Possibilities, challenges and risks creating material cards for forming simulation of modern steel grades

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engineering. tomorrow. together.

thyssenkrupp

Agenda

Material data for FEM simulations

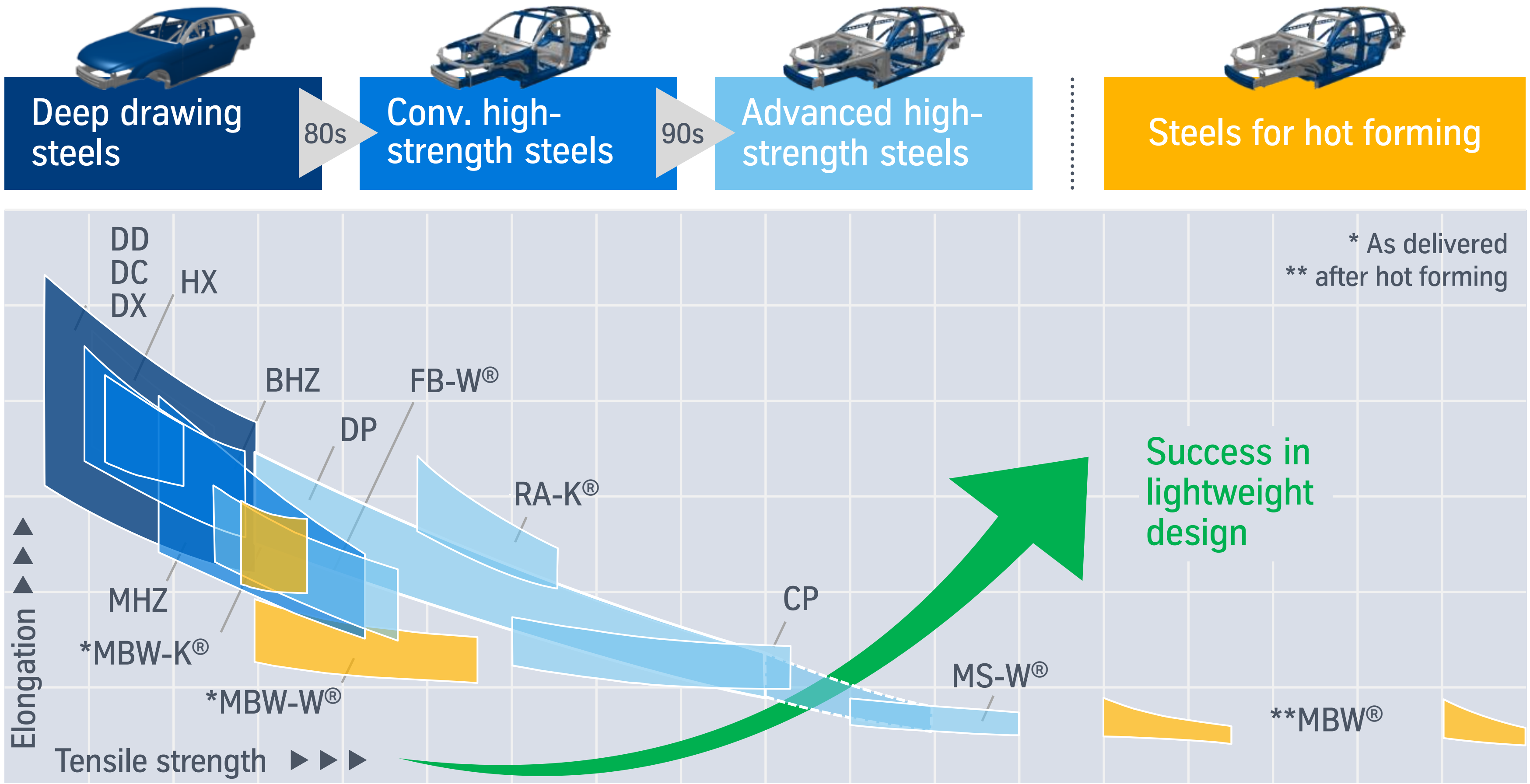
Material model calibration

Validation and examples

Conclusions

Economic lightweight design as driver of innovation

Complete range of modern steels for lightweight engineering



Weight aspects


Safety


Emission reduction


Sizes

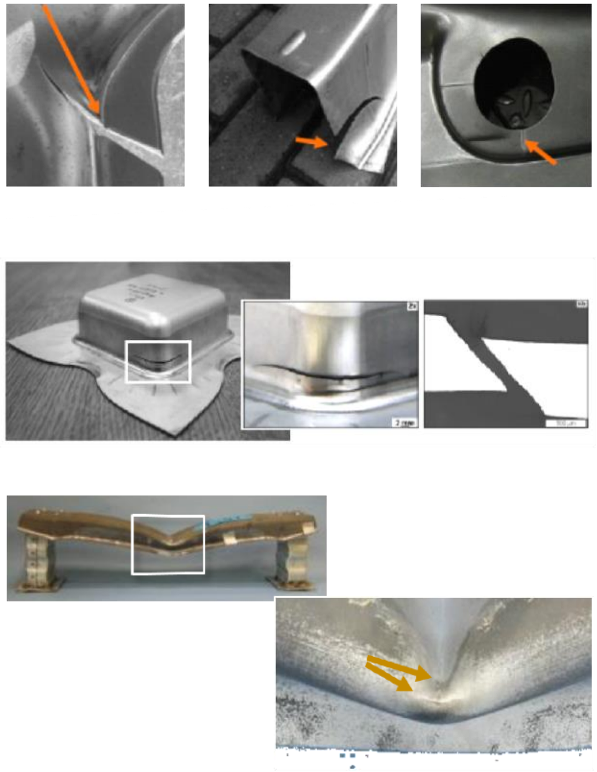

Comfort

Weight increase for recently developed automobiles preventable by lightweight engineering

Development and benefit of forming simulations for product application

A precise prognosis of the processing is the motivation for FEM usage

Real world

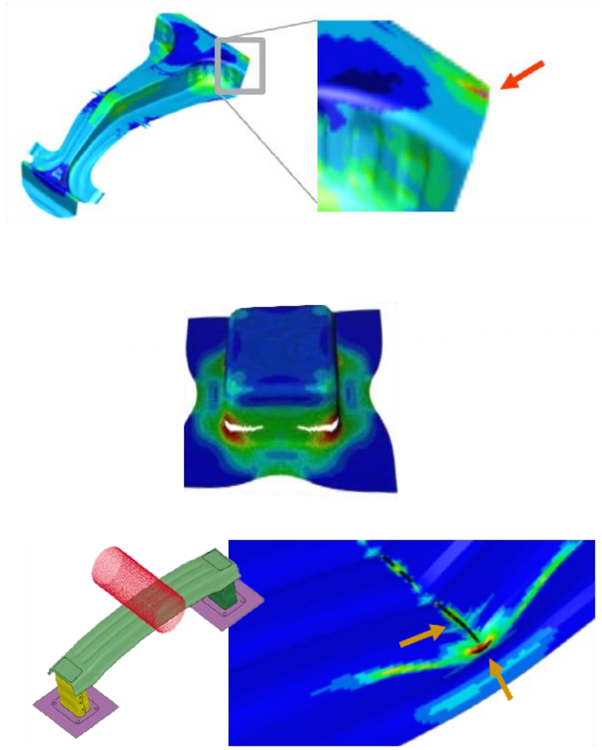


Software

Material model

Boundary conditions

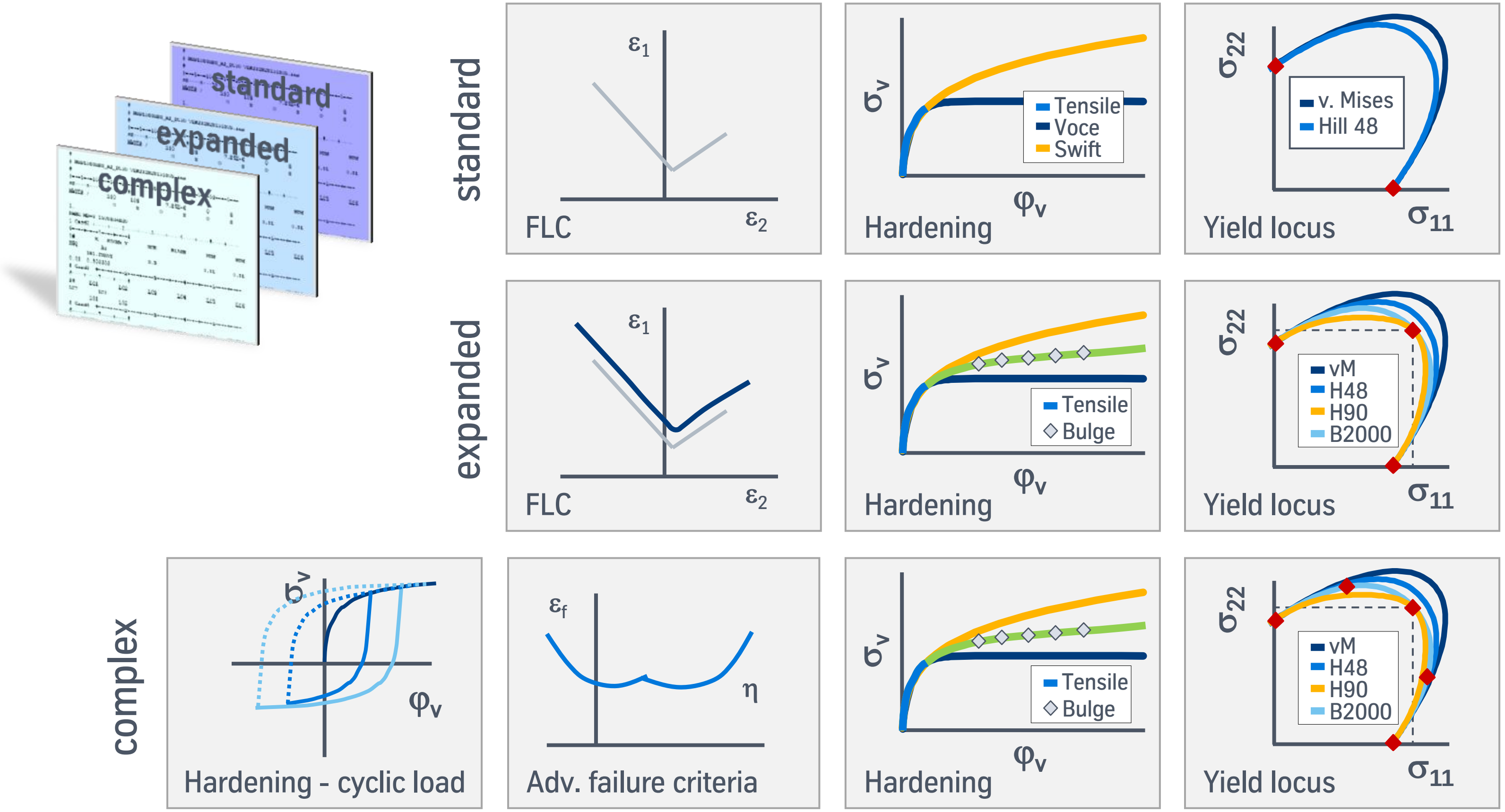
Virtual room



Detailed material description as a key point for part design

From simple feasibility studies to detailed failure prediction

- Qualified and validated material descriptions for forming and crash simulation
  - Standard: Material model generated with standard VDEh-investigations
  - Expanded: Improved plasticity description (flow curves, yield locus)
  - Complex: Enhanced plasticity description combined with advanced failure criteria

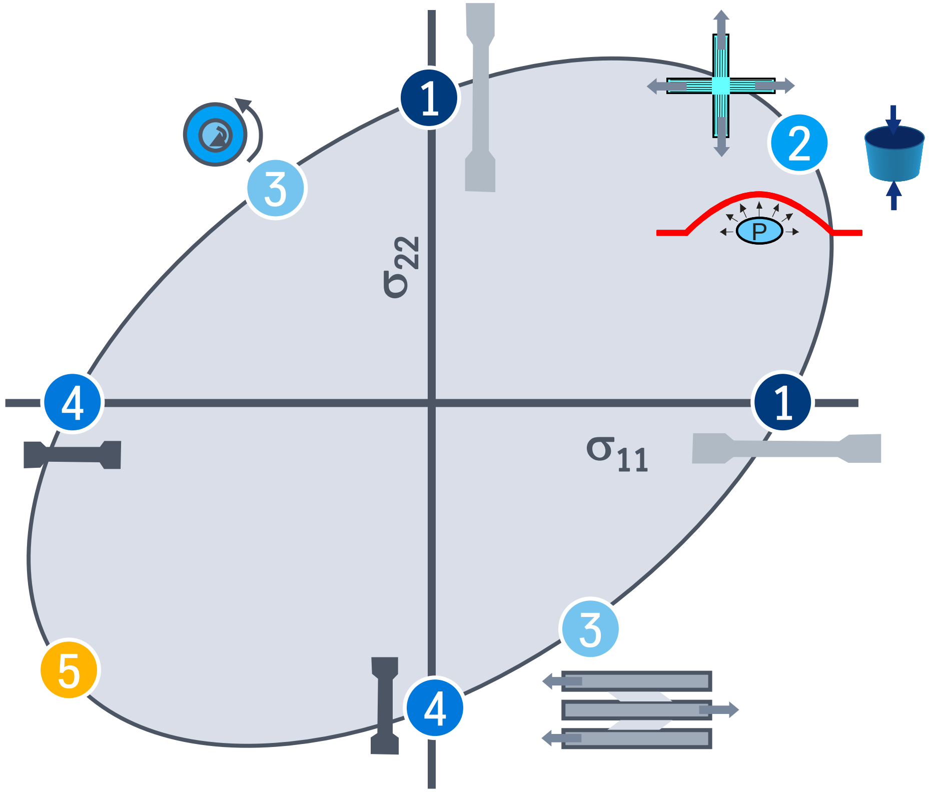


Level of complexity is depended on application, material grade and economic demands

Limit Availability of standardized Experiments for Yield Locus Calibration

Material Specification by Tensile Test

	Test for Yield Locus Calibration	standardized	strain range
1	tensile test (0º, 45º, 90º …)	✓	0% → 25%
2	hydr. bulge test	✓	10% → 70%
	stacked compression test	✗	5% → 40%
	biaxial tension test	✓	0% → 10%
3	shear test (Miyauchi)	✗	5% → 30%
	in-plane torsions test	✗	5% → 90%
4	compression (in-plane)	✗	0% → 10%
5	limited availability	✗	0% → 1-5%



Only for standardized test reproducible, robust and reliable evaluation is promising and proven

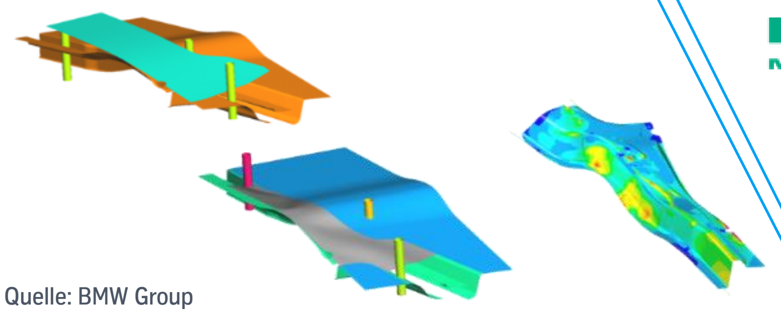
Material input for numerical simulation

Necessary Work & upstream process steps

Customer / application | **Necessary work & upstream process steps**

Simulation purpose:

- Material differentiation
- Process feasibility
- Process robustness
- Process optimization
- Cost optimization



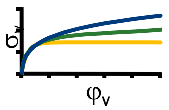
Quelle: BMW Group

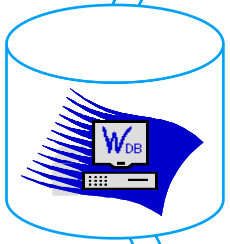
Material modelling

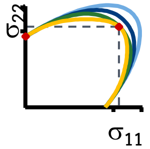
+ individual
+ meaningful

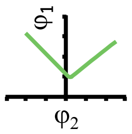
Data processing

- Hardening
- Plasticity
- Failure



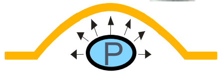


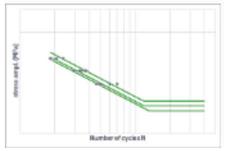




Standardized tests

- Tensile tests
  - Strain rate dependent (0.004 – 250 1/s)
  - Temperature dependent (-40° - 100°)
- Bulge (ISO16808)
- FLC (ISO12004)
- E-modulus
- Cyclic tests





A comprehensive and representative collection of data sets for customer support available

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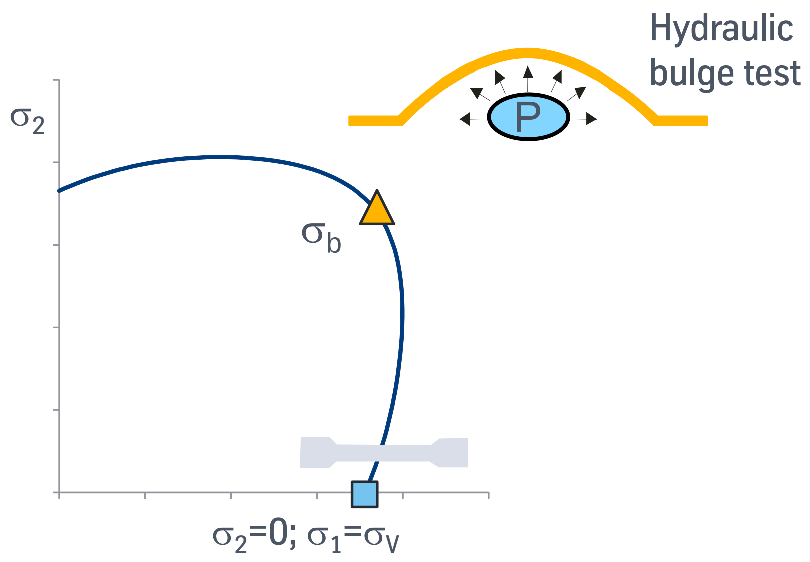
Transformation bulge test data

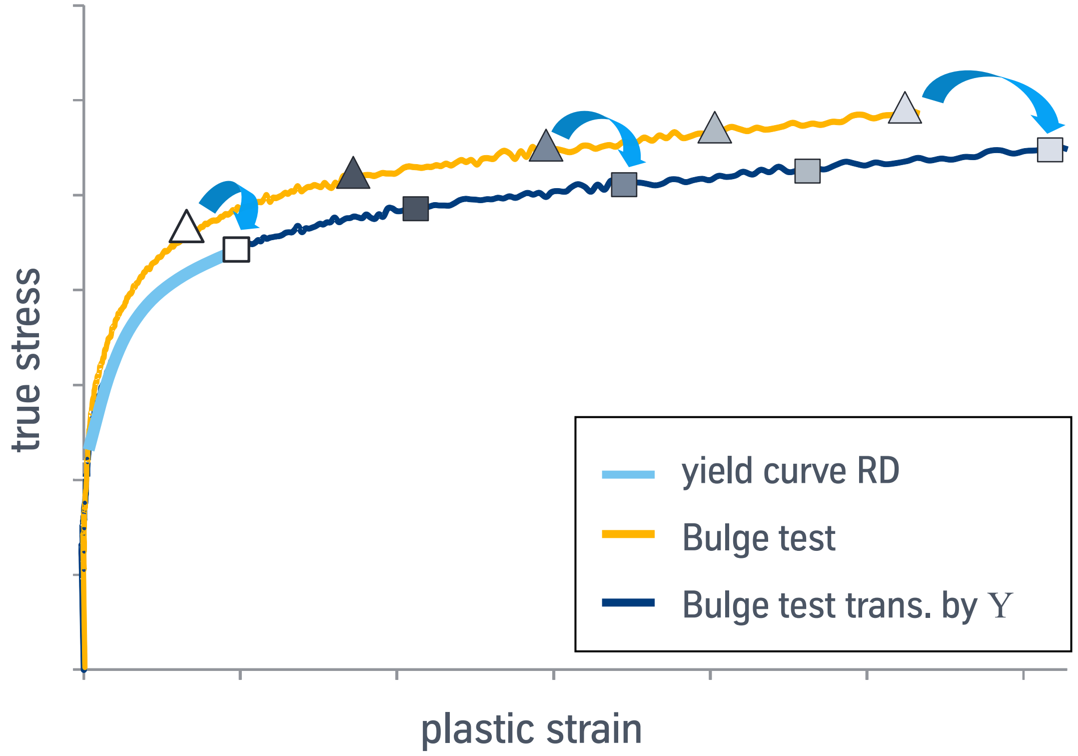


For the assumption of isotropic hardening & conjugated equivalent plastic work:

$$\frac{\sigma_b}{\sigma_1} = \frac{\sigma_b}{\sigma_V} = Y = const.$$

&

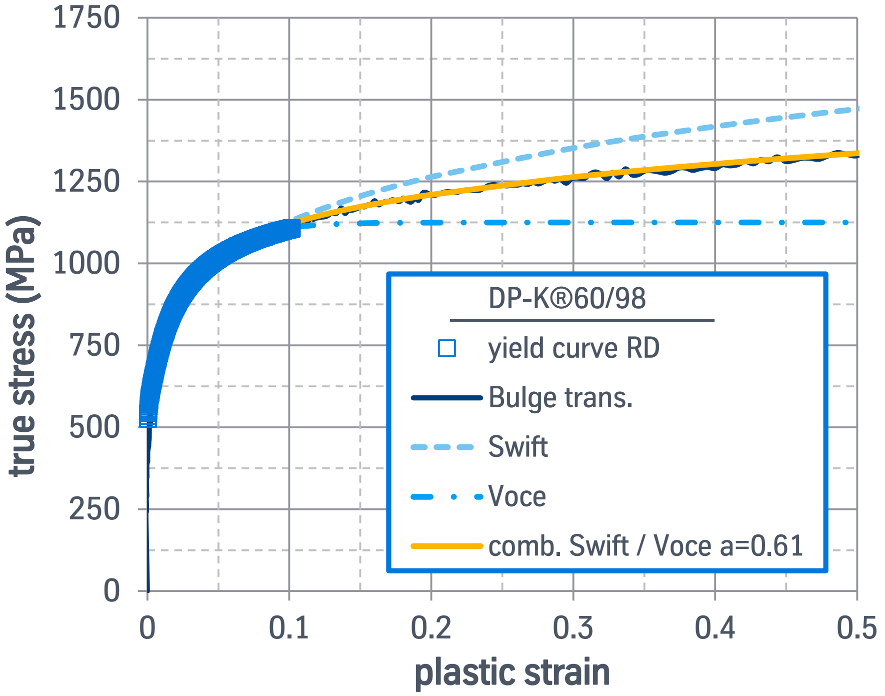
$$\varepsilon_V = \frac{\sigma_b}{\sigma_V}\left(\varepsilon_1 + \varepsilon_2\right) = Y\left(\varepsilon_1 + \varepsilon_2\right)$$



- Established standard approach: transformation of the bulge test data according to ISO16808
- Additional approach based on regression and correlation available for press shop operations or missing bulge test data

Material modelling

Extrapolated Material Data for DP steels



Swift

$$\sigma = a \cdot (\varepsilon_0 + \varepsilon_{eq})^n$$

Voce

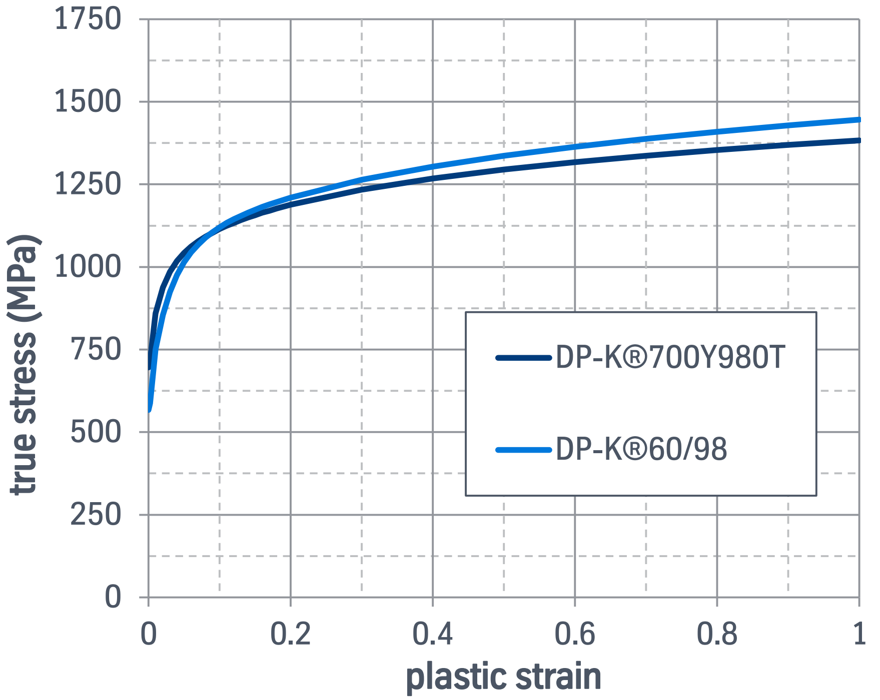
$$\sigma = a \cdot (1 - b \cdot e^{-c \cdot \varepsilon_{eq}})$$

Combination Swift & Voce

$$\sigma = \alpha \cdot Swift + (1 - \alpha) \cdot Voce$$

Ratio

$$Y = \frac{\sigma_{biax}}{\sigma_1}$$



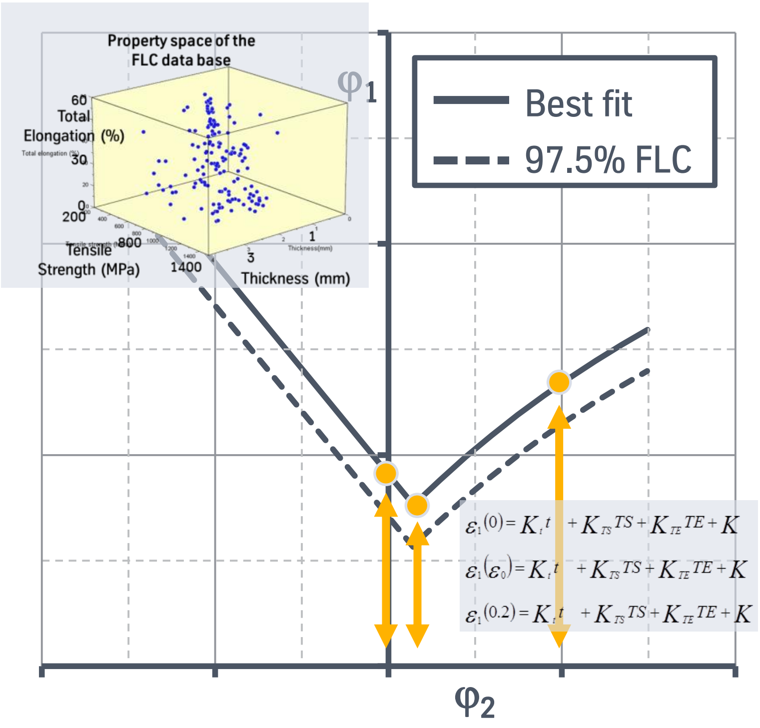
Mechanical properties

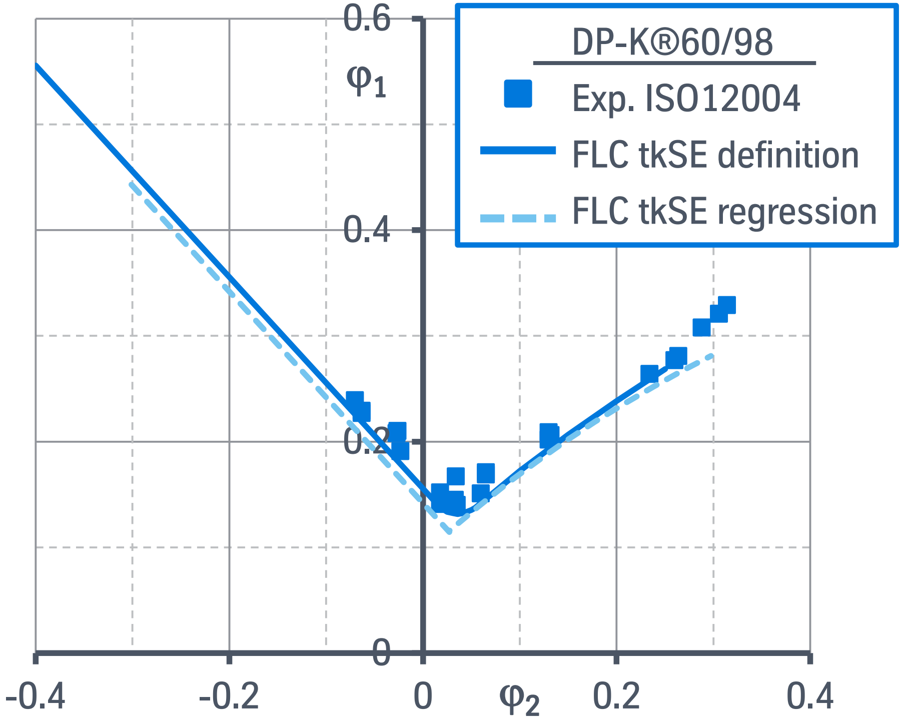
Material	Y.S. (N/mm²)	T.S. (N/mm²)	T.E. (%)	n	r 0°	r 45°	r 90°	Y	α
DP-K®60/98	591	1004	15.2	0.11	0.54	1.2	0.68	1.003	0.61
DP-K®700Y980T	712	993	13.9	0.07	0.71	1.2	0.86	1.009	0.78

Diverse mechanical properties represented in characteristic hardening behavior & extrapolation

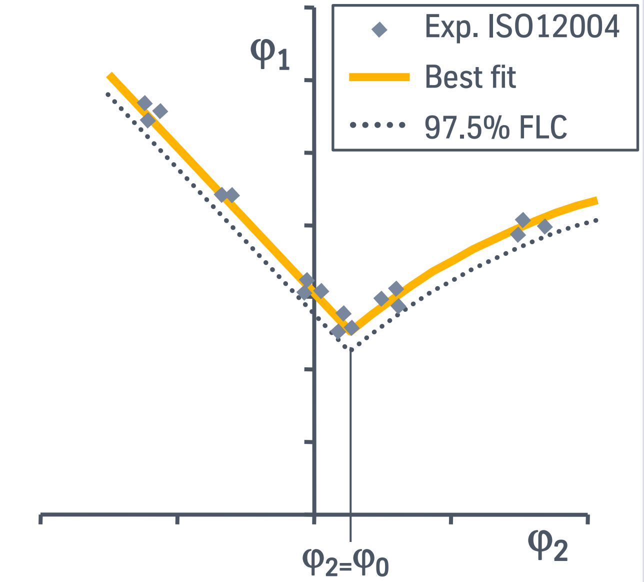
Material modelling

Forming Limit Curve





FLC tkSE definition:



FLC calculation by lin. + exp. function

$\varepsilon_1 = a_0 + a_1\varepsilon_2$; $\varepsilon_2 < \varepsilon_0$

$\varepsilon_1 = b_1 + exp(-b_2\varepsilon_2)$; $\varepsilon_2 > \varepsilon_0$

$a_1 = -1$; $\varepsilon_1(\varepsilon_0) = c$

- For e.g. press shop operations additional FLC regression based on mechanical properties and thickness available
- Calculated FLC confirms experimental evaluated data

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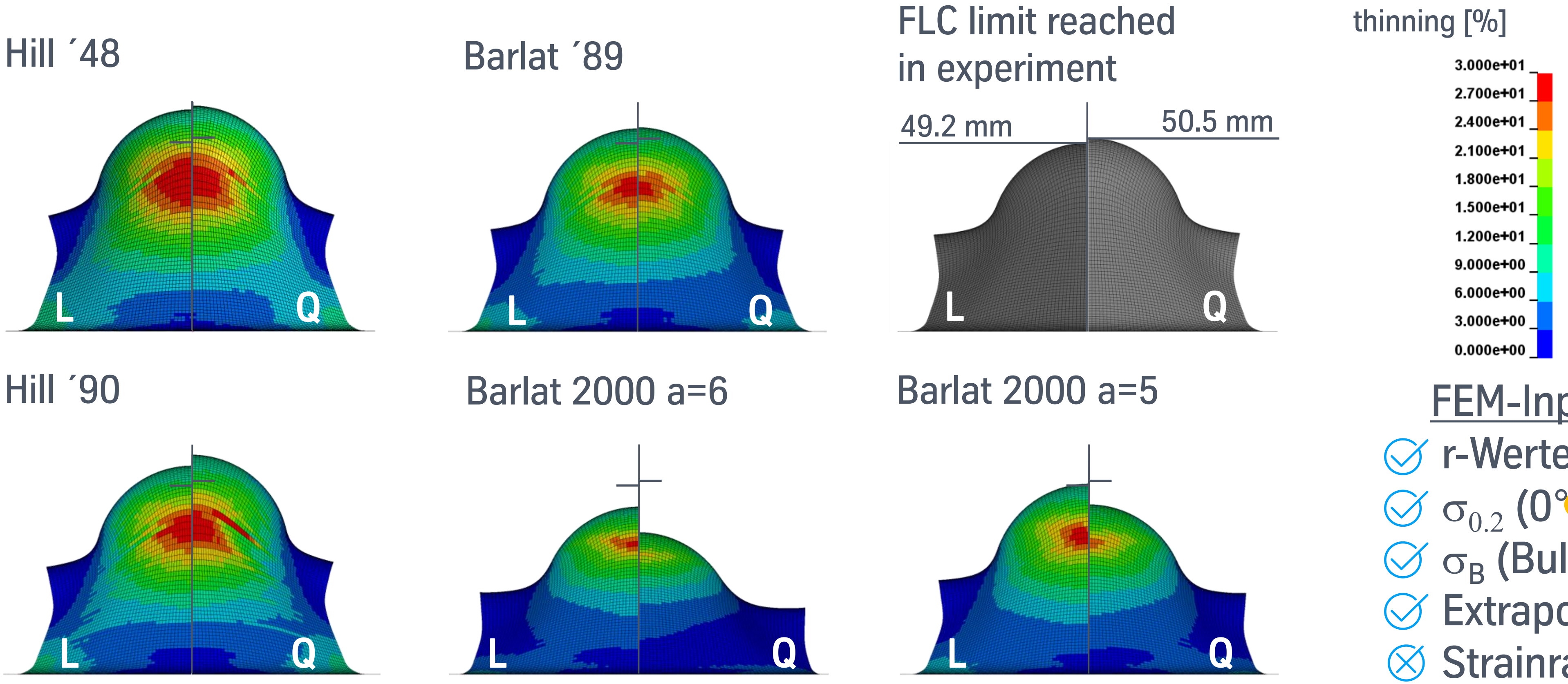
Validation Material Model

Impact of the Yield Locus Calibration onto Laboratory Validation Part



CR5-EG, 1mm

FEM-Input:

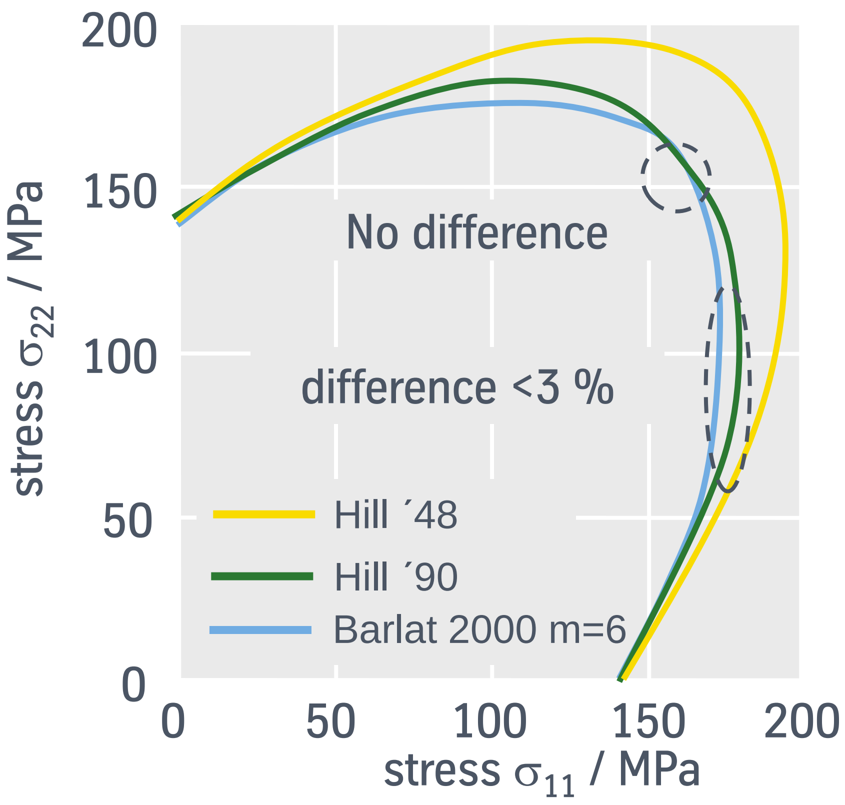
- ✓ r-Werte (0°, 45°, 90°)
- ✓ $\sigma_{0.2}$ (0°, 45°, 90°)
- ✓ σ_B (Bulge)
- ✓ Extrapolation Bulge-Test
- ✗ Strainrate (SR=off)

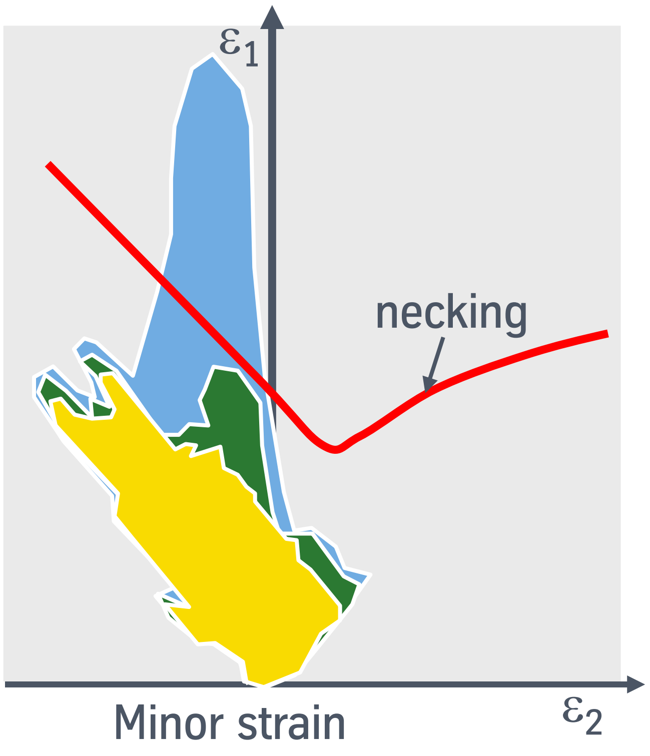
Barlat 2000

- Basic rudimentary calibrated material models can overestimate the forming potential
- Unproved use of values from literature can lead to unrealistic material behavior

Validation Material Model

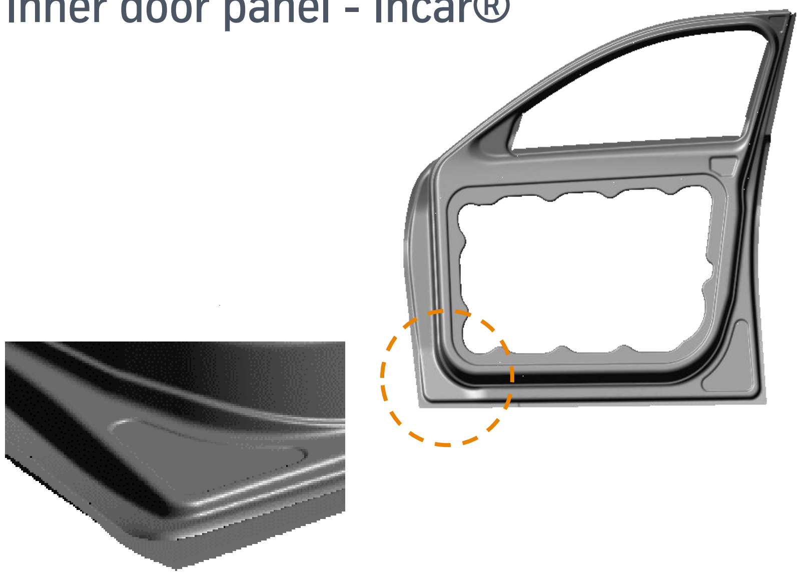
Impact of the Yield Locus Calibration onto a Feasibility Simulation





parameter study, mild steel 0.7mm

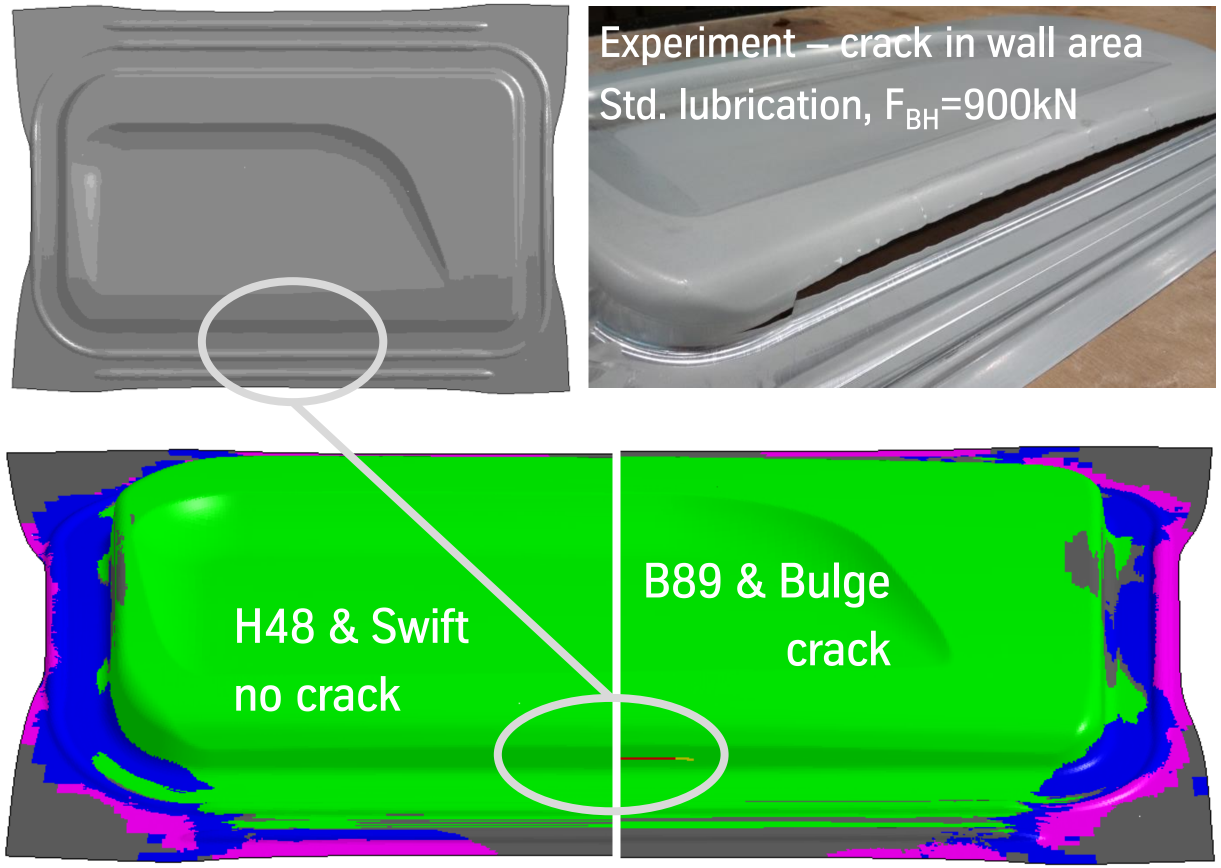
Inner door panel - Incar®

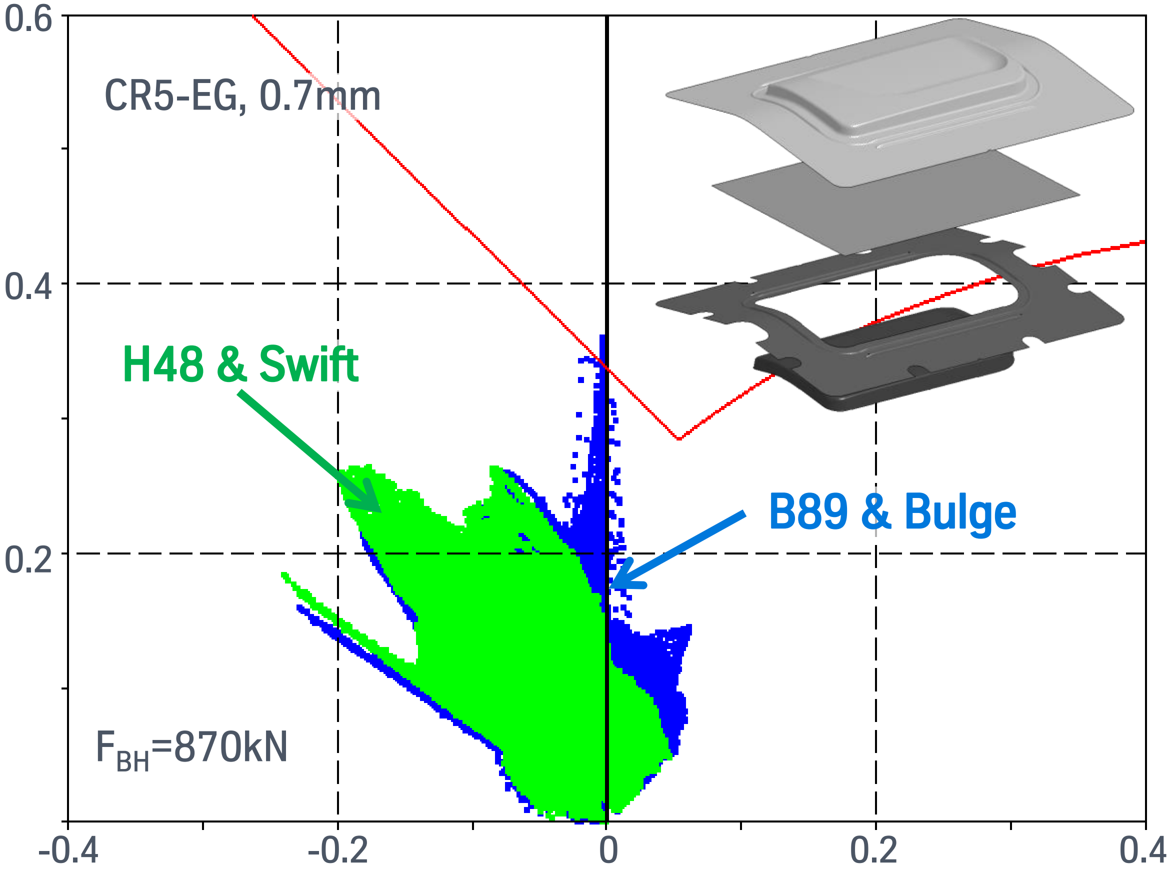


- Unproved use of values from literature can lead to unrealistic material behavior
- An more comprehensive calibrated material model leads to more realistic failure prediction

Validation Material Model

Small Scale Outer Skin Panel – CR5-EG 0.7mm





- The Hill ‘48 overestimates the forming behavior and leads to unrealistic failure prediction
- A material model calibrated by the use of the bulge test for the biaxial stress area gives a more realistic failure prediction

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- A precise prognosis of the processing of modern steel grades is the motivation for FEM usage and is the demand for a reproducible, robust and reliable description of the material behavior in the virtual word.
- The level of complexity is depended on application, material grade and economic demands.
- tkSE provides validated material cards for a wide range of steel grades used by our costumers.
- For standard approaches best experiences has been made by the use of standardized test as tensile and bulge test as well as the FLC. For further slight improvement only not standardized and cost intensive tests are available
- An unproved, not validated use of values from literature can lead to unrealistic material behavior.
- A more comprehensive calibrated material model can lead to more realistic failure prediction in FEM simulation. Additional optimization loops in the tool shop can be prevented.