# Modeling of Joints with Plug Out Separation Modes by Utilizing Cohesive Shells for Full Vehicle Safety Models

Niels Pasligh[1], Emre Ertugus[2], Tobias Erhart[3]

[1] Ford-Werke GmbH
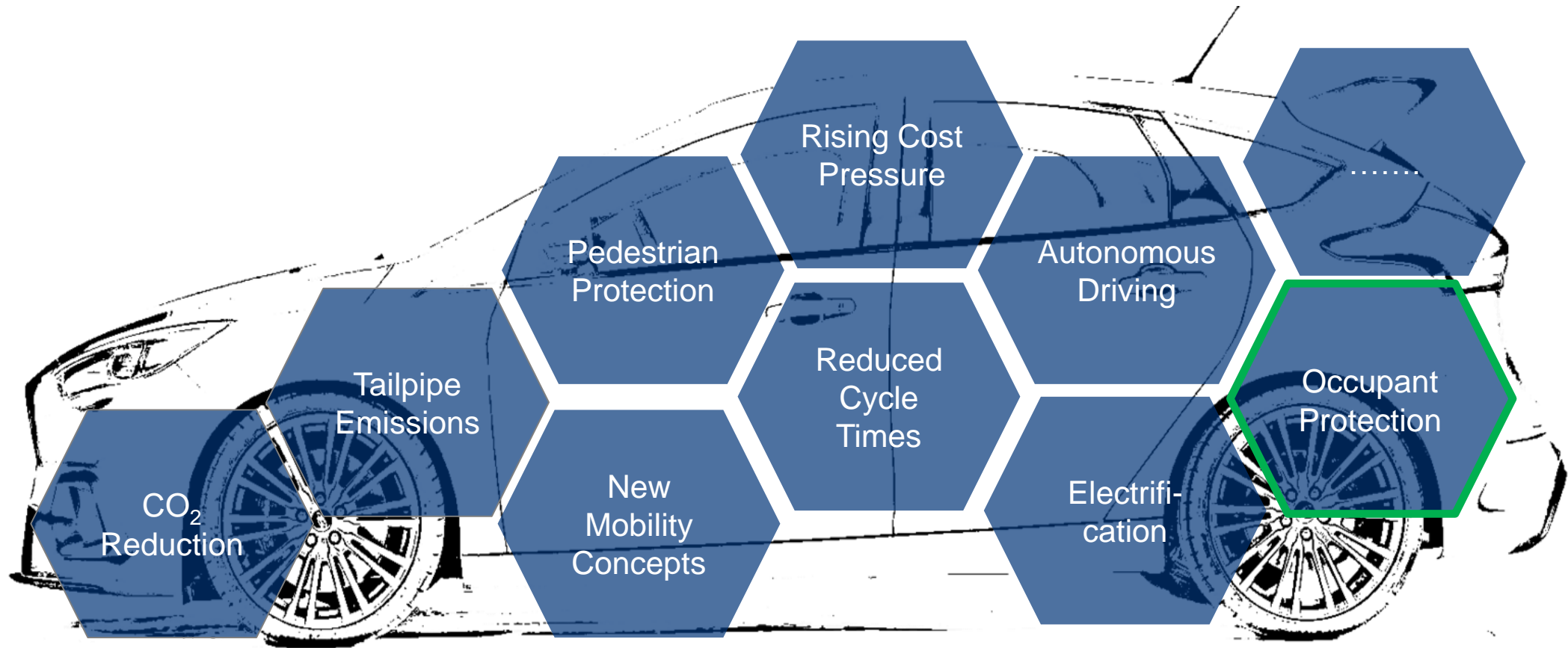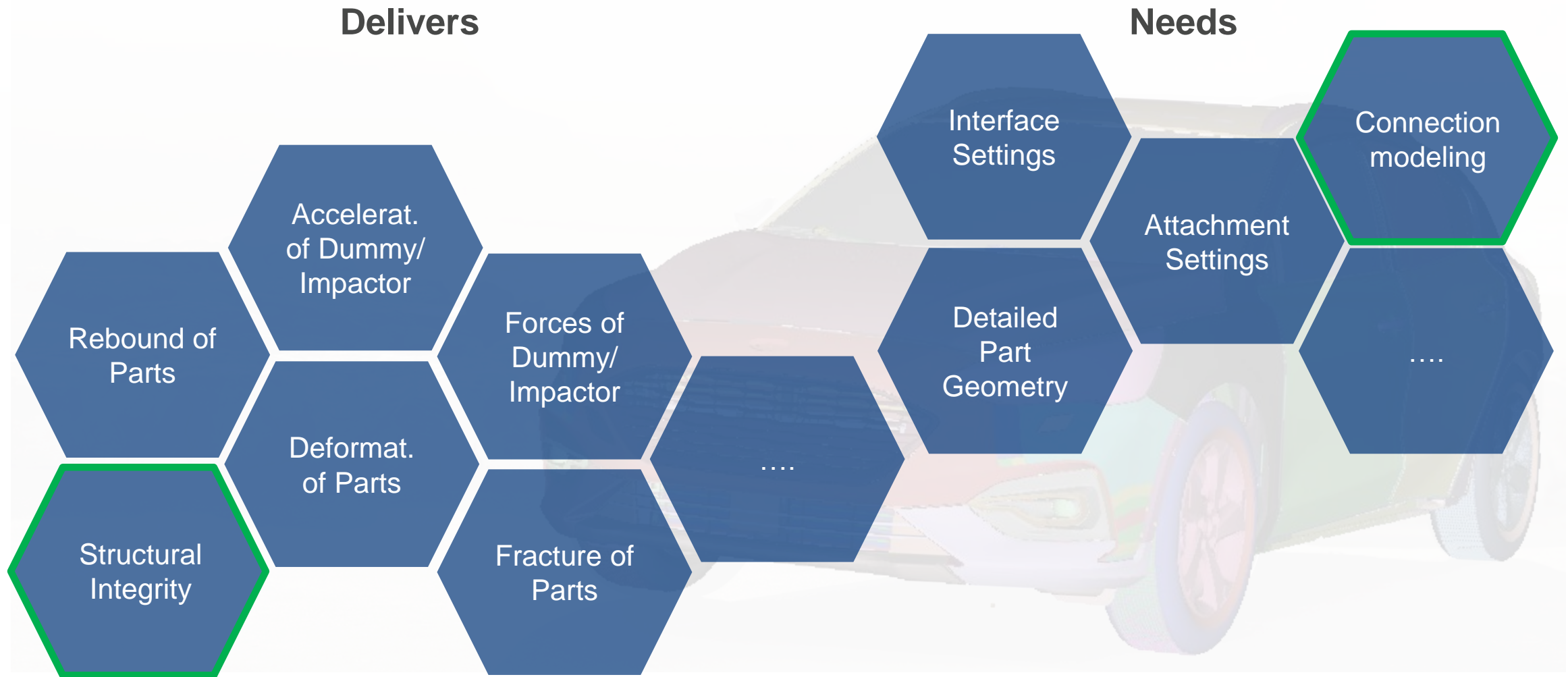
[2] ika - RWTH Aachen University

[3] DYNAmore GmbH

# CONTENTS

# AUTOMOTIVE INDUSTRY CHALLENGES

# Virtual Vehicle Design for Safety

**Delivers**

**Needs**

Rebound of Parts

Accelerat. of Dummy/ Impactor

Structural Integrity

Deformat. of Parts

Forces of Dummy/ Impactor

Fracture of Parts

....

Interface Settings

Detailed Part Geometry

Attachment Settings

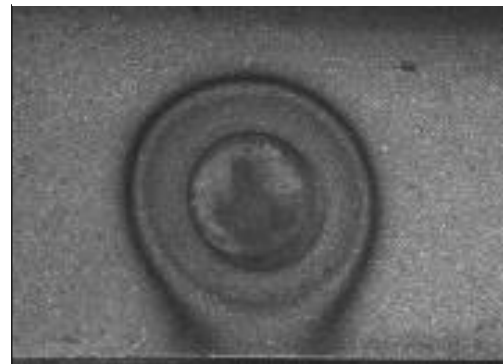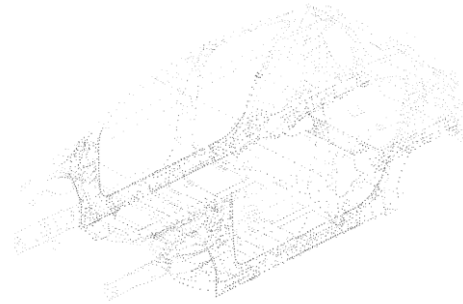Connection modeling

....

# CONNECTIONS IN VEHICLE DESIGN (EXAMPLES)

Self-piercing rivets (SPR)    Resistance Spot welds (RSW)    Laser beam welding (LBW)
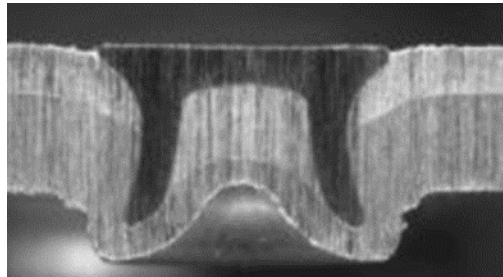
Modeling of Joints with Plug Out Separation Modes by Utilizing Cohesive Shells for Full Vehicle Safety Models – N. Pasligh, E. Ertugus, T. Erhart
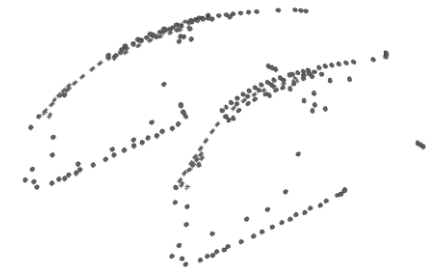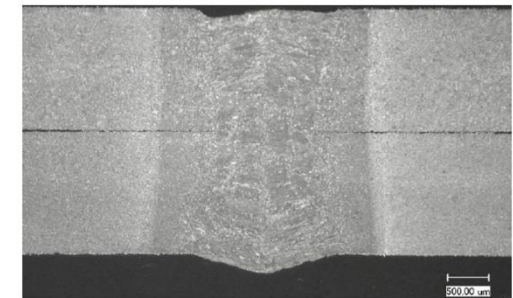
# JOINT HISTORY IN FULL VEHICLE MODELS

## Future

## Today

## Past
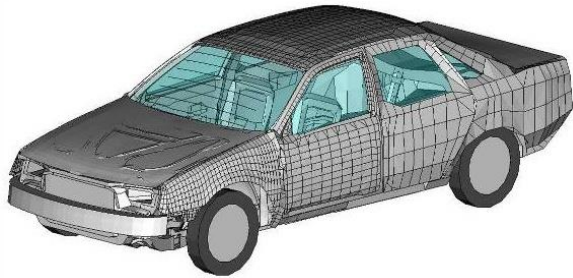
- Mesh size > 50 mm
- 30,000 elements
- **No/ basic joint modeling**
- …

- Mesh size ~ 2 - 5 mm
- > 5 million elements
- **Simplified joint modeling**
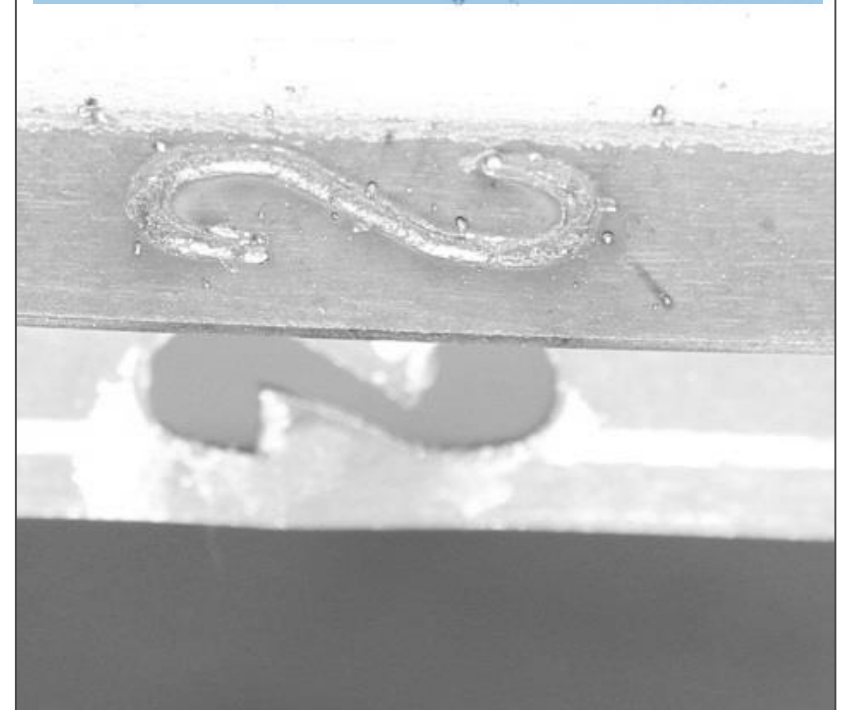- **Implemented joint separation criteria**
- …

- Mesh size even smaller or new approaches
- Multi million elements
- **Detailed joint modeling**
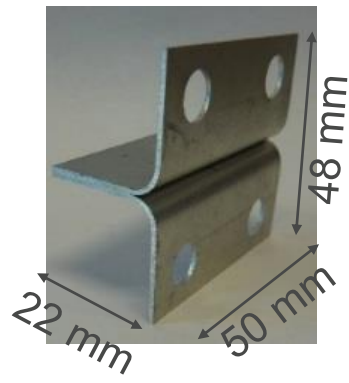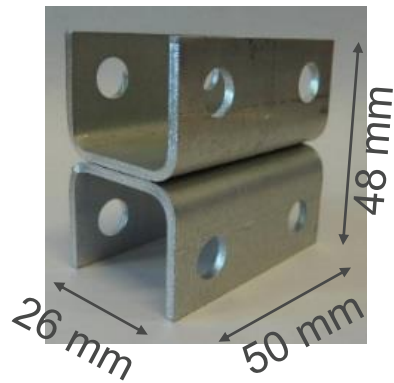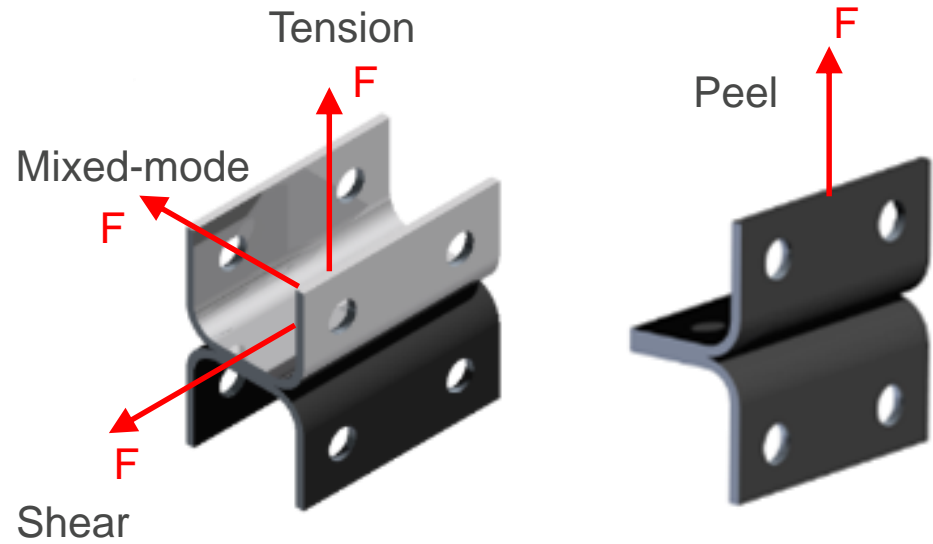- **Complex, interactive separation criteria with ambient dependencies**
- …

Target:

Prediction of laser weld plug out separation mode in a shell meshed environment

26/09/2018 Modeling of Joints with Plug Out Separation Modes by Utilizing Cohesive Shells for Full Vehicle Safety Models – N. Pasligh, E. Ertugus, T. Erhart

# TESTING AND SEPARATION

## Coupon level testing

Tension

Mixed-mode

Shear

Peel

26 mm    50 mm

22 mm    50 mm

48 mm

48 mm

## Indicated separation modes

Interfacial

Plug out

## Separation sketch



Sheet metal

LBW

## CAE realization principle



seam element
shell elements
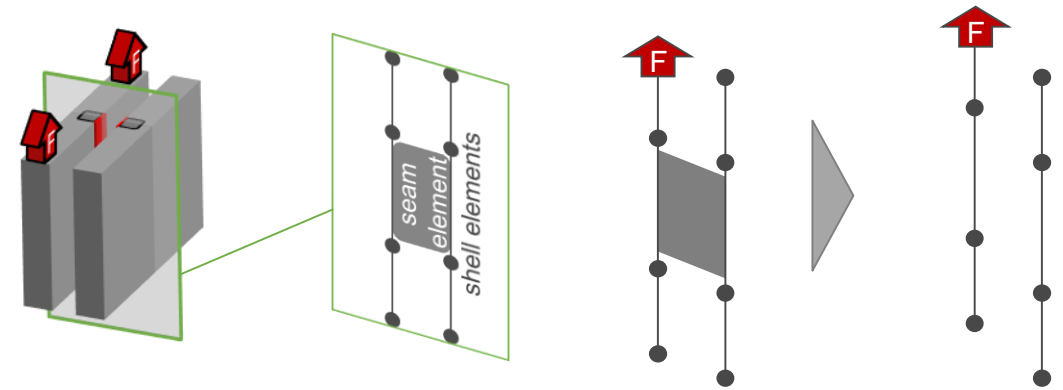
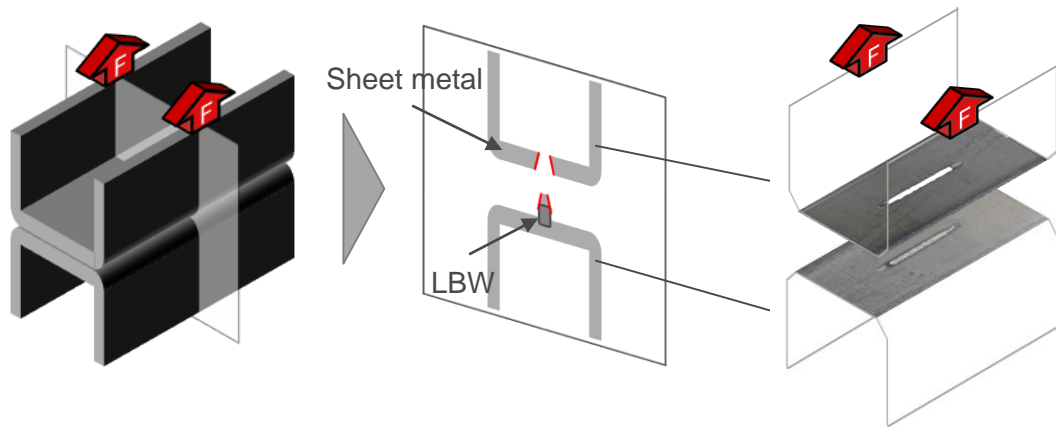**Conventional methods sufficient**
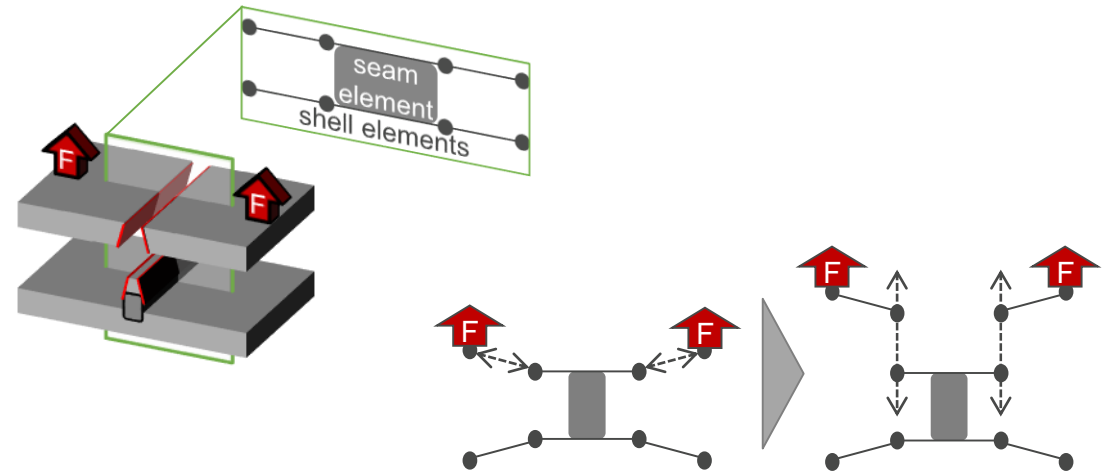
Required CAE principal
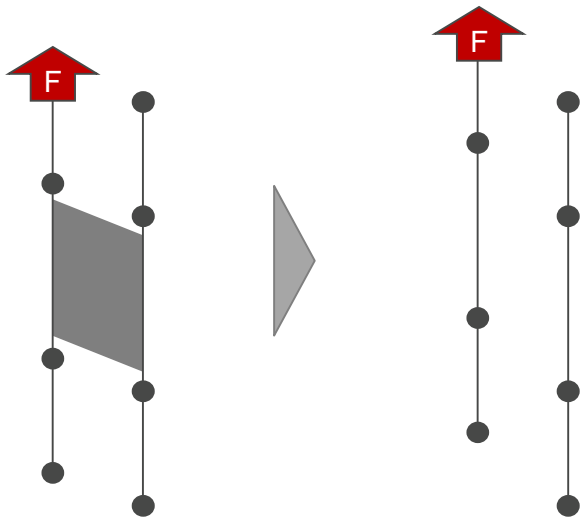
CAE representation

Sheet:  Shells
Joint:  Solids

# PLUG OUT SEPARATION MODE

Separation sketch
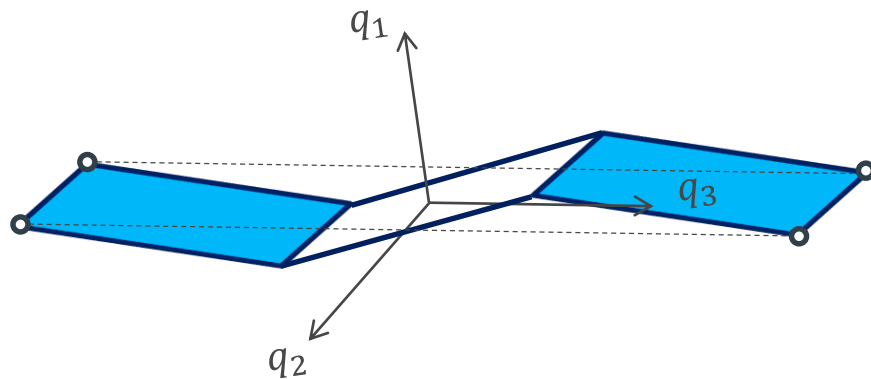
CAE required principle



→ Evaluation of loads in vertical direction of shell mesh necessary
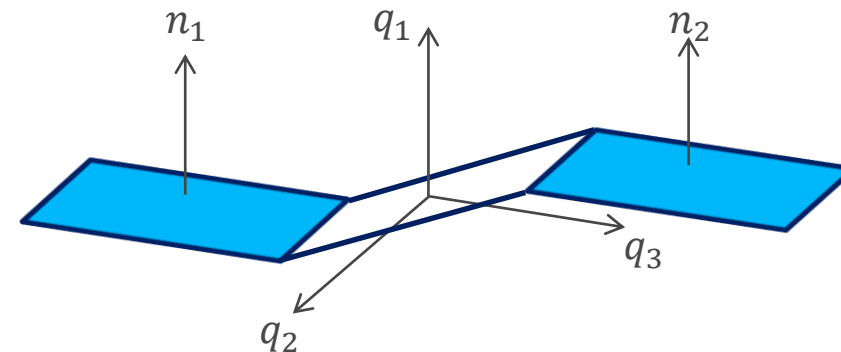
# Cohesive Shell Element

- Existing mid-layer coordinate system ELFORM = 29
- New mid-layer coordinate system ELFORM = -29 (suitable for pure shear)
- *MAT_240 now supports ELFORM = +/-29
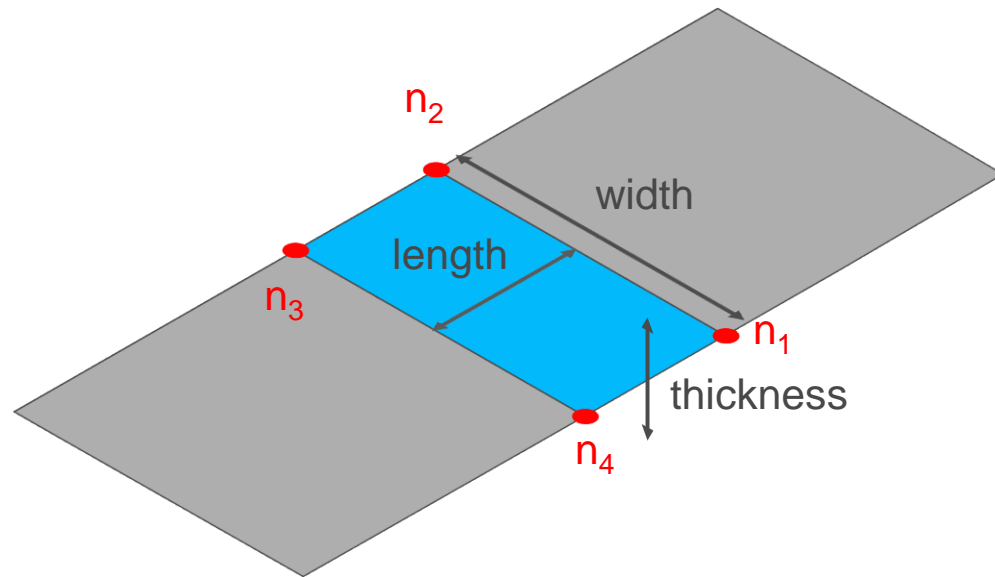
ELFORM = +29 ($q_3$ from nodes)
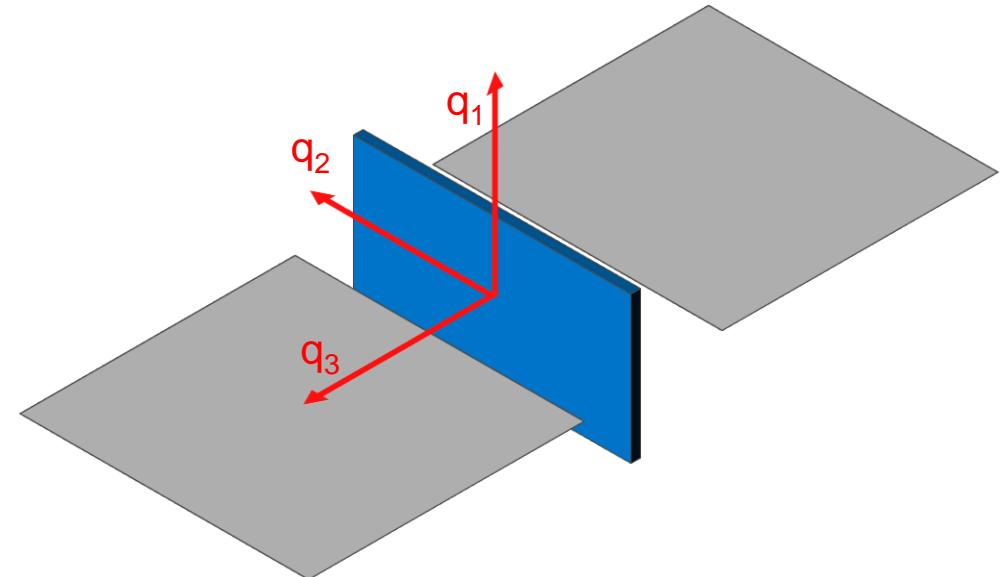
ELFORM = -29 ($q_1$ from normals)

# COHESIVE SHELL ELEMENT "+/- 29"

## Dimensions



Length → 0

## Orientation

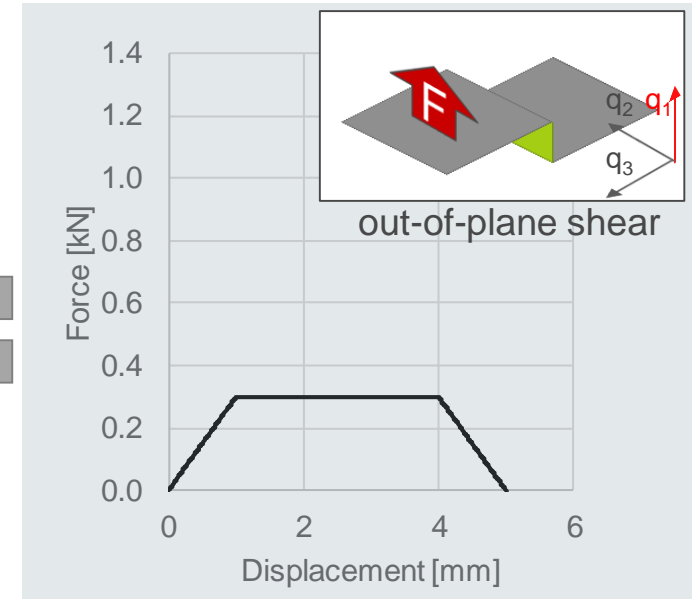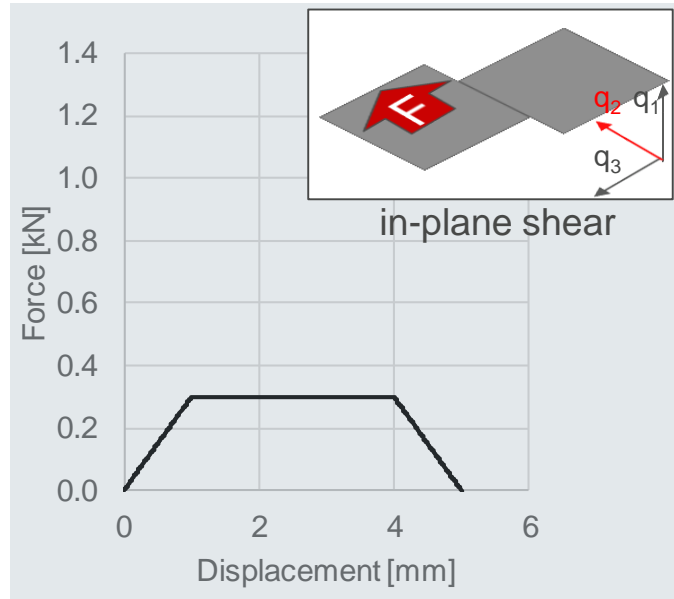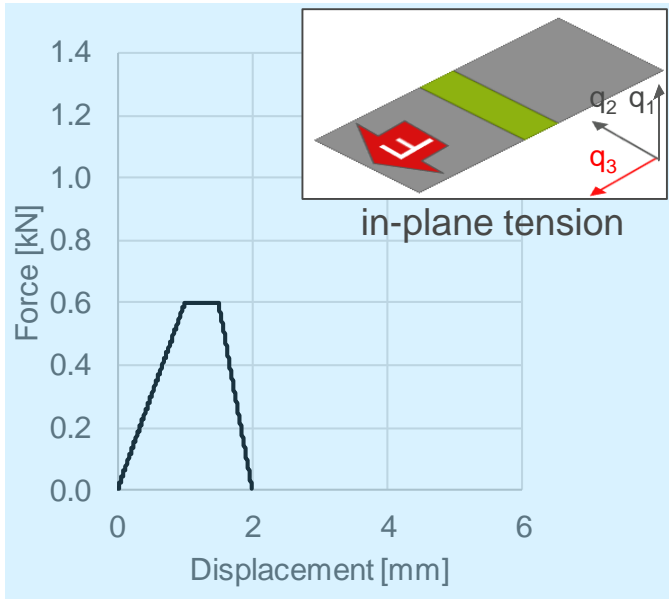# MAT_240 CONVENTIONAL

```
*MAT_COHESIVE_MIXED_MODE_ELASTOPLASTIC_RATE
$#      mid        ro     roflg    intfail      emod       gmod      thick     output
          3   7.85E-06        1         1      0.200      0.100      1.000      0.100
$#    g1c_0    g1c_inf    edot_g1        t0         t1     edot_t        fg1
      0.250      0.000      0.000      0.200      0.000      0.000      0.400          q₃
$#    g2c_0    g2c_inf    edot_g2        s0         s1     edot_s        fg2
      0.400      0.000      0.000      0.100      0.000      0.000      0.750      q₂   q₁
```



in-plane tension



in-plane shear



out-of-plane shear

# MAT_240_3MODES

- New option includes a third deformation and fracture mode

- Makes sense in combination with cohesive shell elements with tension (I), in-plane shear (II), and out-of-plane shear (III) modes

- Ingredients:

  - Total mixed-mode displacement: $\quad \delta_m = \sqrt{<\delta_I>^2 + \delta_{II}^2 + \delta_{III}^2}$

  - Mixed-mode damage initiation: $\quad \left(\frac{<\sigma_I>}{N}\right)^2 + \left(\frac{\tau_{II}}{S}\right)^2 + \left(\frac{\tau_{III}}{T}\right)^2 = 1,\quad N, S, T$ ... strength values

  - Mixed-mode propagation criterion: $\quad \left(\frac{G_I}{G_I^c}\right) + \left(\frac{G_{II}}{G_{II}^c}\right) + \left(\frac{G_{III}}{G_{III}^c}\right) = 1,\quad G_{(c)}$ ... (critical) energy release rates
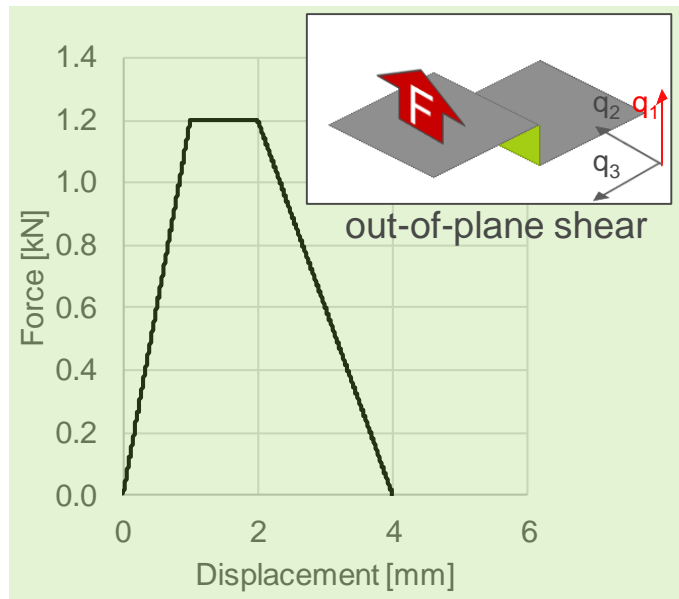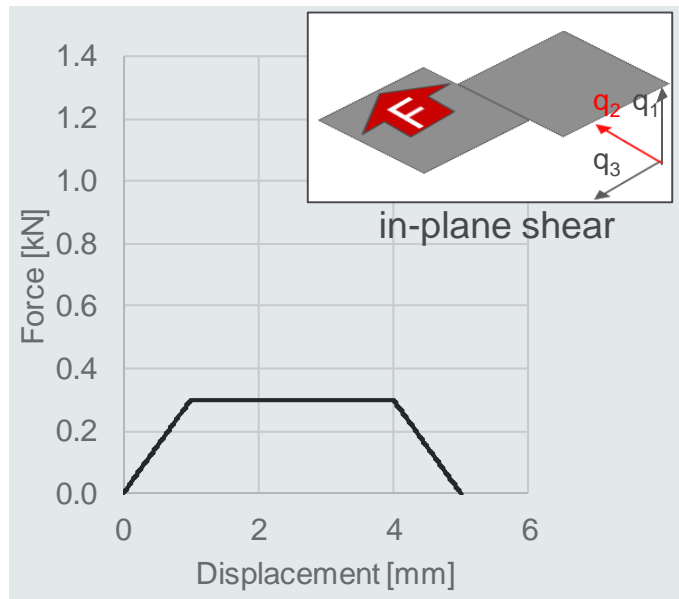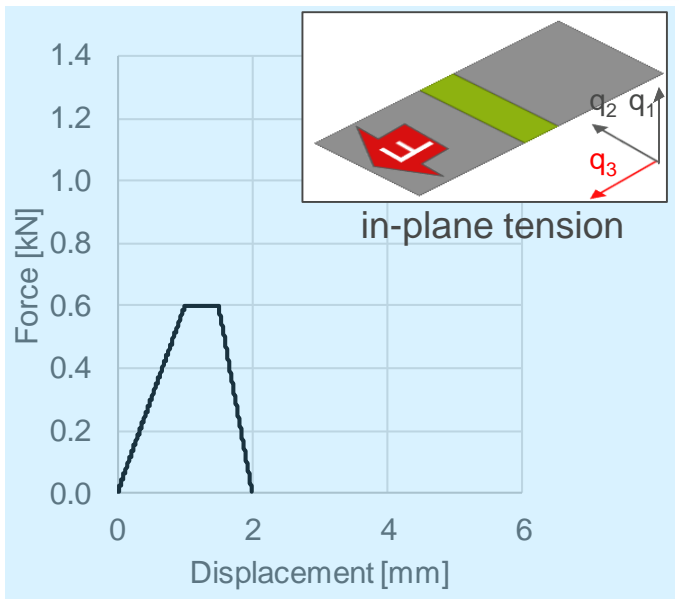  (power law with exponent=1)

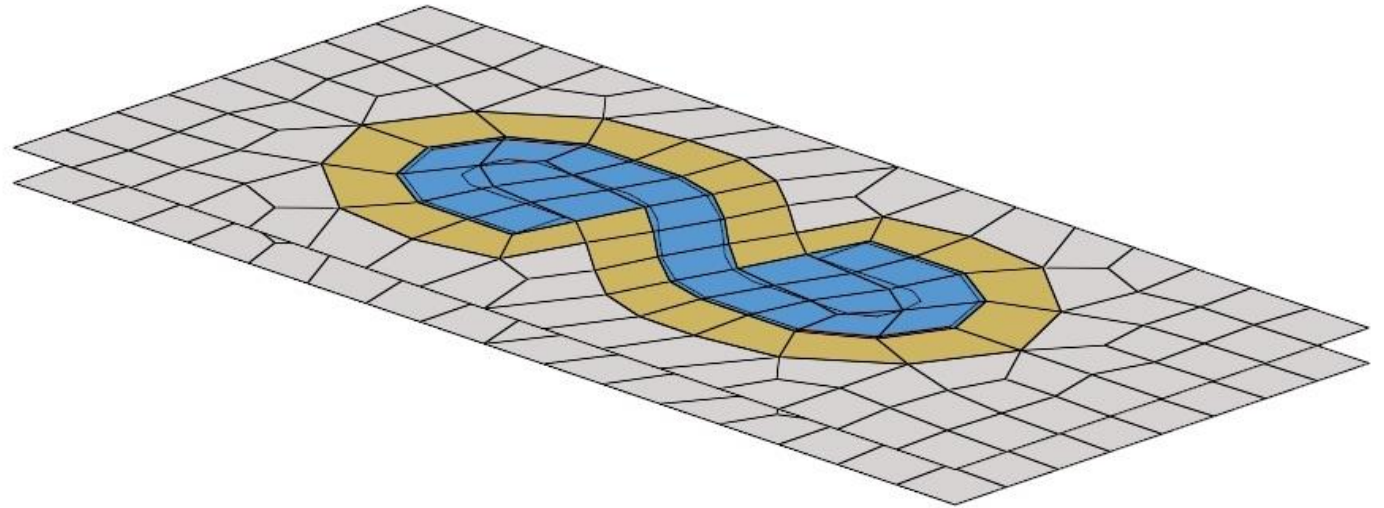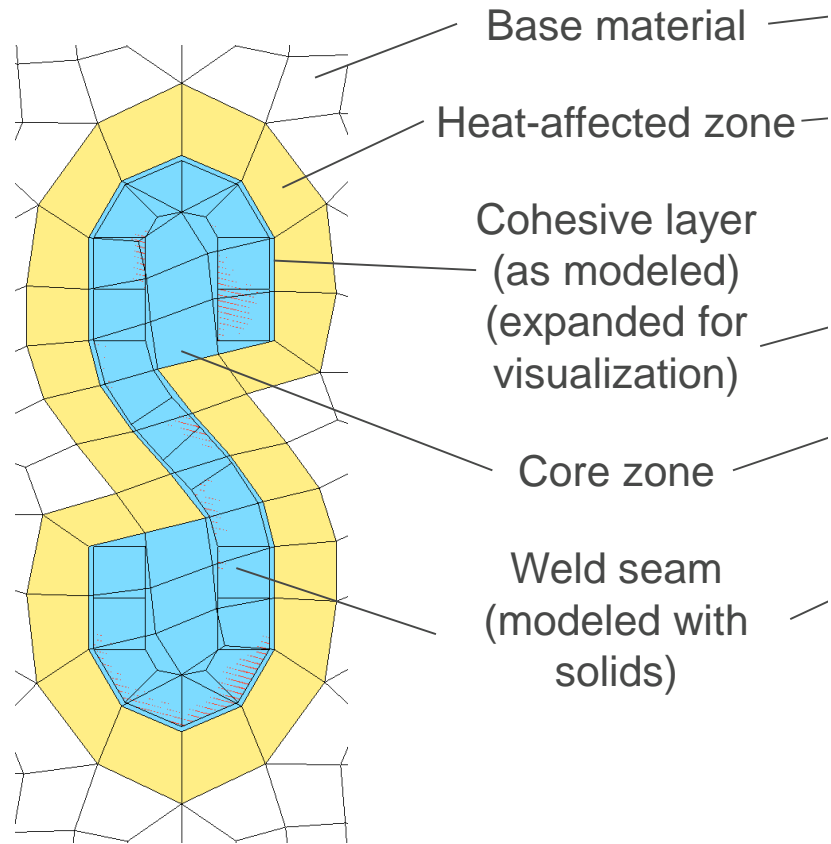  (without _3MODES, mode **II** and mode **III** are assumed to be the same)

# MAT_240_3MODES EXTENSION

```
*MAT_COHESIVE_MIXED_MODE_ELASTOPLASTIC_RATE_3MODES
```

| $# | mid | ro | roflg | intfail | emod | gmod | thick | output |
|---|---|---|---|---|---|---|---|---|
| | 3 | 7.85E-06 | 1 | 1 | 0.200 | 0.100 | 1.000 | 0.100 |

| $# | g1c_0 | g1c_inf | edot_g1 | t0 | t1 | edot_t | fg1 |
|---|---|---|---|---|---|---|---|
| | 0.250 | 0.000 | 0.000 | 0.200 | 0.000 | 0.000 | 0.400 |

$q_3$

| $# | g2c_0 | g2c_inf | edot_g2 | s0 | s1 | edot_s | fg2 |
|---|---|---|---|---|---|---|---|
| | 0.400 | 0.000 | 0.000 | 0.100 | 0.000 | 0.000 | 0.750 |

$q_2$

| $# | g3c_0 | g3c_inf | edot_g3 | r0 | r1 | edot_r | fg3 |
|---|---|---|---|---|---|---|---|
| | 1.000 | 0.000 | 0.000 | 0.400 | 0.000 | 0.000 | 0.400 |

$q_1$

| $# | gmod3 |
|---|---|
| | 0.400 |

in-plane tension

in-plane shear

out-of-plane shear

Base material

Heat-affected zone

Cohesive layer
(as modeled)
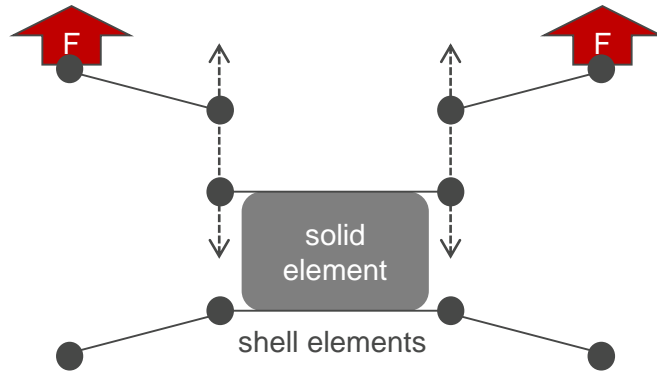(expanded for
visualization)
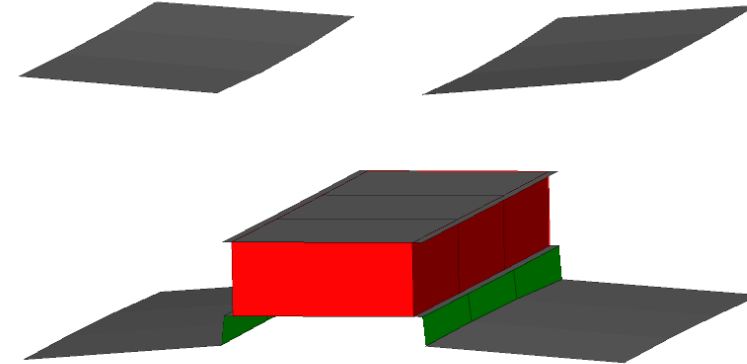
Core zone

Weld seam
(modeled with
solids)

# REPRESENTATION OF PLUG OUT SEPARATION MODE

Required CAE principal

Achieved CAE representation



Sheet: Continuum shells
+ Cohesive shells
Joint: Solids

solid element

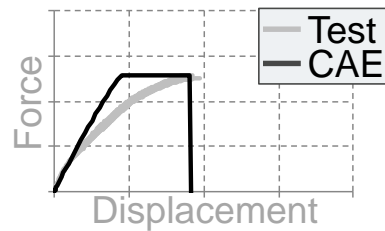shell elements

## Load case & Results

## Input determination
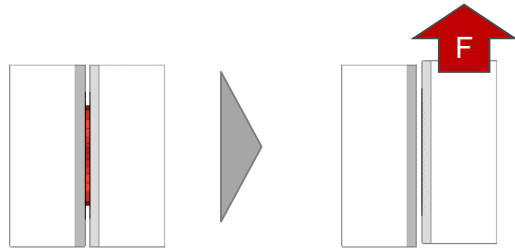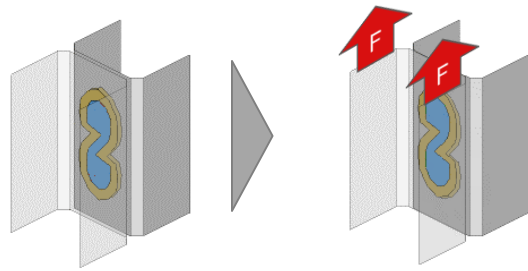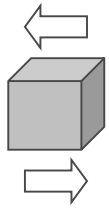


```
*MAT_COHESIVE_MIXED_MODE_ELASTOPLASTIC_RATE_3MODES
$#       mid         ro      roflg     intfail       emod       gmod      thick     output
           3    7.85E-06          0           1      0.200      0.100      1.000      0.100
$#      g1c_0     g1c_inf    edot_g1         t0         t1     edot_t        fg1
        0.250       0.000      0.000      0.200      0.000      0.000      0.400
$#      g2c_0     g2c_inf    edot_g2         s0         s1     edot_s        fg2
        0.400       0.000      0.000      0.100      0.000      0.000      0.750
$#      g3c_0     g3c_inf    edot_g3         r0         r1     edot_r        fg3
        1.000       0.000      0.000      0.400      0.000      0.000      0.400
$#      gmod3
        0.400
```
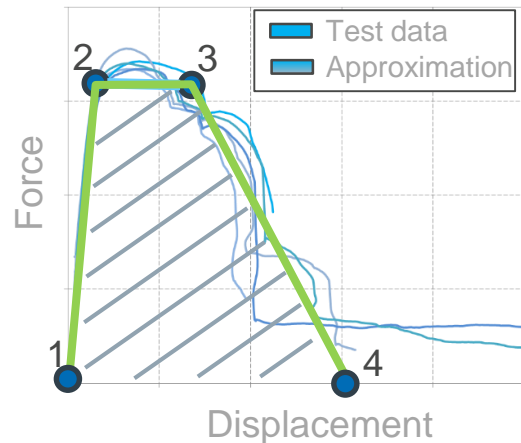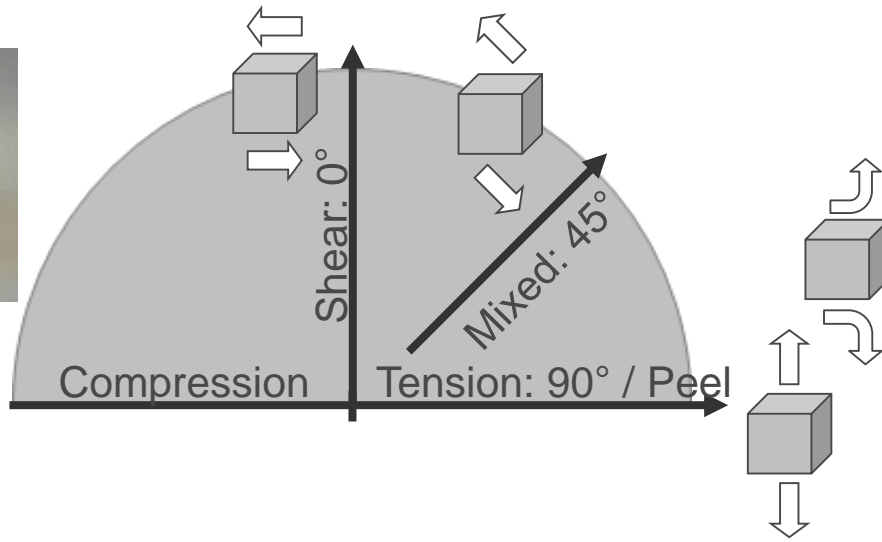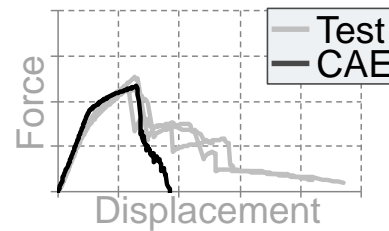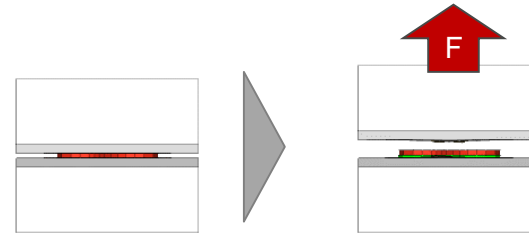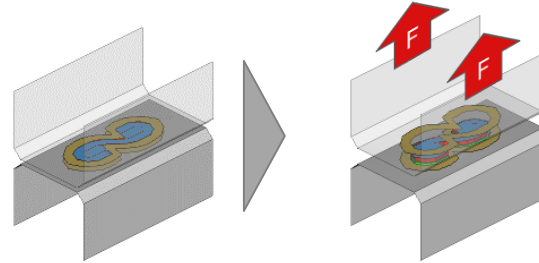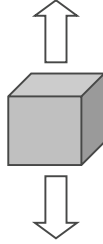
Strength

Shape approximation

Energy consumption

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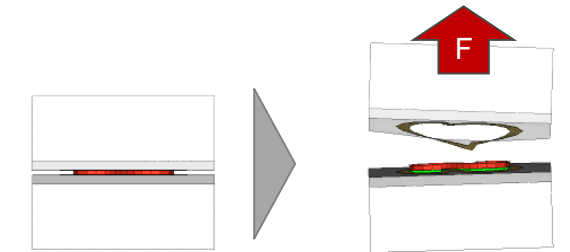15. Deutsches LS-DYNA Forum 2018, © 2018 Ford Motor Company, All Rights Reserved

KS-2 0°

KS-2 90°

KS-2 Peel

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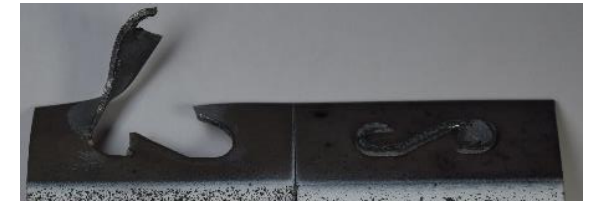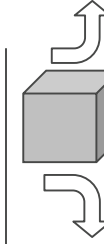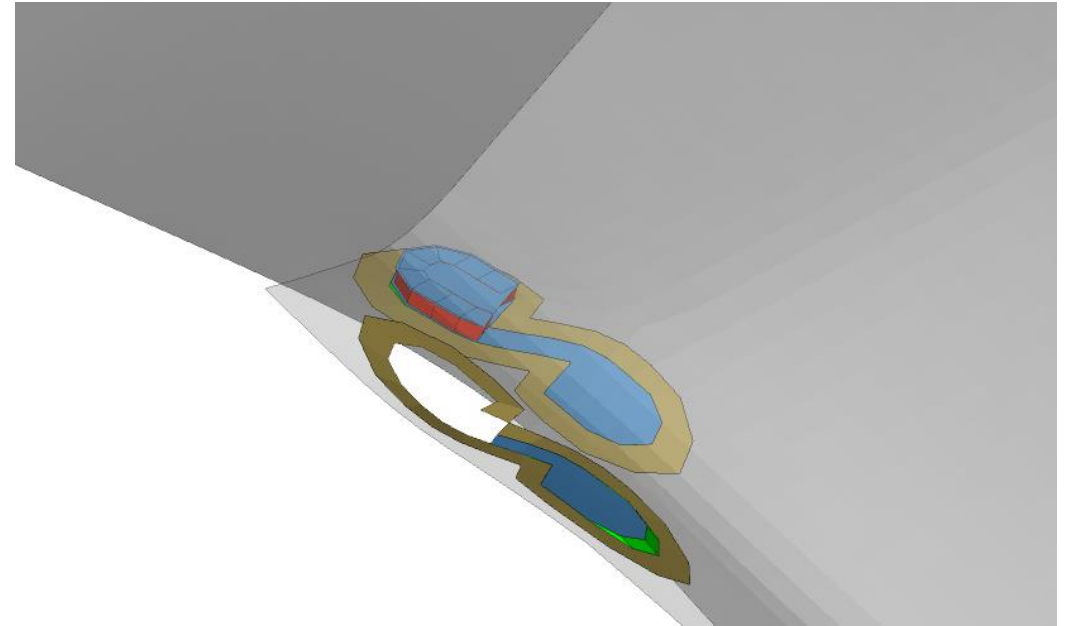15. Deutsches LS-DYNA Forum 2018, © 2018 Ford Motor Company, All Rights Reserved

Mixed separation on a prototype

Corresponding CAE prediction

# CONCLUSION

- Developed CAE approach for plug out separation modes for shell meshed full vehicle models

- Cohesive shells reflect the plug out fracture criterion in the joining area

- CAE approach transferable to further joining technologies

Result:

Predicted plug out separation mode in a shell mesh environment

# THANK YOU!