4a Technology Day 2020 – Plastics on the test rig – Testing and simulation

First results of full-field calibration (FFC) applied to polymer materials

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ZIM
Zentrales Innovationsprogramm Mittelstand

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DYNA MORE

DYNAmore

- **Who we are**
  - More than 100 people
  - Civil and mechanical engineers, mathematicians, computer scientists, etc.
  - Employees from 13 different countries
- **Headquarters in Stuttgart**
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  - Swiss – Zurich
  - Italia – Torino
  - France – Versailles
  - USA – Dublin, Ohio

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  - Dresden
  - Langlingen (Wolfsburg)
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- **Customer-dedicated Offices**
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  - Gothenburg (Volvo)

Contents

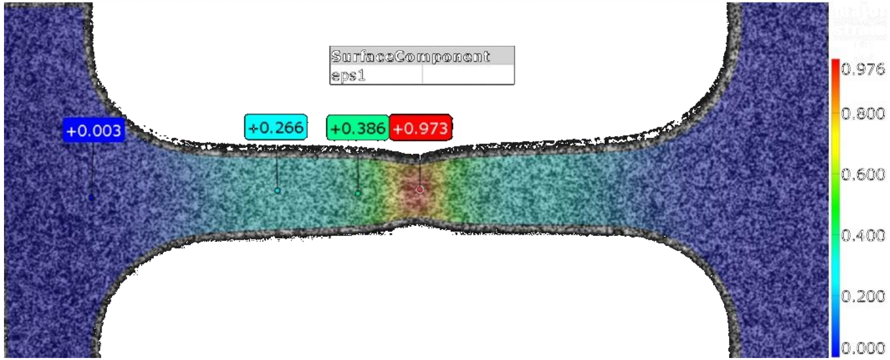
- Motivation
- Strain calculation in ARAMIS
- Implementation of FFC with LS-OPT
- Application of the method
  - Validation
  - Sheet metal CR210IF
  - PC/ABS
- Summary & conclusions
- Outlook

Contents

Strain measurement

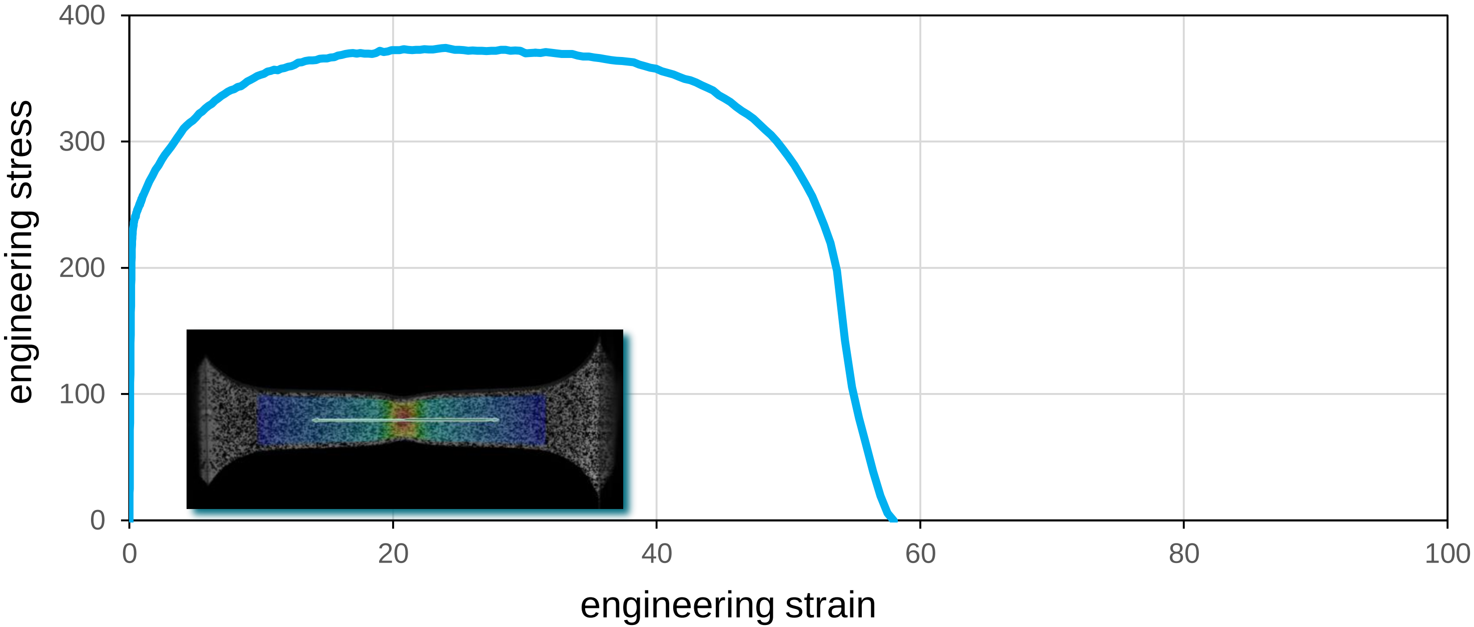
- Classical scheme of characterizing the yield behavior of a material
  - Tensile test delivers engineering stress vs. strain curve for a specific reference length.
  - Identification of material parameters via reverse engineering strategy, with which the test is simulated and the resulting stress strain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

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



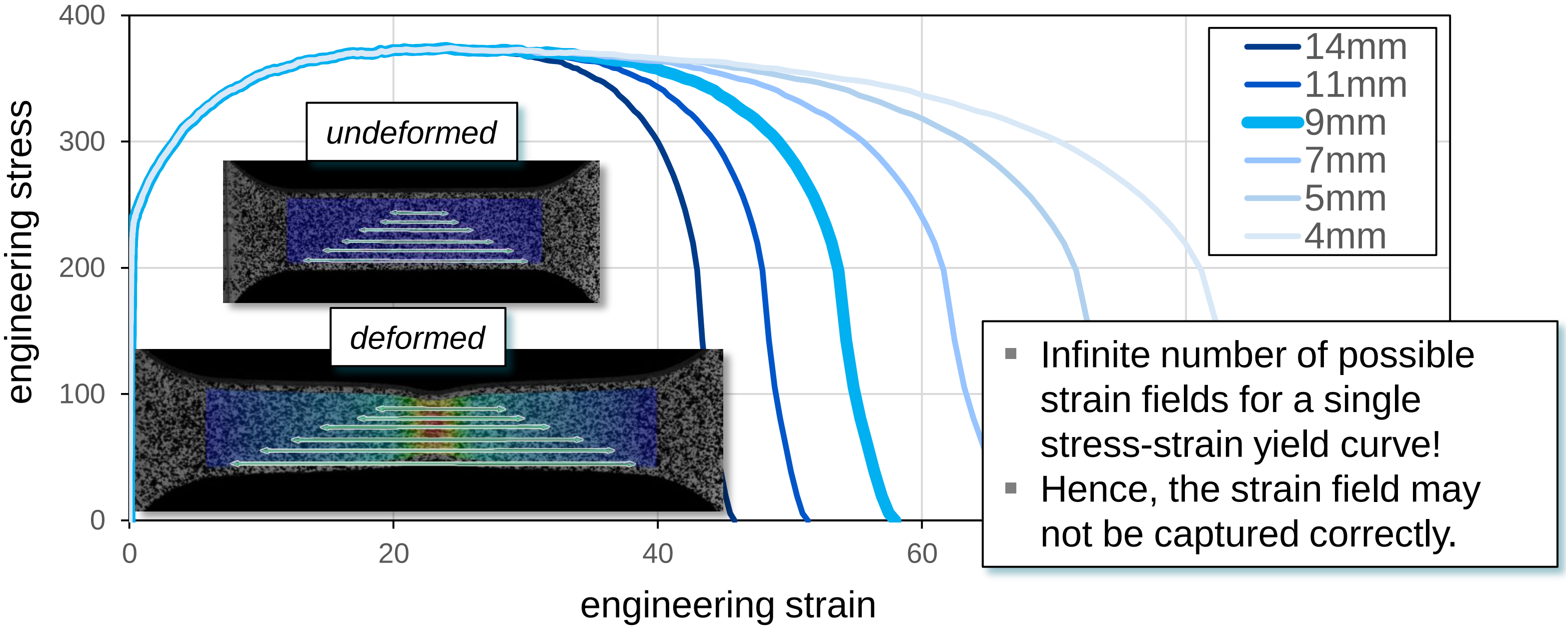
Strain localization in DIC

- 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.

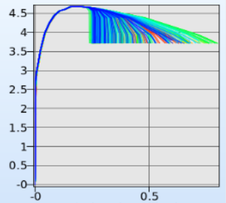
Concept

Experiment

Measurement:
- Force
- Strain field

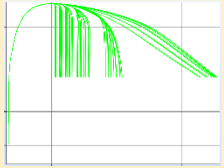
Optimization

Input from experiment



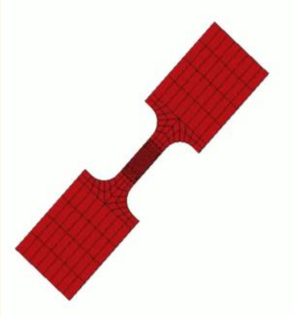
Force vs. strain

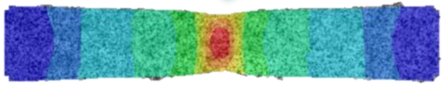
Input from simulation



Force vs. strain

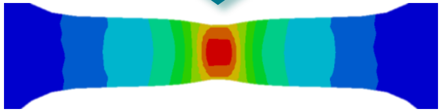
Simulation





Measured strain field

Objective:
identical strain fields in time

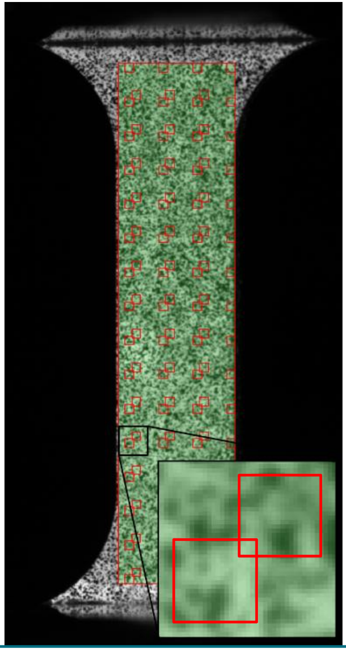


Simulated strain field

Contents

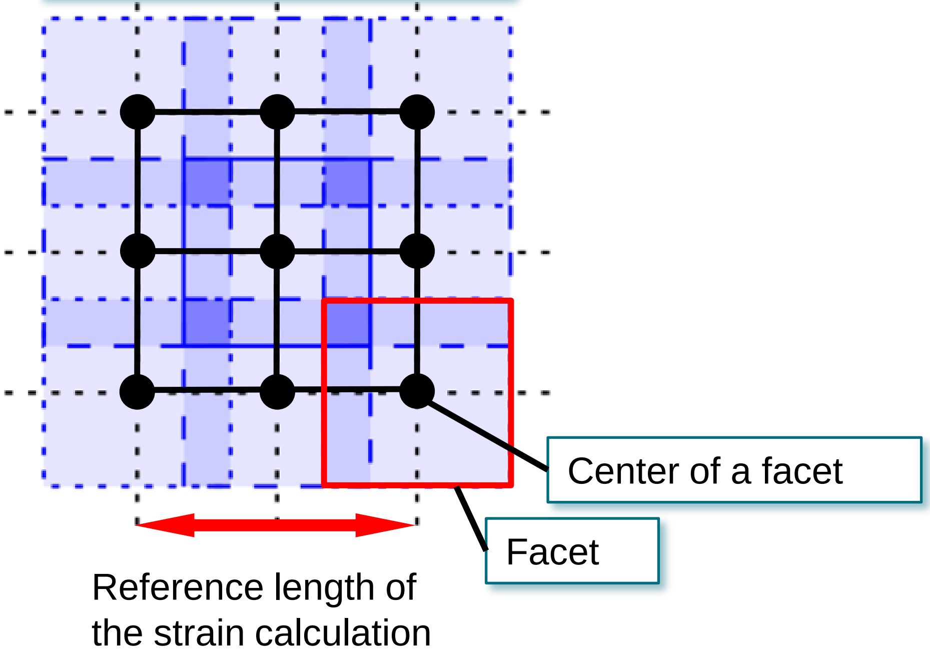
Strain calculation in ARAMIS

- ARAMIS v6



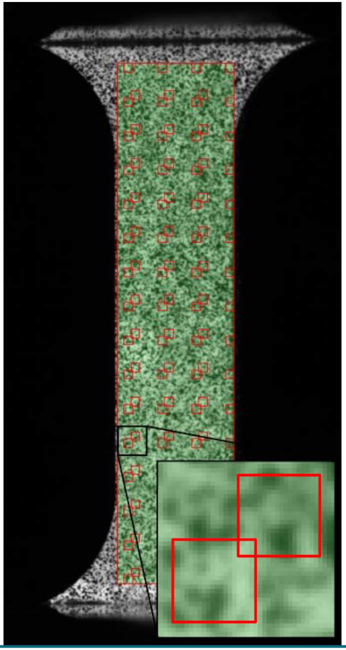
Visualization in ARAMIS

Schematic representation



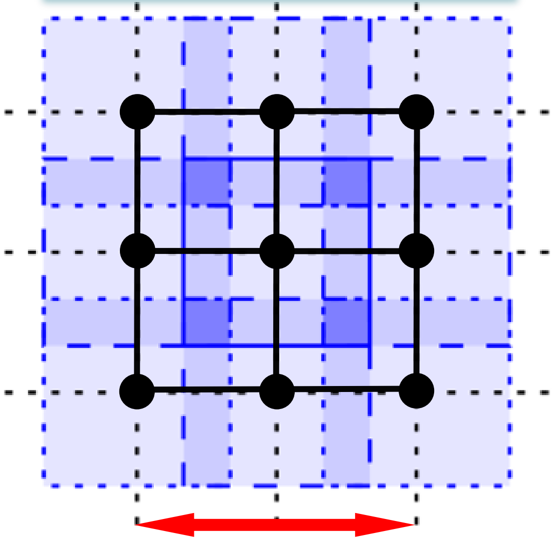
Strain calculation in ARAMIS

- ARAMIS v6

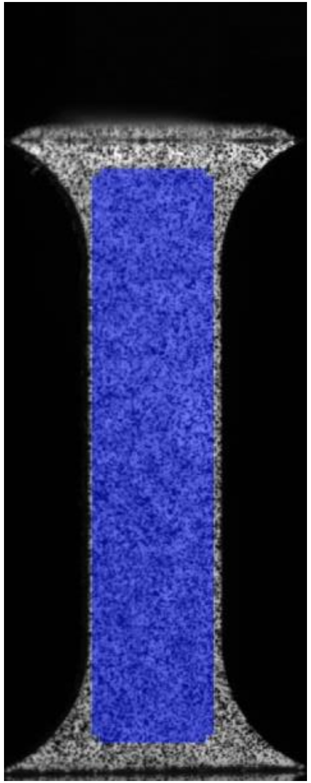


Visualization in ARAMIS

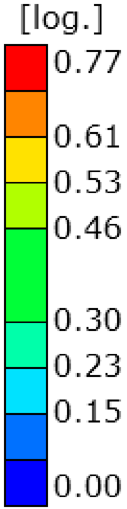
Schematic representation



Reference length of
the strain calculation

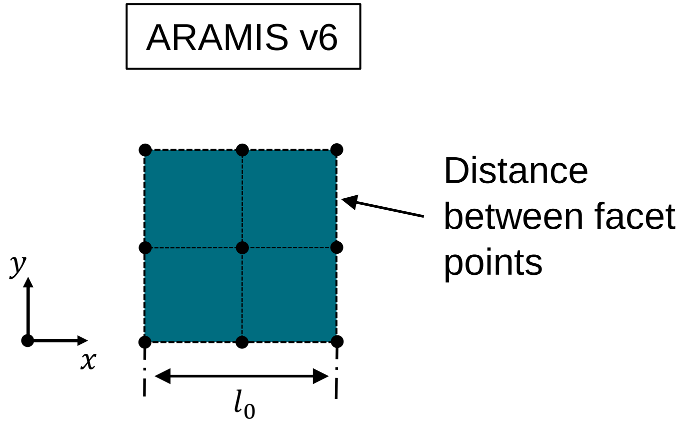


x-strain



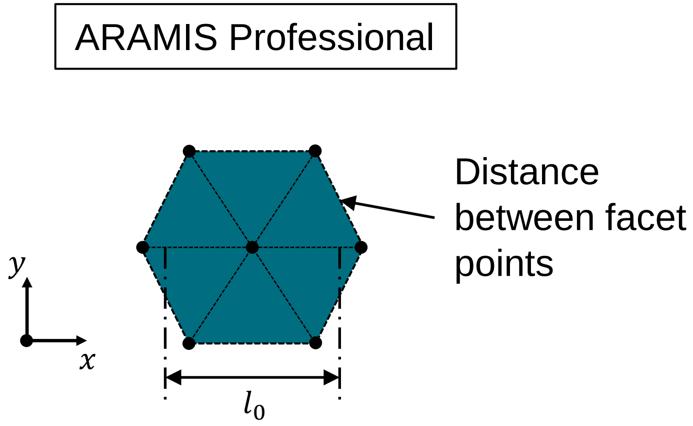
Strain calculation in ARAMIS

- ARAMIS v6 vs ARAMIS Professional



The reference length l_0

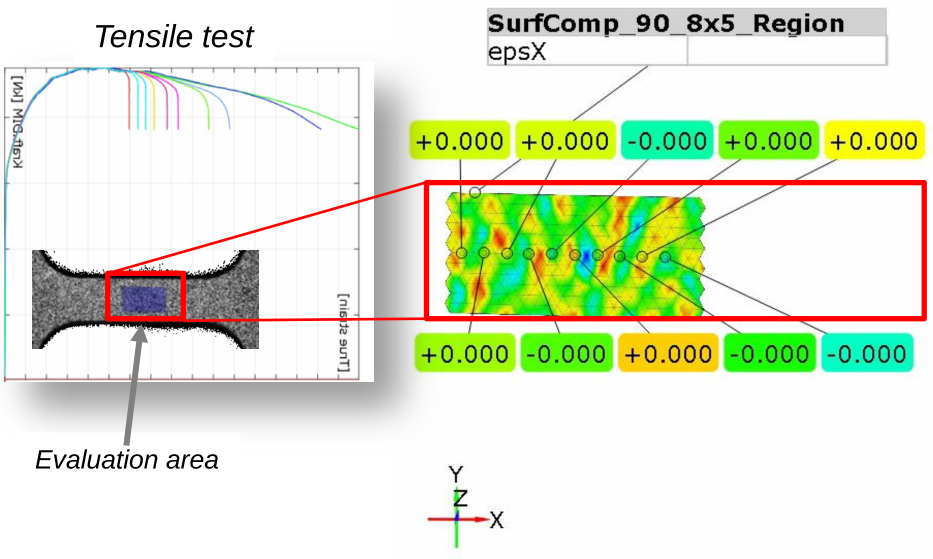
is twice the facet point distance

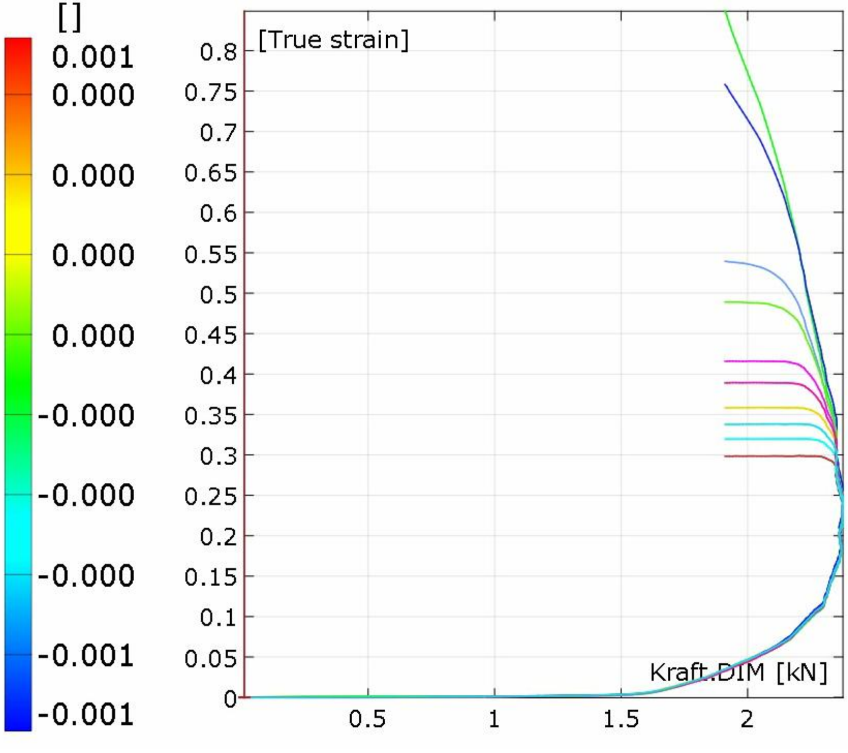


The reference length l_0 in any direction is determined by the mean length of the hexagon. (0.75*double_facet_point_distance)

Strain calculation in ARAMIS

- ARAMIS output – force vs. true strain





Contents

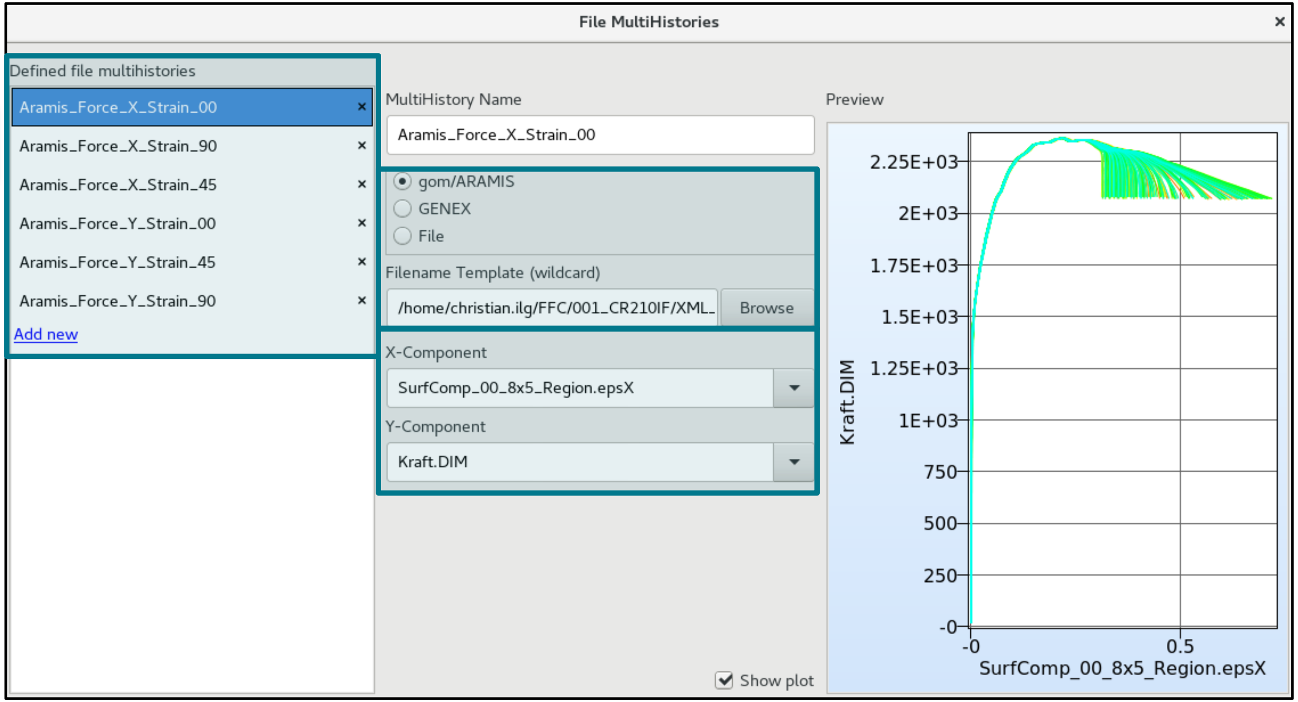
Implementation of FFC with LS-OPT

- New interface in LS-OPT

1. Define multi-histories

2. Insert load stages

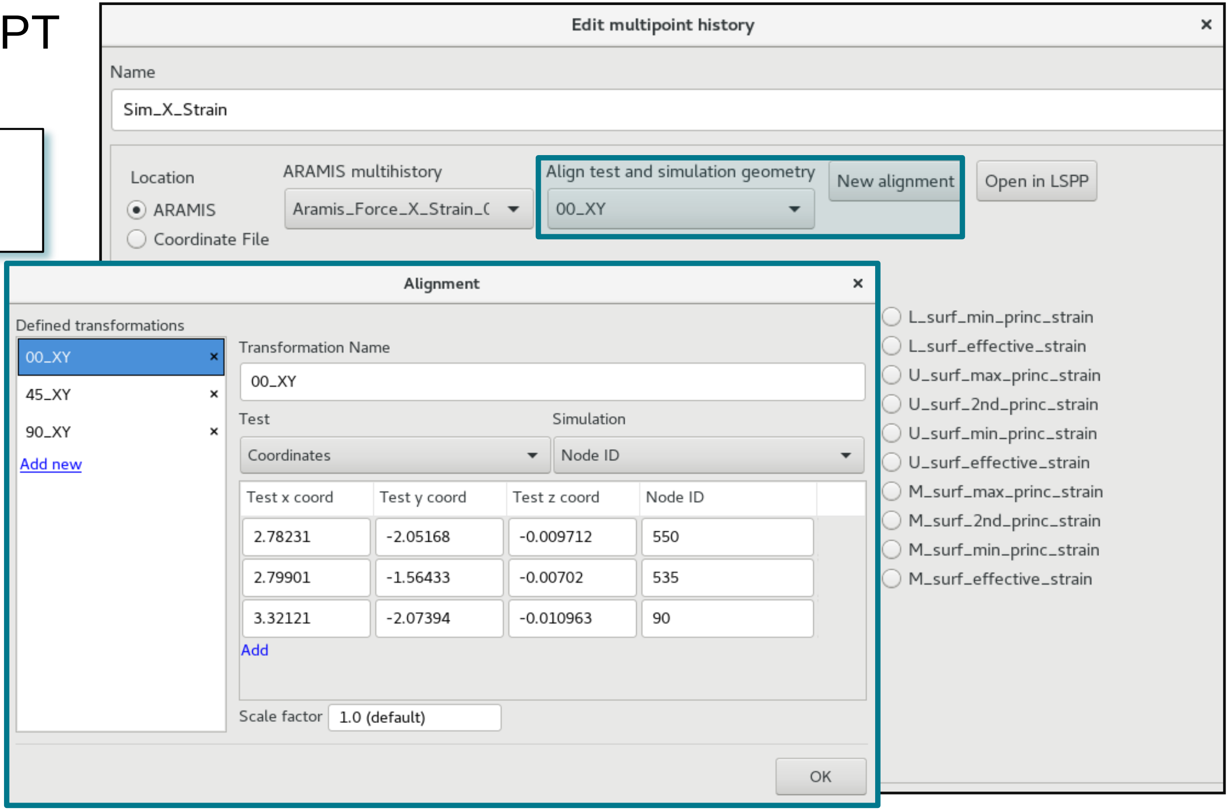
3. Definition of axes



Implementation of FFC with LS-OPT

- New interface in LS-OPT

Alignment of simulation and experiment



Implementation of FFC with LS-OPT

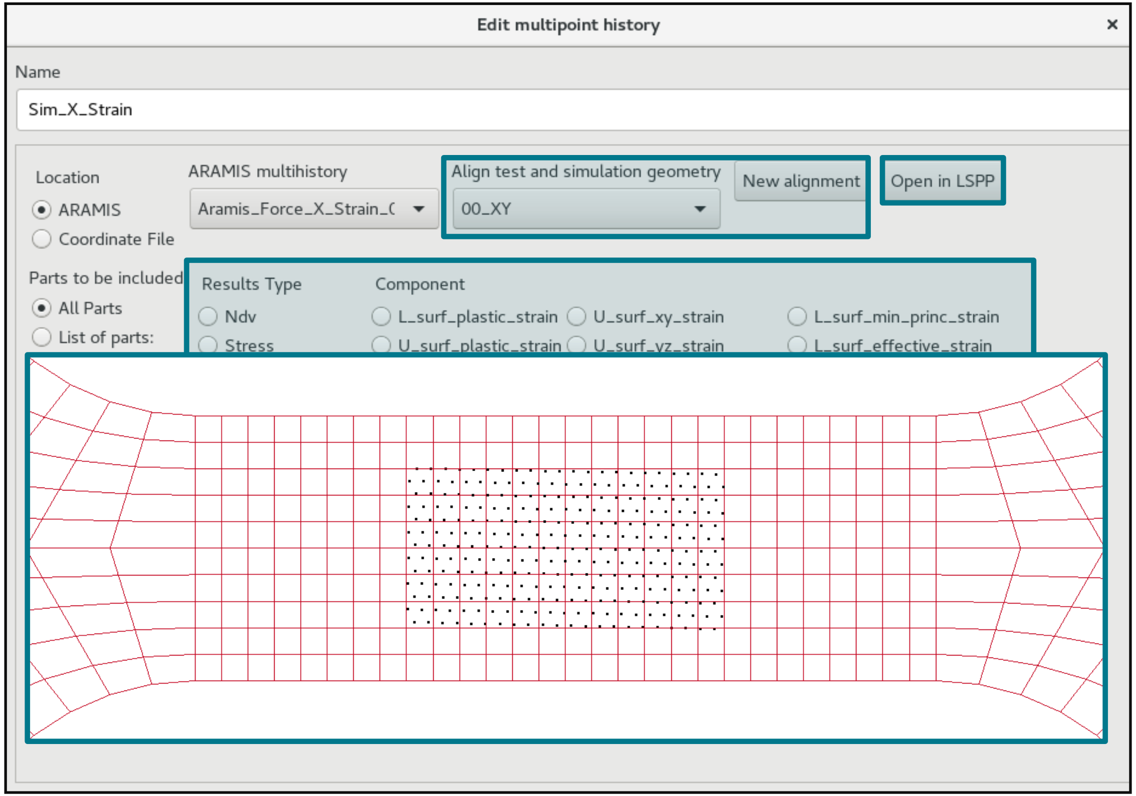
- New interface in LS-OPT

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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Application

- Validation of the anisotropic MAT_036 constitutive model
  - Assumptions in the simulation model of the validation:
    - Anisotropic constitutive model: *MAT_036 (*MAT_3-PARAMETER_BARLAT)
    - Yield locus parameters assumed constant (not optimized at present)
    - Two parameters for the yield curve extrapolation
    - Damage and failure are not considered
- FFC based on experimental data: sheet metal CR210IF, PC/ABS
  - Assumptions in the simulation model of CR210IF:
    - The same as for the validation
  - Assumptions in the simulation model of PC/ABS:
    - Isotropic constitutive model: *MAT_024 (*MAT_PIECEWISE_LINEAR_PLASTICITY)
    - Six parameters for the yield curve
    - Damage and failure are not considered

Yield curve generation – Metal

- Parametrization of the yield curve

Direct calculation of the yield curve until A_g

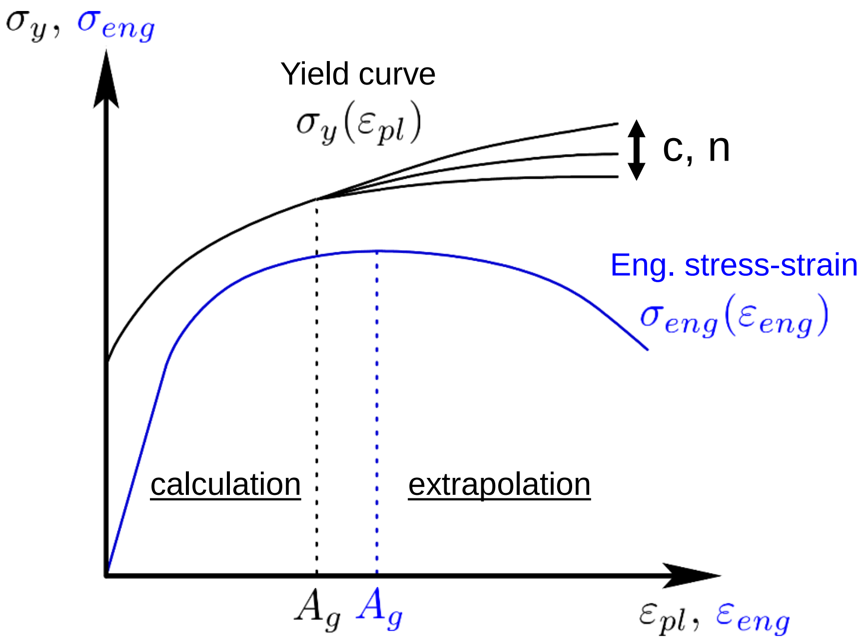
$$\sigma_y = \sigma_{eng}(1+\varepsilon_{eng})$$
$$\varepsilon_{pl} = \ln(1+\varepsilon_{eng}) - \frac{\sigma_{eng}}{E}$$

Extrapolation from A_g with Hockett-Sherby

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

C^1-continuity at A_g:

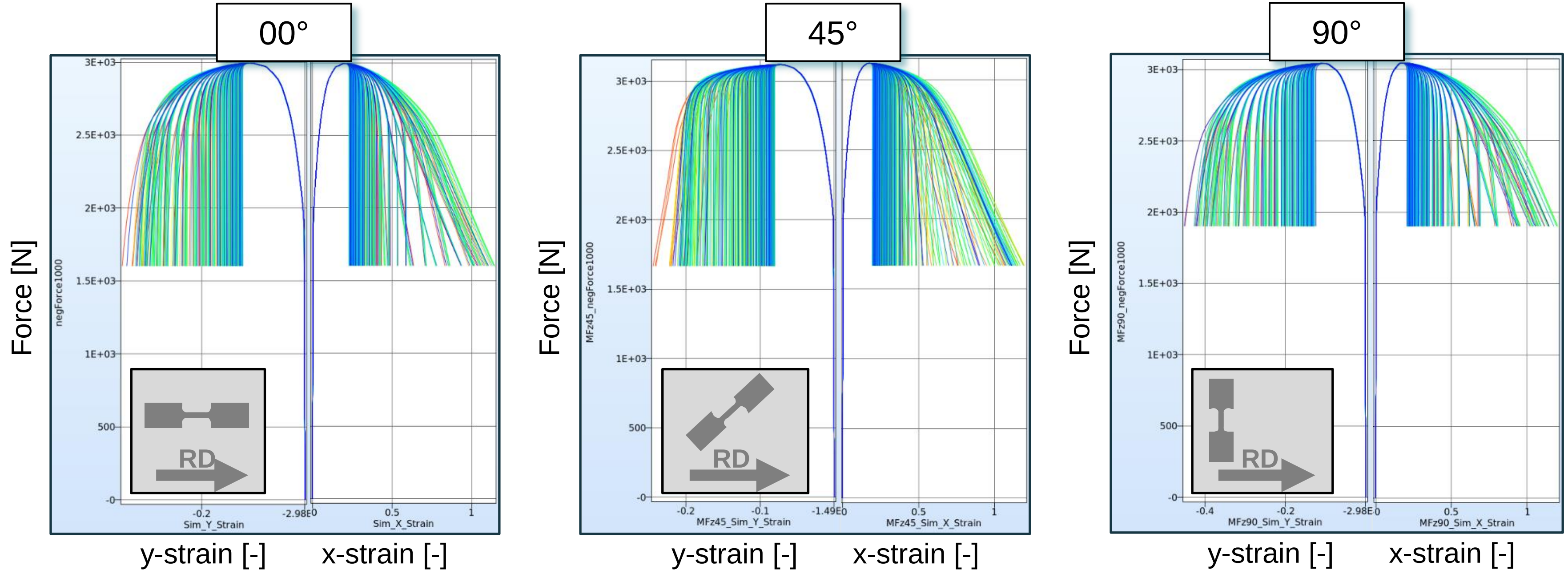
- Reduction of the function by two variables



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

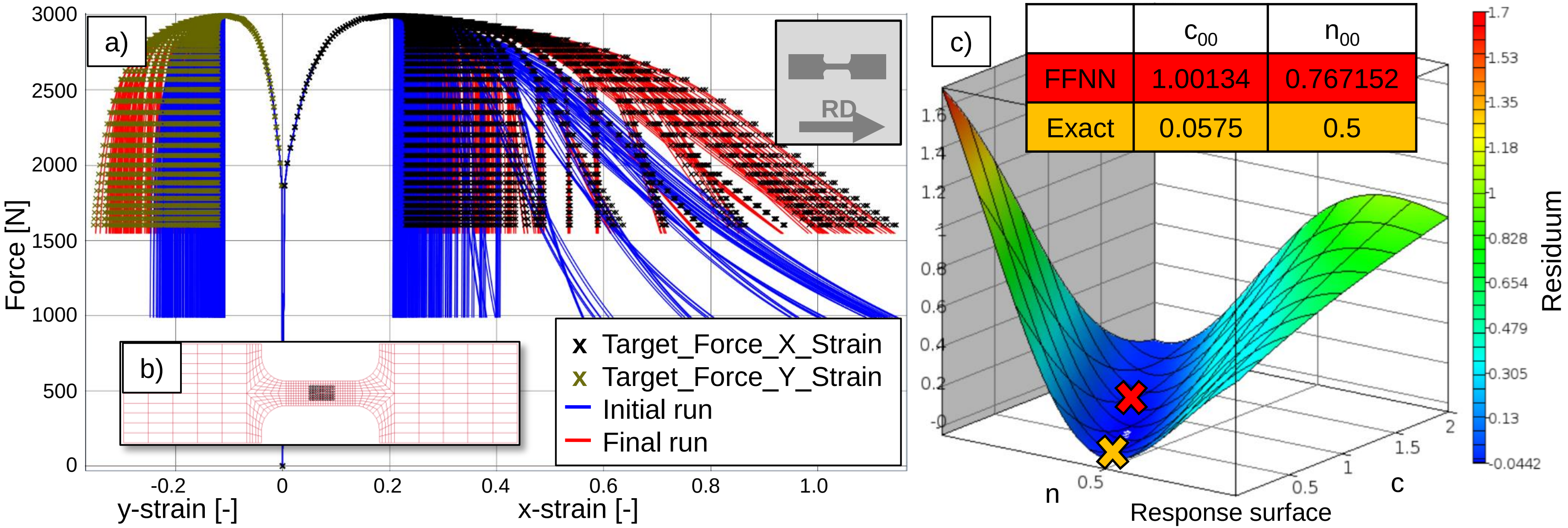
Validation of method for MAT_BARLAT

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



Validation of method for MAT_BARLAT

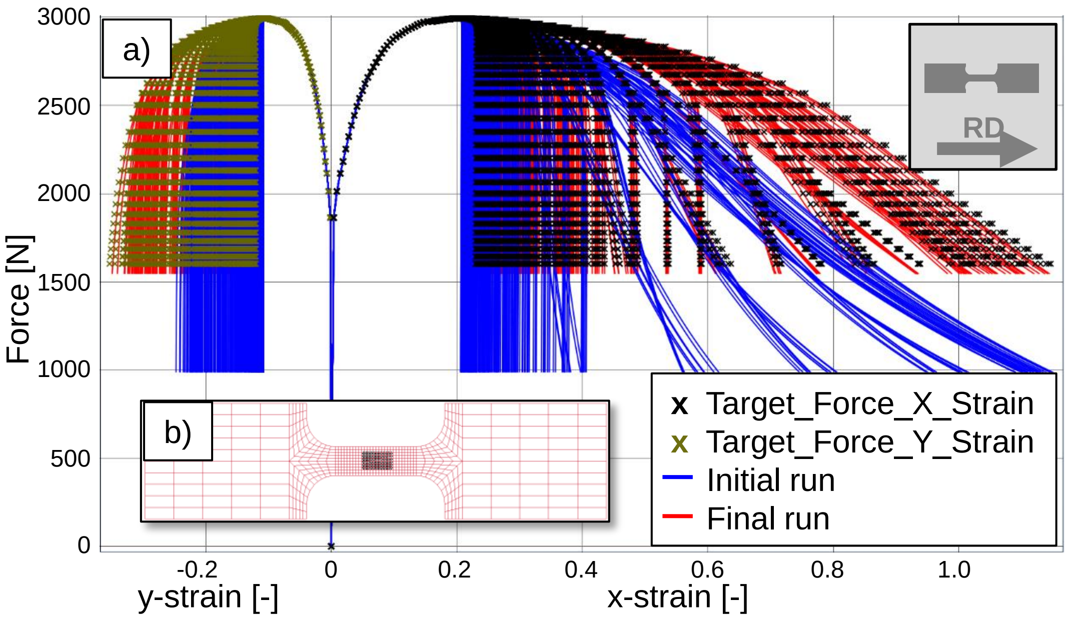
- Optimization results with FFNN for 0°

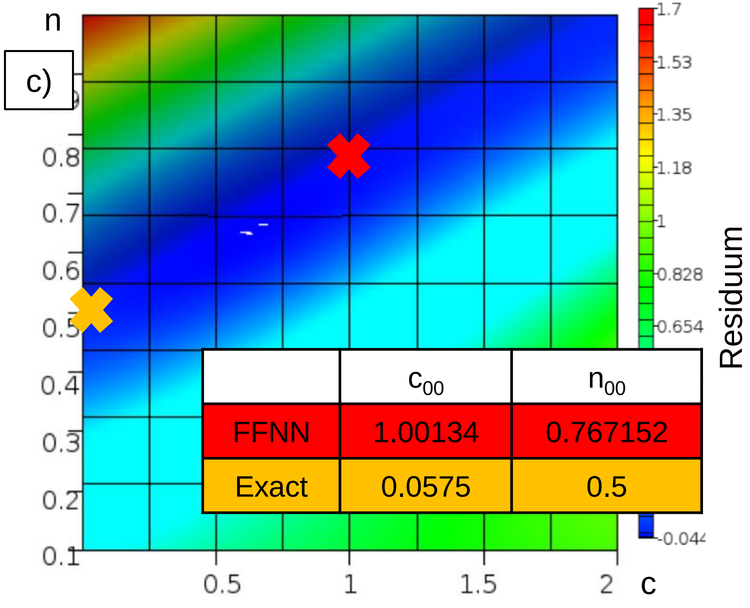


	c_{00}	n_{00}
FFNN	1.00134	0.767152
Exact	0.0575	0.5

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

Response surface

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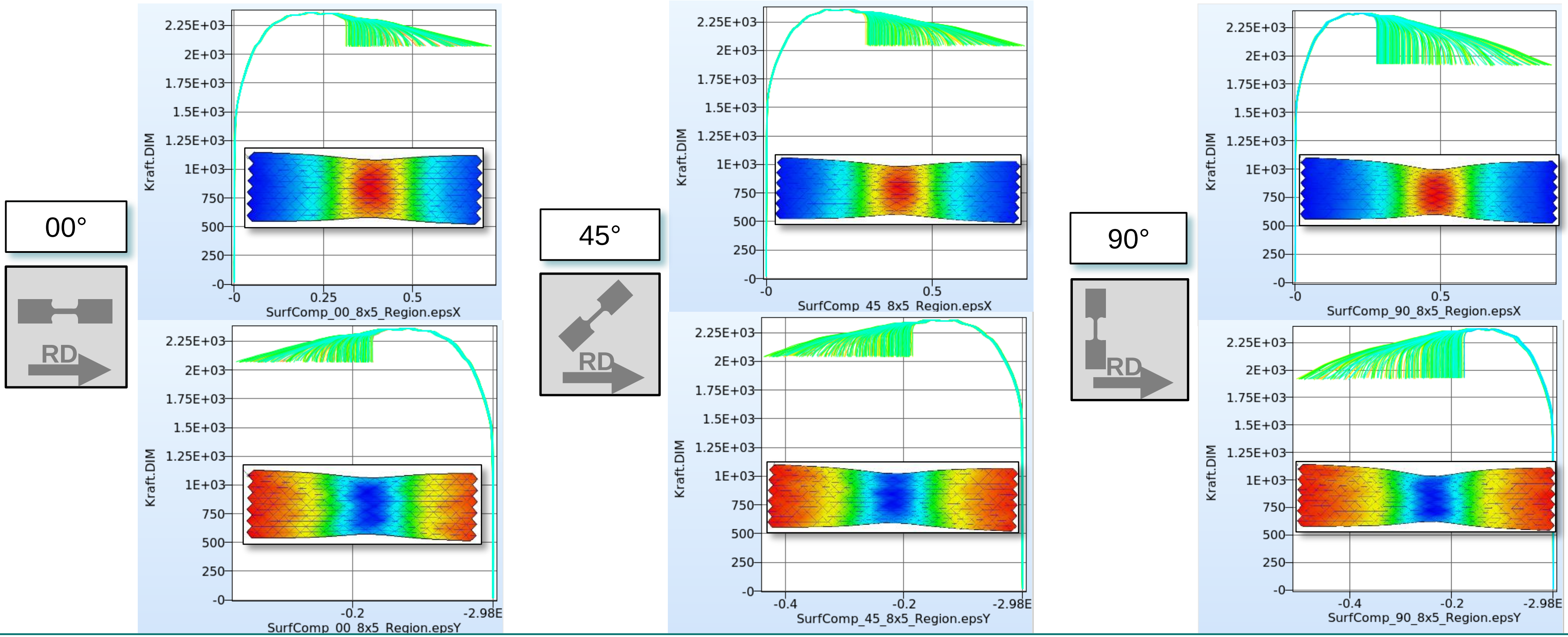
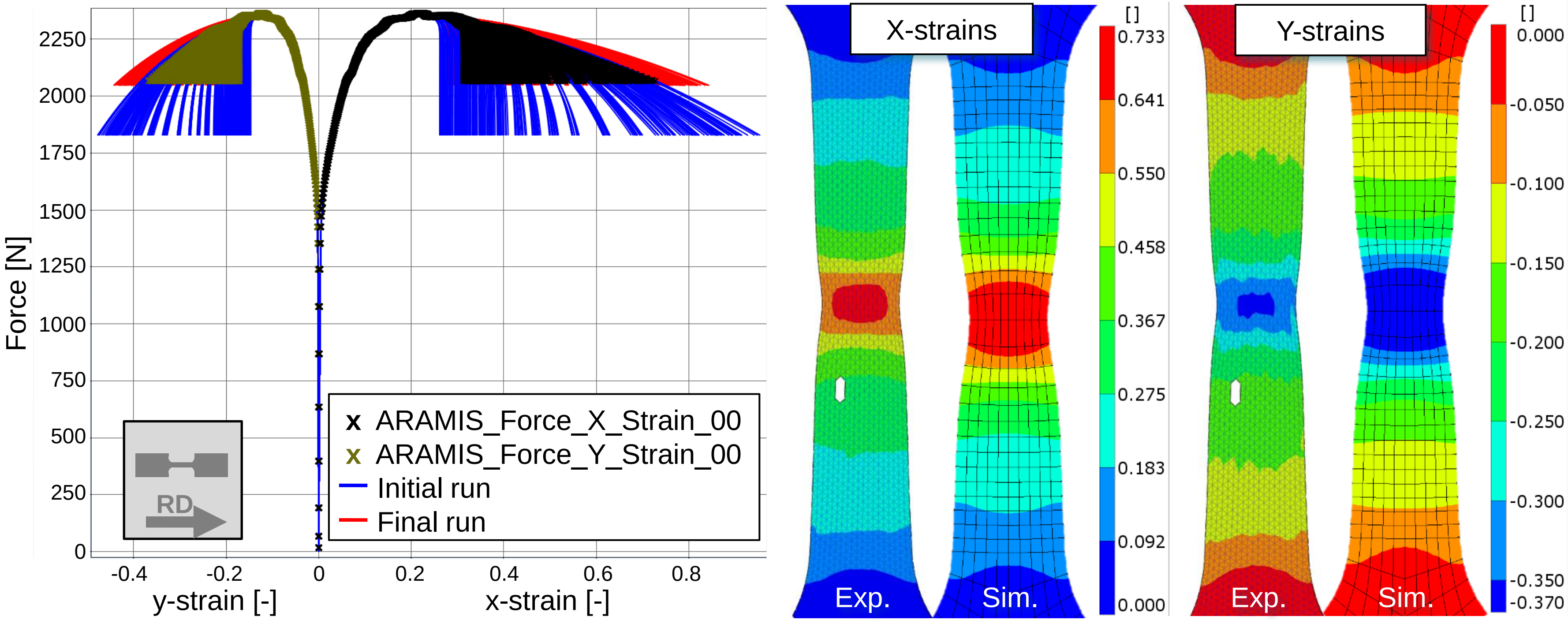
MAT_BARLAT parameter optimization from experimental data

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



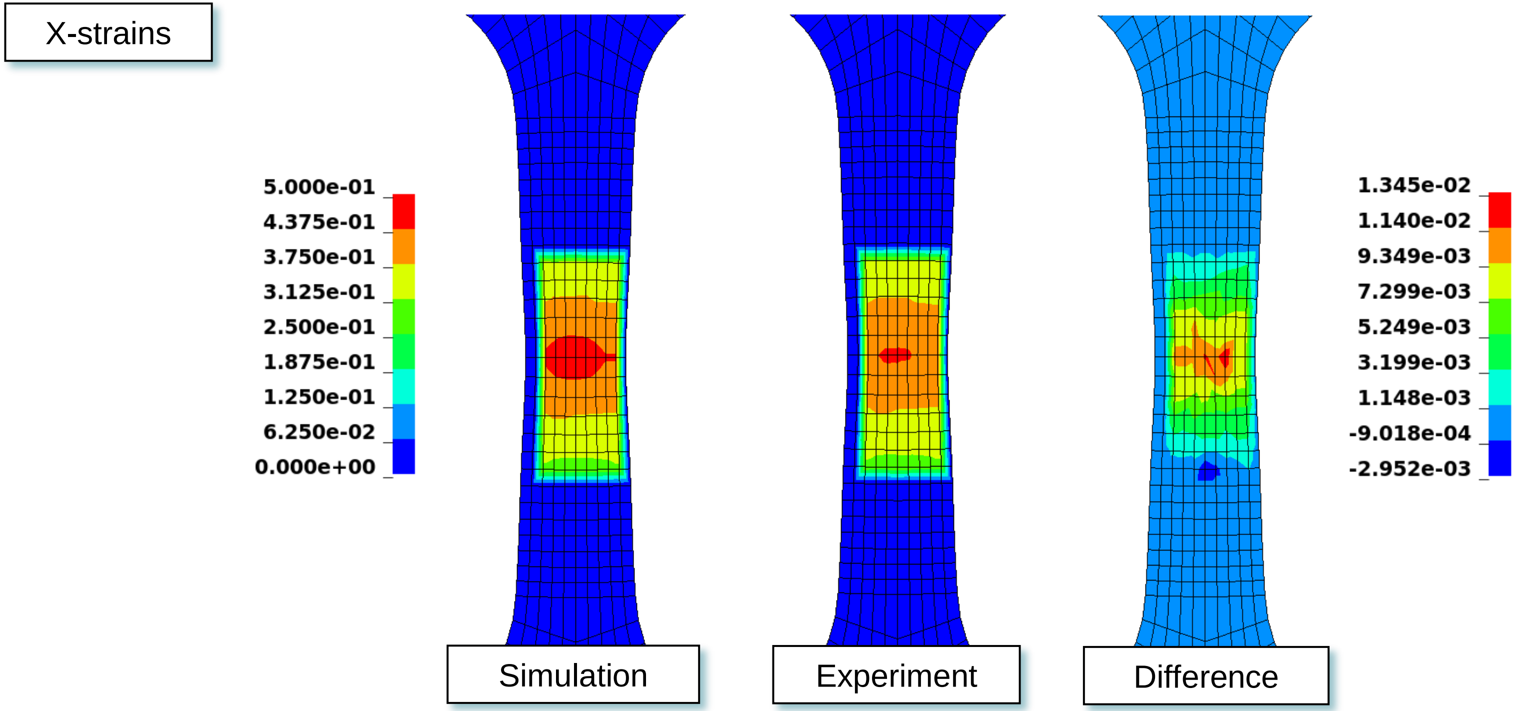
MAT_BARLAT parameter optimization from experimental data

- Optimization strategy: Sequential Response Surface Method (SRSM)



MAT_BARLAT parameter optimization from experimental data

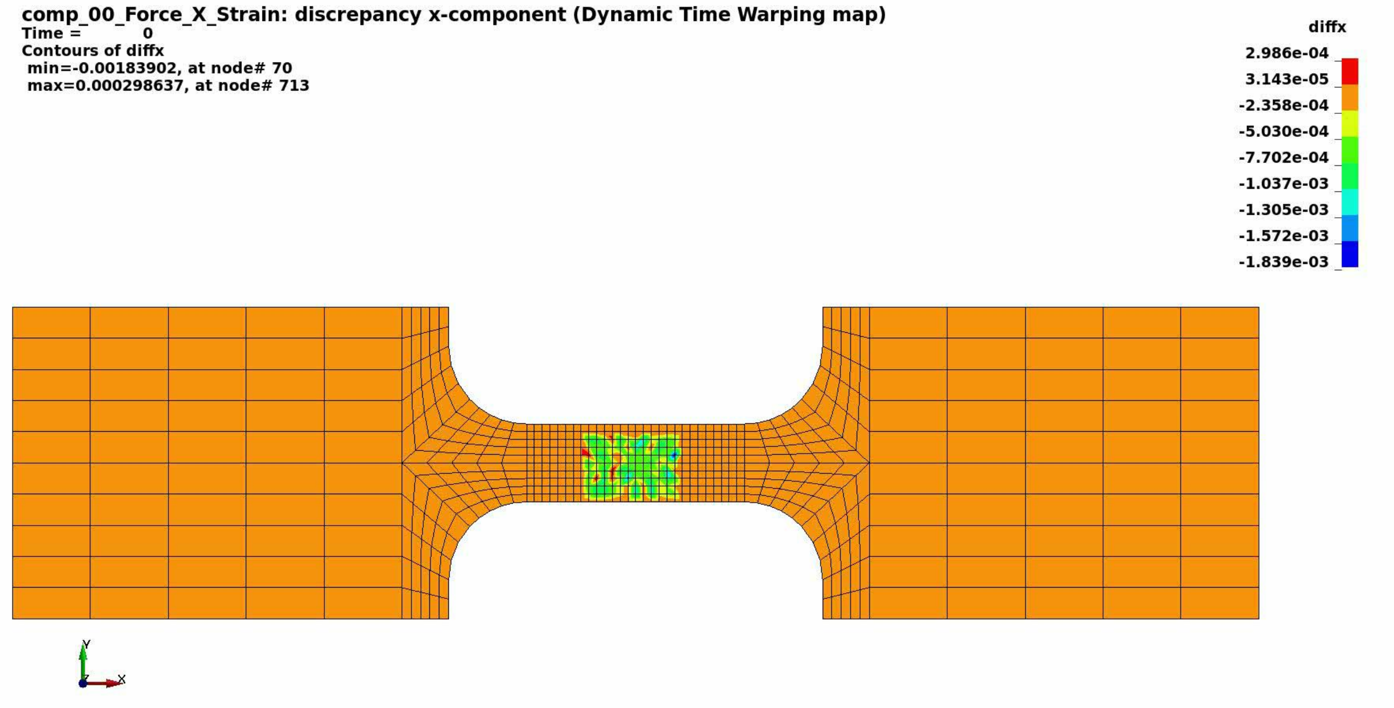
- Comparison of the strainfields in LS-PrePost



MAT_BARLAT parameter optimization from experimental data

- Comparison of the strainfields in LS-PrePost

X-strains



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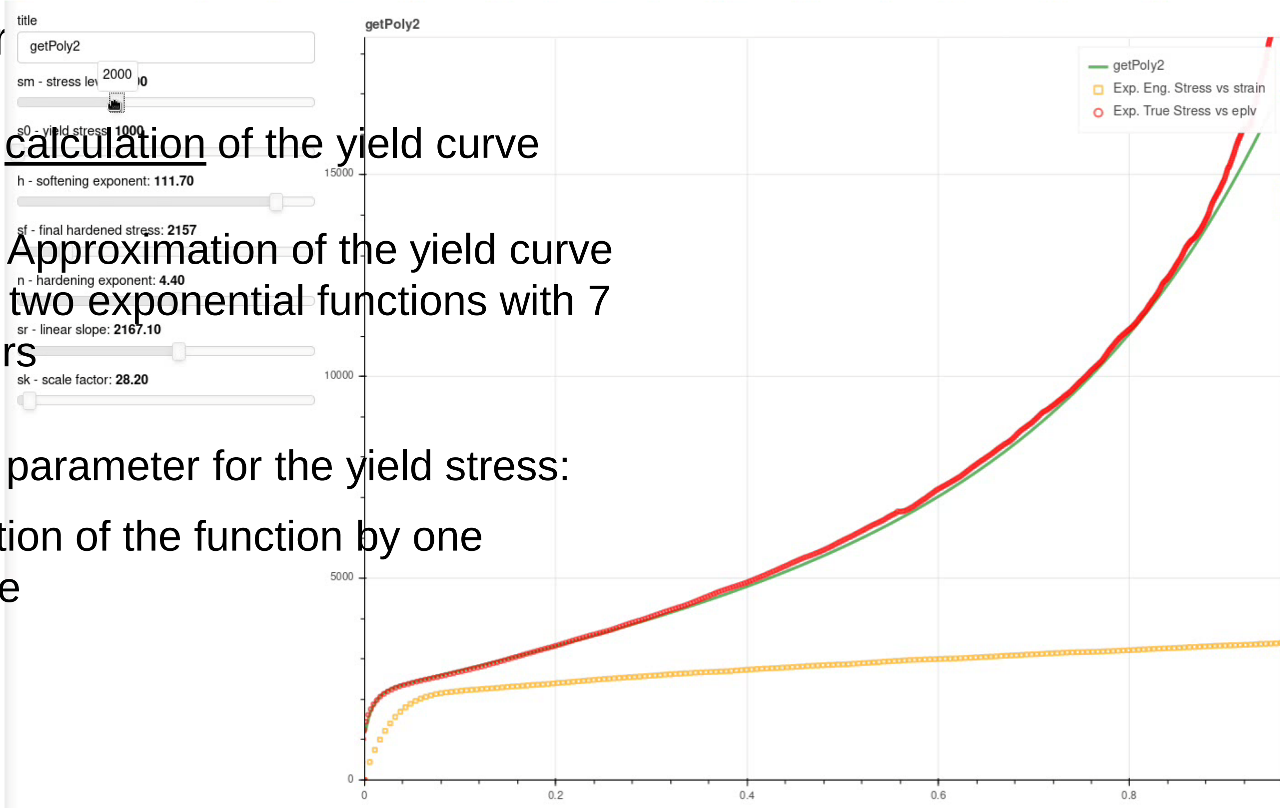
Yield curve generation – PC/ABS

- Parametr



No direct <u>calculation</u> of the yield curve

<u>Function:</u> Approximation of the yield curve based on two exponential functions with 7 parameters

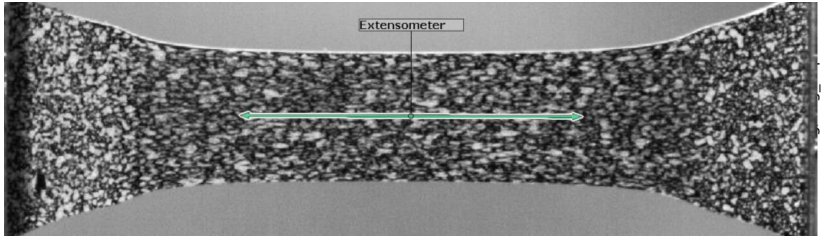
One fixed parameter for the yield stress:

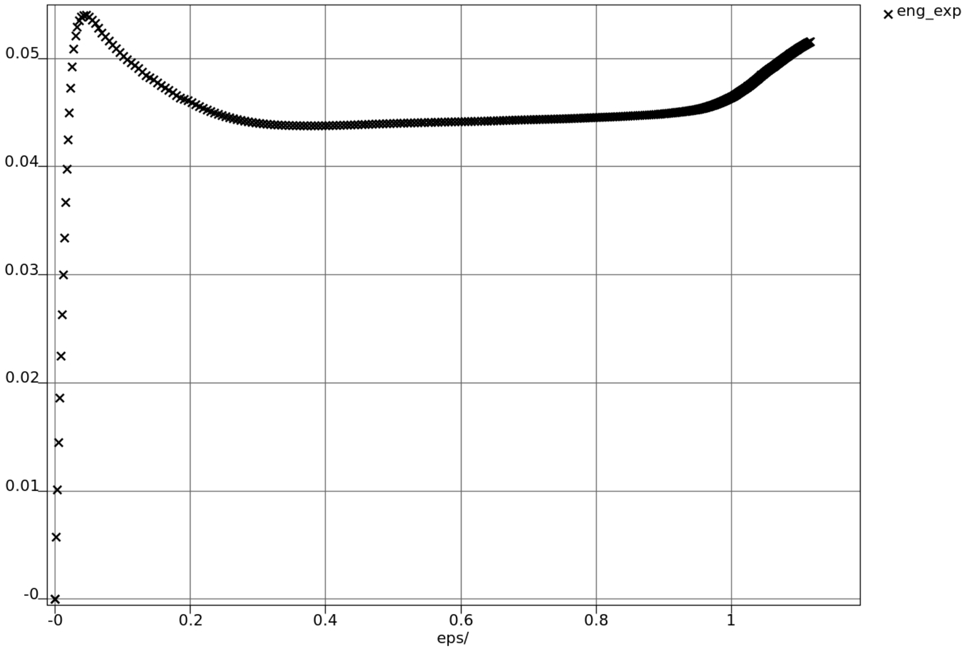
- ➢ Reduction of the function by one variable

N. Karajan

MAT_024 parameter optimization from experimental data

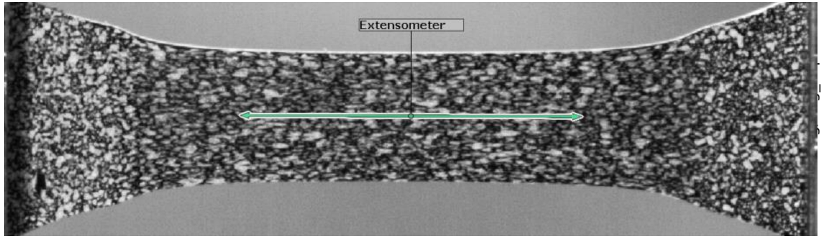
- First optimization run based on an a single stress strain curve
- Input from the experiment:

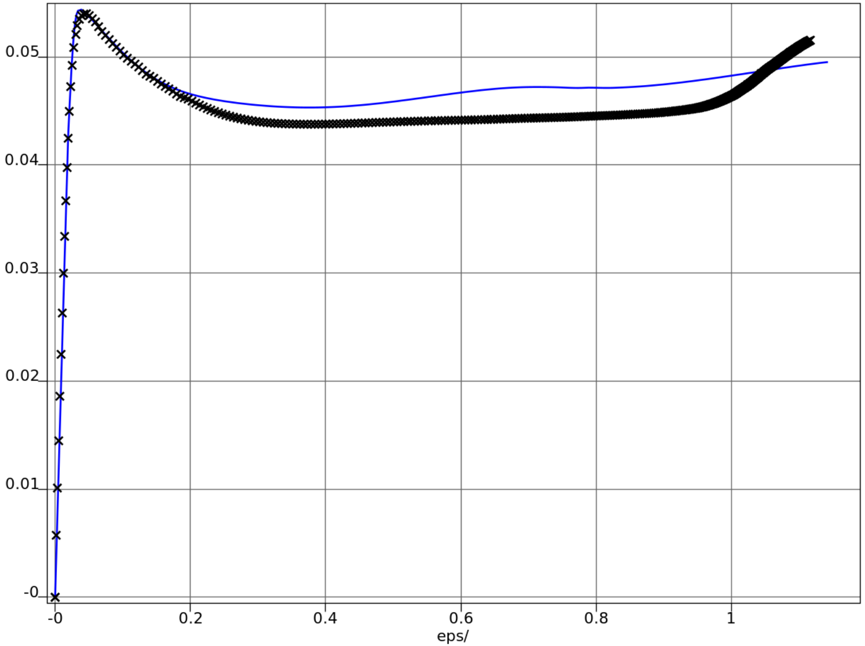




MAT_024 parameter optimization from experimental data

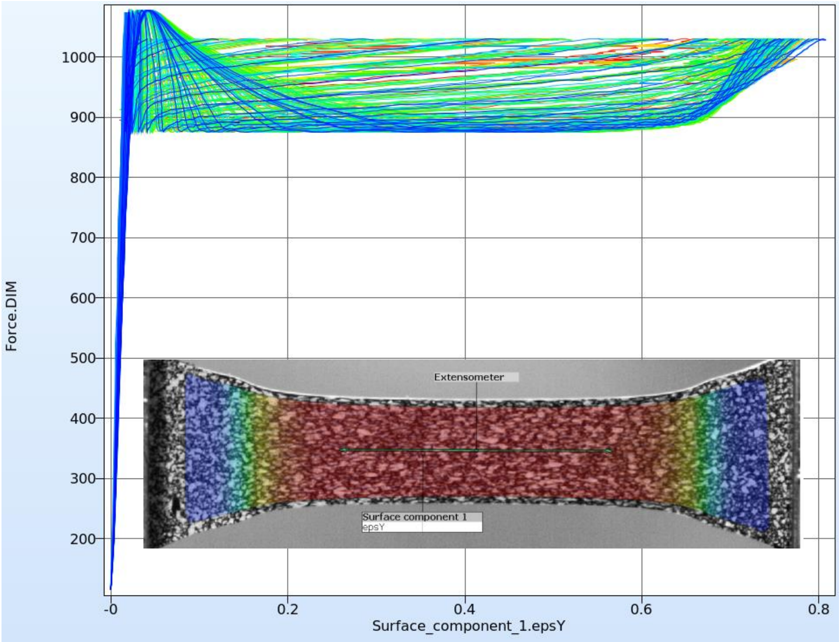
- First optimization run based on an a single stress strain curve
- Input from the experiment: Result:

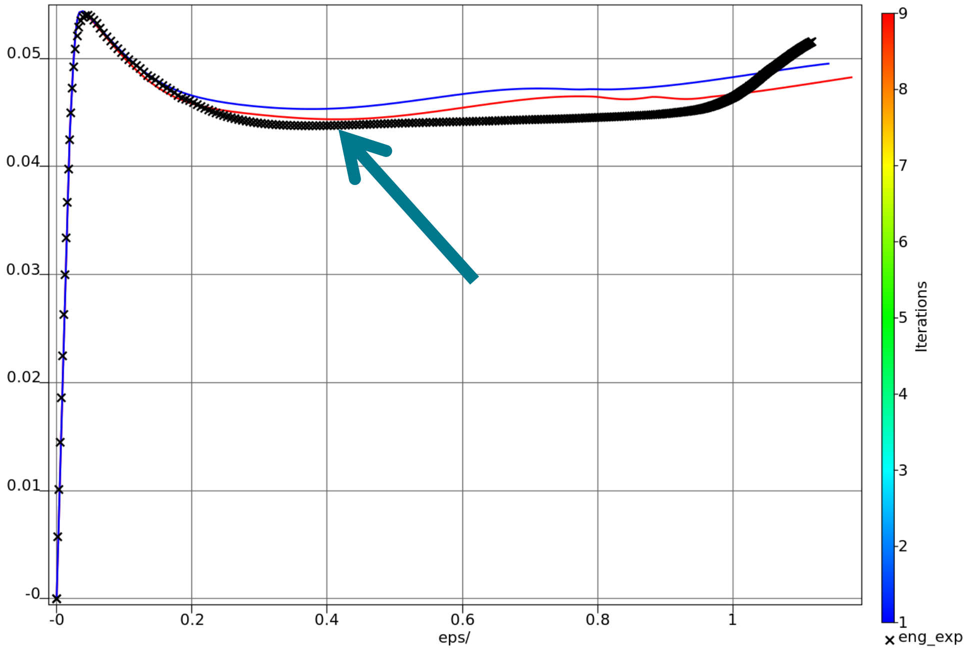




MAT_024 parameter optimization from experimental data

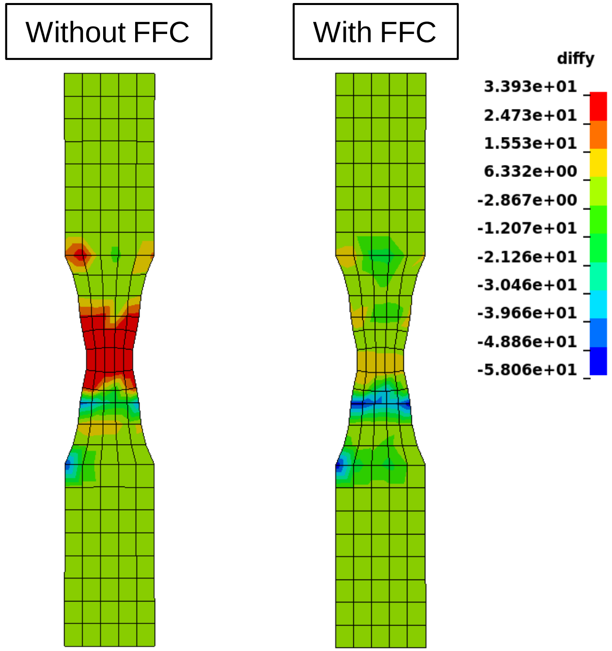
- Second optimization run based on an a single stress strain curve + FFC
- Input from the experiment: Result:

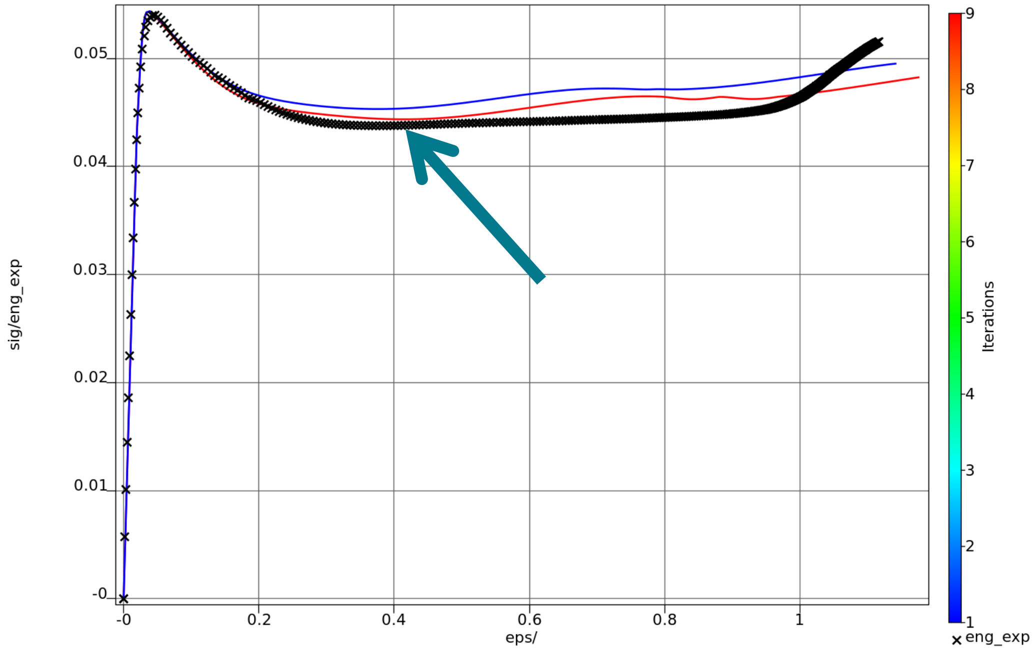




MAT_024 parameter optimization from experimental data

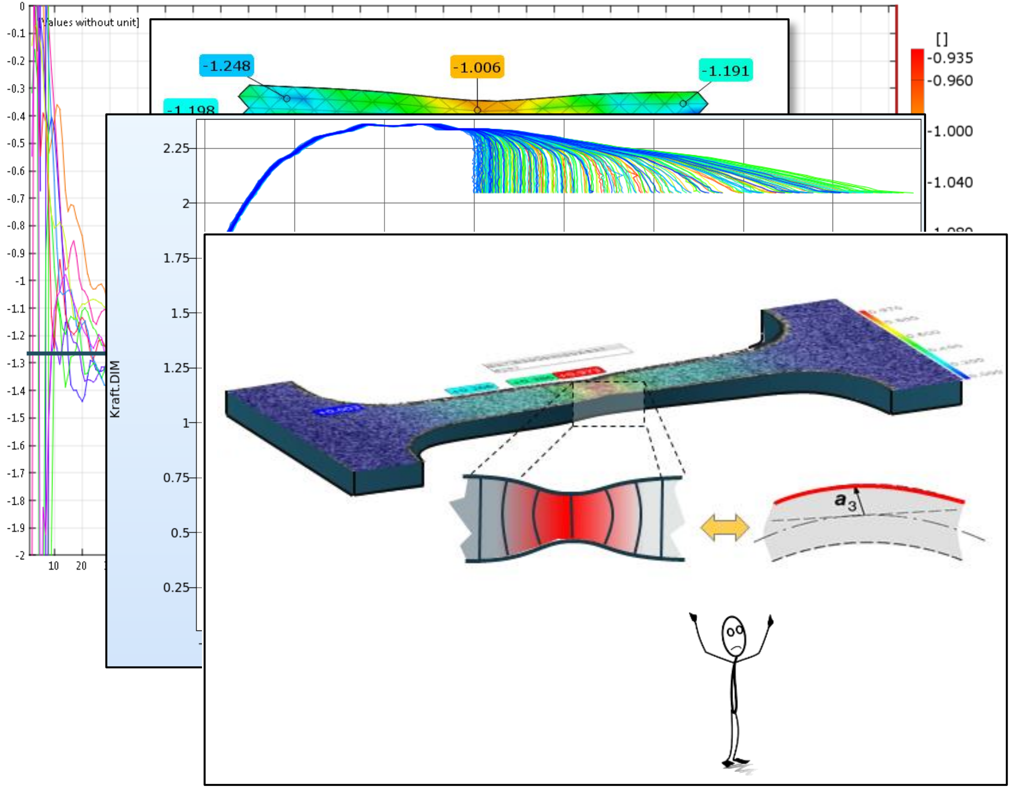
- Second optimization run based on an a single stress strain curve + FFC
- Visualization of the differences in the y-strains:





Limitations

- Possible reasons of deviations
  - Material model:
    - Varying R-value
    - No damage
  - Variables → limited vs. complex
  - Noise
  - Strain rate dependency
  - Heat evolution
  - Surface measurement
  - Shell assumptions



Contents

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 PC/ABS.

- 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 (metal)
  - 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 is available in LS-OPT 6.0

The DYNAmore – Material Competence Center

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  - Validation of material cards
  - Extended parameter identification
  - Consulting for material model selection
- Your benefits:
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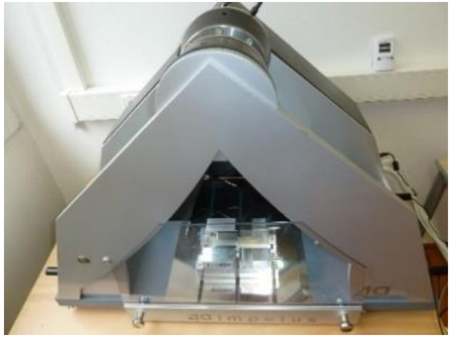
  - Comprehensive knowledge



Your questions, please