Dynamore Express

Robustness in (Sheet) Metal Forming with LS-OPT

Mathias Merten, Katharina Liebold

DYNAmore GmbH

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Outline

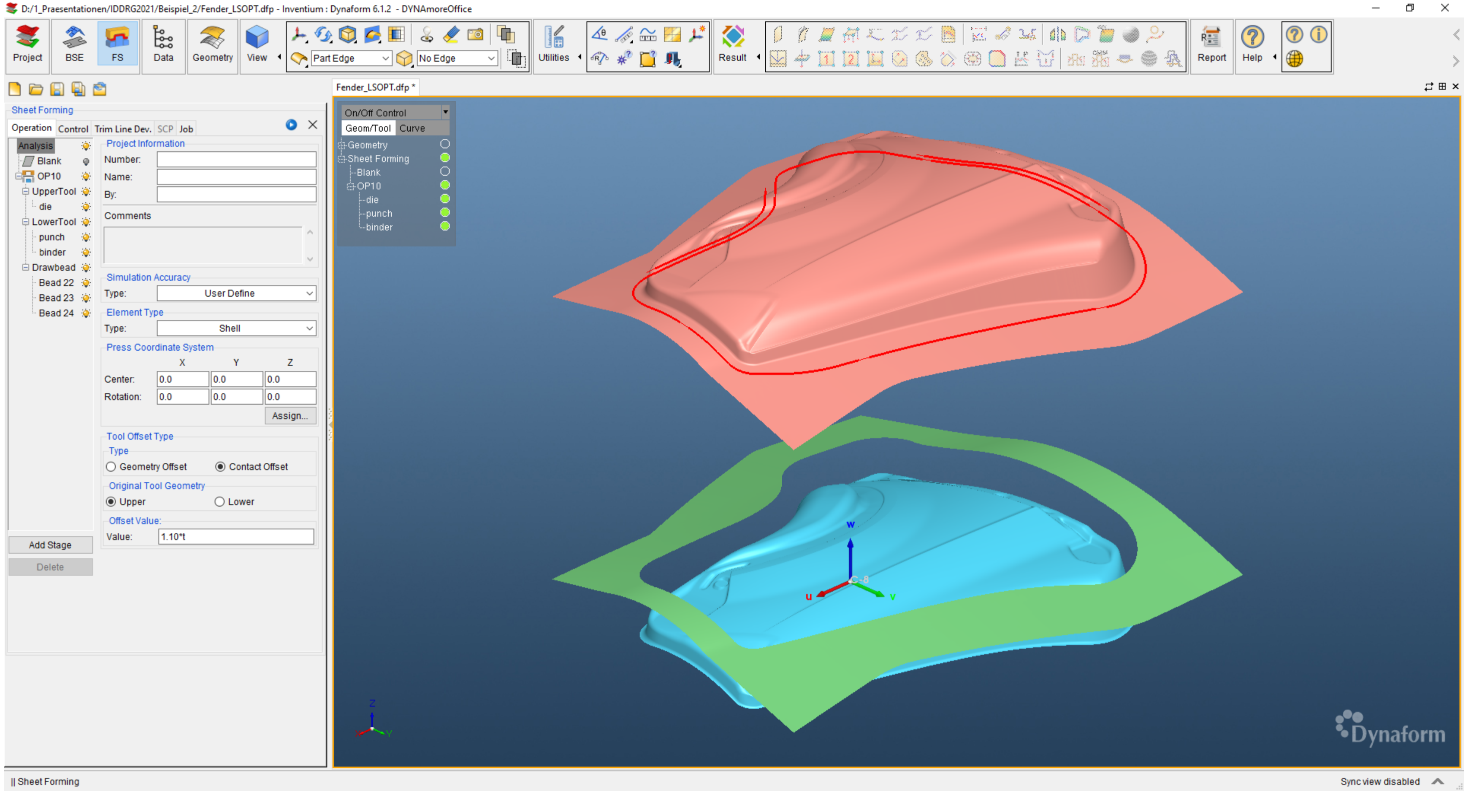
1. Motivational Introduction Example

2. Metamodels and Classifier

3. Results and Visualization

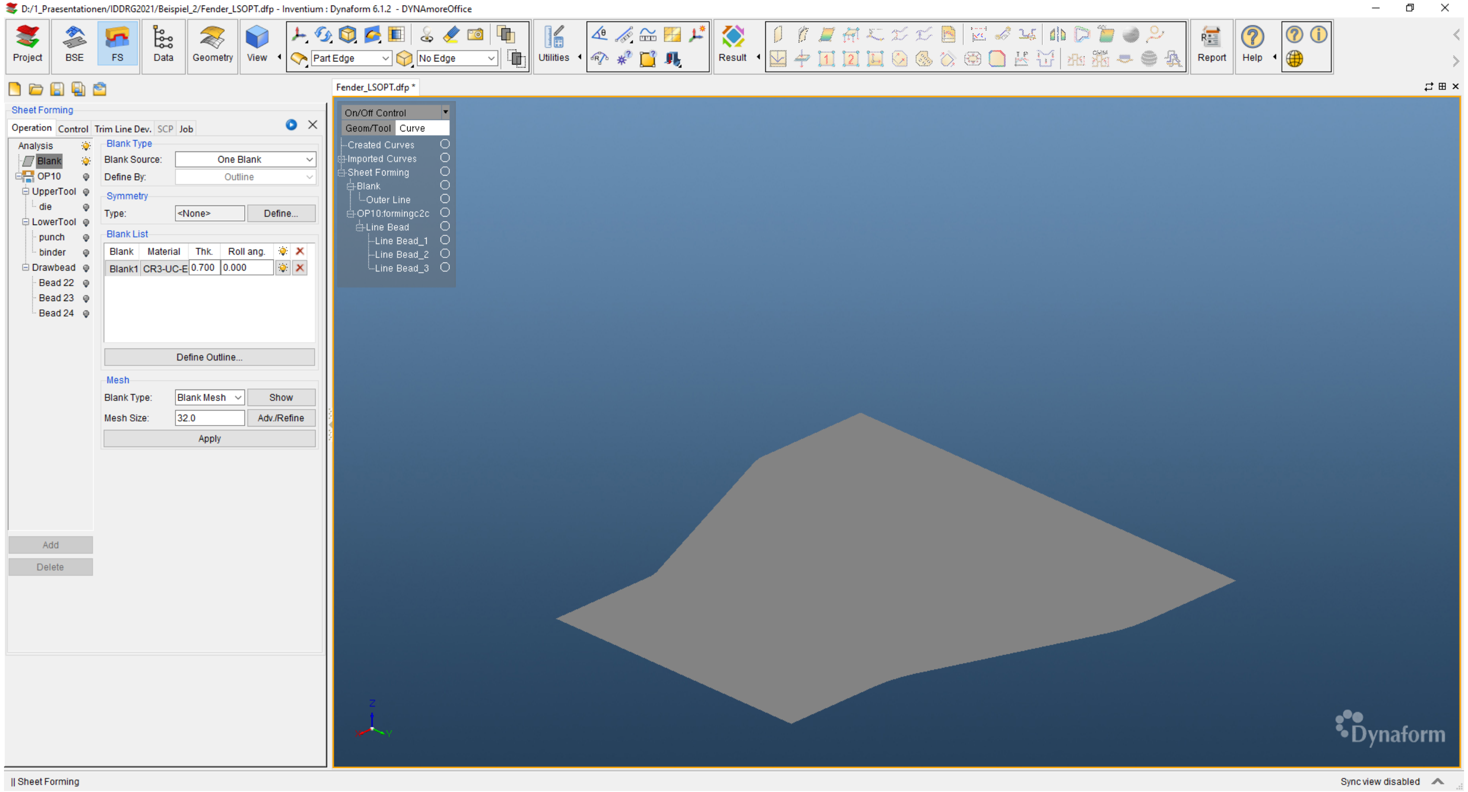
4. Summary and Outlook

Sheet Metal Forming Simulation with Dynaform® (eta)



DYNA MORE

Sheet Metal Forming Simulation with Dynaform® (eta)



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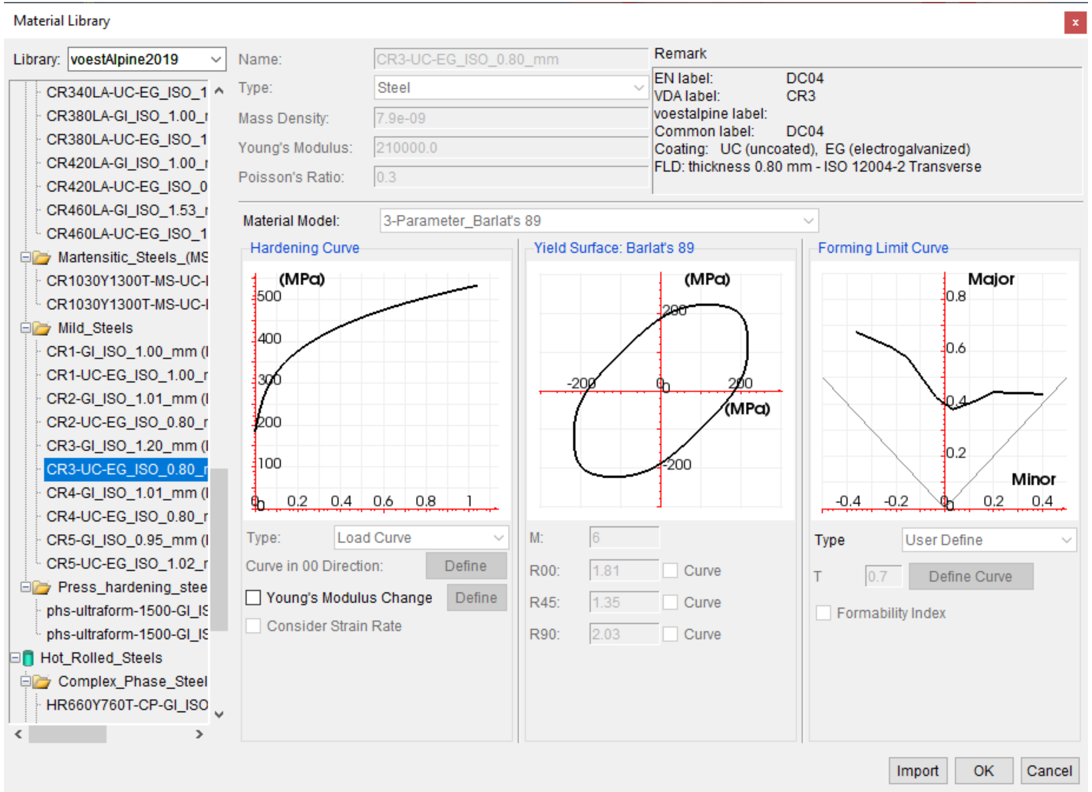

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You are here: Home / Products / Material Cards

Material Cards

In cooperation with the Austrian steel producer voestalpine, DYNAmore has created a material database for over 60 different steel types for metal forming simulations.

In cooperation with the Austrian steel producer voestalpine, DYNAmore has created a material database for over 60 different steel types. The data is based on tests carried out by voestalpine. DYNAmore has converted the data into the LS-DYNA Keyword format for metal forming simulations. These material cards are also available as material libraries for Dynaform 5.9.4 and 6.0.5. We provide the user license free of charge to our customers. If you are interested, please contact our sales staff.

Contact

Kathleen Fritz
@ Kathleen Fritz
t +49 711 459600273
f +49 711 45960029

Kathrin Faas
@ Kathrin Faas
t +49 711 459600274
f +49 711 45960029

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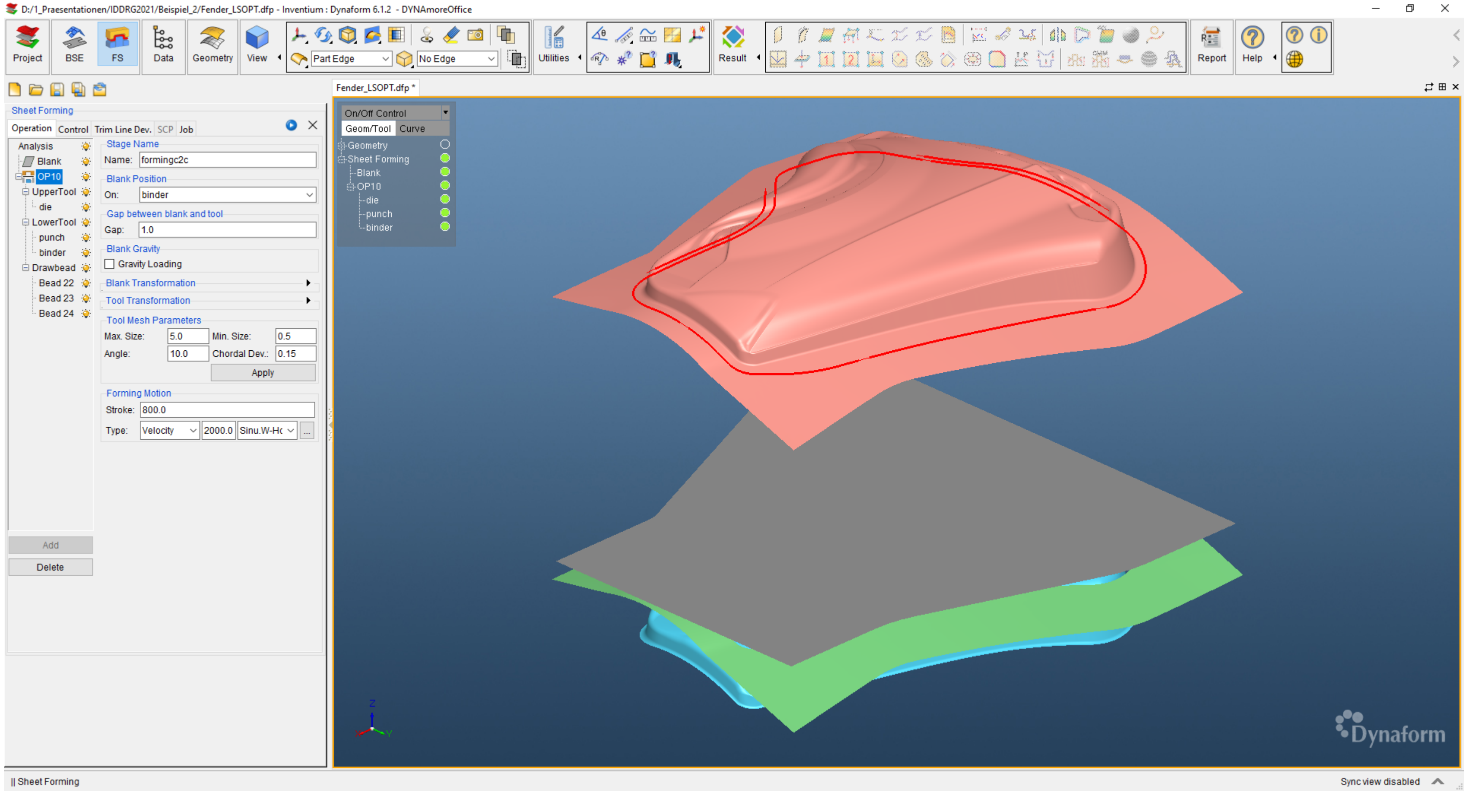
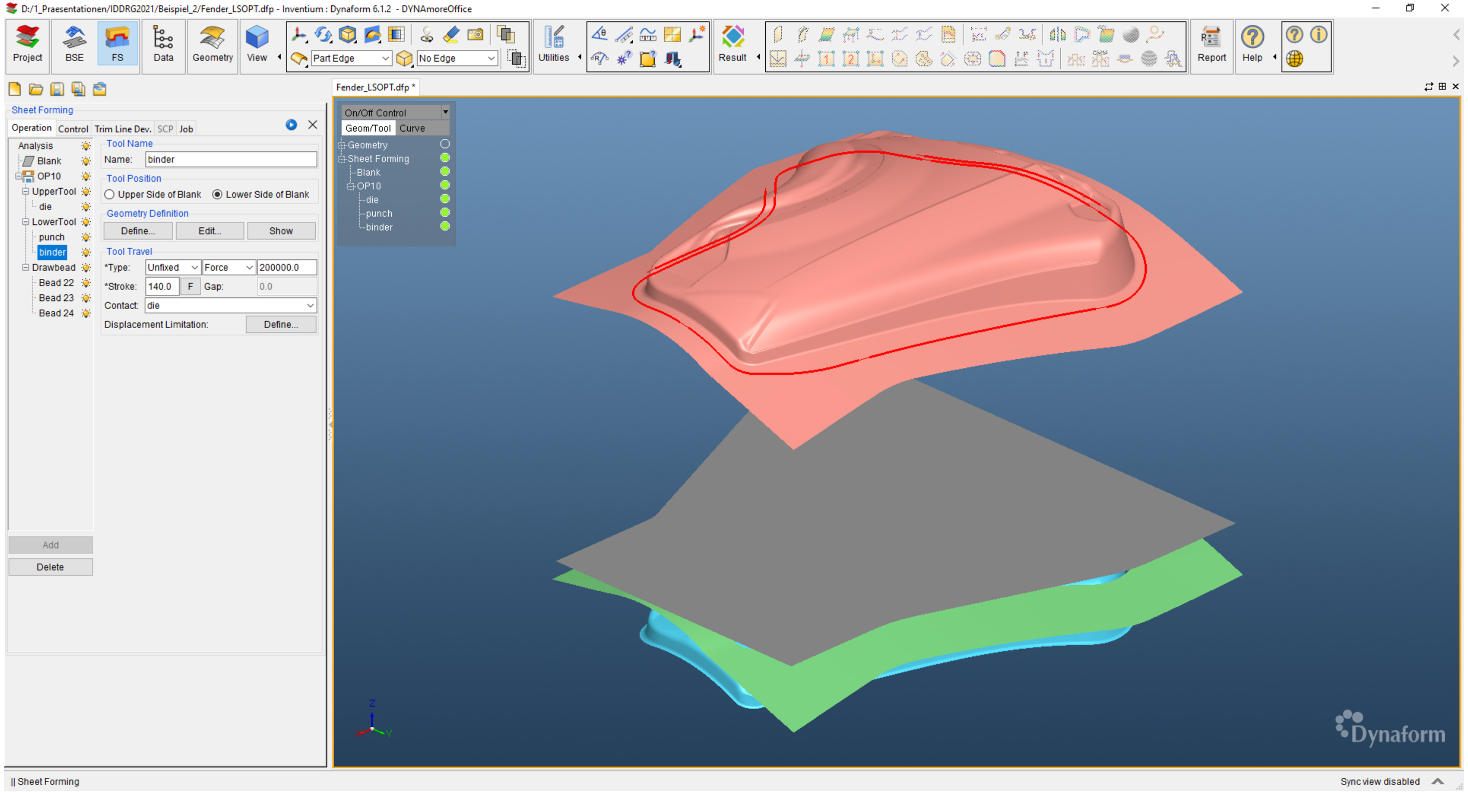
Sheet Metal Forming Simulation with Dynaform® (eta)



Sheet Metal Forming Simulation with Dynaform® (eta)



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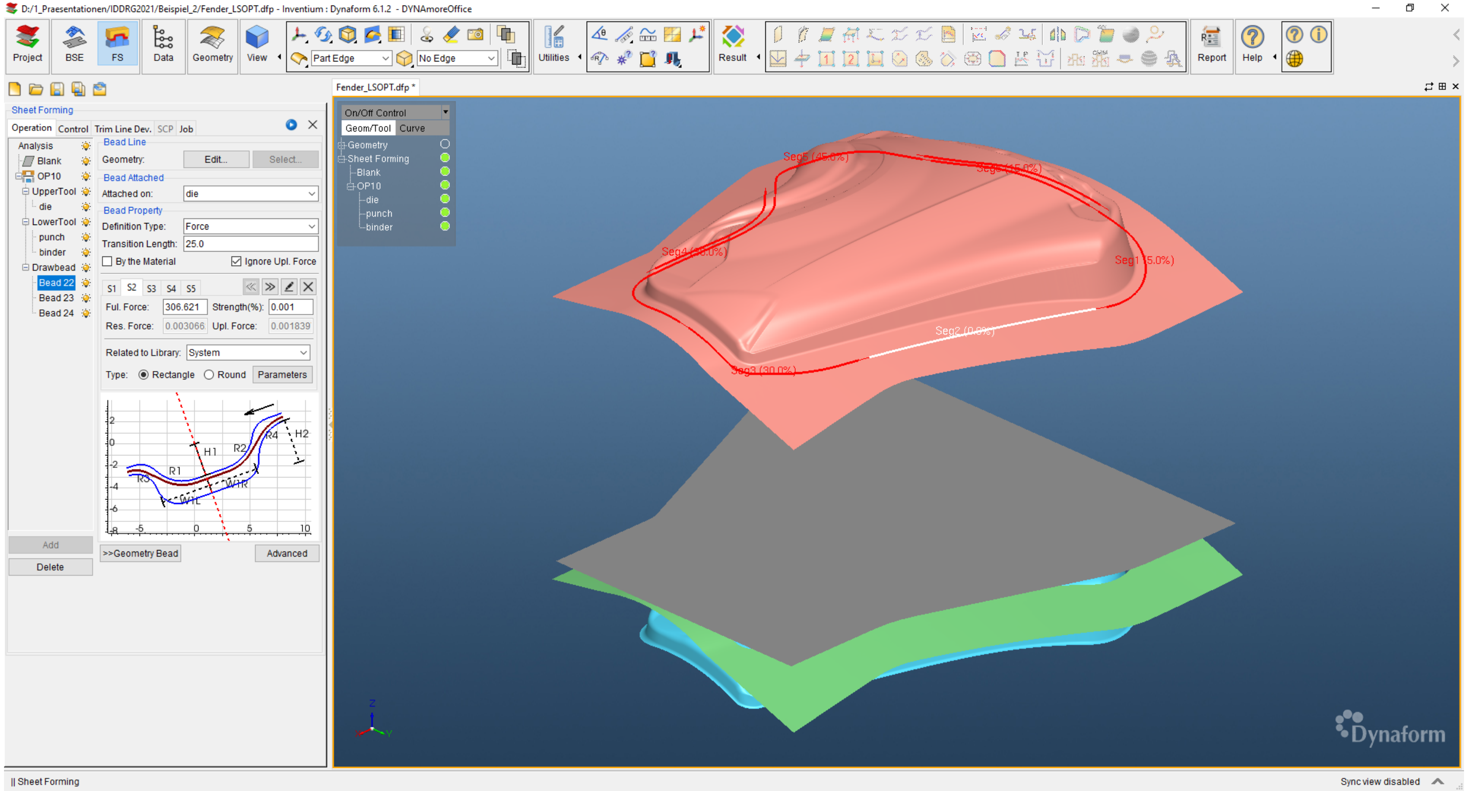
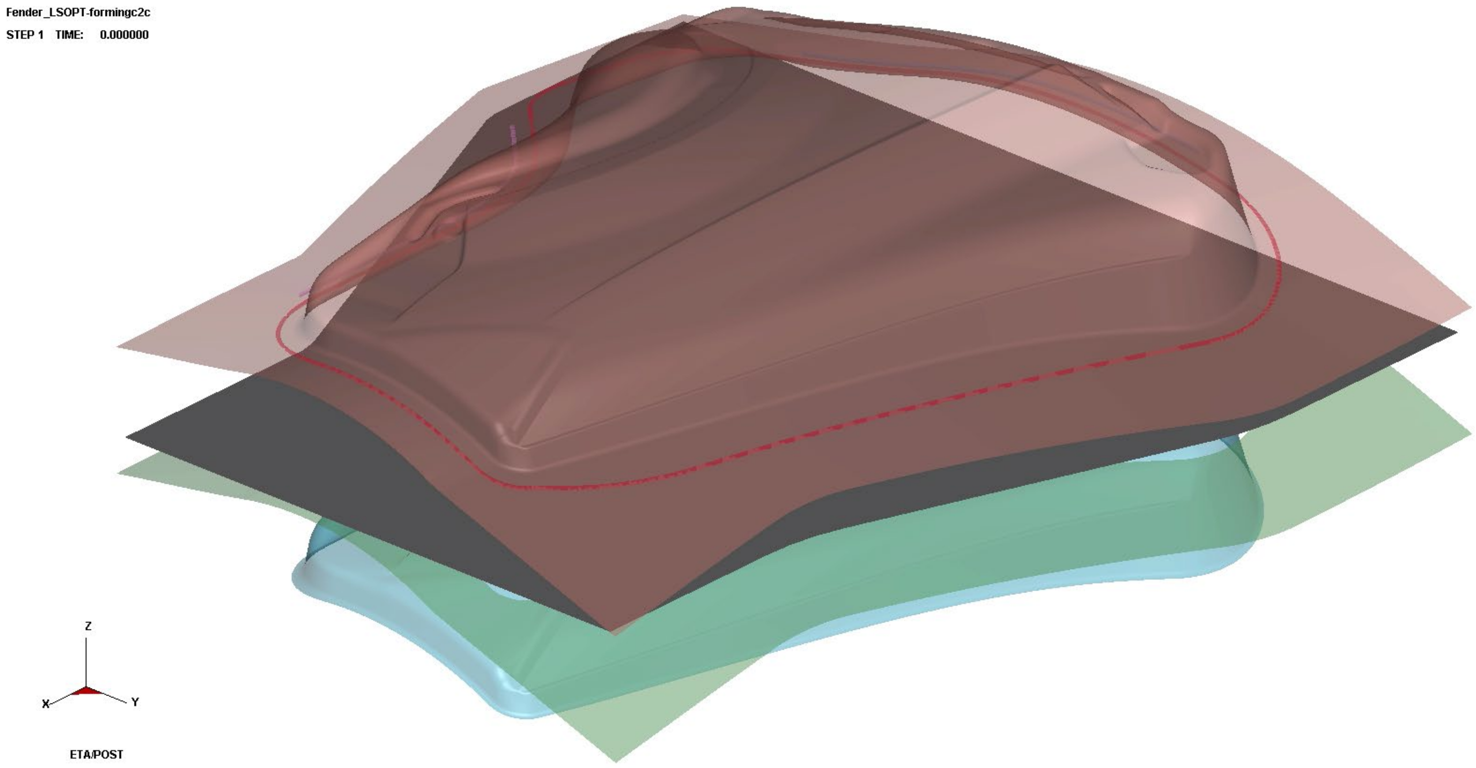


Sheet Metal Forming Simulation with Dynaform® (eta)

Case Study – Process



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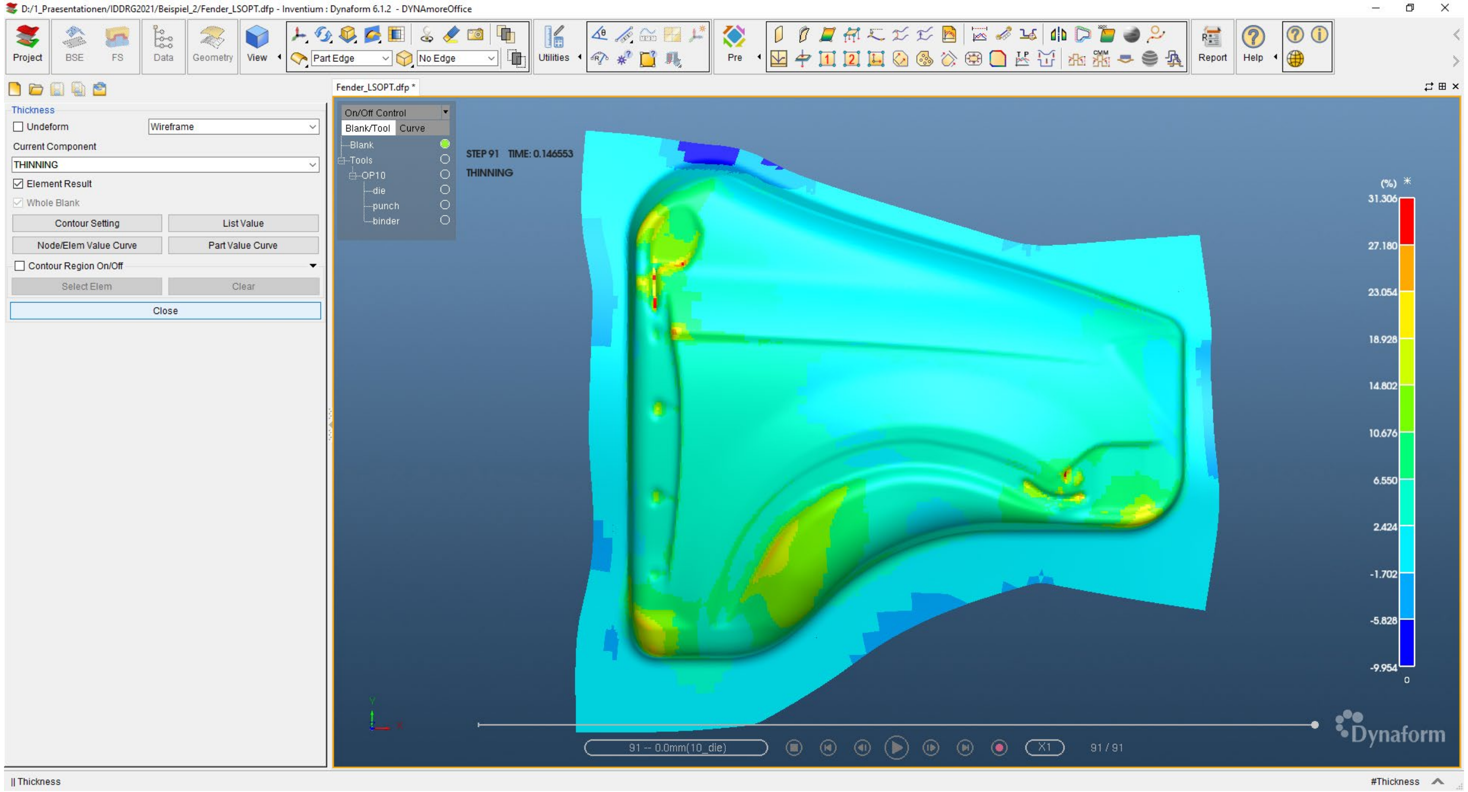

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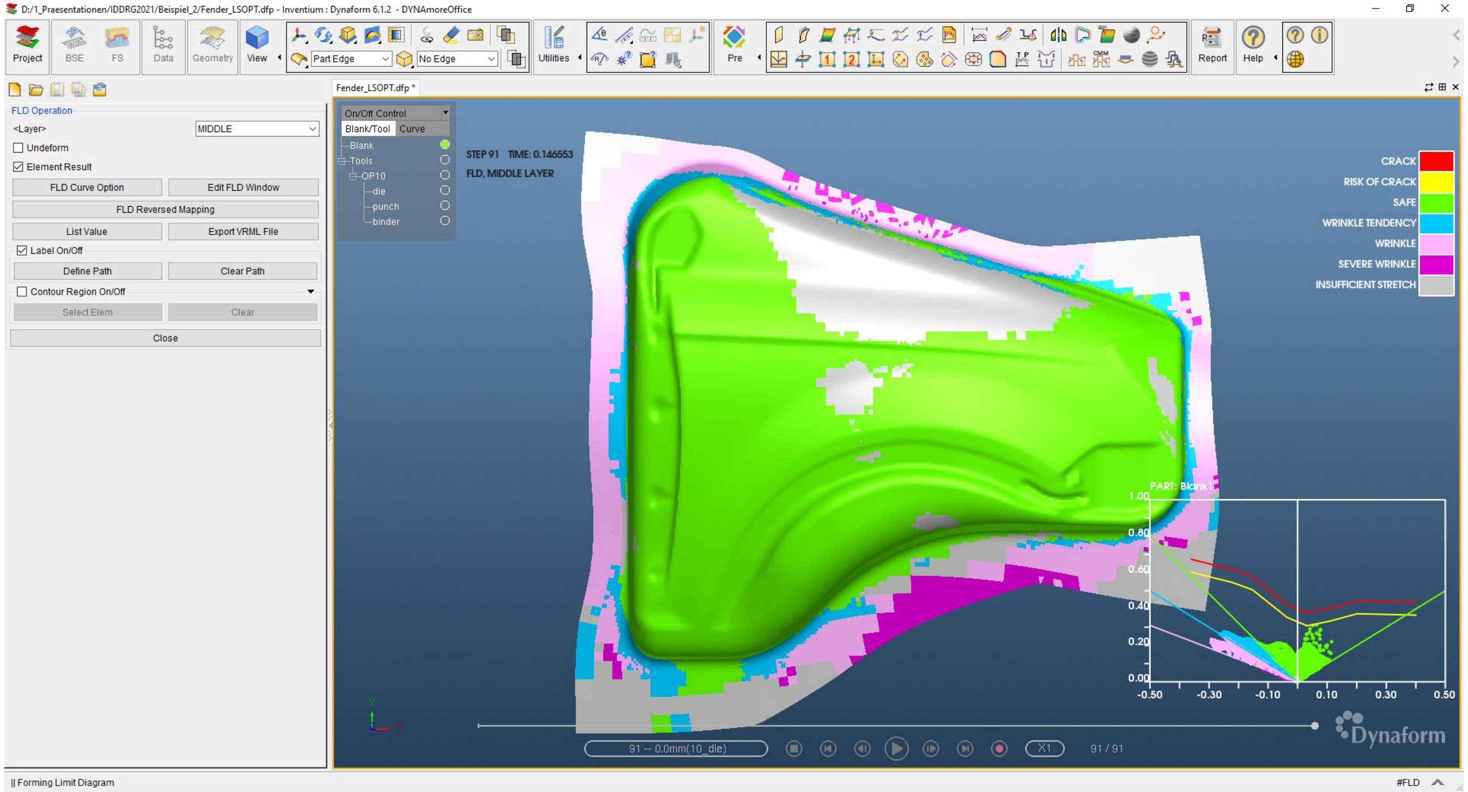


Sheet Metal Forming Simulation with Dynaform® (eta)

MAT_3-PARAMETER_BARLAT_*{OPTION}

This is Material Type 36. This model was developed by Barlat and Lian [1989] for modeling sheets with anisotropic materials under plane stress conditions. Lankford parameters may be used to define the anisotropy. This particular development is due to Barlat and Lian [1989]. *MAT_FLD_3-PARAMETER_BARLAT is a version of this material model that includes a flow limit diagram failure option.

Available options include:

<BLANK>

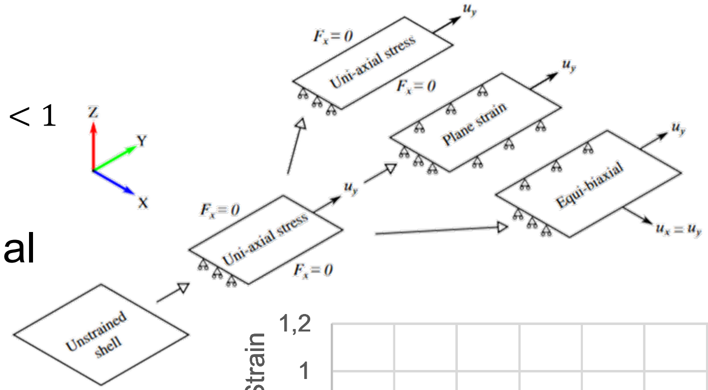
NLP

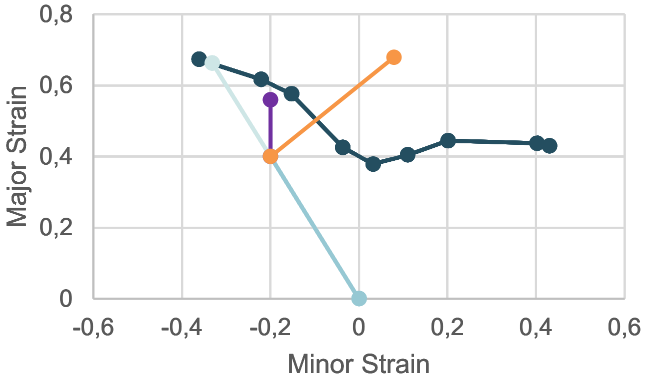
The NLP option estimates failure using the Formability Index (F.I.), which accounts for the non-linear strain paths seen in metal forming applications (see the Remarks). The NLP field in Card 4b *must* be defined when using this option. The NLP option is also available for *MAT_037, *MAT_125, and *MAT_226.

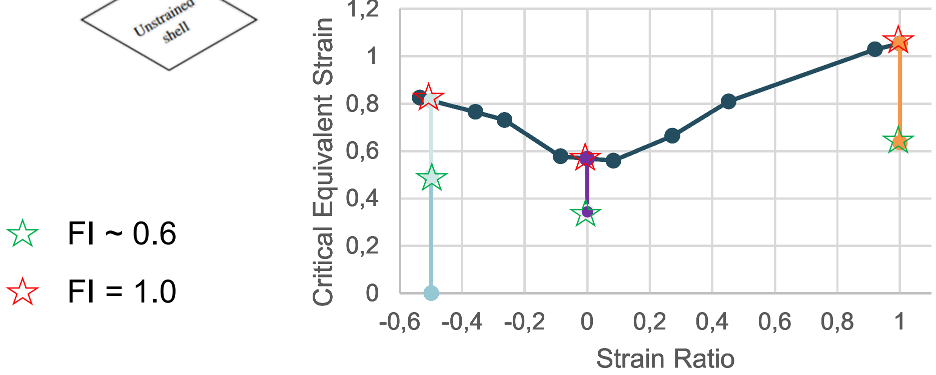
Sheet Metal Forming Simulation with Dynaform® (eta)

- Scalar measurement for formability in case of nonlinear strain paths
- Based on converted FLC
- Example:
  - uni-axial pre-strain
  - followed by uni-axial, plane strain, bi-axial

$$FI = \sum_{i}^{n} \frac{\Delta\varepsilon_{eq}^{i}}{\varepsilon_{eq}^{fail}\left(\Delta\varepsilon_2/\Delta\varepsilon_1\right)} < 1$$







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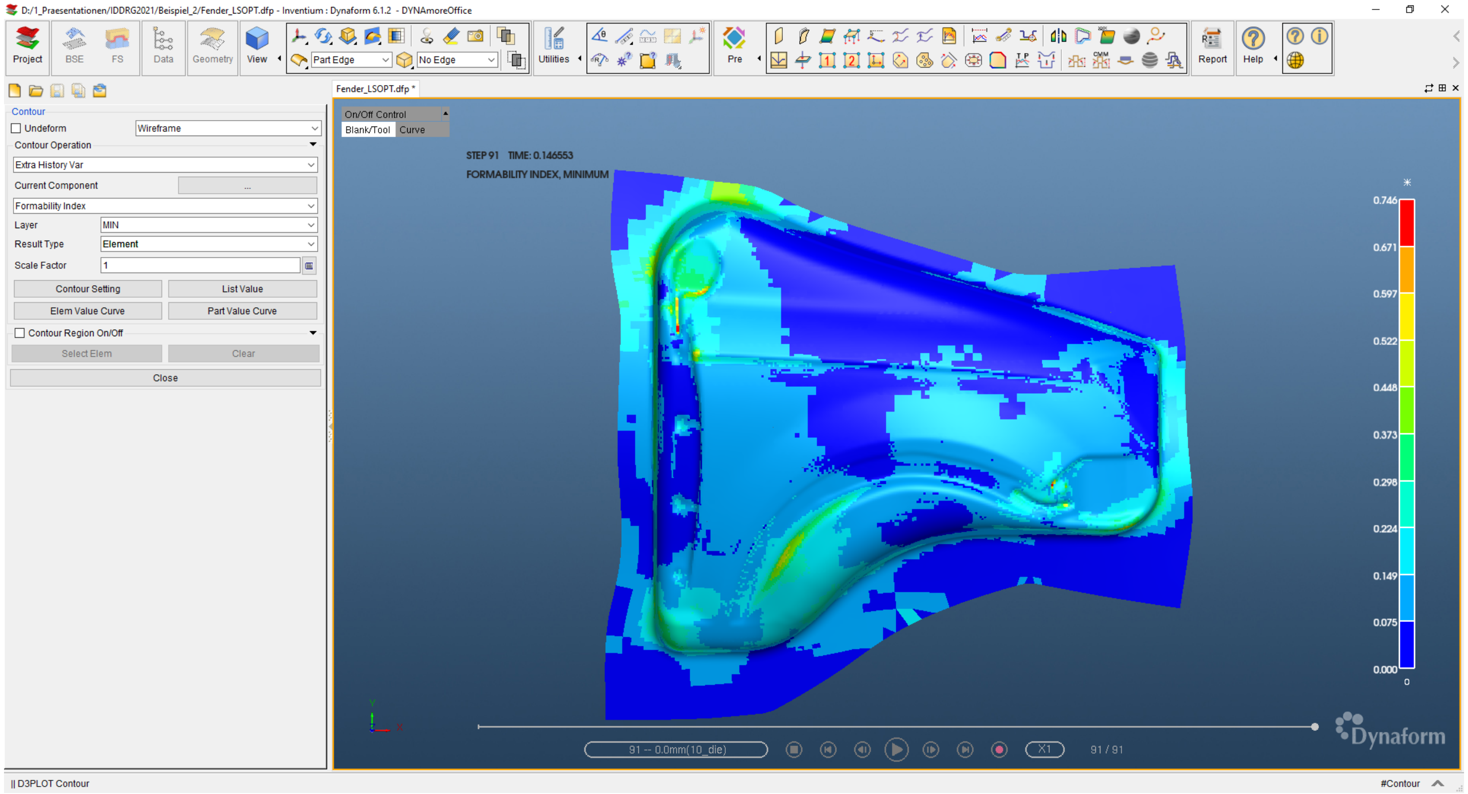
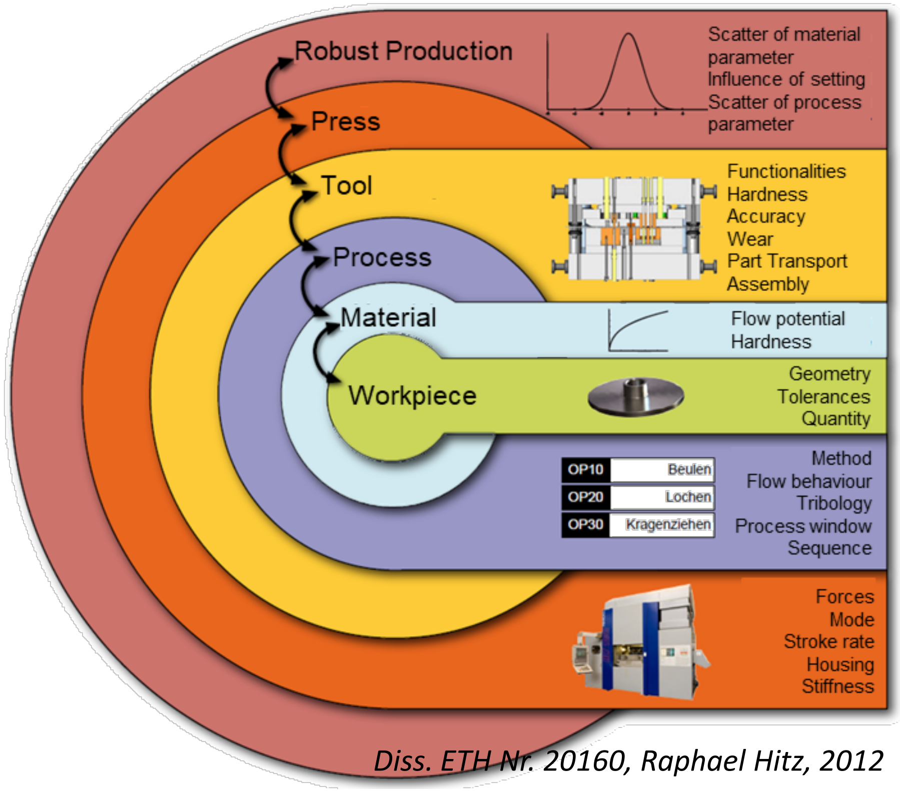
Sheet Metal Forming Simulation with Dynaform® (eta)



Sheet Metal Forming Simulation with Dynaform® (eta)

- Everything within specifications
  - (Of course: Depends on the specification in the showcase)
- Let‘s start production!
- What could go wrong?

Robustness and Numerical Process Simulation



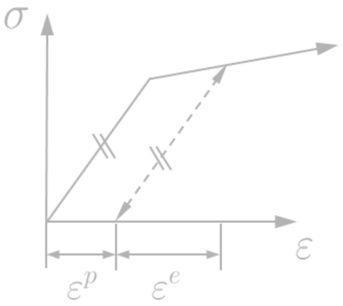
Diss. ETH Nr. 20160, Raphael Hitz, 2012

- Workpiece
  - CAD discretization during meshing
- Material
  - One material card
- Process
  - Operation sequences / method
  - Boundary conditions
- Tool
  - Working surface
- Press
  - Generally neglected
- Scatter of all parameters
  - Generally neglected

Robustness and Numerical Process Simulation

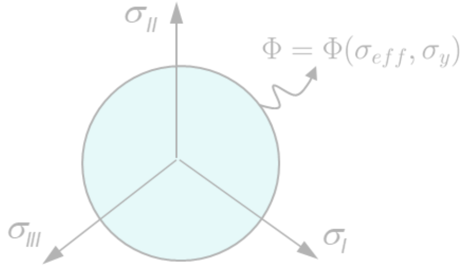
ELASTIC LAW

$$\boldsymbol{\sigma} = \mathbb{D}^e : \boldsymbol{\varepsilon}^e$$



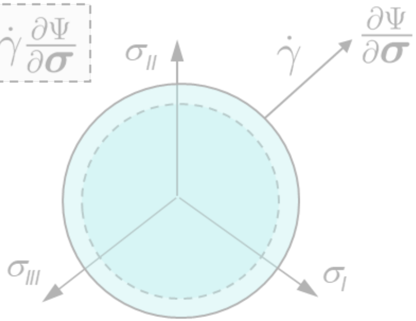
YIELD CRITERION

$$\Phi = \sigma_{eff} - \sigma_y(\varepsilon^p)$$

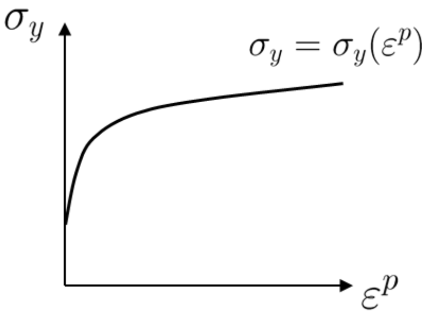


PLASTIC FLOW

$$\dot{\boldsymbol{\varepsilon}}^p = \dot{\gamma}\frac{\partial \Psi}{\partial \boldsymbol{\sigma}}$$



HARDENING LAW



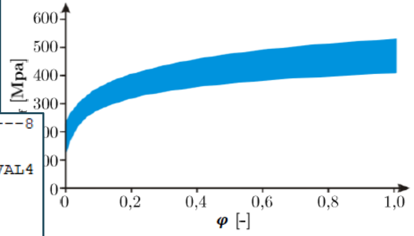
Robustness and Numerical Process Simulation

- Literature study for DC04
  - Gosh-type hardening
    - $\sigma_y(\varepsilon_p) = k(\varepsilon_0 + \varepsilon_p)^n - p$
    - $k = \frac{R_m(A_g+1)-R_{p02}}{[\varepsilon_0+ln(A_g+1)]^n-\varepsilon_0{}^n}$
    - $p = k\varepsilon_0{}^n - R_{p02}$
    - ε_0, A_g, n fixed

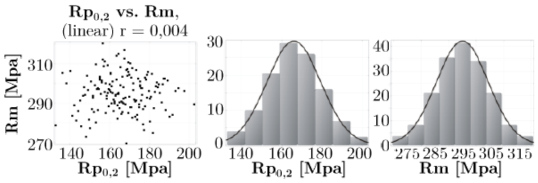
```
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*PARAMETER
$     PRMR1          VAL1     PRMR2          VAL2     PRMR3          VAL3     PRMR4          VAL4
  R      HR           5.0
  R n_Gosh  -0.137766
  Re0_Gosh  0.0325023
  R      ag          0.24
  R    rp02         166.0
  R      rm         295.0
$
*PARAMETER_EXPRESSION
$     PRMR1                                                              EXPRESSION
 R  k_Gosh  (rm*(ag+1.0)-rp02)/((e0_Gosh+log(ag+1.0))**n_Gosh-e0_Gosh**n_Gosh)
 R  p_Gosh  k_Gosh*e0_Gosh**n_Gosh - rp02
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
```

	$Rp_{0,2}$	Rm	ϵ_0	m
Minimum	130 MPa	263 MPa	-	-
Maximum	225 MPa	328 MPa	-	-
Mittelwert	166 MPa	295 MPa	0,0325023	-0,137766
Standardabweichung	13,5 MPa	9,5 MPa	-	-
Verteilungsfunktion	Normal	Normal	-	-

Tabelle 2.4.: Verwendete Parameter für DC04. k und p wurden jeweils gemäß der Gleichungen 2.15 und 2.16 berechnet.



(a) NLO-Hüllkurven für DC04.

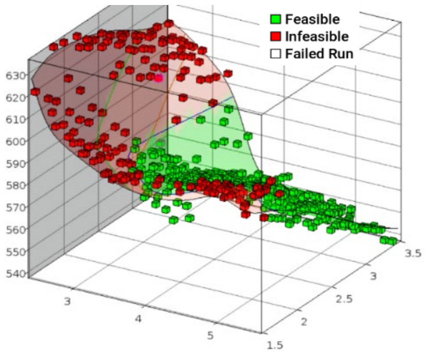


(b) Materialparameterstreuungen und Histogramme für DC04.

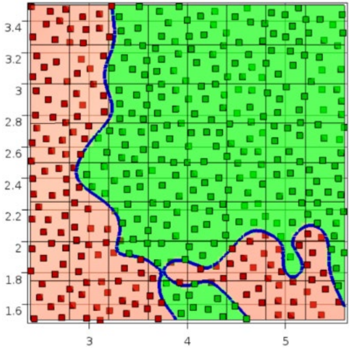
DISS. ETH Nr. 24853, FLORIAN QUETTING, 2018

Virtual Robustness Analysis

- Highly nonlinear finite element simulations are computationally expensive
  → metamodel or classifier approximations are used to evaluate statistics



Metamodel
Approximation of response



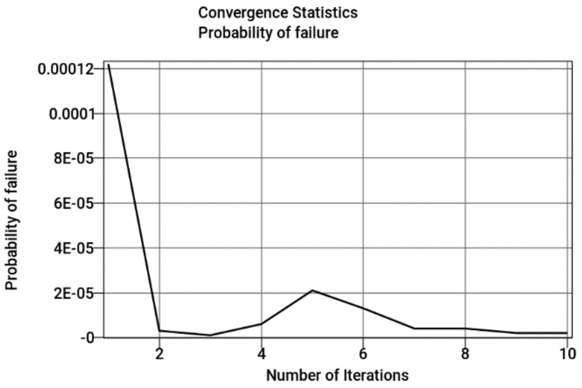
Classifier (Support Vector Classification)
Approximation of constraint boundary

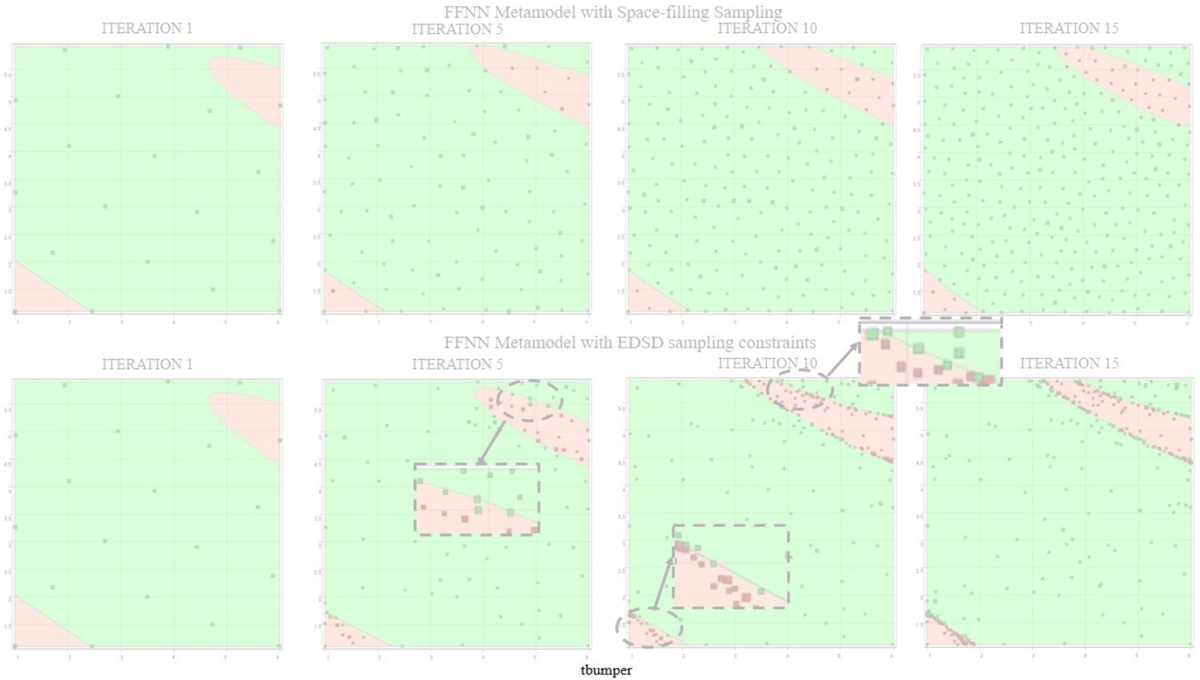
- Feasibility of each design

→ Constraints for optimization or reliability analysis
→ Adaptive Sampling

Sequential Monte Carlo Analysis

- Iteratively add space-filling or adaptively selected samples
- Convergence
  - metamodel accuracy
  - probability of failure



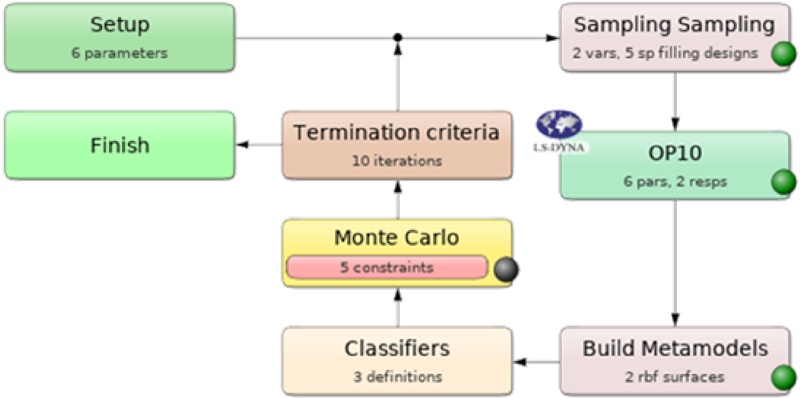


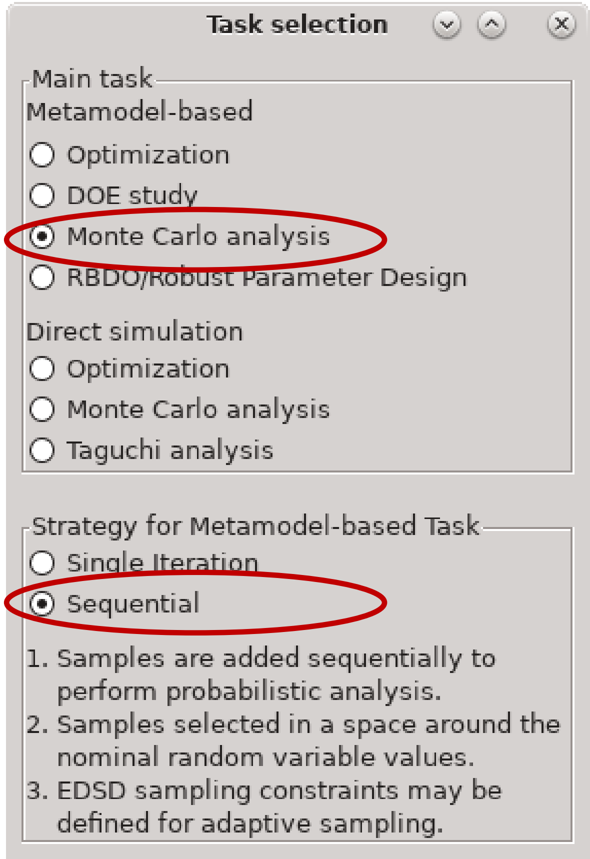
Case Study – Setup for Robustness Analysis

- Sequential metamodel-based Monte Carlo Analysis
  - 5 simulations per iteration, 10 iterations

→ Improvement of metamodel and classifier approximation in each iteration

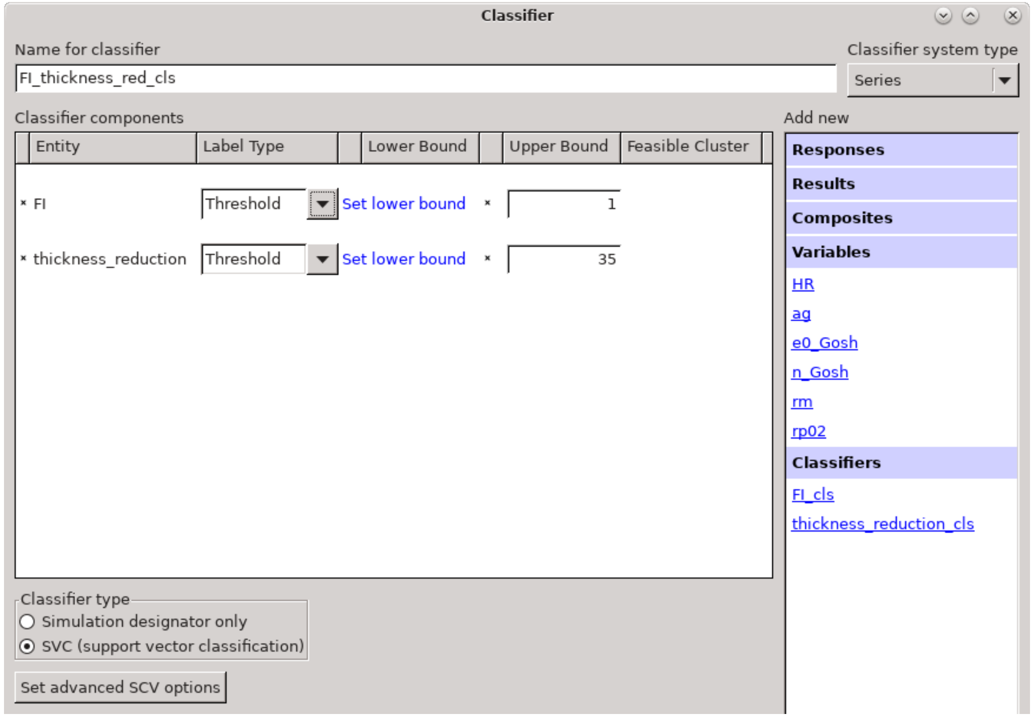
→ Improvement of estimation of probability of failure, mean value, standard deviation, …





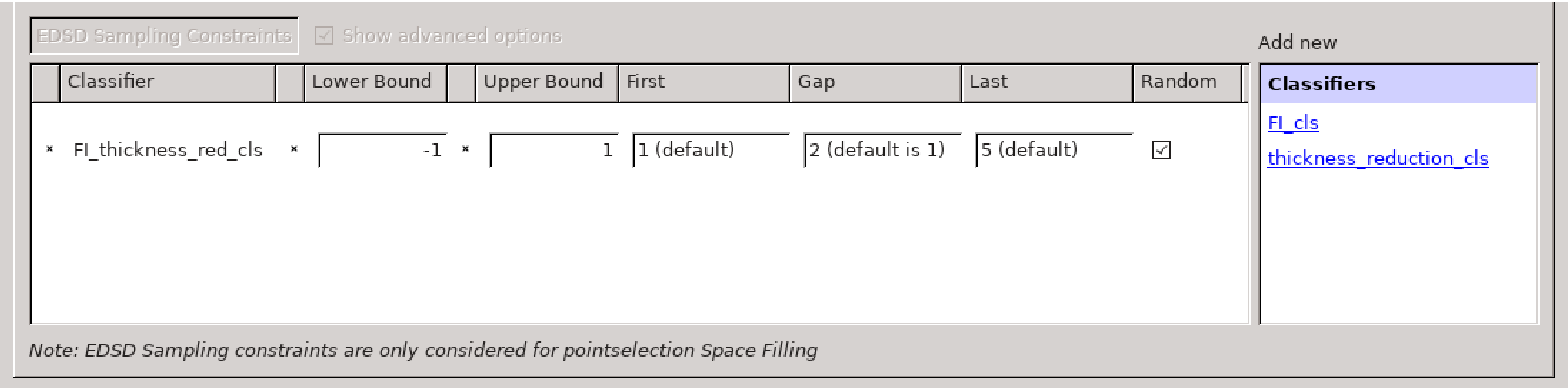
Case Study – Setup for Robustness Analysis

- Definition of classifiers



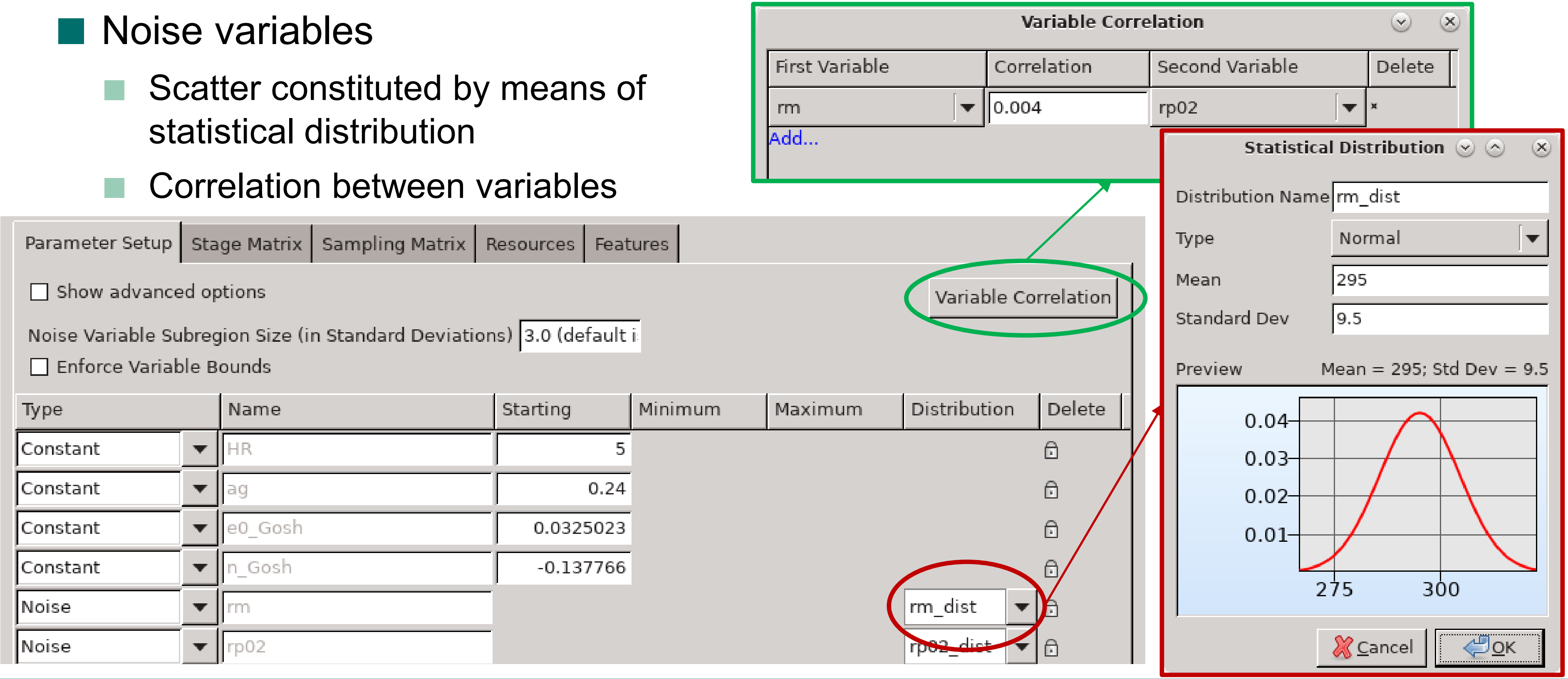
Case Study – Setup for Robustness Analysis

- Adaptive Sampling – using classifiers!
  - 3 points adaptive (near classifier boundary) using classifier with components
    - $max_{EL}[min_{IP}(\boldsymbol{FI})] < 1$
    - $max_{EL}(\boldsymbol{thickness\ reduction}) < 35$
  - 2 space filling points



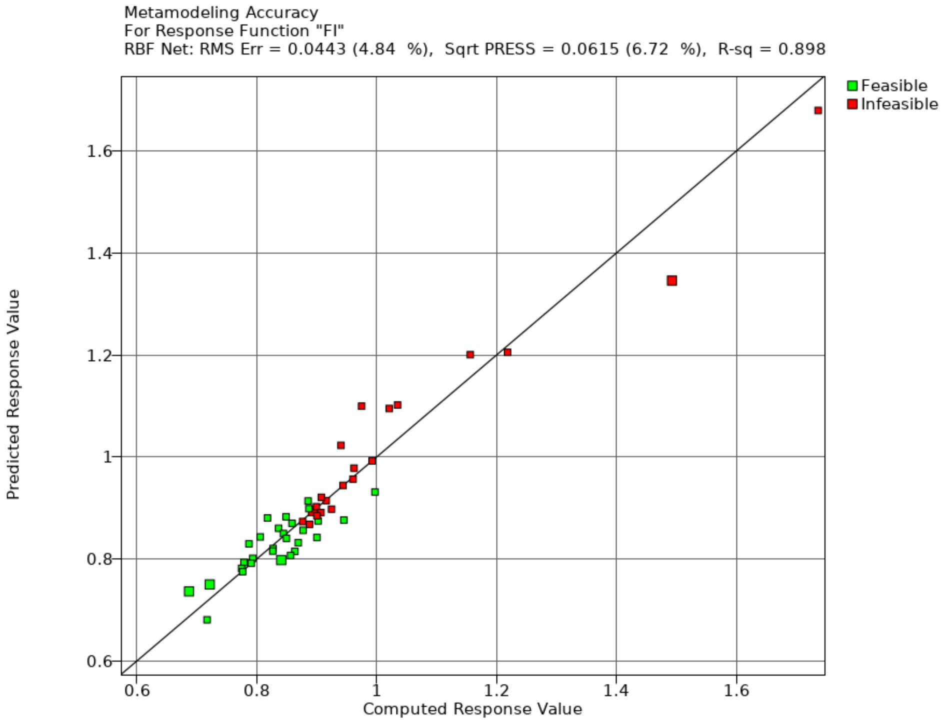
Case Study – Setup for Robustness Analysis

- Noise variables
  - Scatter constituted by means of statistical distribution
  - Correlation between variables

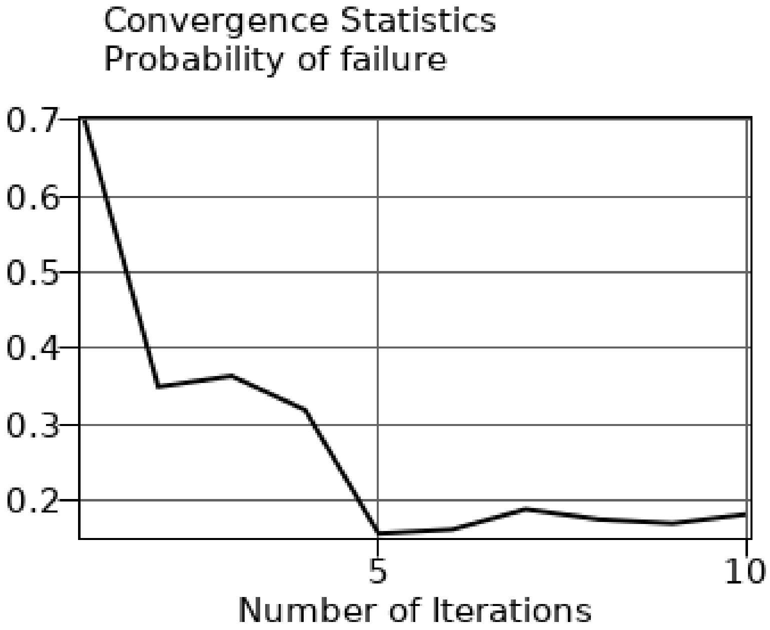


Case Study – Metamodel Quality and Convergence

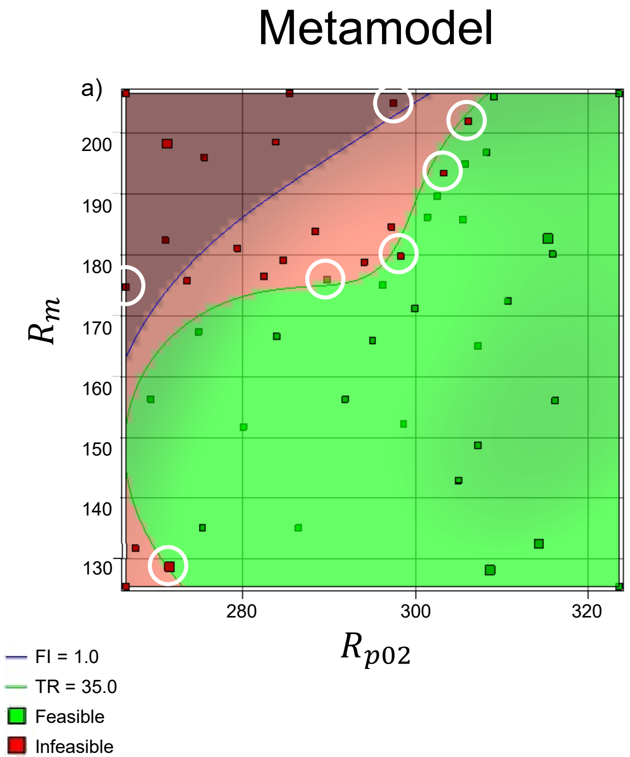
- Metamodel quality

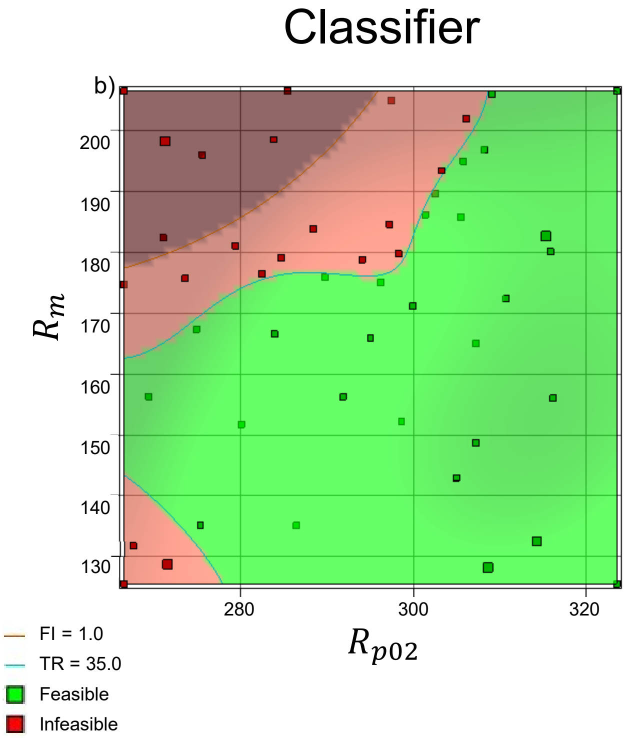


- Convergence

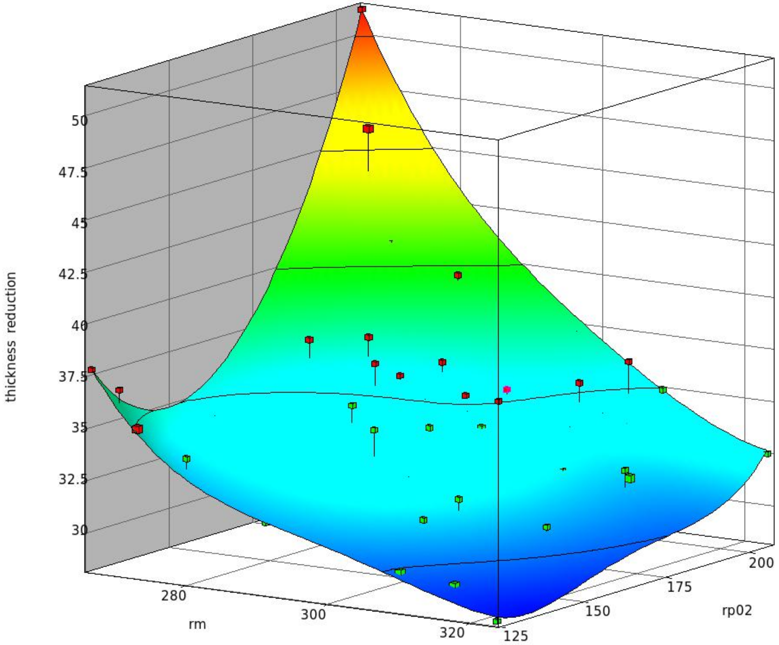


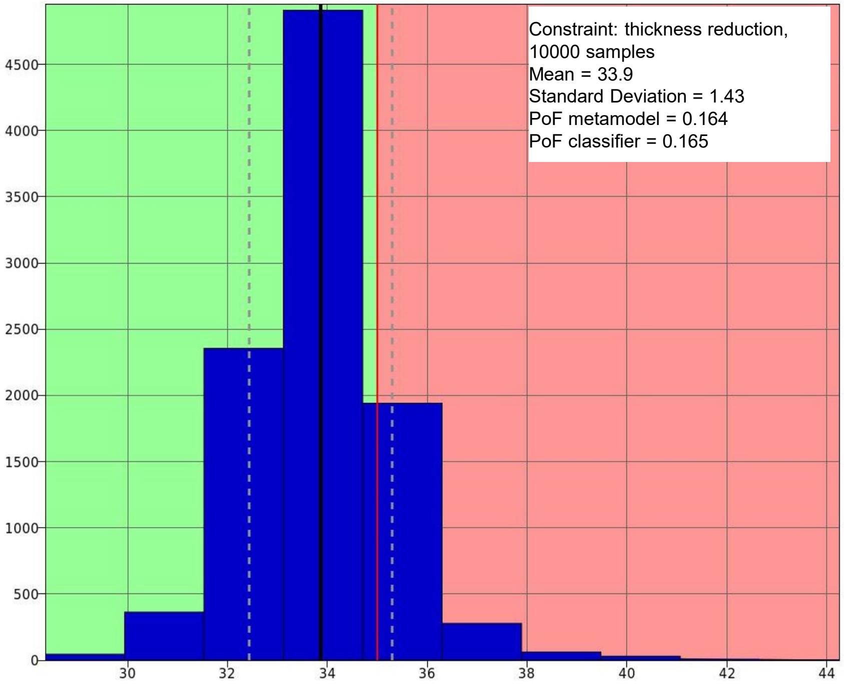
Case Study – Comparison of Failure Boundaries



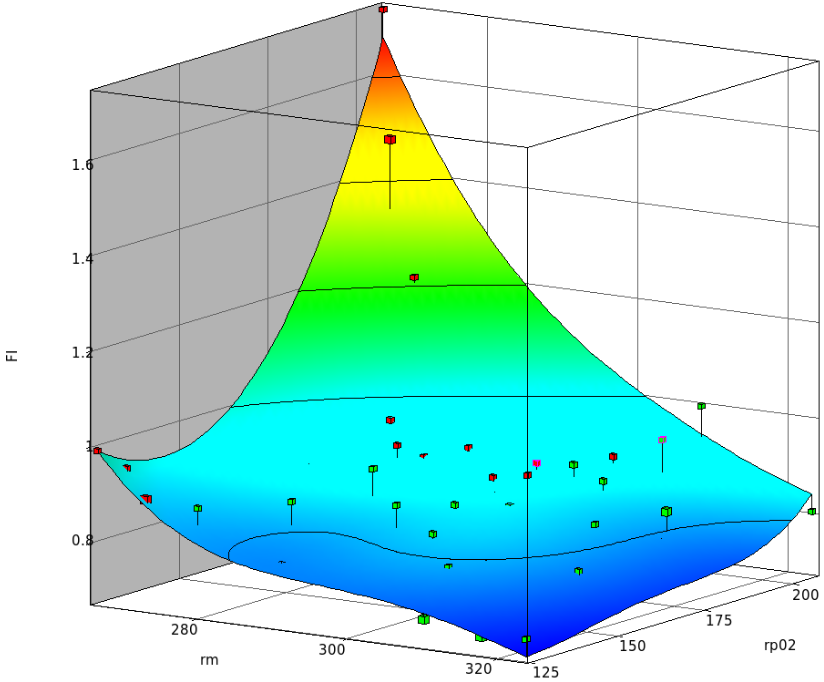


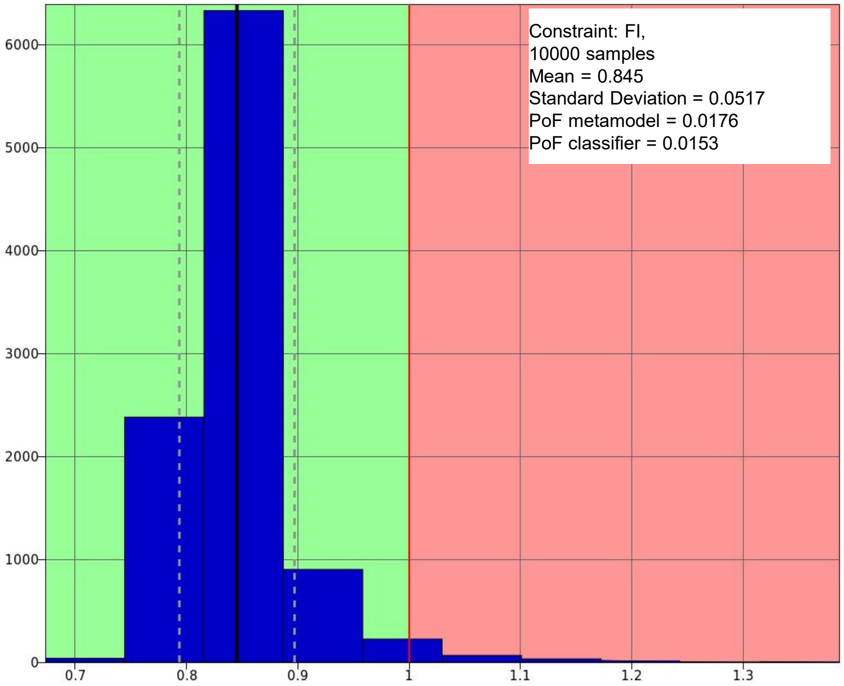
Case Study – Thickness Reduction





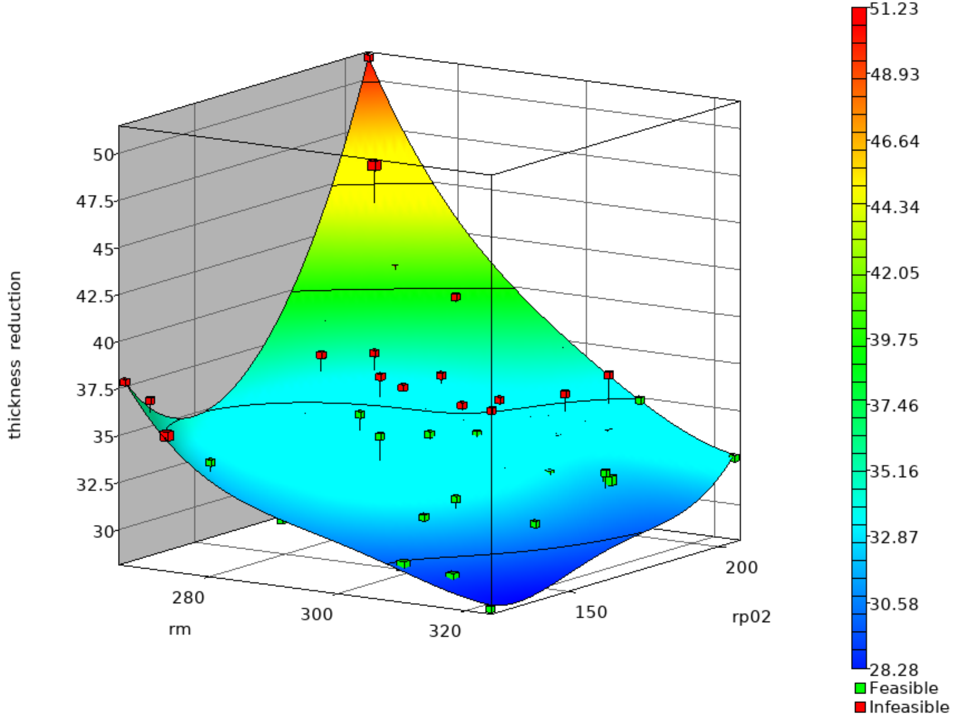
Case Study – Formability Index

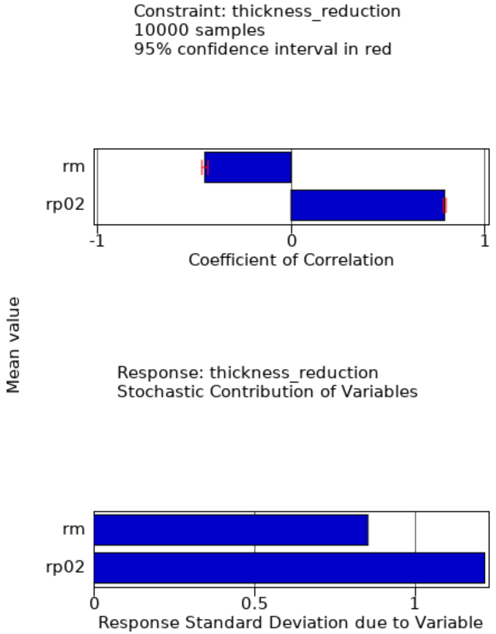




Case Study – Sensitivities

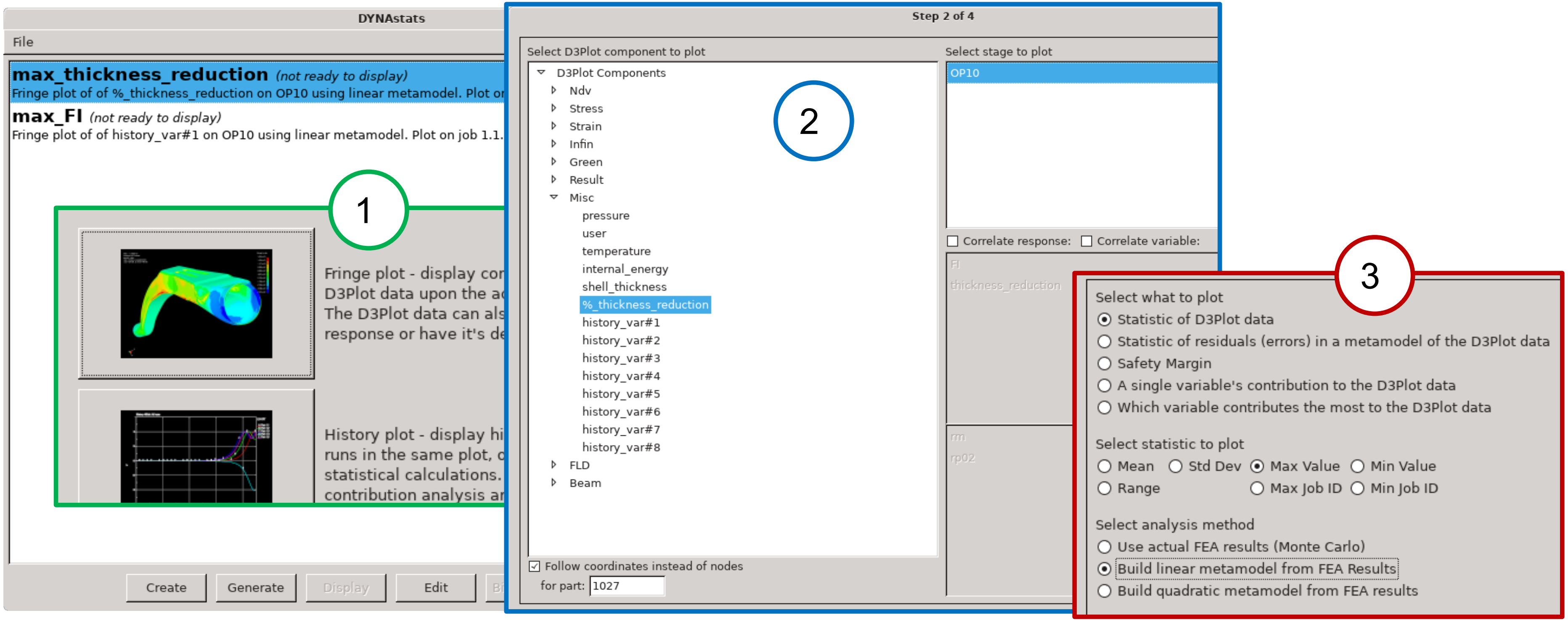
- Which parameter influences the responses?





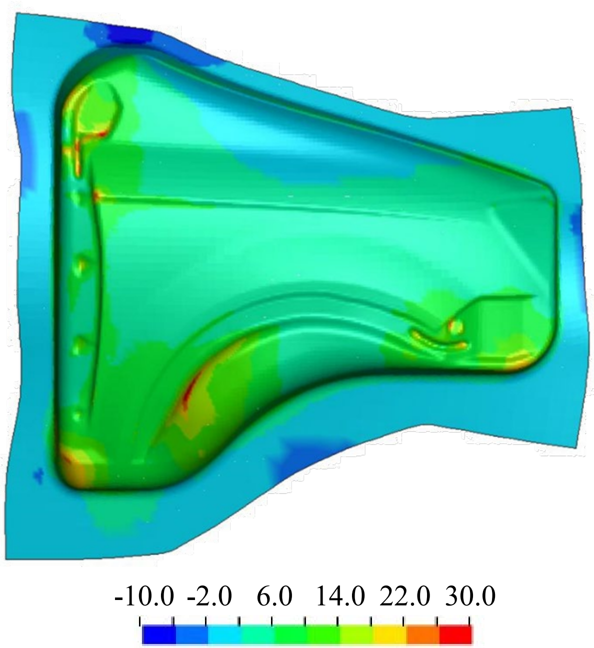
Case Study - DYNAStats

- Statistical values as fringe component in LS-PrePost

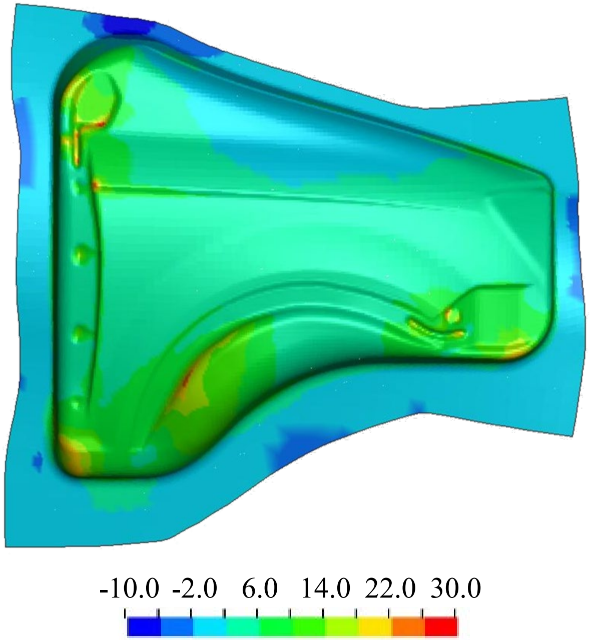


Case Study – Identification of critical zones

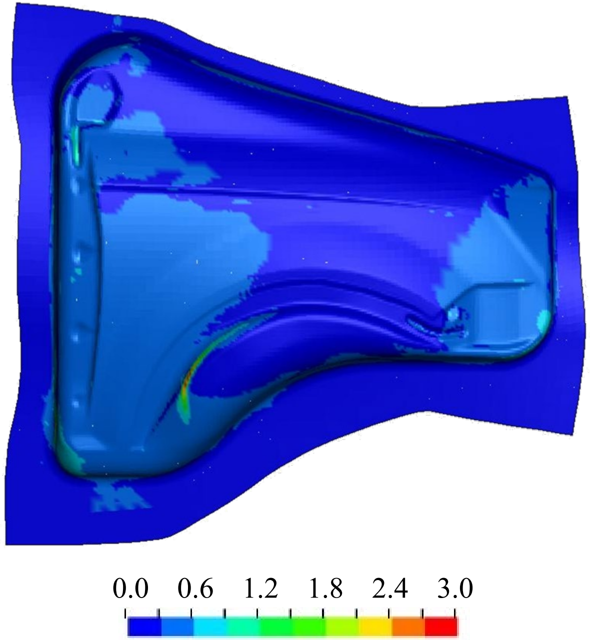
- Based on calculated simulations to generate the metamodels



Maximum Value



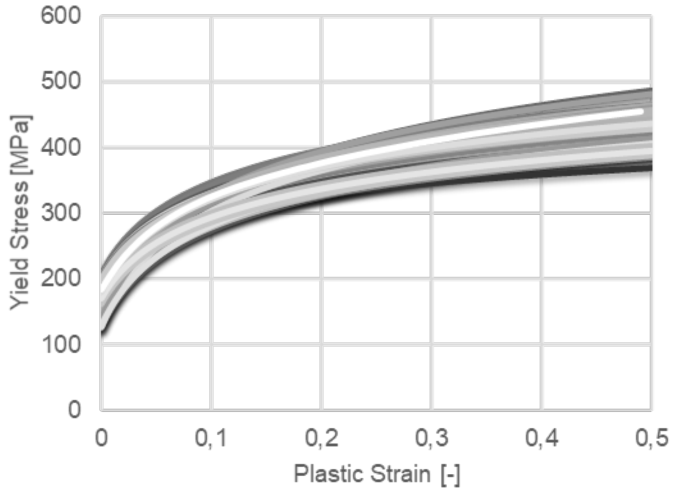
Mean Value

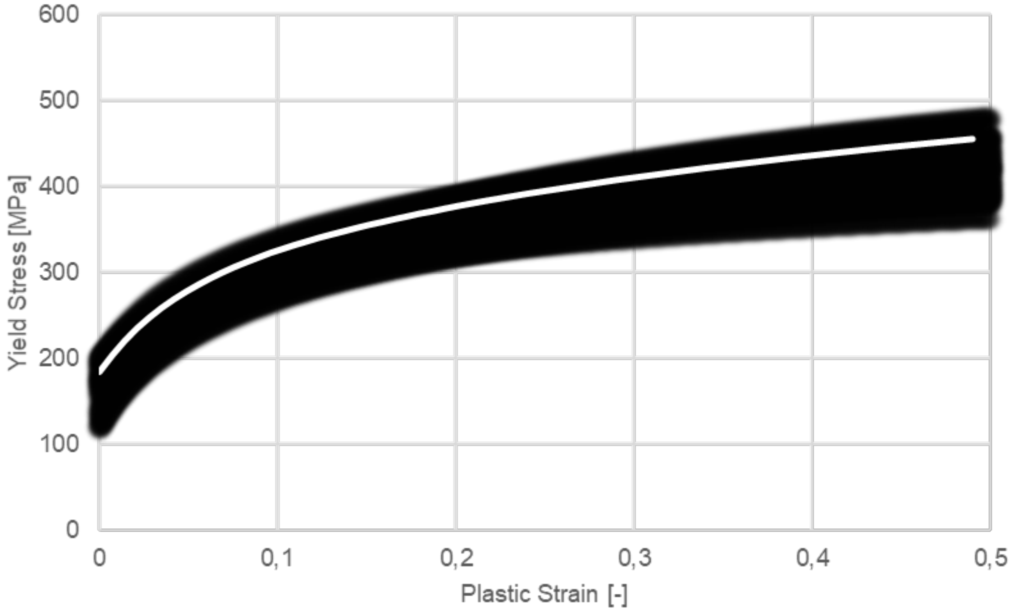


Standard Deviation

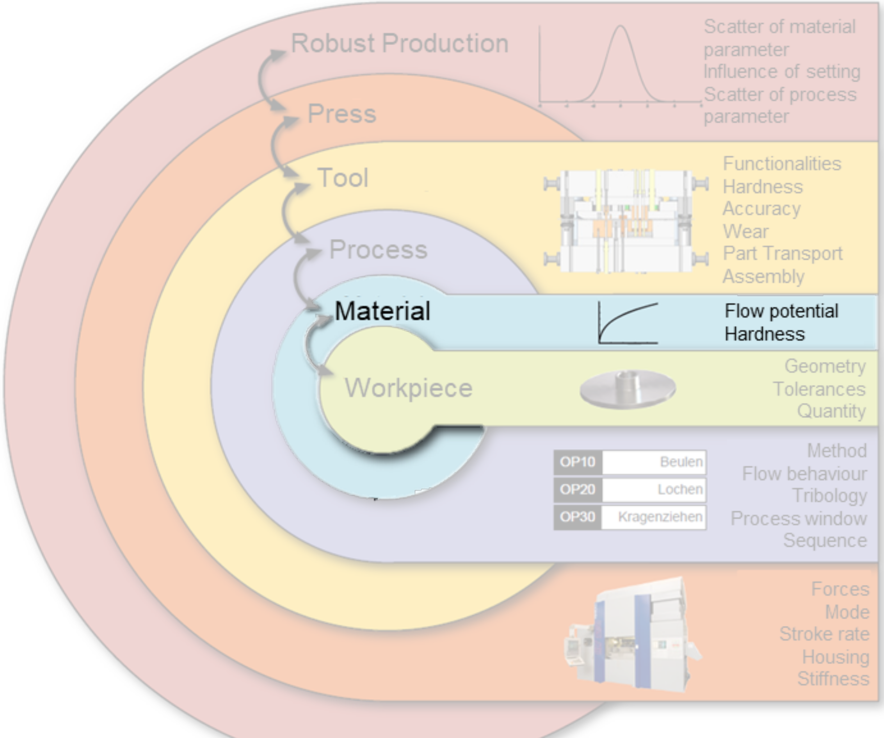
Summary

- Comparison of initial yield curve to the yield curves of the 50 simulations
  - NOT a scaling
  - Shape and slope changes





Summary

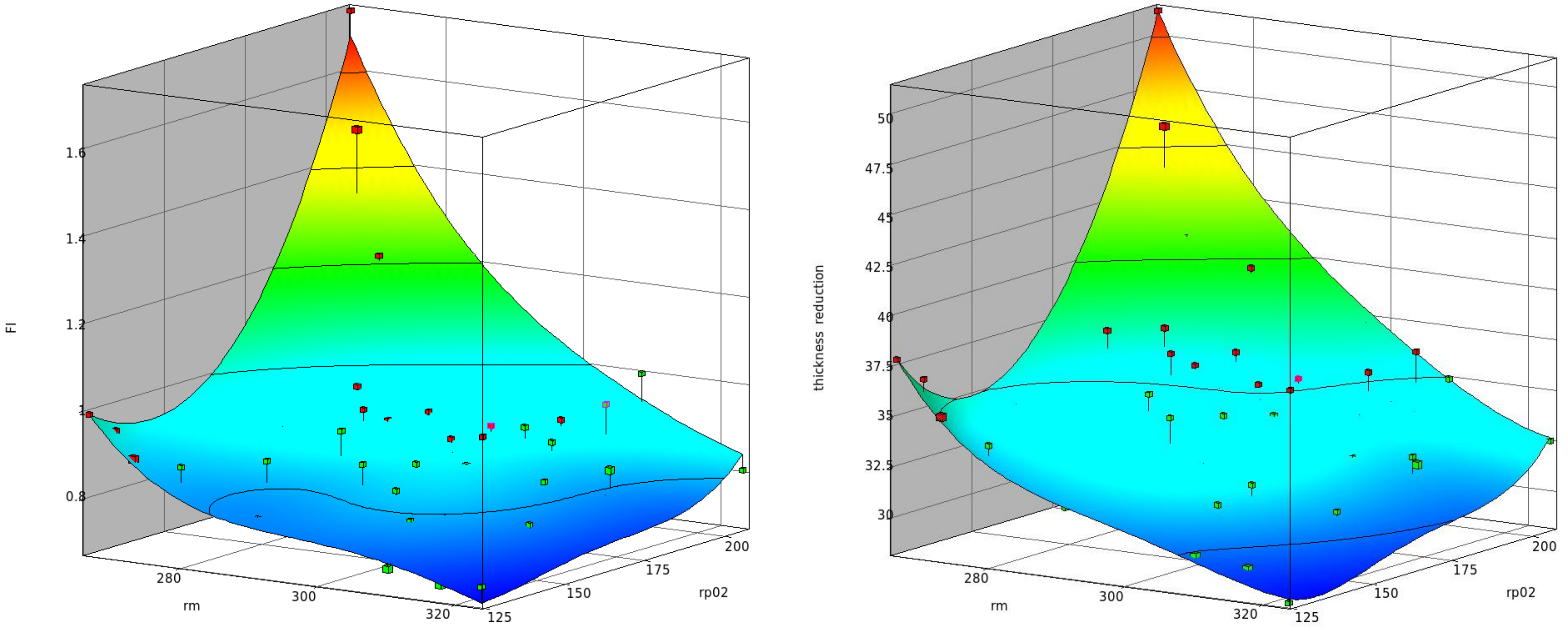


Diss. ETH Nr. 20160, Raphael Hitz, 2012

- Workpiece
  - CAD discretization during meshing
- Material
  - One material card (one part of it)
- Process
  - Operation sequences / method
  - Boundary Conditions
- Tool
  - Working surface
- Press
  - Not in general accounted for
- Scatter of all parameters
  - Not in general accounted for

Summary

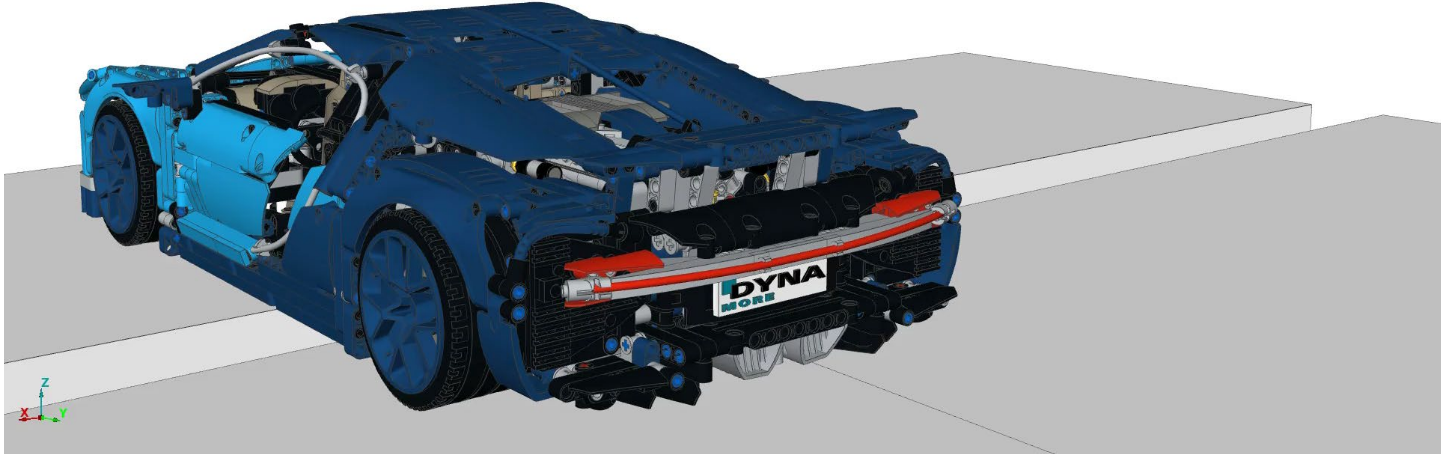
- The metamodels in this case are quite similar, due to assumptions.



Outlook

- LS-Dyna inputs can be easily parametrized
  - *PARAMETER(_EXPRESSION)
  - *PART_MOVE
  - *CONTROL_FORMING_INITIAL_THICKNESS
  - *CONTACT ... (FS, FD, …)
  - *DEFINE_CURVE (SFA, SFO, OFFA, OFFO, …)
  - …
- Challenges:

1. Having a suitable simulation model of your process
2. Finding the right parameters for your case
3. Getting a reliable range of data for your parameters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