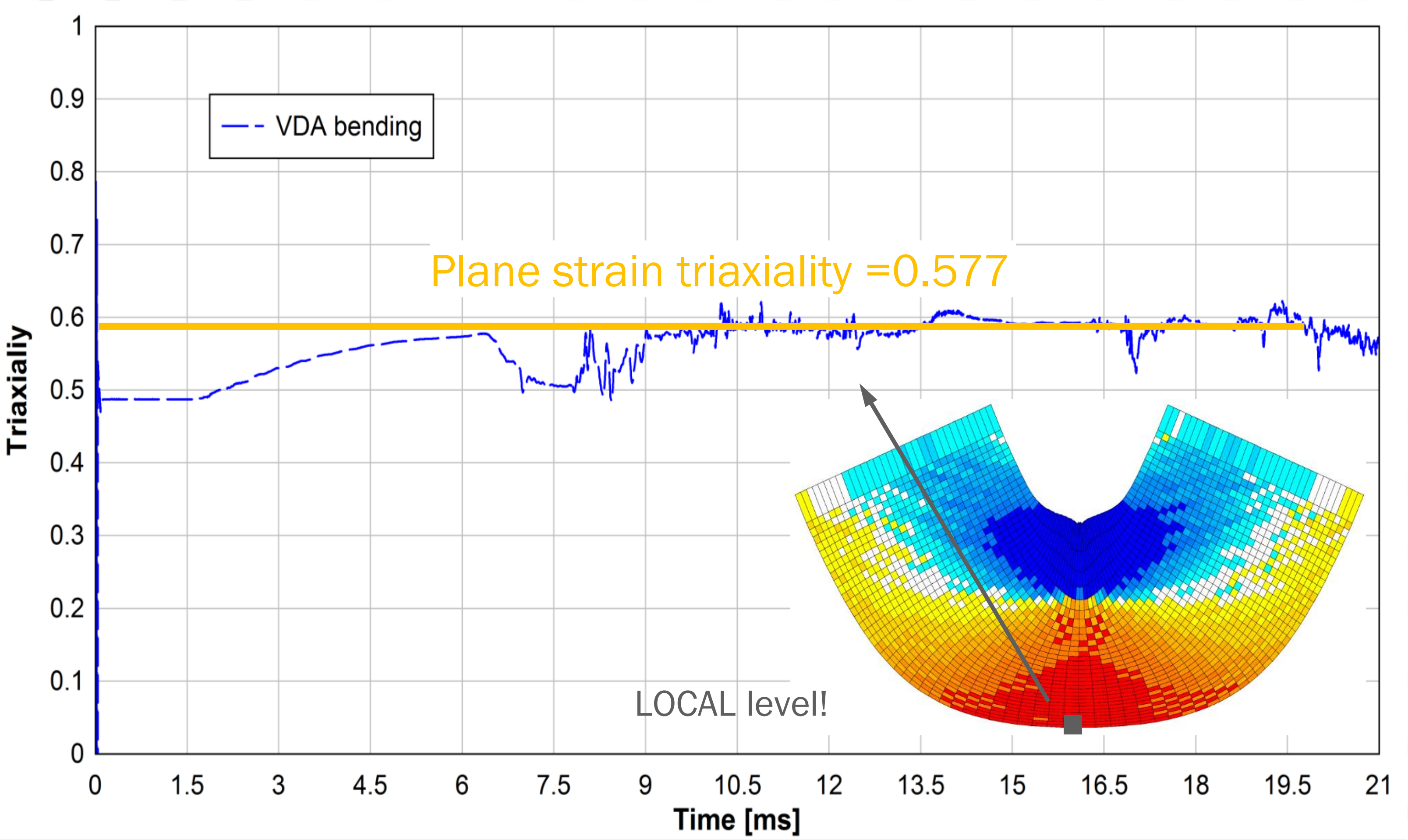


- Practically plane stress!
- Relates to no necking



[Londono et. al, 2018]

VDA BEND – STRESS STATE



[Londono et. al, 2018]

Plane Strain Tension ($\boldsymbol{\sigma_z = 0}$):

$$\sigma_{ij} = \begin{bmatrix} \sigma_x & 0 & 0 \\ 0 & \nu\sigma_x & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

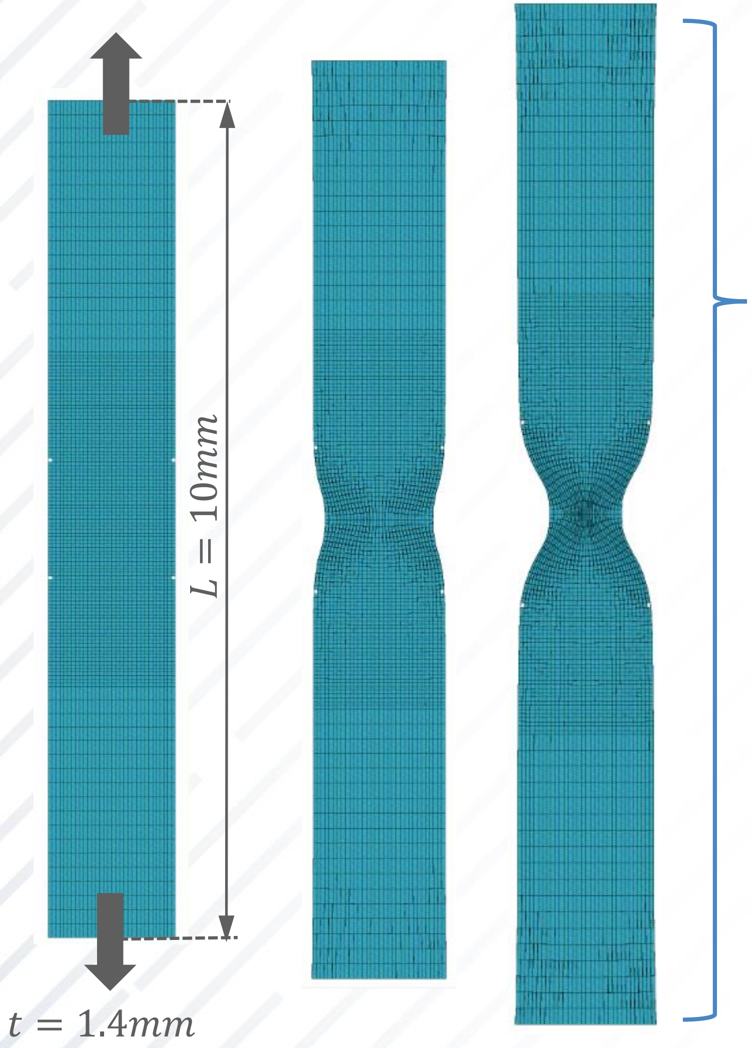
$$\sigma_{eff} = \sigma_x\sqrt{(1 - \upsilon + \upsilon^2)}$$

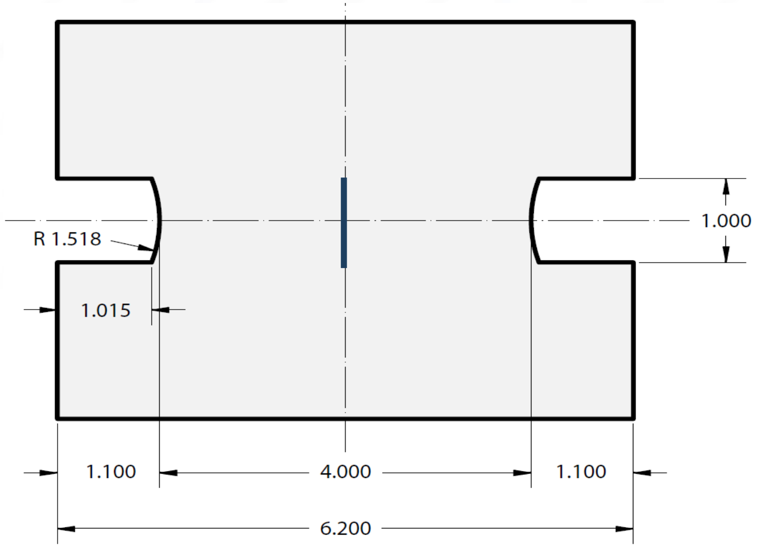
$$\sigma_m = \frac{1}{3}(1 + \upsilon)\sigma_x$$

$$T = \frac{1}{\sqrt{3}} = 0.577 \quad (\upsilon = 0.5)$$

Plane strain triaxiality =0.577

IN-PLANE TENSION – PLANE STRAIN (MBW1500)

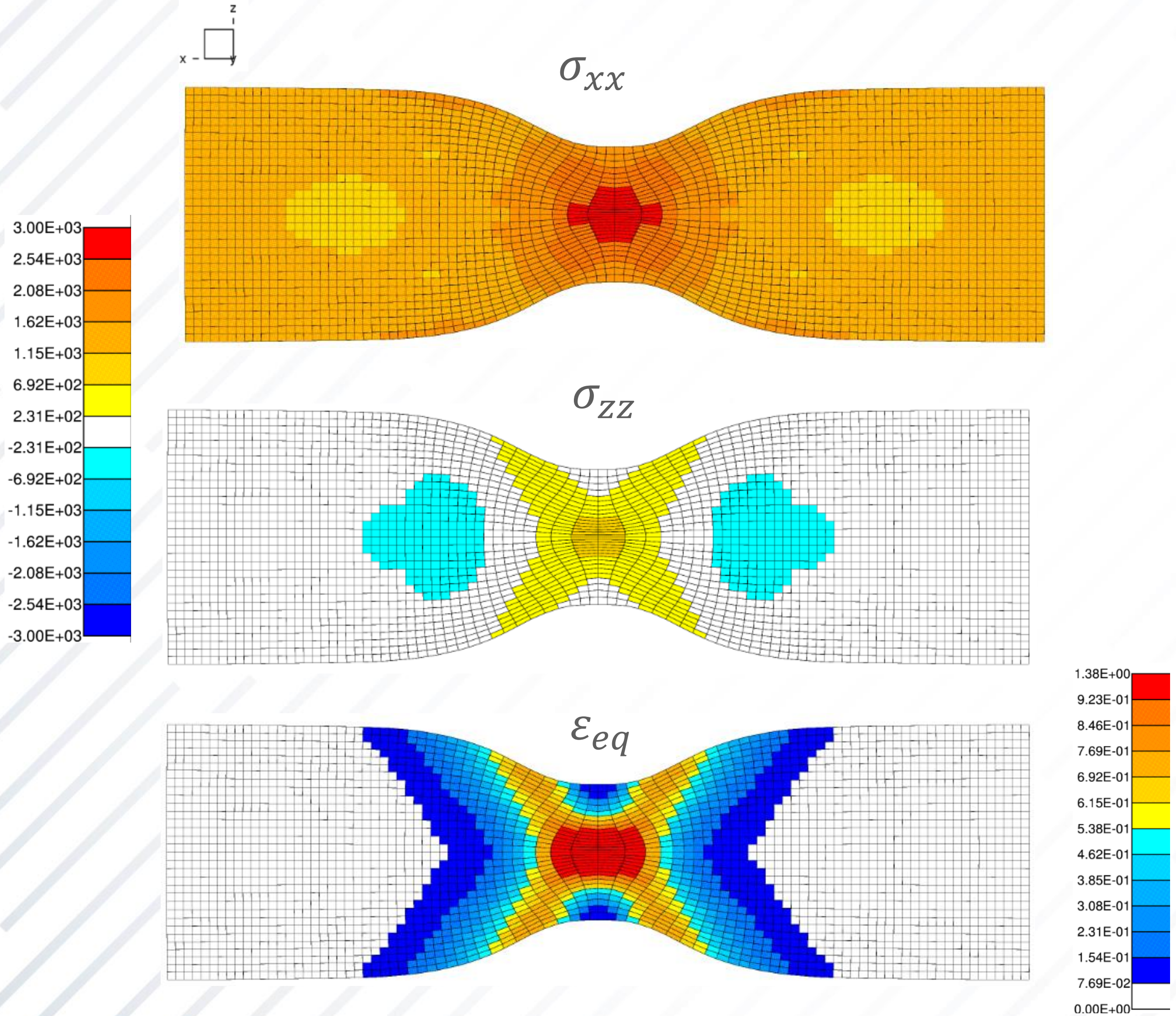


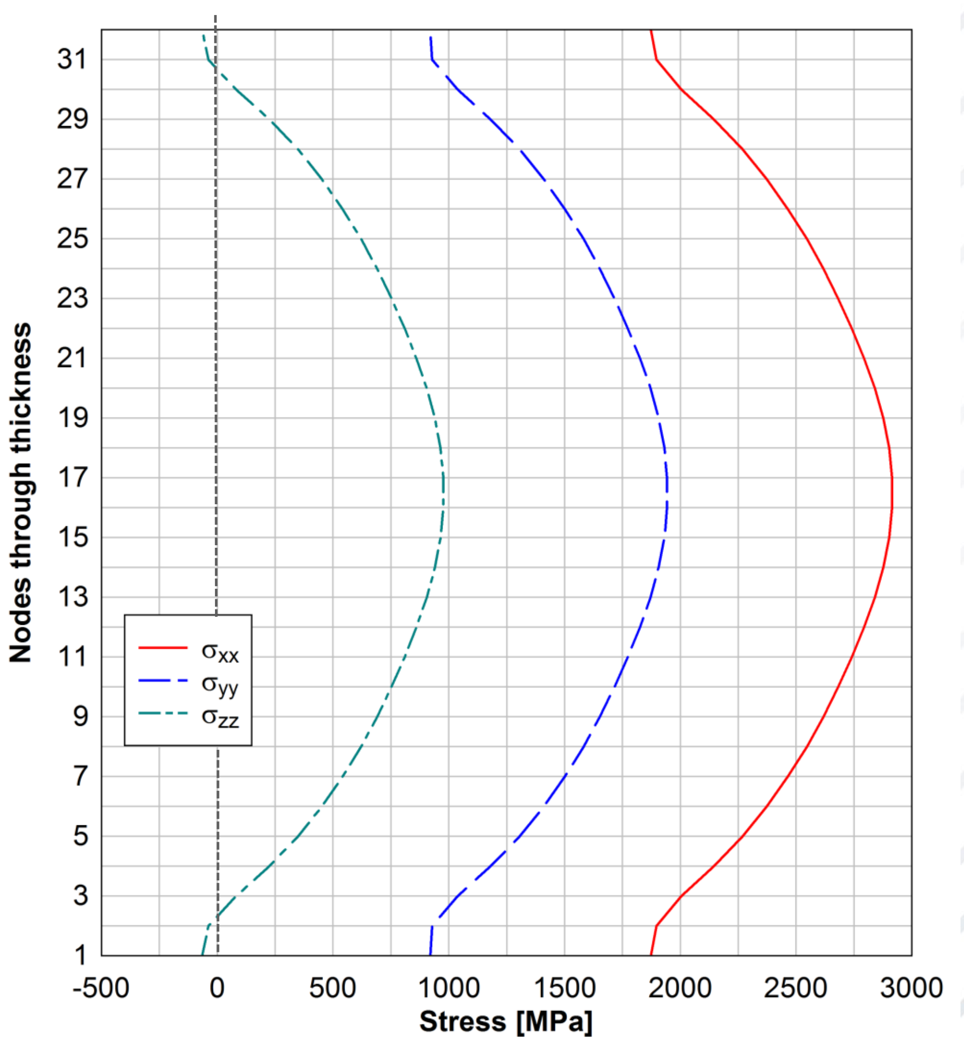


- 0.04mm solid elements (32 through thickness)
- In-plane plane strain tensile simulation (plasticity only)

IN-PLANE TENSION – STRESS STATE

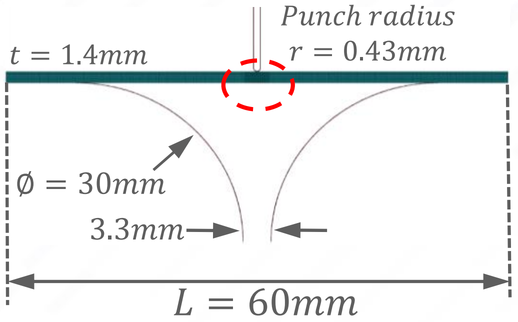
$$\sigma_{zz} \approx 1000MPa$$

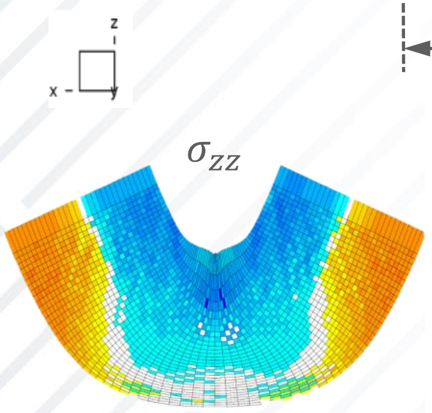


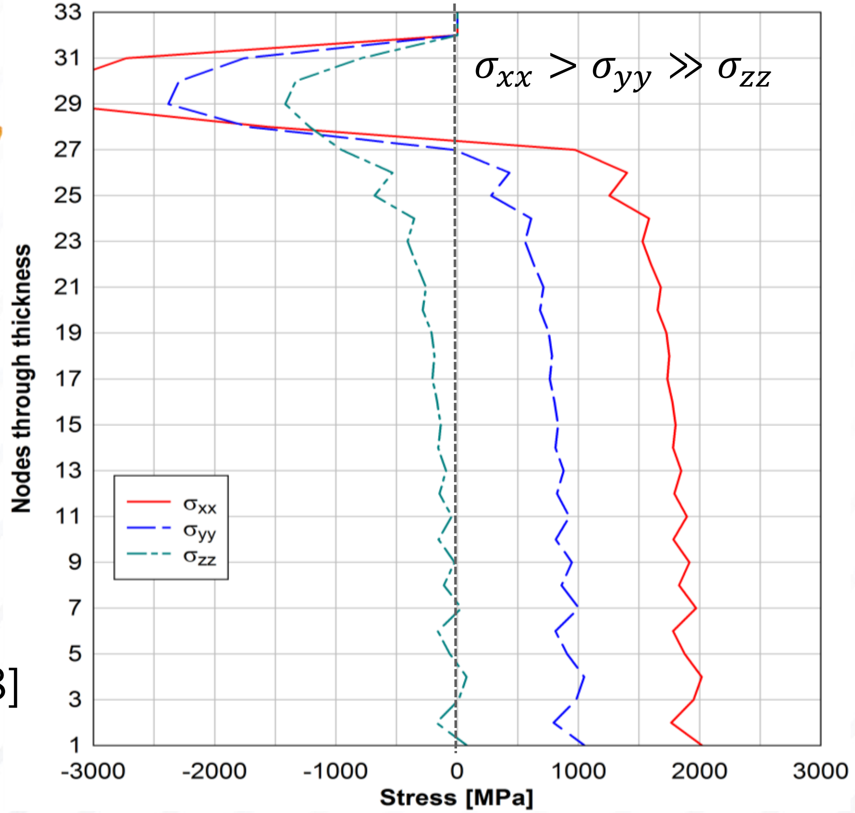


[Londono et. al, 2018]

IN-PLANE TENSION VS. VDA BEND– STRESS STATE

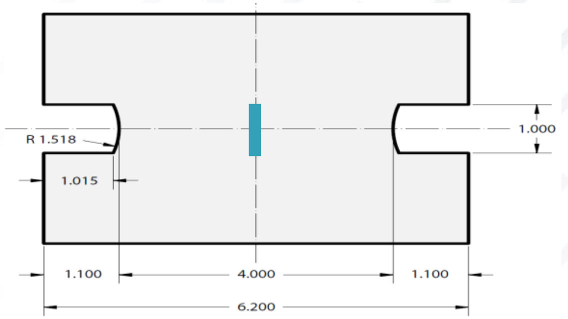


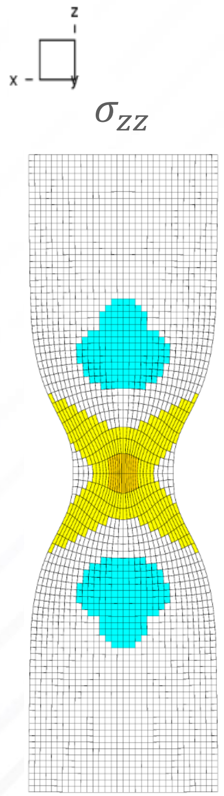




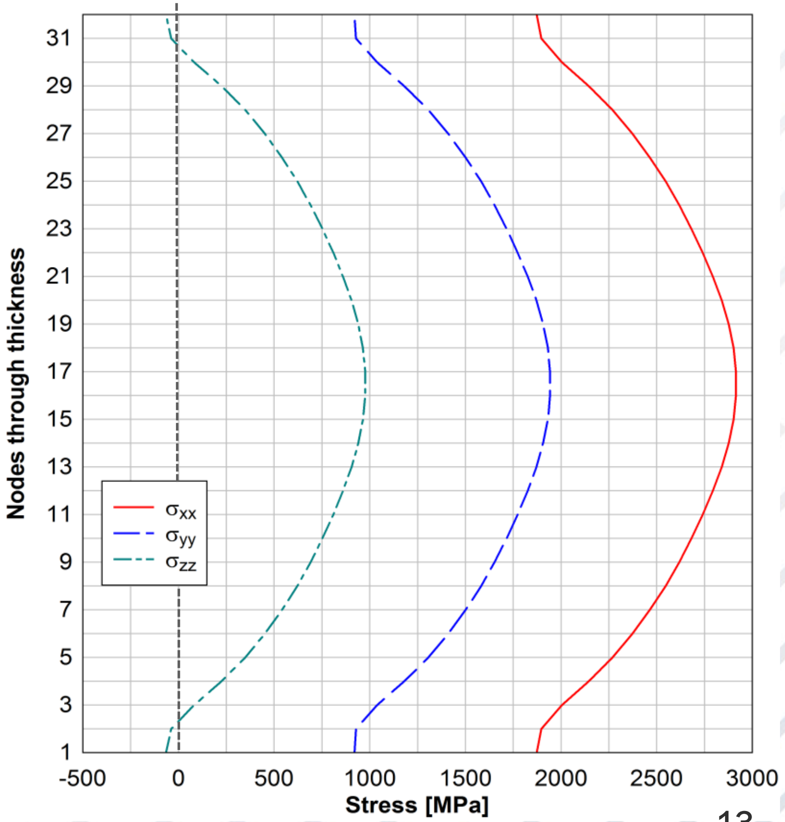
$\sigma_{zz}$is very small in fracture zone

[Londono et. al, 2018]

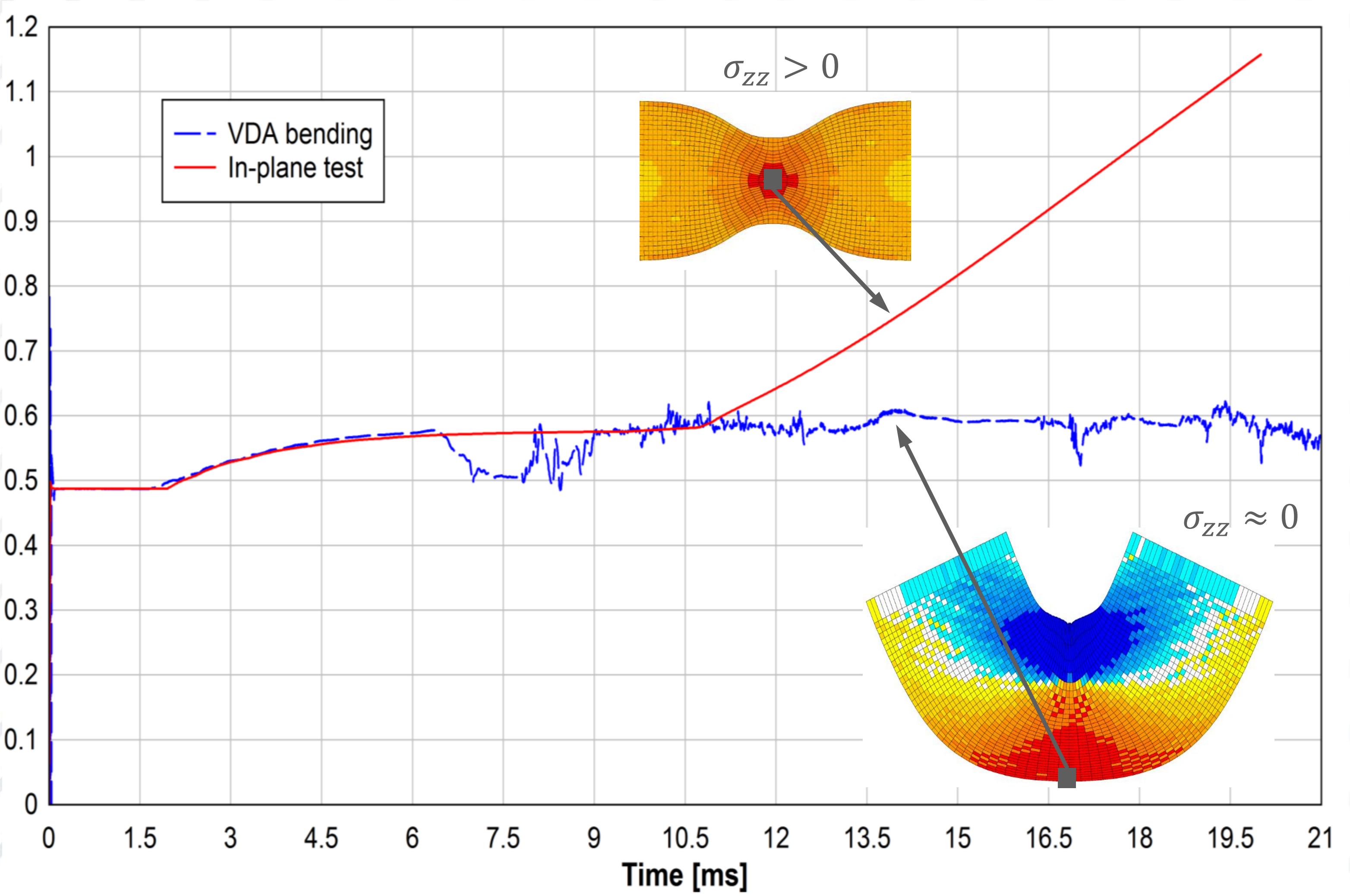




$\sigma_{zz} \approx 1000MPa$ is very small in fracture zone



IN-PLANE TENSION VS. VDA BEND– STRESS STATE



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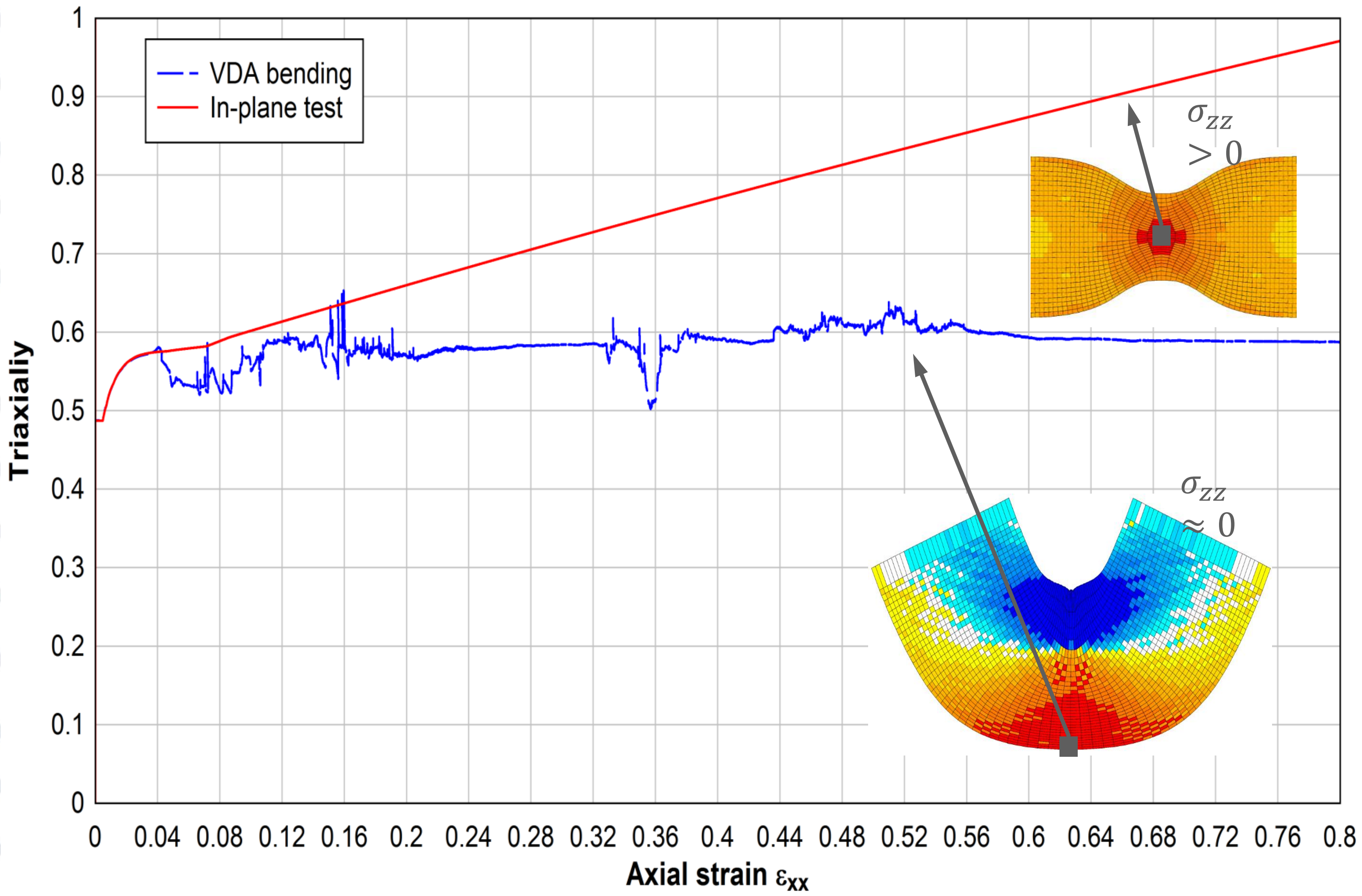
$$\sigma_m = \frac{1}{3}(1 + \nu)\sigma_x$$

$$T = \frac{1}{\sqrt{3}} = 0.577 \quad (\nu = 0.5)$$

[Londono et. al, 2018]

IN-PLANE TENSION VS. VDA BEND– STRESS STATE



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$$\sigma_{eff} = \sigma_x\sqrt{(1 - v + v^2)}$$

$$\sigma_m = \frac{1}{3}(1 + v)\sigma_x$$

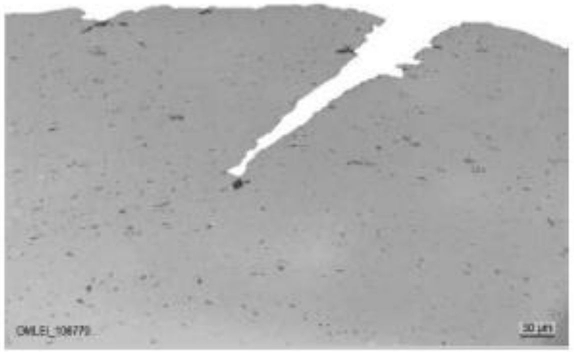
$$T = \frac{1}{\sqrt{3}} = 0.577 \quad (v = 0.5)$$

[Londono et. al, 2018]

PREVIOUS EFFORTS - CORRELATIONS

$\sigma_{zz} \approx 0.5\sigma_{yy}$

$\sigma_{zz} \approx 0$



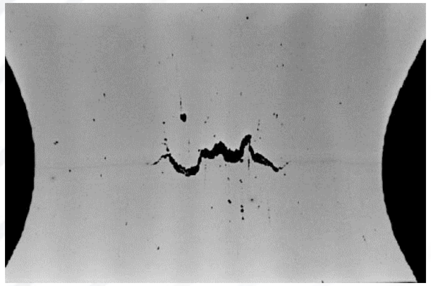
Correlations proposed (e.g. Bandpay):

$$\bar{\varepsilon_b}^f = \bar{\varepsilon_m}^f + \Delta\bar{\varepsilon}^f(\rho, t)$$

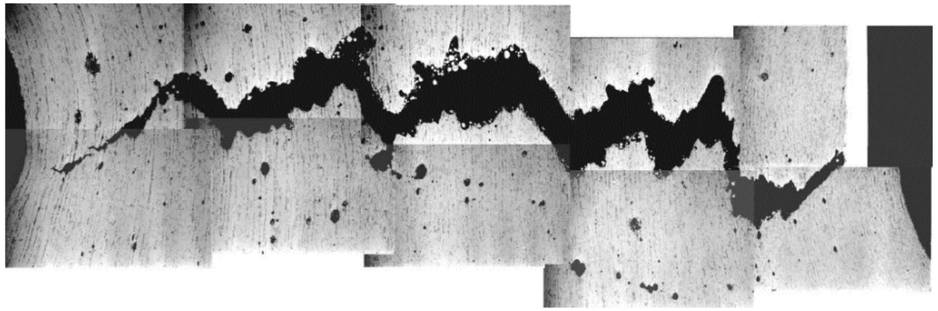
- PRELIMINARY: In-plane and bending strains develop under different stress state
- Correlations obtained by adding in-plane and bending strains probably not approppriate

MODELING CHALLENGE – LENGTH SCALES

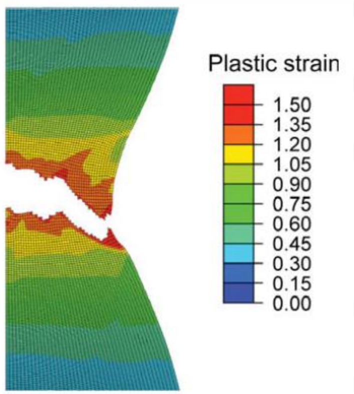
Micromechanically-motivated models:



Benzerga, Leblond
2010



Xue et al, 2010

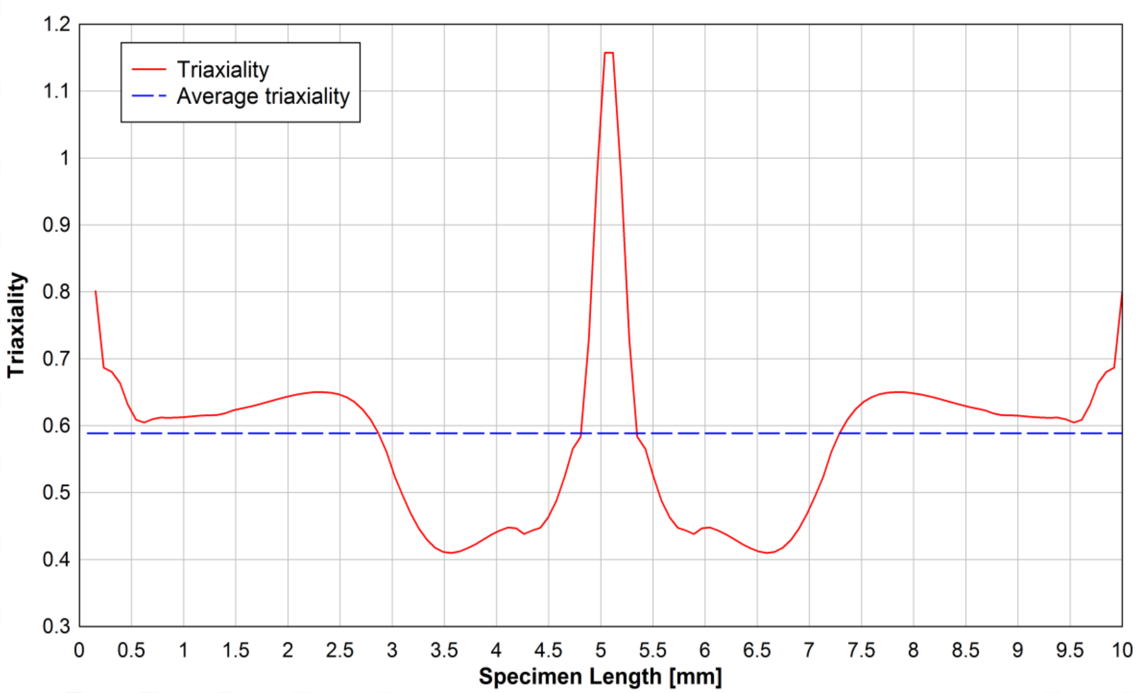


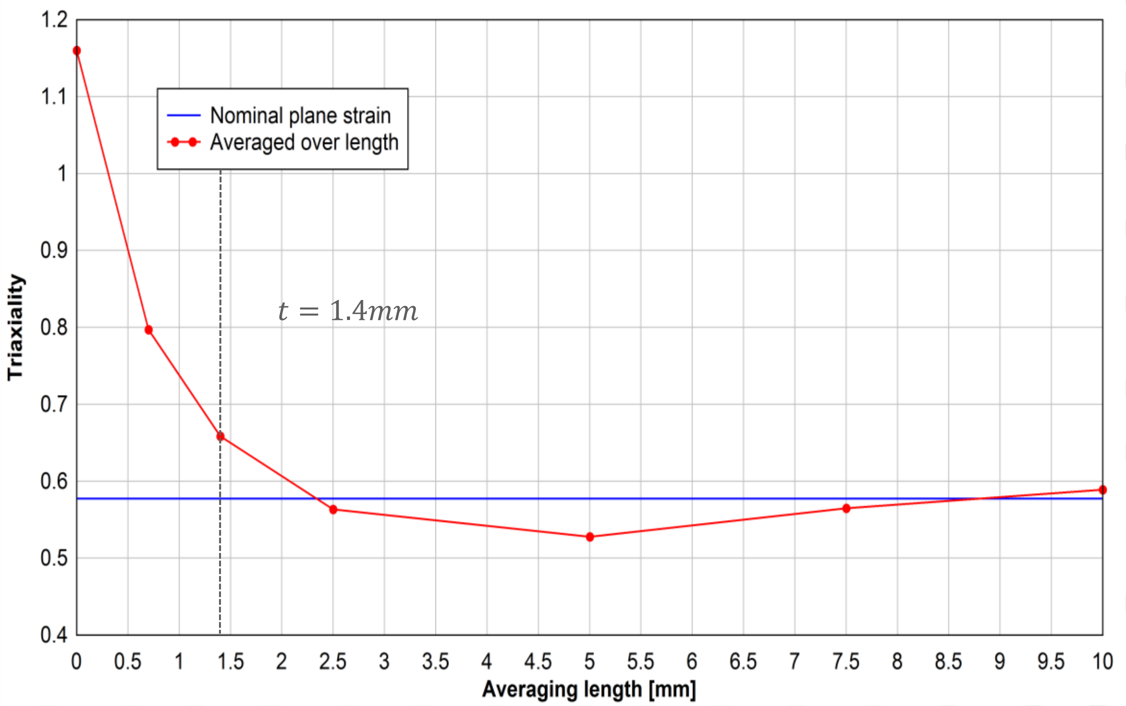
Structural models:

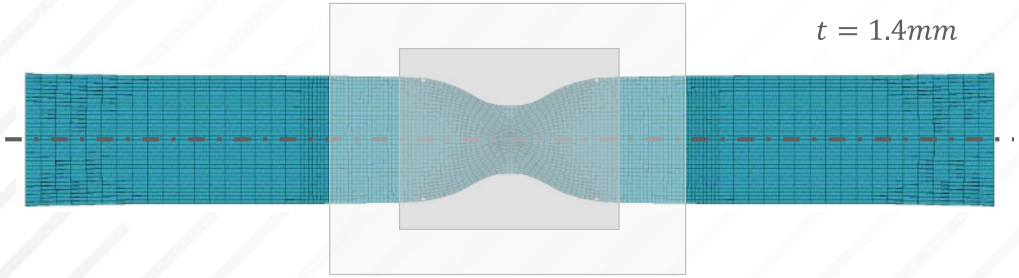
?

- Vast length scale differences to bridge
- Need for a new approach to solve the problem

IN-PLANE PLANE STRAIN TENSION – ELEMENT SIZE



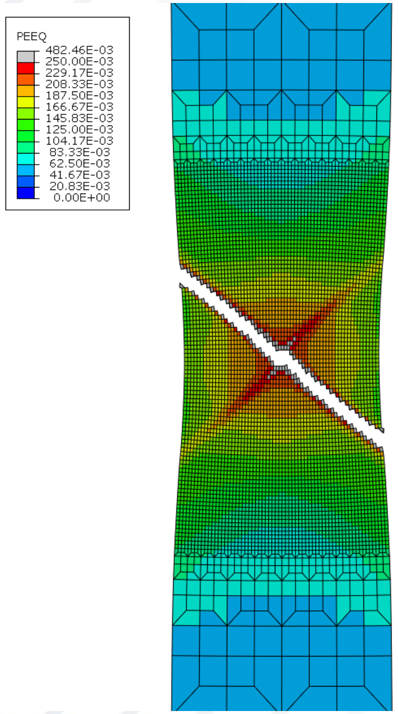


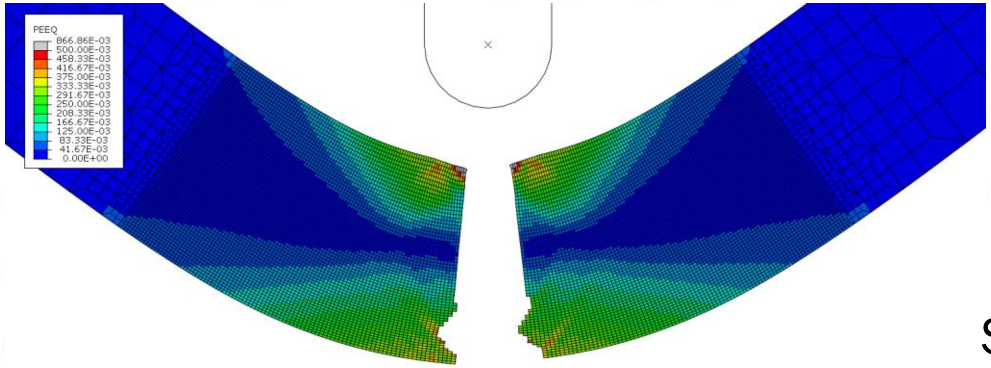


- Illustration of the importance of the element size → *shell elements cannot be used reliably if in-plane dimension is smaller than thickness!*

CURRENT INVESTIGATIONS

- Challenge: Enhance current shell formulations to predict bending vs. tension loading

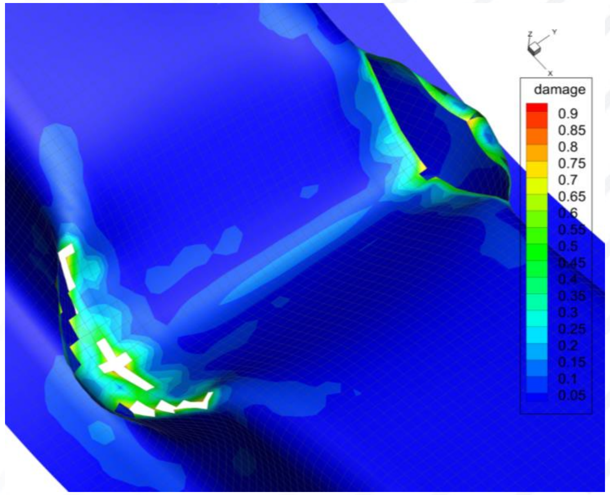




Gurson simulations

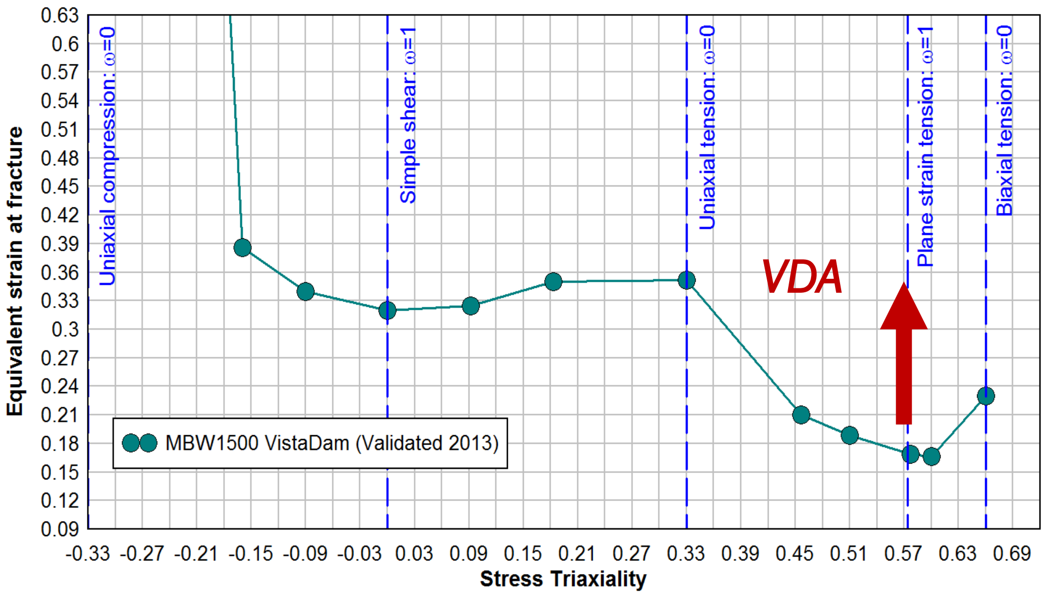
Improve our understanding of the stress states on a detailed model

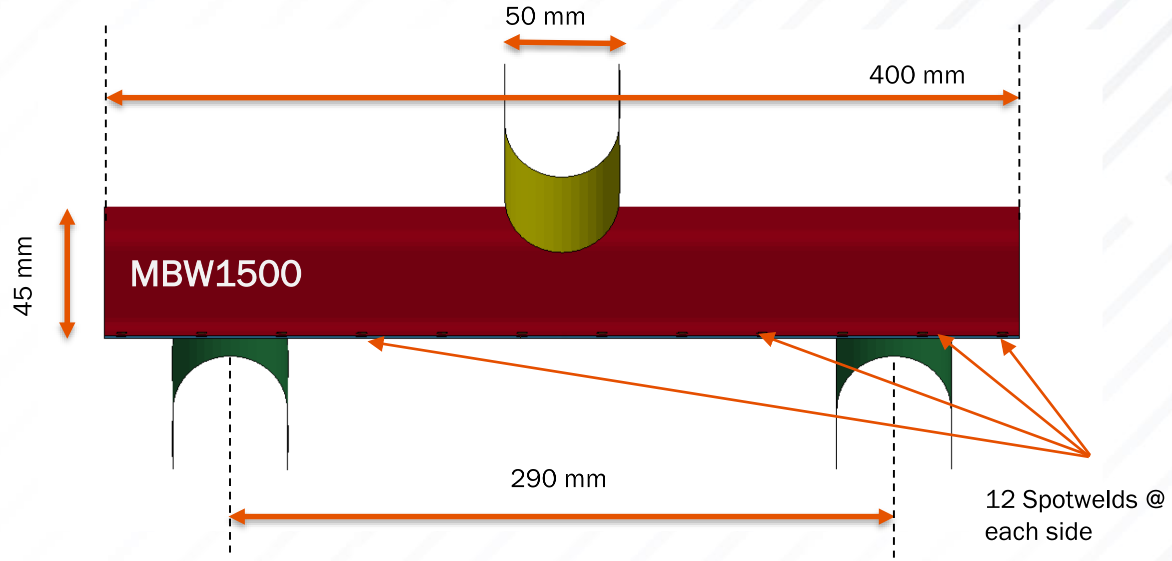
Stress state mapping



Enhanced shell element formulation

BENDING – MBW1500 – 2013-2017 DATA (2MM GL)





Data points for MIT MMC model parameter identification

Ford
ArcelorMittal

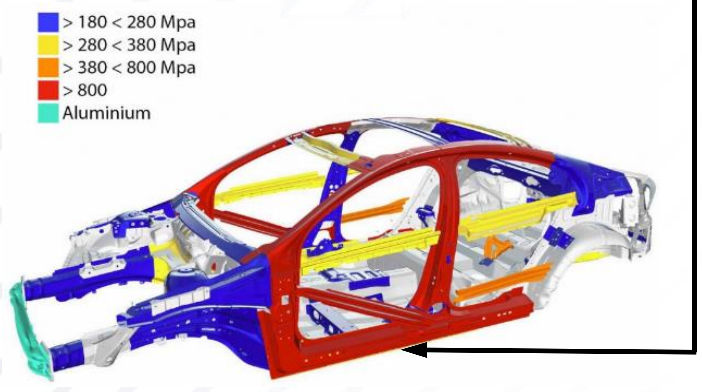
	Triaxiality	Lode angle	Fracture strain	VistaDam
Uniaxial	0.379	0.839	0.346	0.35
Cut-out	0.537	0.295	0.207	0.19
Plane strain	0.565	0.040	0.133	0.16
Biaxial	0.645	-0.870	0.232	0.22
Equi-biaxial	0.662	-0.999	0.255	0.24

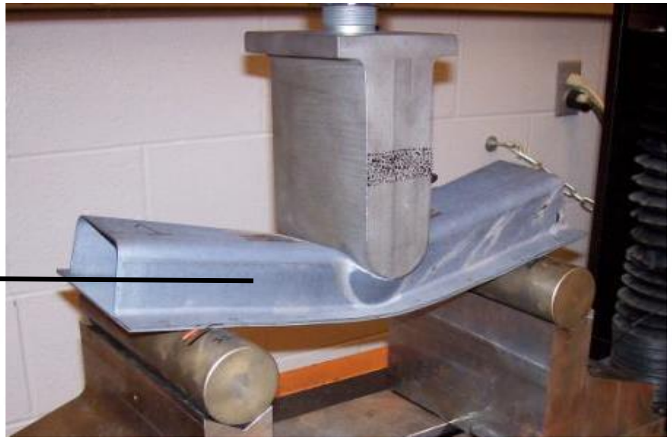
Gang Huang, Sriram Sadagopan et al., AM (GDIS 2014)

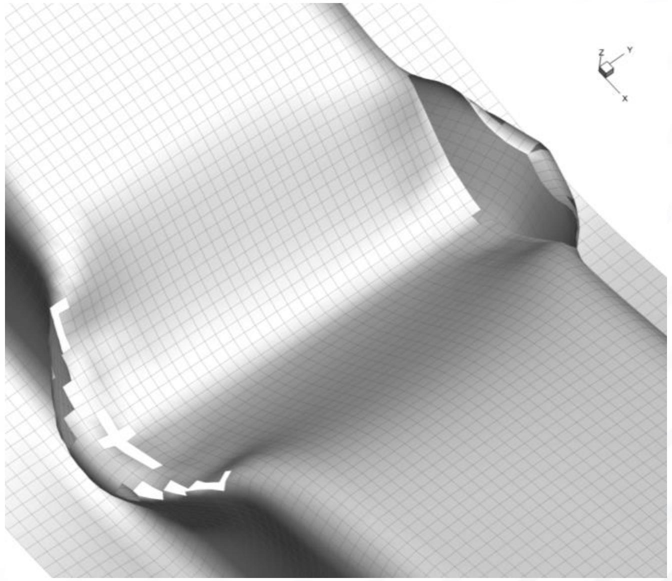
Available PS data:

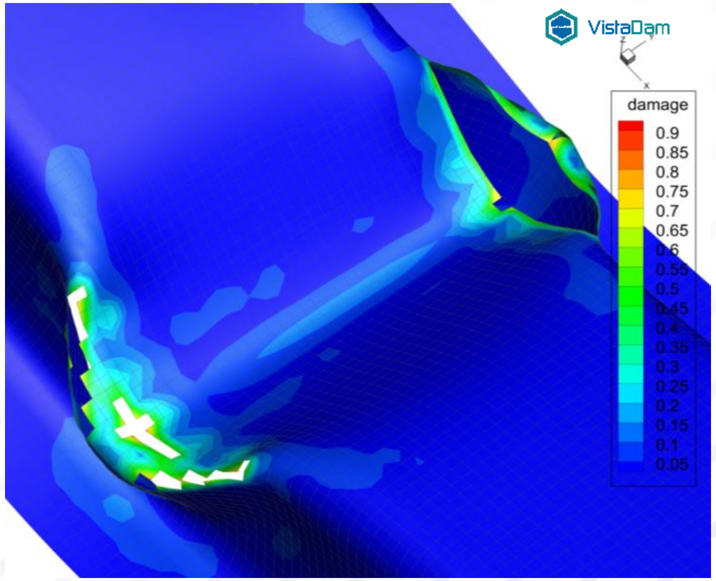
- In-plane (2013):
  $\varepsilon_{cr} = 16\%$
- In-plane (2017):
  $\varepsilon_{cr} = 13\%$
- VDA bending (2017):
  $\varepsilon_{cr} = 38\%$

ROCKER BEAM THREE-POINT BENDING









SUMMARY & NEXT STEPS

- Significant advances in ductile fracture modeling over last ~10 years
- Large scale modeling with shell elements not well addressed by most existing approaches
- VDA bending analysis → fundamentally different than in-plane tensile behavior – effect of transverse normal stress
- Accuracy improvements → potential weight savings
- Shell elements within the through-thickness necking cannot represent the actual stress state
- NEXT STEPS: Formulate a damage accumulation rule for GISSMO and other models in LSDyna that allows different damage accumulation rate in bending

ACKNOWLEDGMENT

- References:
  - VistaMat Suite – www.vistamat.com
  - Woelke, P., Abboud, N. (2012) "Modeling Fracture in Large Scale Shell Structures". J. of the Mechanics and Physics of Solids; 60, 12, 2044-2063
  - Nahshon, K., Hutchinson, J. W. (2008). Modification of the Gurson model for shear failure. European Journal of Mechanics-A/Solids, 27(1), 1-17.
  - Londono, J., Woelke, P., Knoerr L., Dykeman, J., Malcolm S., (2018), "Fundamental Differences between Fracture Behavior of Thin Sheets under Plane Strain Bending and Tension", IDDRG 2018, Waterloo CA

- Co-workers:
  - Juan G. Londono – Thornton Tomasetti
  - Pawel B. Woelke – Thornton Tomasetti
  - Rasmus G. Andersen – Technical University of Denmark
  - Kim Lau Nielsen – Technical University of Denmark

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