15th German LS-DYNA Forum

# Parameter Identification of the *MAT_036 Material Model using Full-Field Calibration

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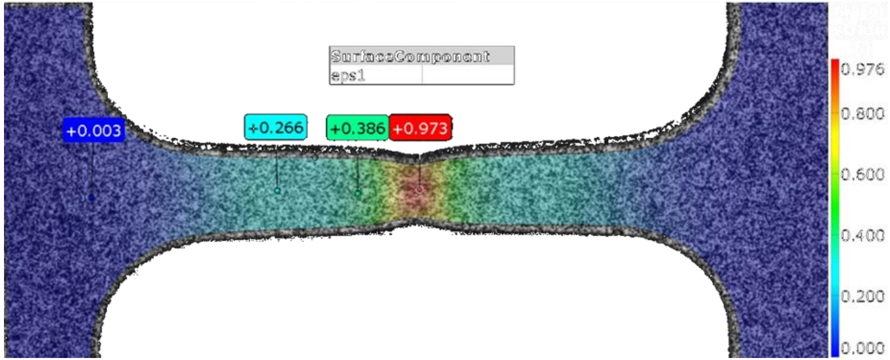
## Contents

## Strain measurement

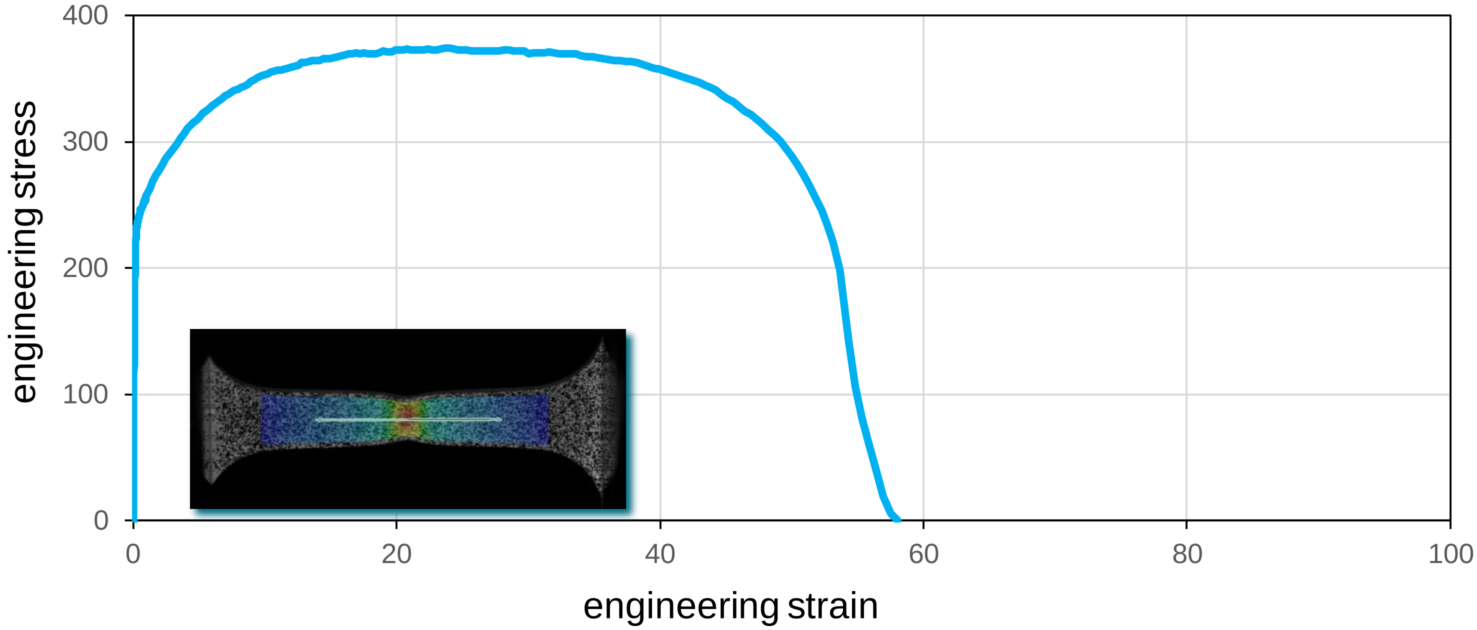
- Classical scheme of characterizing the yield behavior of a material
  - Tensile test delivers engineering stress vs. strain curve for a specific reference length.
  - Identification of material parameters via reverse engineering strategy, with which the test is simulated and the resulting stress strain curves were compared to the testing results.

- Drawbacks:
  - The area with the highest strains, the localization area, is not considered explicitly.



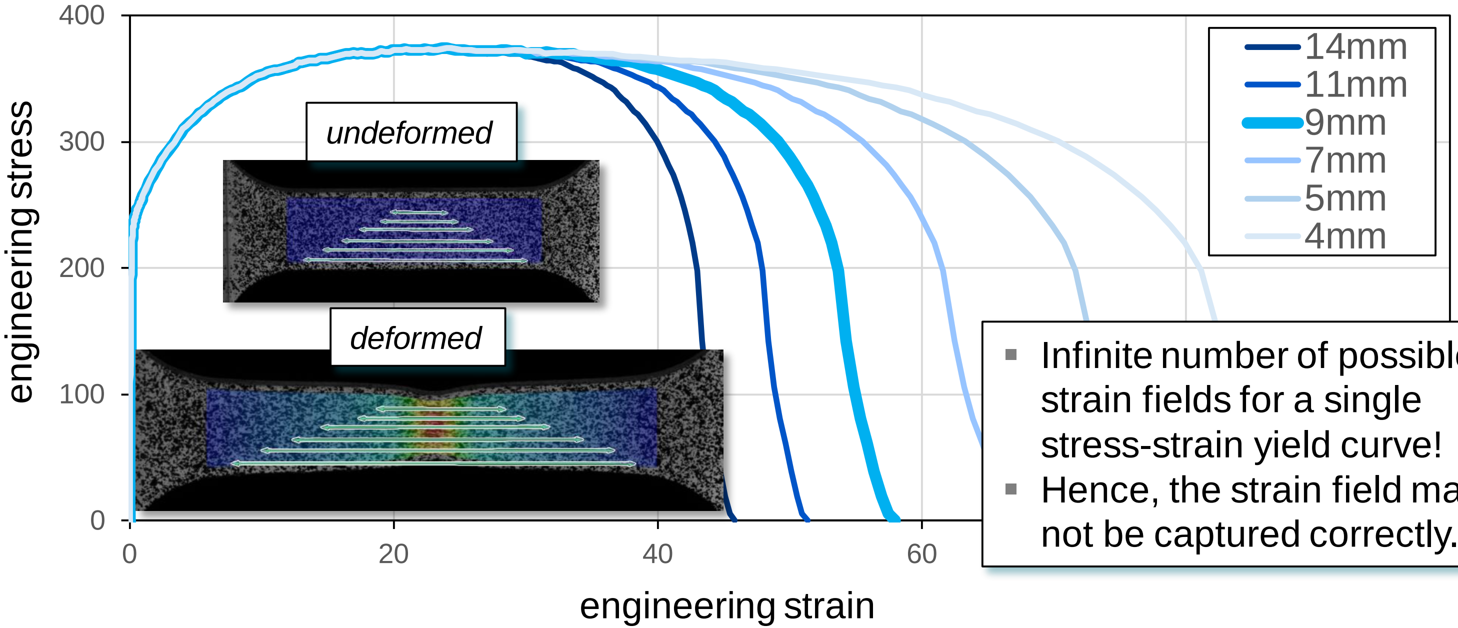
# Strain localization in DIC

- Traditional method for the evaluation of tensile tests
  - Engineering stress-strain curve with a predefined reference length (here: $l_0$ = 9 mm)



# Strain localization in DIC

- Traditional method for the evaluation of tensile tests
  - Engineering stress-strain curve for different reference lengths




- Infinite number of possible strain fields for a single stress-strain yield curve!
- Hence, the strain field may not be captured correctly.

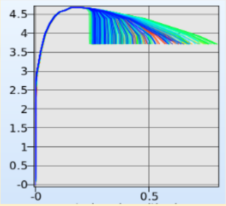
# Concept

## Experiment


Measurement:
- Force
- Strain field

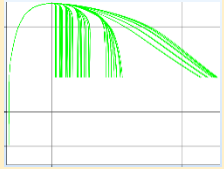
## Optimization

Input from experiment



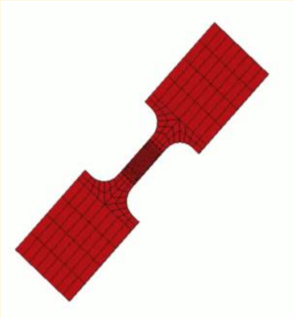

*Force vs. strain*

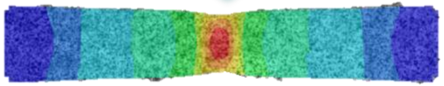
Input from simulation



*Force vs. strain*

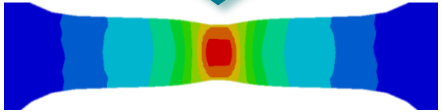
## Simulation





Measured strain field

Objective:
identical strain fields in time

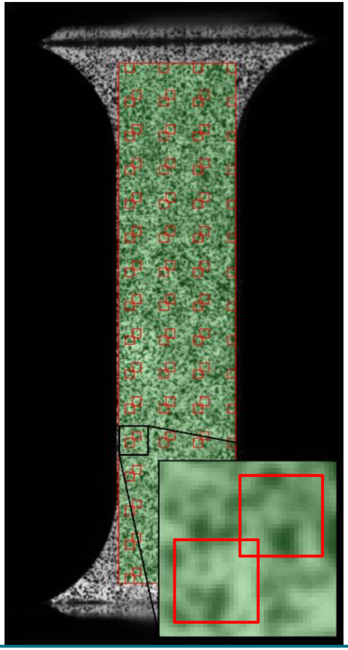


Simulated strain field

## Contents

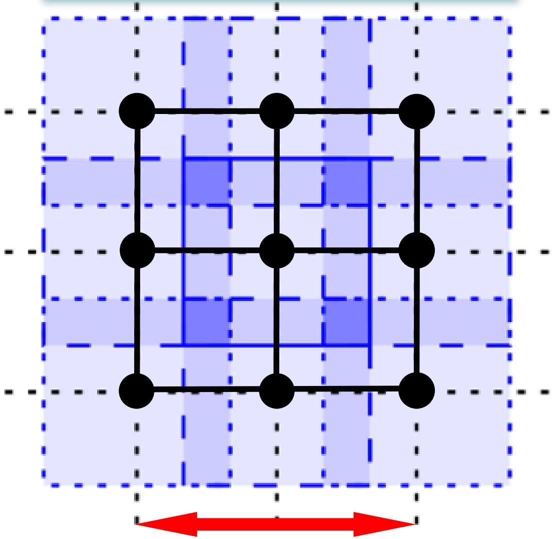
# Strain calculation in ARAMIS

- ARAMIS v6

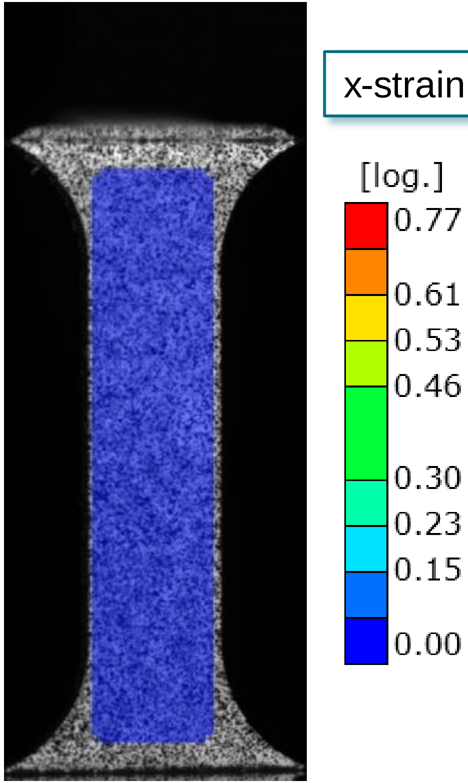


Visualization in ARAMIS

Schematic representation



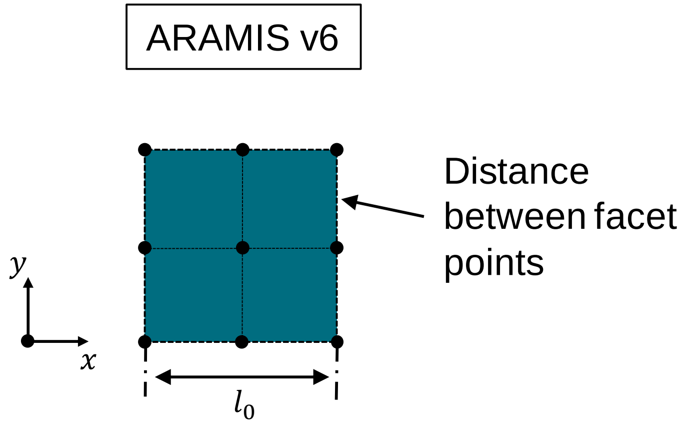
Reference length of
the strain calculation



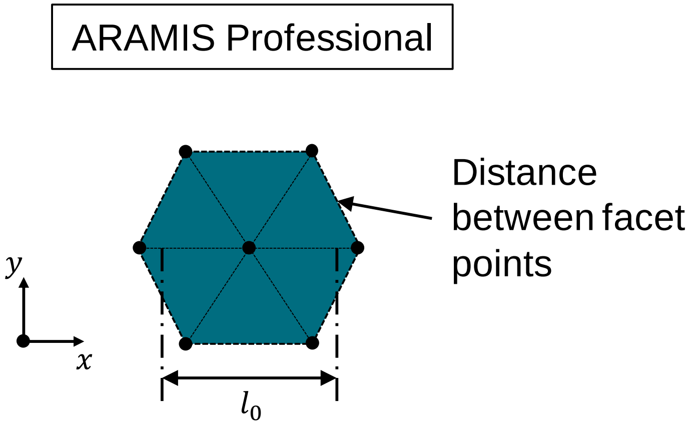
x-strain

# Strain calculation in ARAMIS

- ARAMIS v6 vs ARAMIS Professional



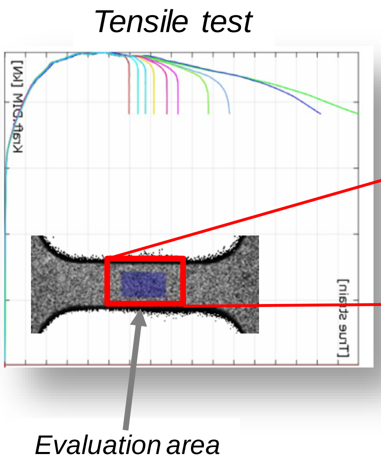

The reference length $l_0$
is twice the facet point distance

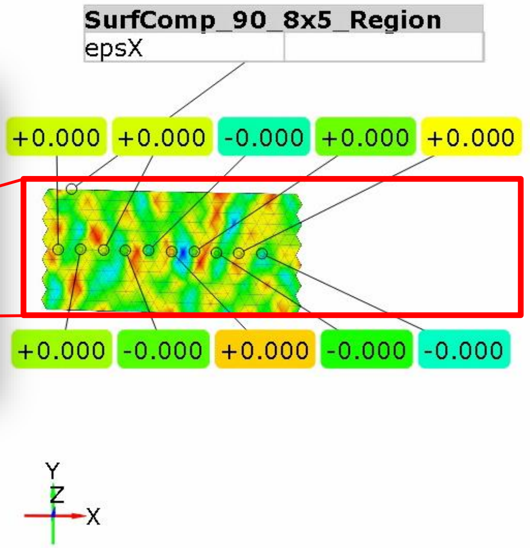


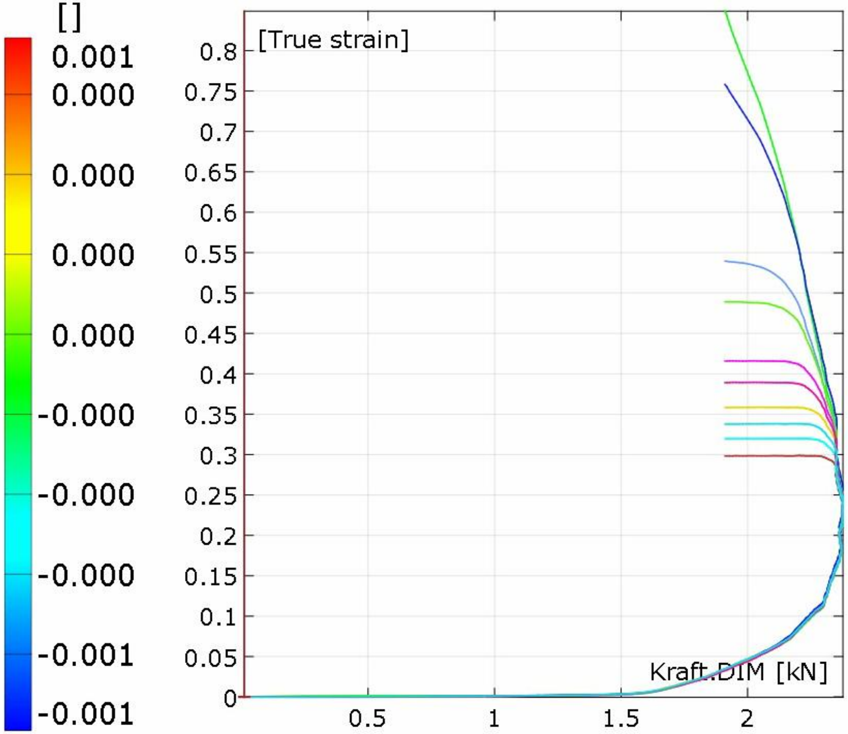

The reference length $l_0$ in any direction is determined by the mean length of the hexagon. (0.75*double_facet_point_distance )

# Strain calculation in ARAMIS

- ARAMIS output – force vs. true strain



## Contents

- Motivation
- Strain calculation in ARAMIS
- Implementation of FFC with LS-OPT
- Proof of concept
- Summary & conclusions
- Outlook

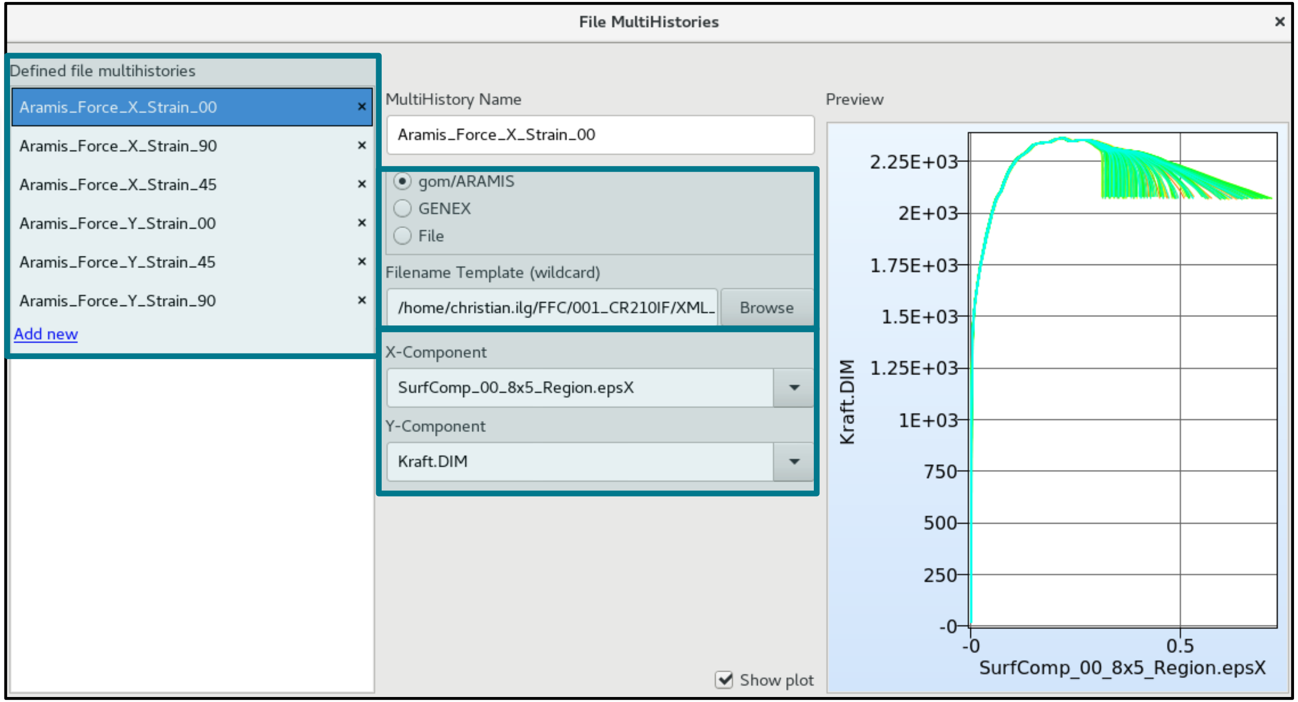
# Implementation of FFC with LS-OPT

- New interface in LS-OPT

1. Define multi-histories

2. Insert load stages

3. Definition of axes



# Implementation of FFC with LS-OPT

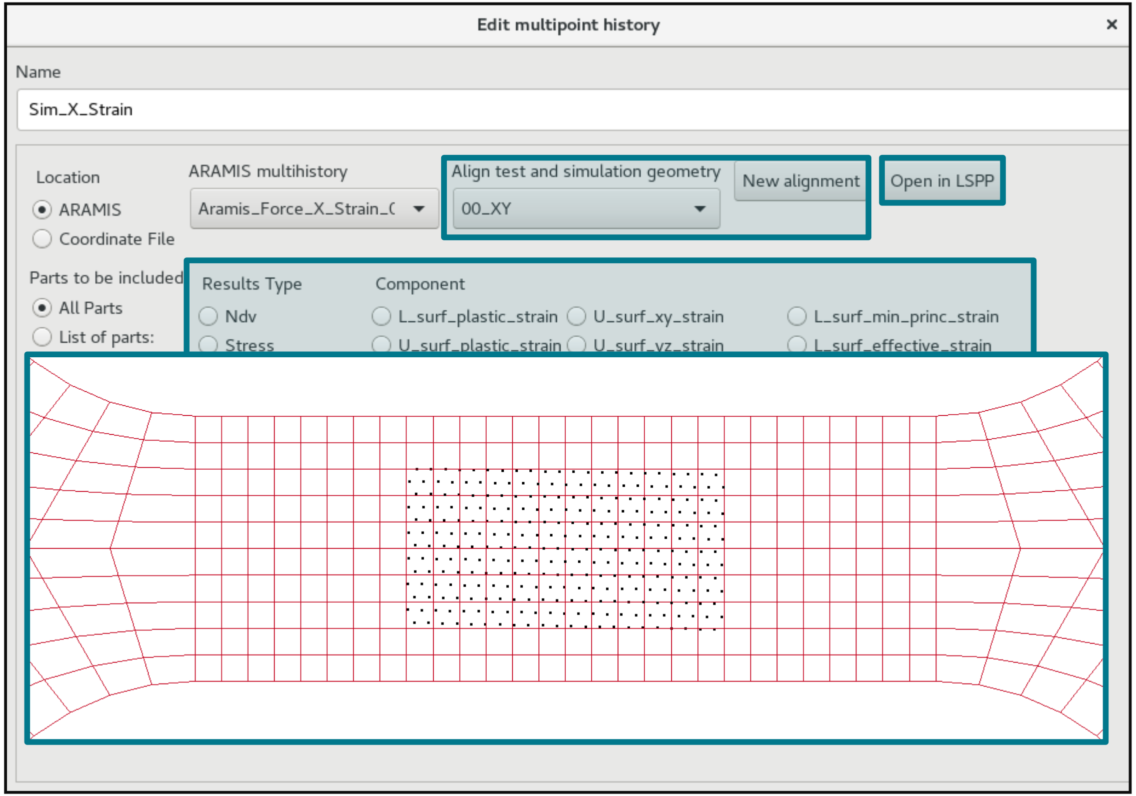
- New interface in LS-OPT

Alignment of simulation and experiment

Possibility to visualize the alignment in LS-PrePost

Selection of the variables from the simulation to be compared

Choose mapping method between test and simulation



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# Proof of concept

- Validation of the anisotropic MAT_036 constitutive model

- Assumption in the simulation model:
  - Anisotropic constitutive model: *MAT_036 (*MAT_3-PARAMETER_BARLAT)
  - Yield locus parameters assumed constant (not optimized at present)
  - Reducing the number of free parameters for the yield curve
  - Damage and failure are not considered

- Material: sheet metal CR210IF

# Proof of concept

- Parametrization of the yield curve

Direct calculation of the yield curve until $A_g$

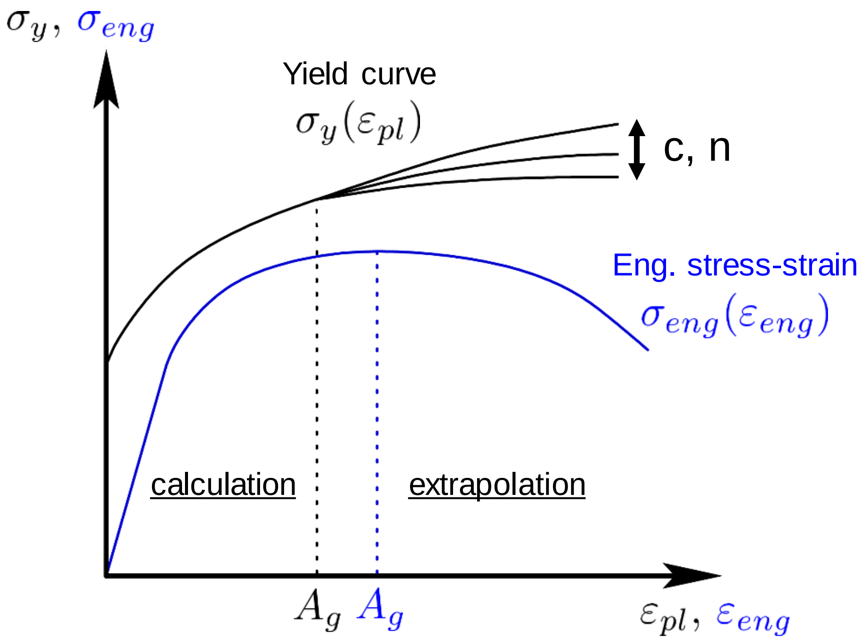
$$\sigma_y = \sigma_{eng}(1+\varepsilon_{eng})$$
$$\varepsilon_{pl} = \ln(1+\varepsilon_{eng}) - \frac{\sigma_{eng}}{E}$$

Extrapolation from $A_g$ with Hockett-Sherby

$$\sigma_y(\varepsilon_{pl}) = A - B\,e^{(-c\,\varepsilon_{pl}^n)}$$

$C^1$-continuity at $A_g$:

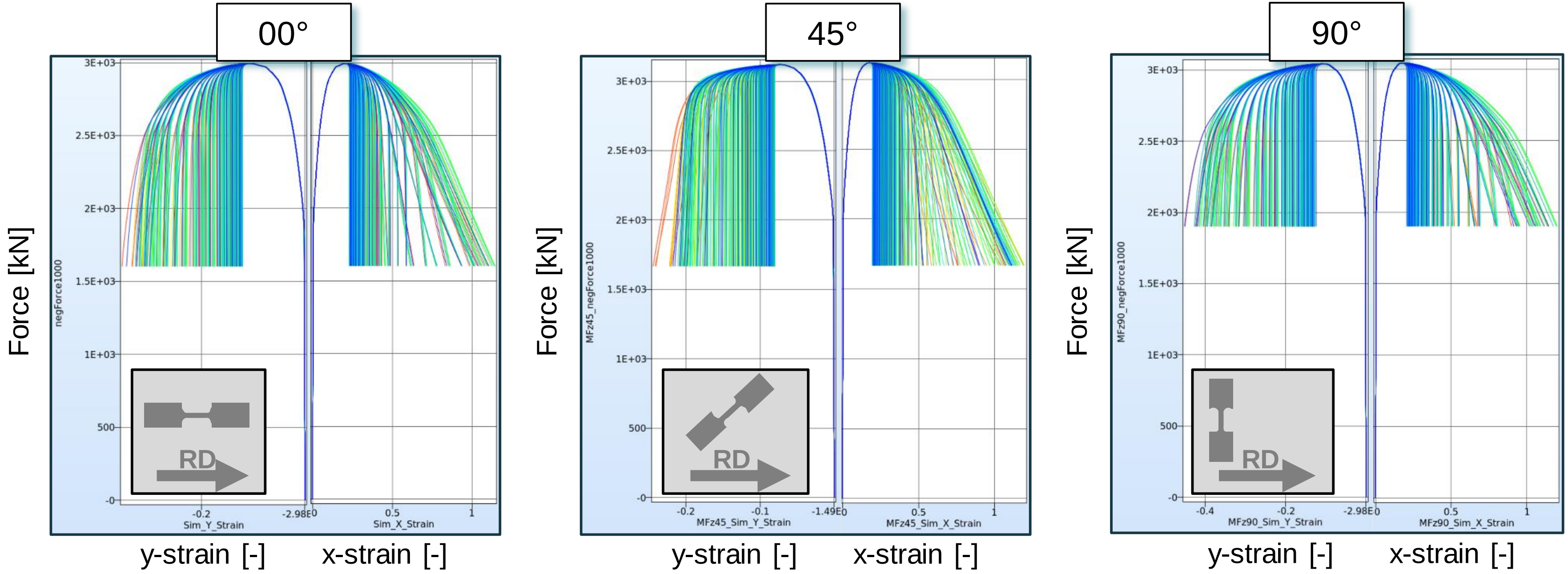
- ➢ Reduction of the function by two variables




Remaining variables *c* and *n* are chosen as optimization variables

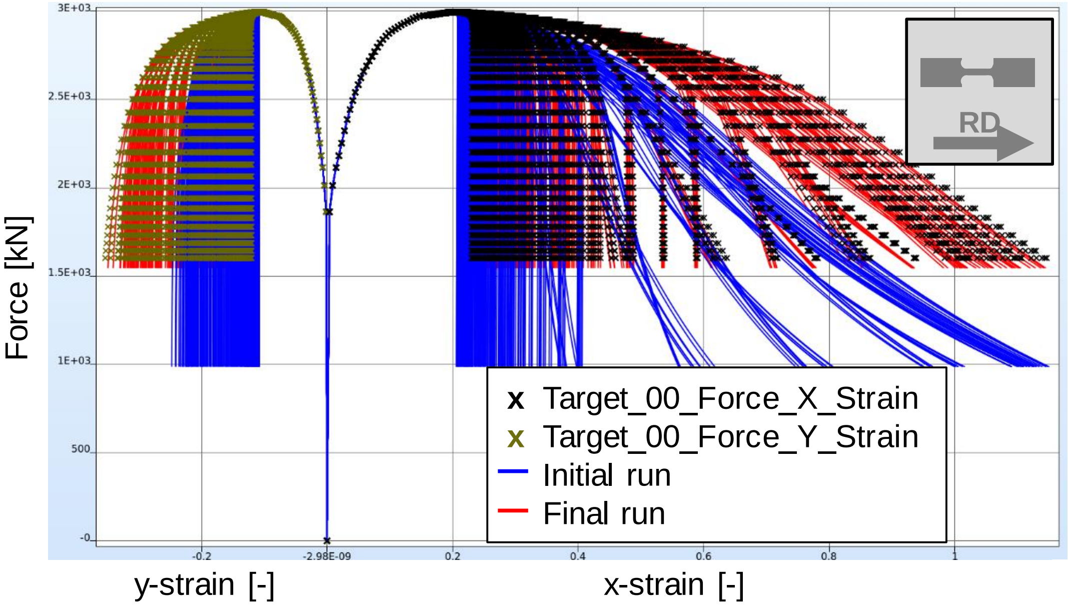
# Validation of method for MAT_BARLAT

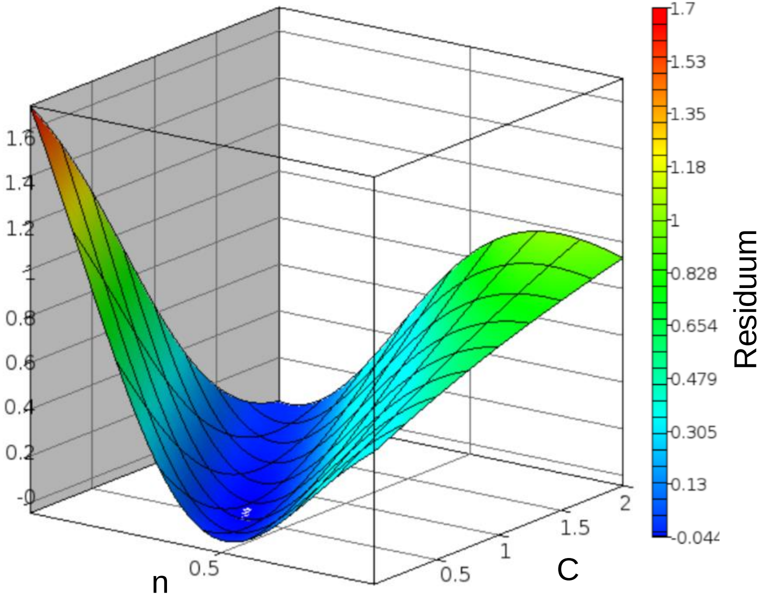
- Purely virtual: Target strain field generated from simulation.
- Optimization strategy: Feed-forward neural network (FFNN)



# Validation of method for MAT_BARLAT

- Optimization results with FFNN for 0°

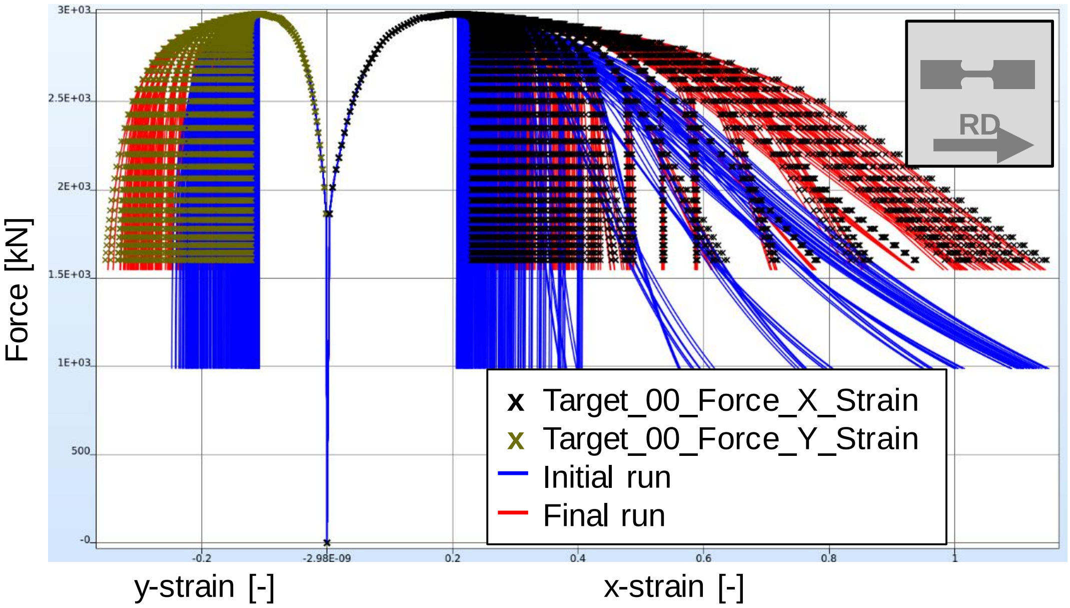


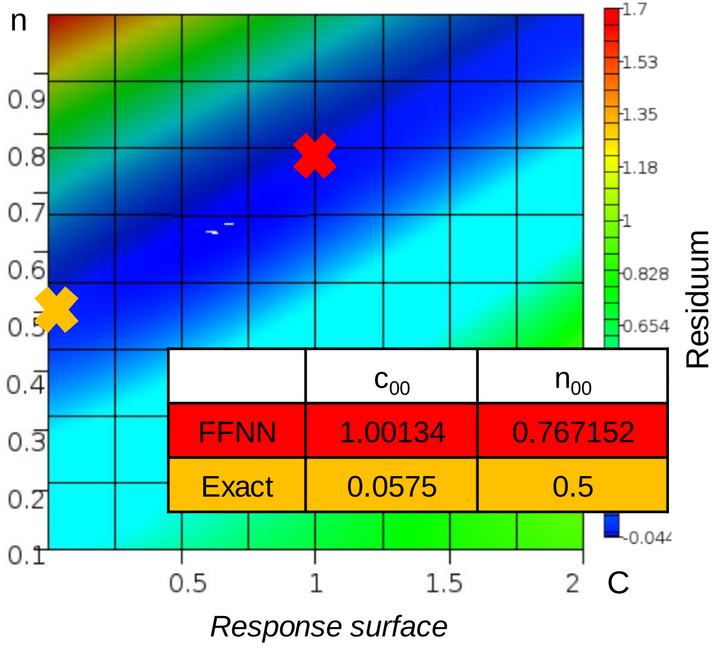




*Response surface*

# Validation of method for MAT_BARLAT

- Optimization results with FFNN for 0°



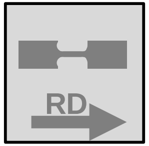



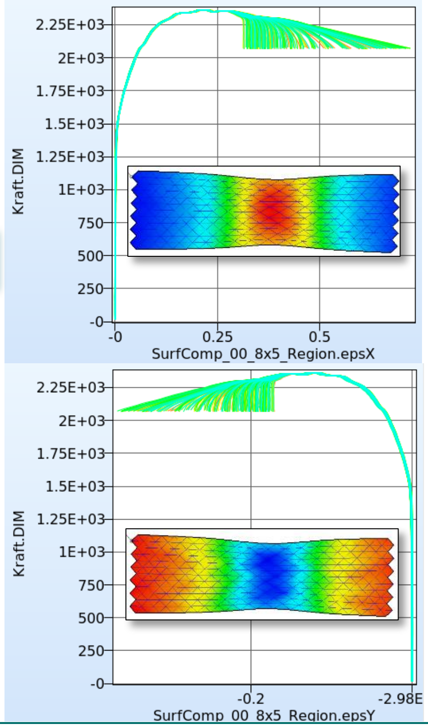

| | $c_{00}$ | $n_{00}$ |
|---|---|---|
| FFNN | 1.00134 | 0.767152 |
| Exact | 0.0575 | 0.5 |

# MAT_BARLAT parameter optimization from experimental data

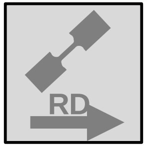
- Input: Curves from experiments w.r.t. the rolling direction (CR210IF)

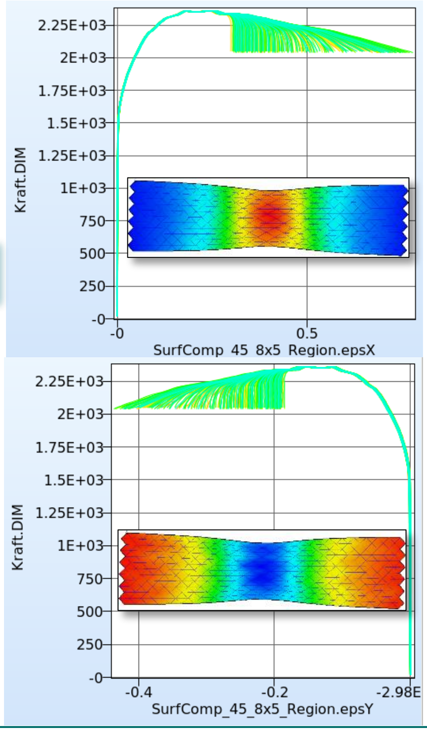
00°



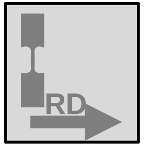



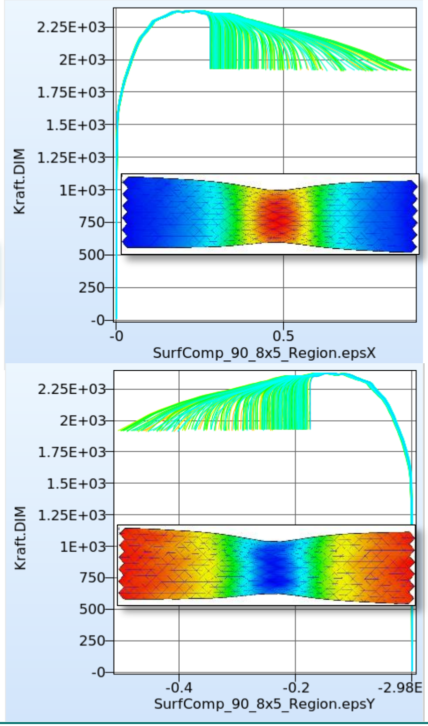

45°



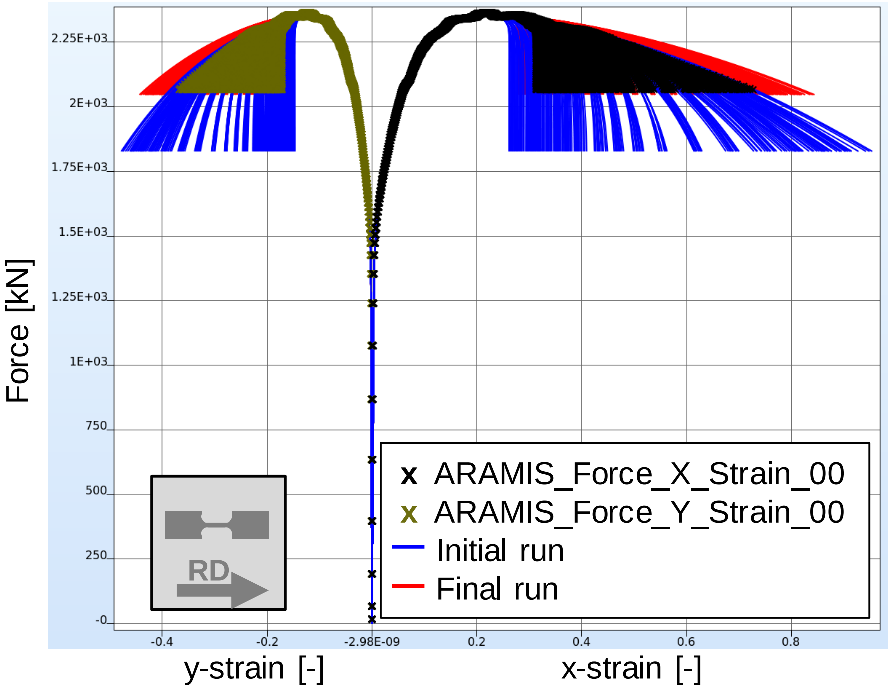

90°

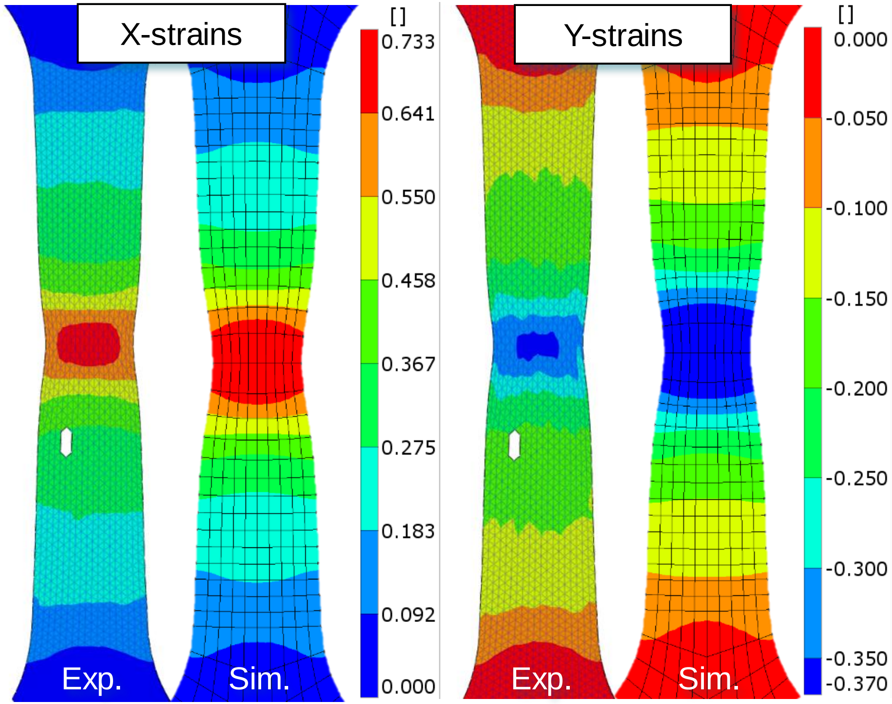


# MAT_BARLAT parameter optimization from experimental data

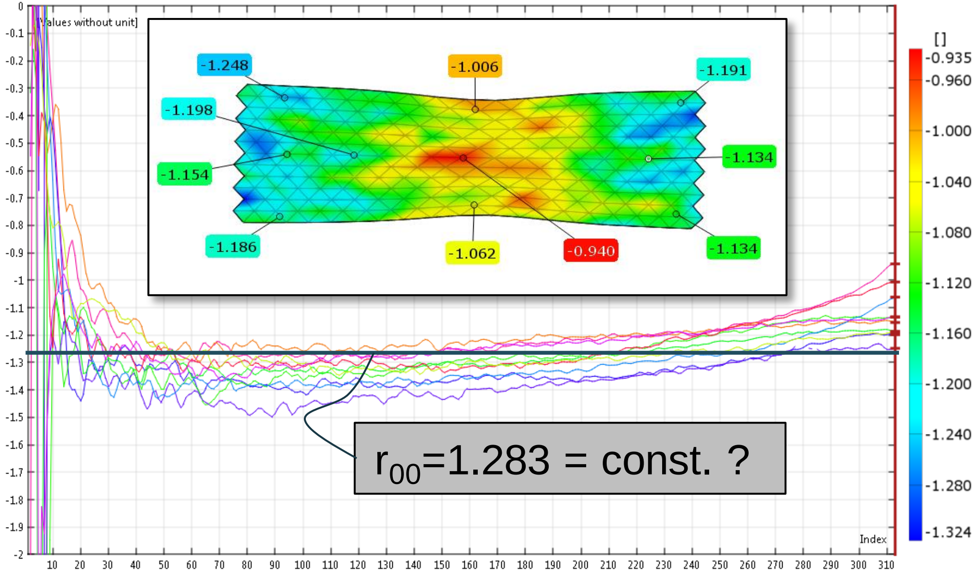
- Optimization strategy: Sequential Response Surface Method (SRSM)

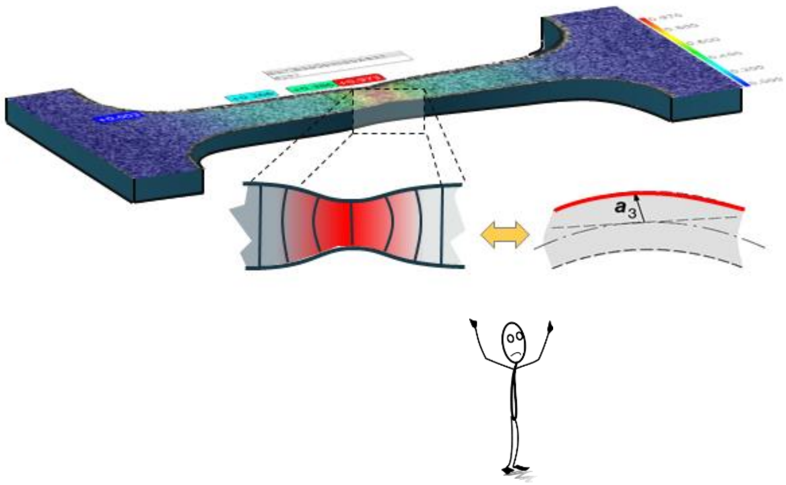


# MAT_BARLAT parameter optimization from experimental data

- Reason for differences – varying R-value, surface measurement, shell assumptions

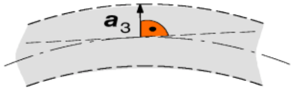


# Shell theories / Shell models – limitations

- **3-parameter shell model: Kirchhoff-Love**
  (cross section **straight** and unstretched,
  no shear deformations, i.e. normal to mid surface)

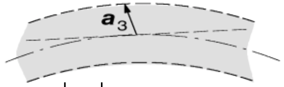
$$\sigma_{zz} = 0, (\varepsilon_{zz} = 0)$$
$$\gamma_{xz} = \gamma_{yz} = 0$$




$|a_3| = const.$

- **5-parameter shell model: Reissner-Mindlin**
  (cross section **straight** and unstretched,
  shear deformations possible)

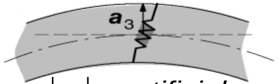
$$\sigma_{zz} = 0, (\varepsilon_{zz} = 0)$$
$$\gamma_{xz} \neq 0;\ \gamma_{yz} \neq 0$$




$|a_3| = const.$

- **6- or 7-parameter shell model:**
  (cross section **straight** but stretchable)

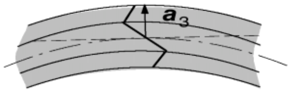
$$\sigma_{zz} \neq 0, \varepsilon_{zz} \neq 0$$
$$\gamma_{xz} \neq 0;\ \gamma_{yz} \neq 0$$

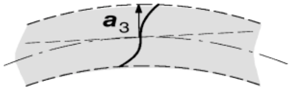



$|a_3| = artificial$

- **Higher order shell theory: multi-layer or -director:**
  (not straight and stretchable)

$$\sigma_{zz} \neq 0, \varepsilon_{zz} \neq 0$$
$$\gamma_{xz} \neq 0;\ \gamma_{yz} \neq 0$$



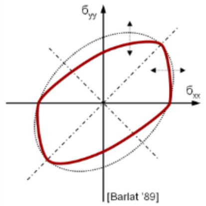
# Shell theories / Shell models – limitations

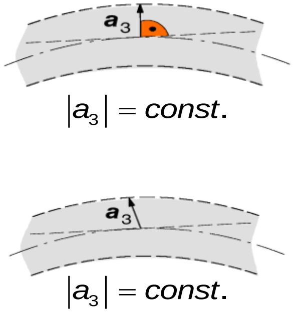
- **3-parameter shell model: Kirchhoff-Love**
  (cross section **straight** and unstretched,
  no shear deformations, i.e. normal to mid surface)

- **5-parameter shell model: Reissner-Mindlin**
  (cross section **straight** and unstretched,
  shear deformations possible)

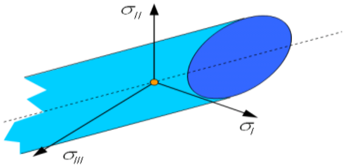
- **6- or 7-parameter shell model:**
  (cross section **straight** but stretchable)

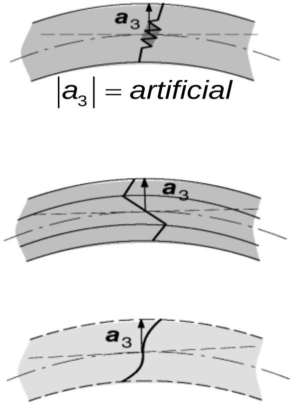
- **Higher order shell theory: multi-layer or -director:**
  (not straight and stretchable)




*Reduced constitutive models (2D „plane stress“)*




*Full 3D constitutive models*

# Shell theories / Shell models – limitations

- **3-parameter shell model: Kirchhoff-Love**
  (cross section **straight** and unstretched,
  no shear deformations, i.e. normal to mid surface)

- **5-parameter shell model: Reissner-Mindlin**
  (cross section **straight** and unstretched,
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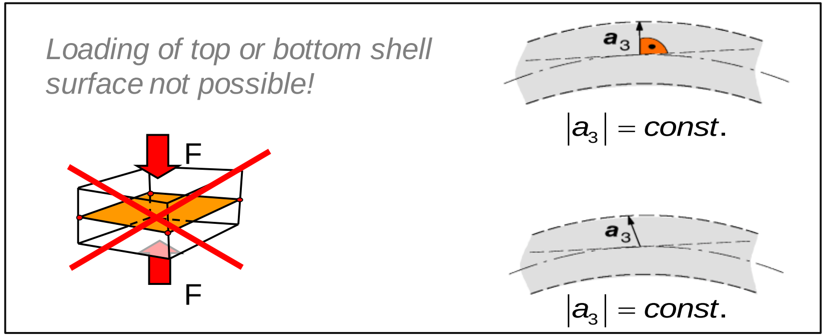
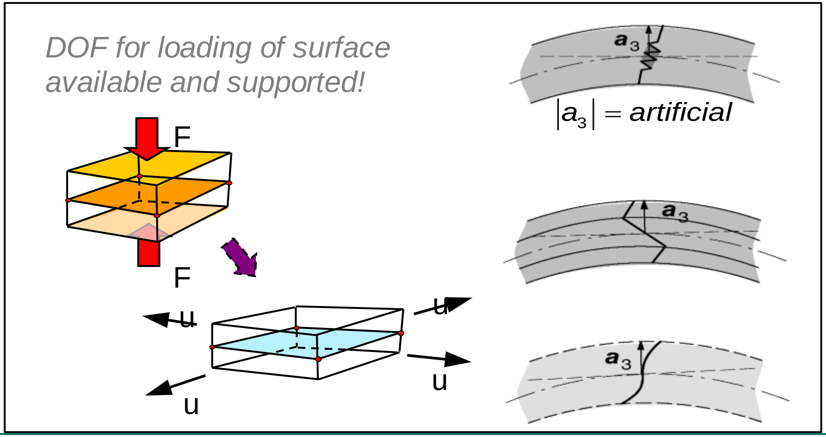
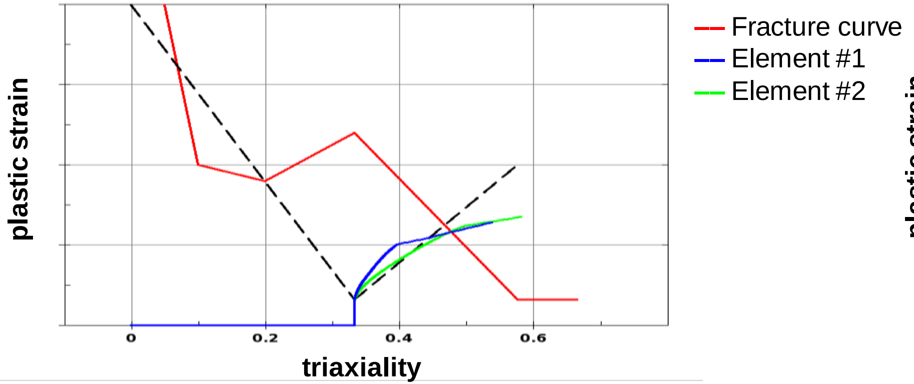
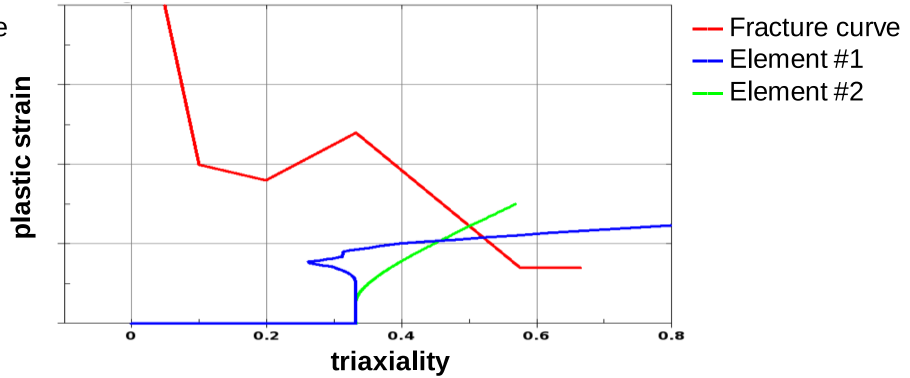


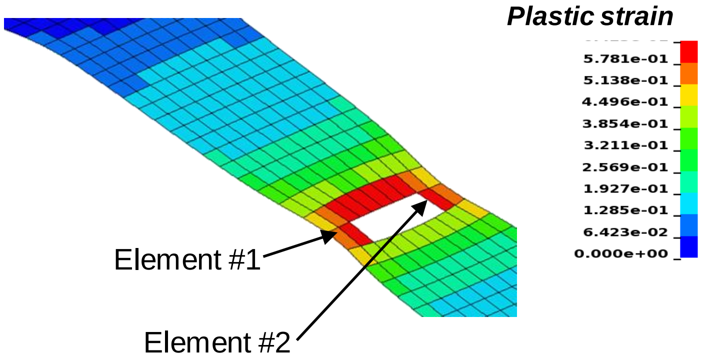



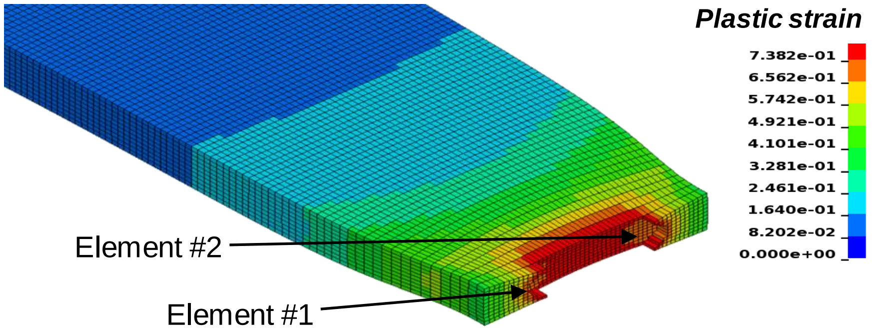
# Shell vs. solid: Tension test

Comparison with a finite element model with small volume elements



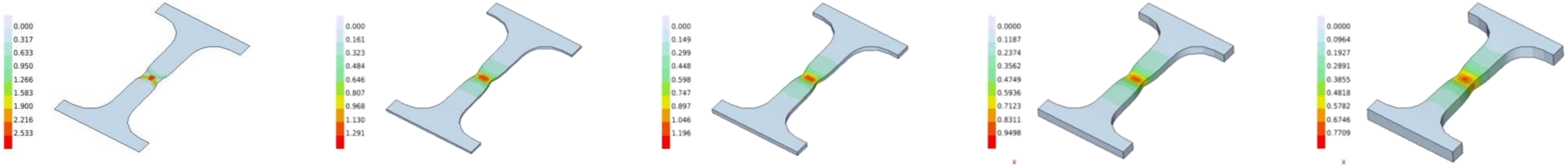



# The limits of classical shell models

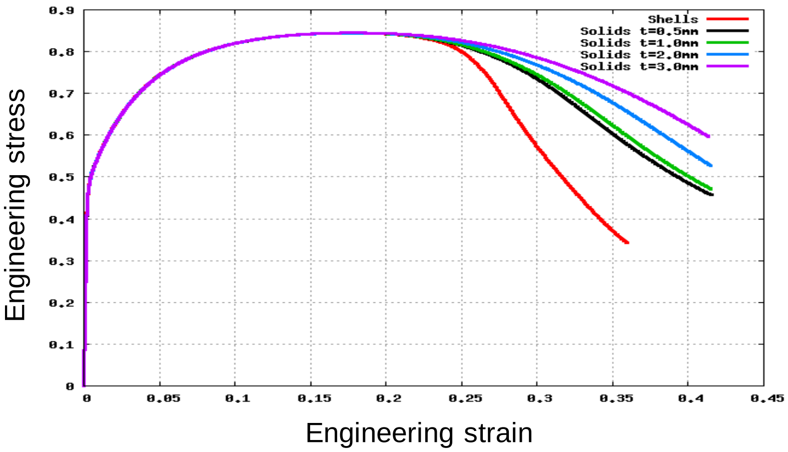
## No plane sections: mini tension test coupon with MAT_24

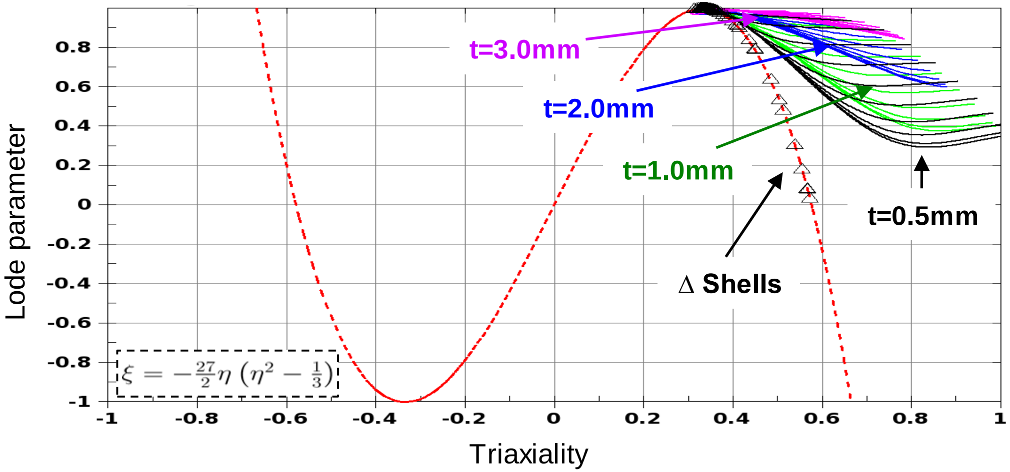
*Shells t=1.0mm* | *Solids t=0.5mm* | *Solids t=1.0mm* | *Solids t=2.0mm* | *Solids t=3.0mm*



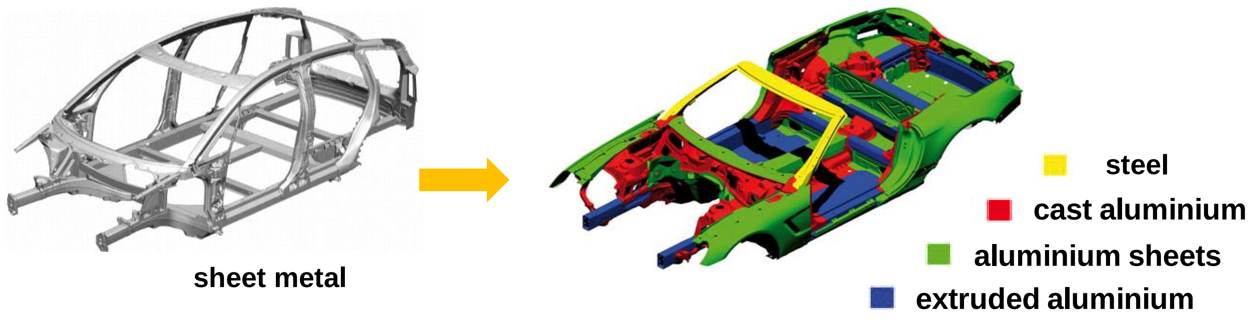
*[etyp=16]*

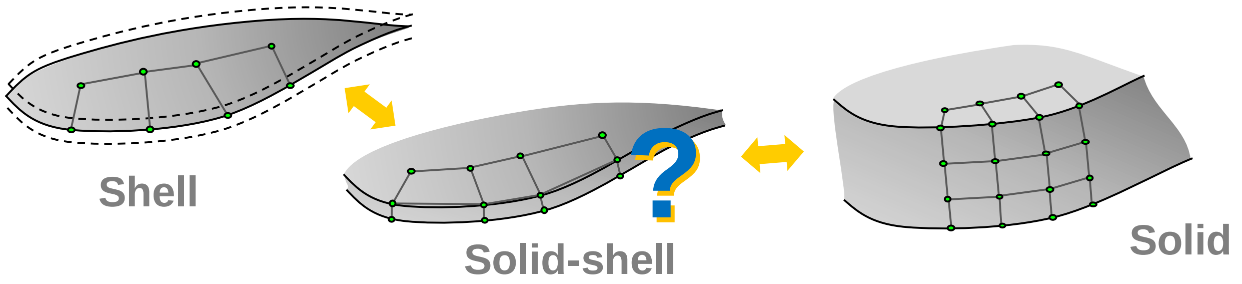
*Contours of plastic strain.* $L_e$*=0.125mm*



# Parameter identification: Transition from shells to solids?




Shell elements work very well for thin structures!

**Caution required if**

- extremely small bending radii
- strong lateral loading and high lateral stresses
- damage, localization and rupture

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# Summary & conclusions

- Clearly, yield curve extrapolation is depending on reference length.
- Hence many possible solutions for global force vs. displacement behavior.
- Implementation of FFC interface in LS-OPT to facilitate application of method.
- Method was validated with numerical, artificial data for Barlat-model.
- Method was applied to measured data of CR210IF and Barlat-model.

- It can be concluded that the approach delivers sufficiently close results w.r.t. the posed question:
  **Keep in mind a spatial model as well a constitutive model are applied to represent reality.**

➡ **The limits of the classical discretization with shells may sometimes be closer than expected!**

# Outlook

- Increasing the number of parameters to be optimized
  - More complex approach for yield curve extrapolation.
  - 2-3 additional parameters for the yield locus.

- Investigation of different specimen geometries may be worthwhile

**The multi-point history option will be available in LS-OPT in next release.**

# Your questions, please