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Virtual Material Testing for Stamping Simulations Based on Polycrystal Plasticity

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Overview

- Introduction
- Crystal Plasticity FEM
- Virtual Specimen (RVE)
- Fit Example 1: Vegter Yield Locus
- Fit Example 2: LS-Dyna MAT_103
- Conclusions

INPRO Shareholders

BASF Coatings AG

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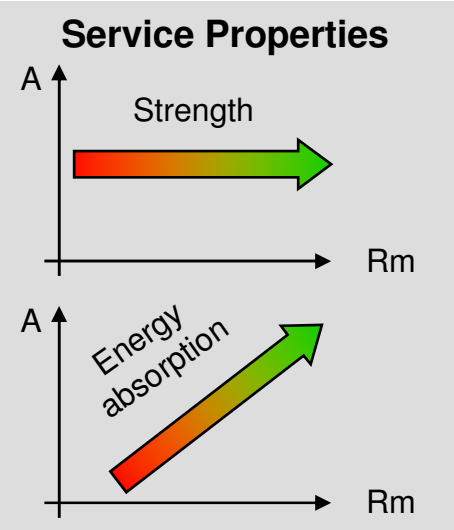
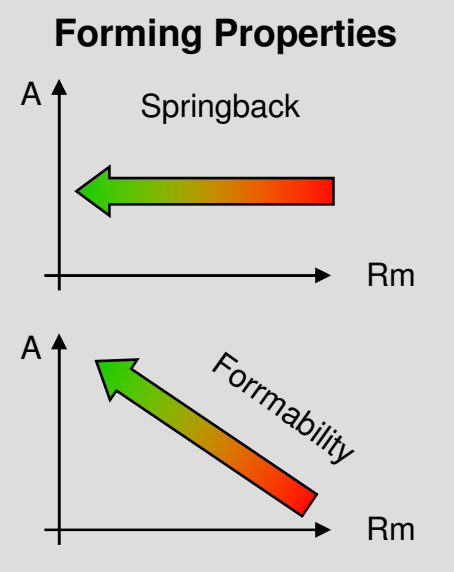
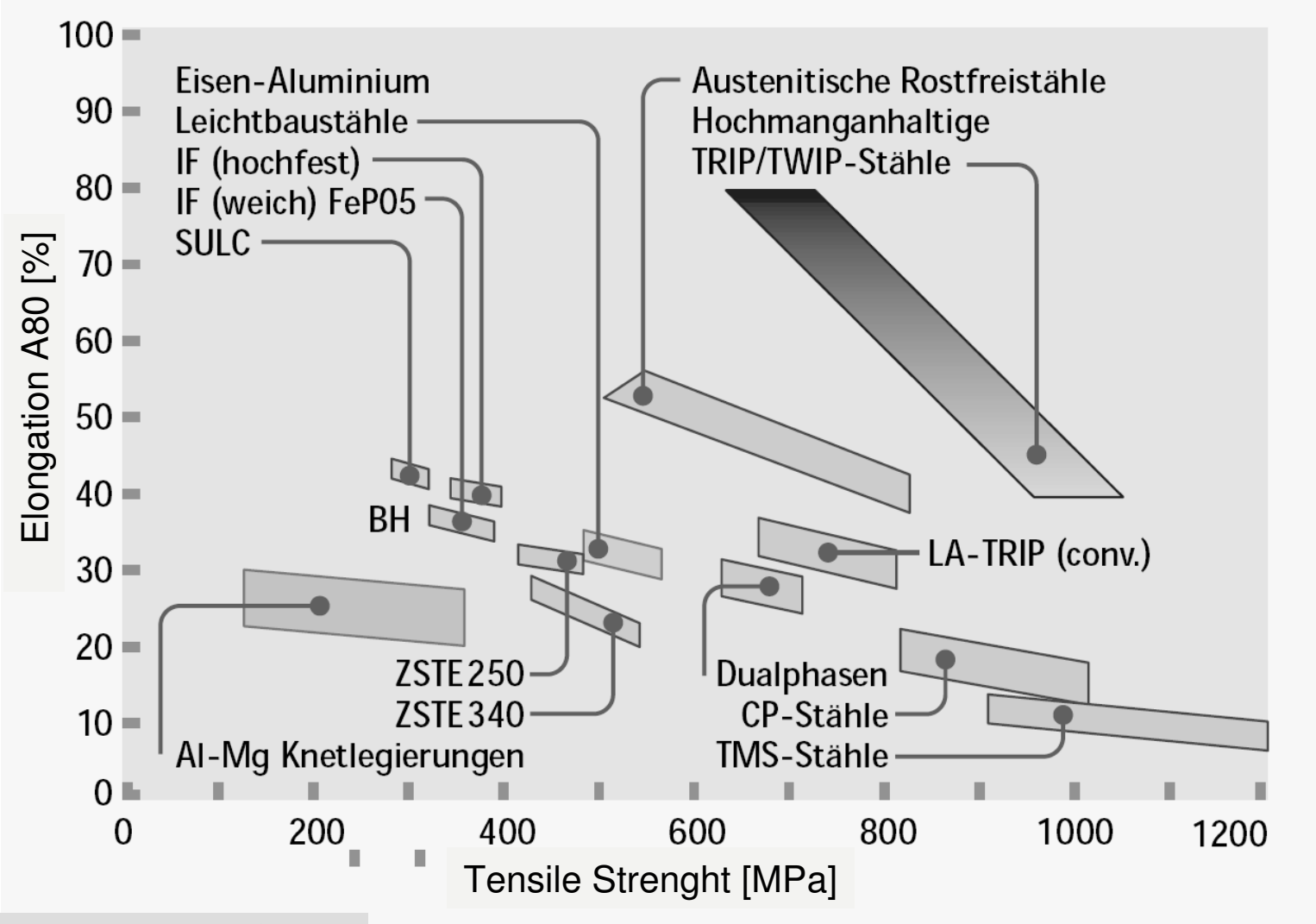
Properties of Deep Drawing Sheet Metal







bad → good

[MaxPlanckForschung 3/2004]

Springback Compensation

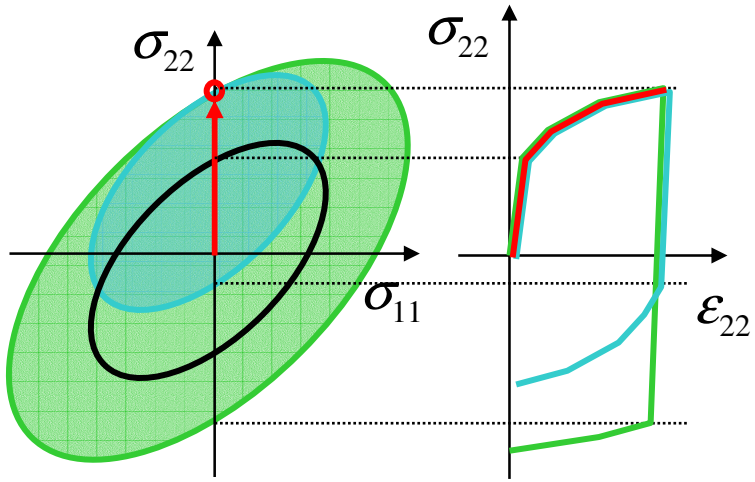
- Shaping the die such that the stamped part has the target shape after springback
- To reduce iterative tooling, high precision planning (simulation) tools are required

Precise Springback Simulations Depend on Appropriate Models:

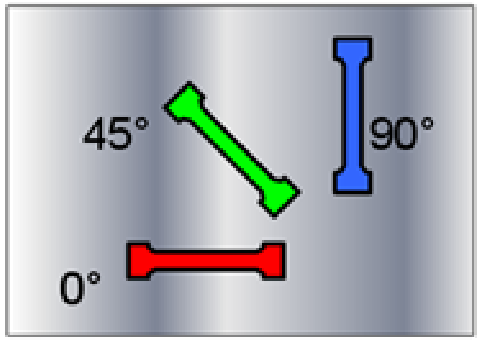
- Tool shape, sheet discretization
- Contact and friction
- Elasto-plastic sheet material

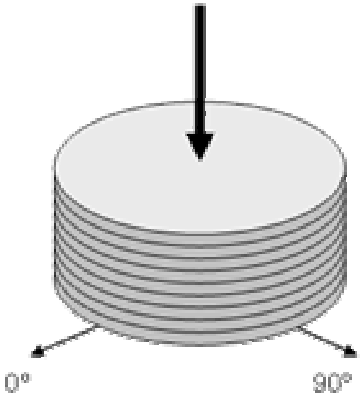
Material Model Requirements

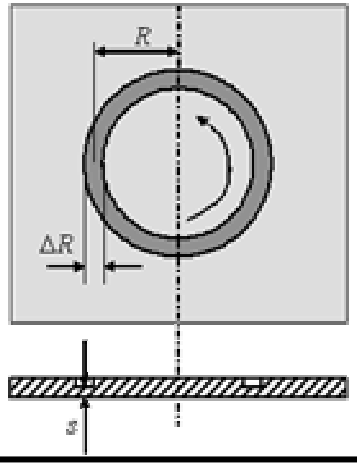
- Reliable stress prediction
- Multiaxial loads
- Changing load direction (including load reversal)
- Account for sheet orthotropy,
- **Kinematic** and **isotropic** hardening



Material Testing

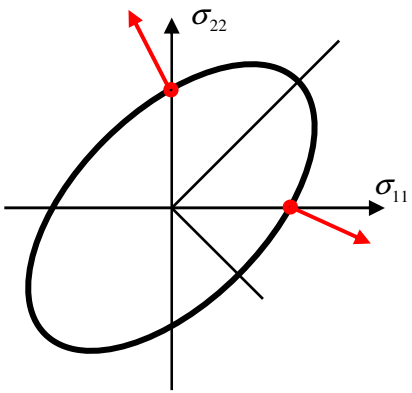


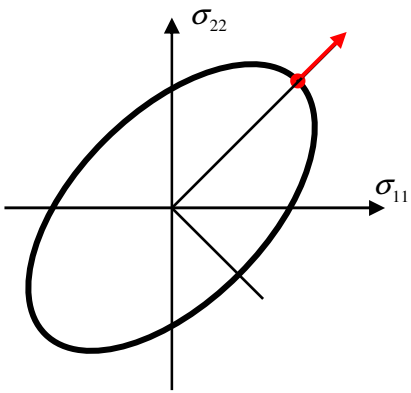


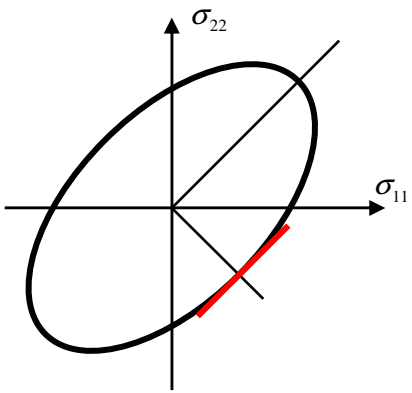


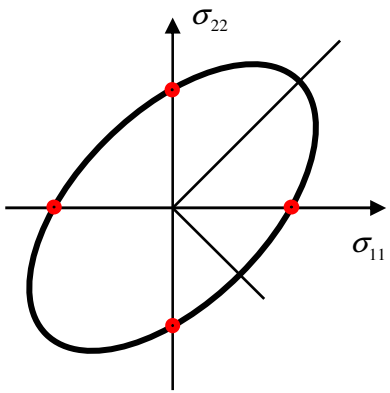
[IWM Freiburg]

Tension	Stack Compression	Shear	Tension-Compression



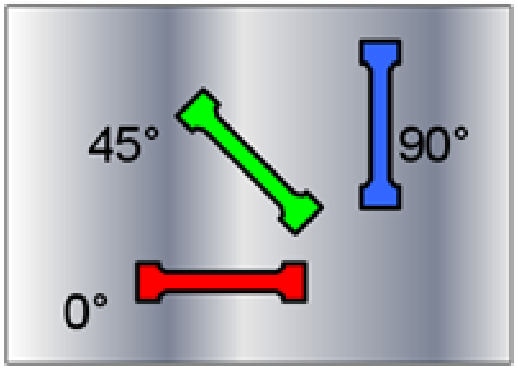




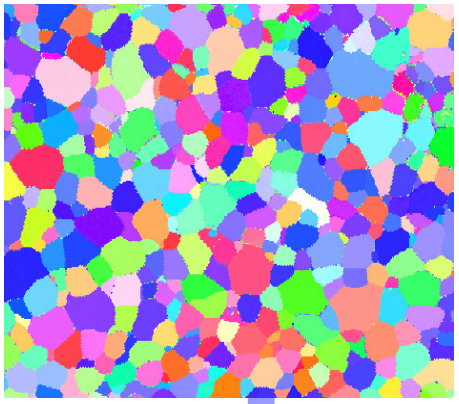


Other Sources of Knowledge

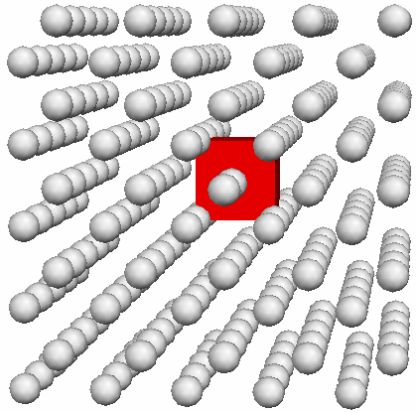
Macro-scale: Real Material



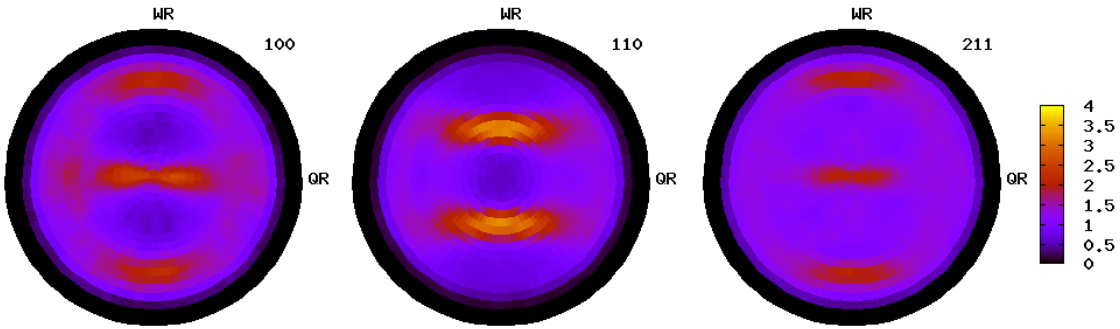
Meso-scale: single crystalline grains

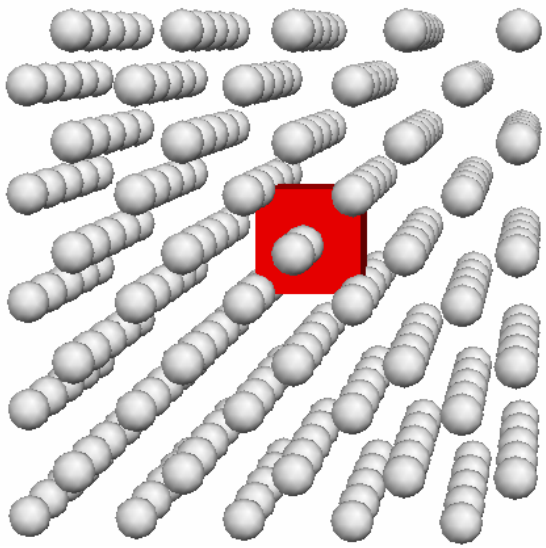


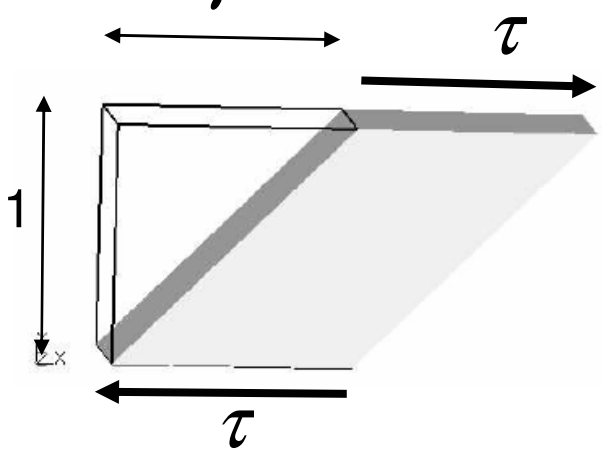
Micro-scale: atomic lattice



Preferred Orientations







Elastic

Material		⟨100⟩					
	E	G	ν	c_{11}	c_{12}	c_{44}	A
Fe	134	118	0.367	233	135	118	2.41
Al	63	28	0.36	107	61	28	1.22
Cu	67	75	0.42	168	121	75	3.19

Plastic

$$\dot{\gamma}^{\alpha} = \dot{\gamma}_0 \left| \frac{\tau^{\alpha}}{\tau^{\alpha}_{crit}} \right|^{1/m} \operatorname{sign}\left(\tau^{\alpha}\right)$$

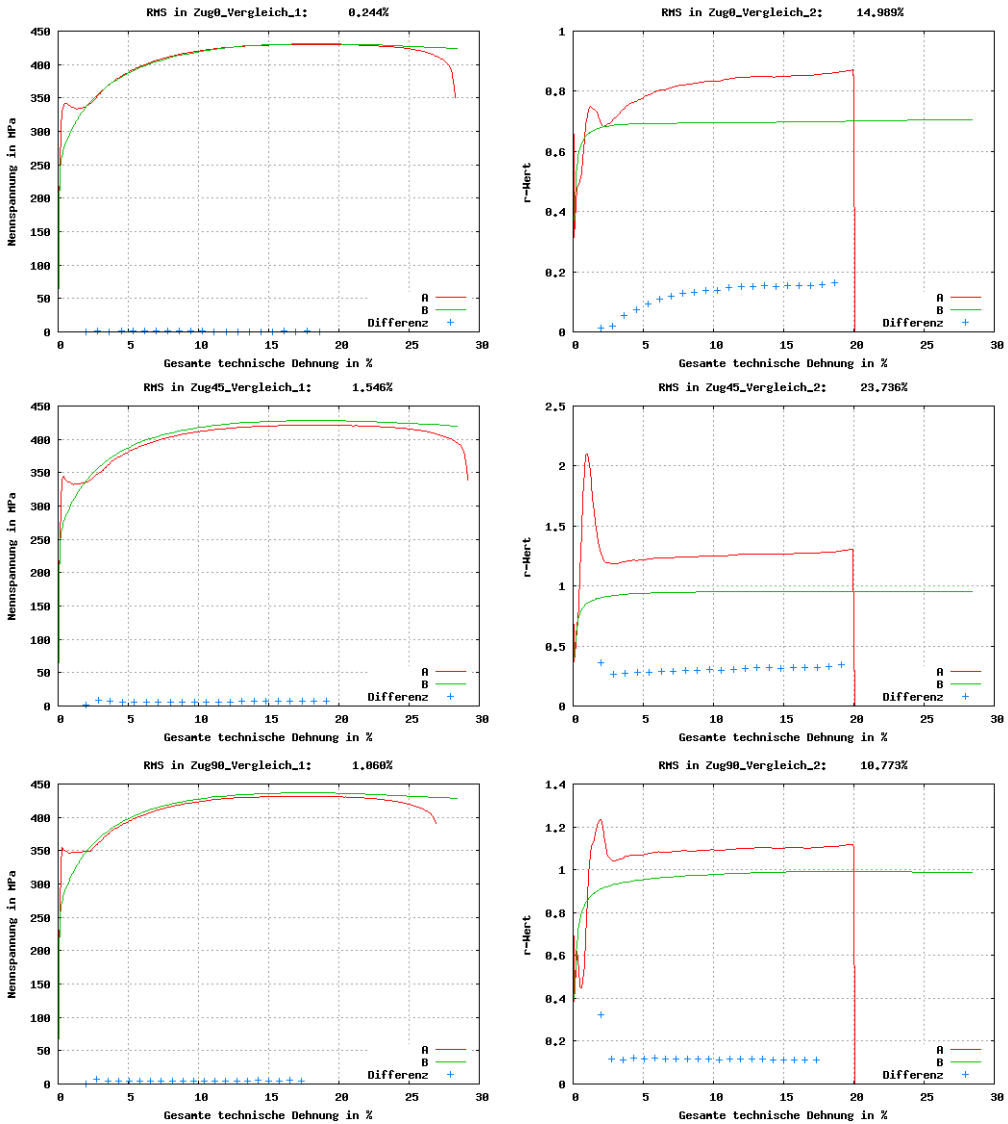
$$\dot{\tau}^{\alpha}_{crit} = \sum_{\beta} h^{\alpha\beta} \left|\dot{\gamma}^{\beta}\right|, \qquad h^{\alpha\beta} = q^{\alpha\beta} h^{(\beta)}, \qquad h^{(\beta)} = h_0 \left\{ 1 - \frac{\tau^{\beta}_{crit}}{\tau_s} \right\}^{a}$$

τ_s, a, h_0, q_{ki} material parameters

Calibration

- **Focus on bcc (ferritic) steel**
  - mild steel DC04 (St14)
  - high strength low alloy steel H320LA (ZStE 340)
- **Texture input: 100, 110, 211 pole figures**
- **Slip systems and hardening parameters**
  - 48 slip systems containing 111 direction
  - Yield curve is fitted to a single uniaxial tensile test (0°)
- **Results shown for H320LA**
  - Yield curves and r-values for simulated tensile tests 0, 45, 90°
  - Yield curves: error 1-1.6%
  - r-values: error 10-24%
- **Possible improvements**
  - Adjustment of hardening matrix (self- vs. latent hardeing)

Real test
Virtual test



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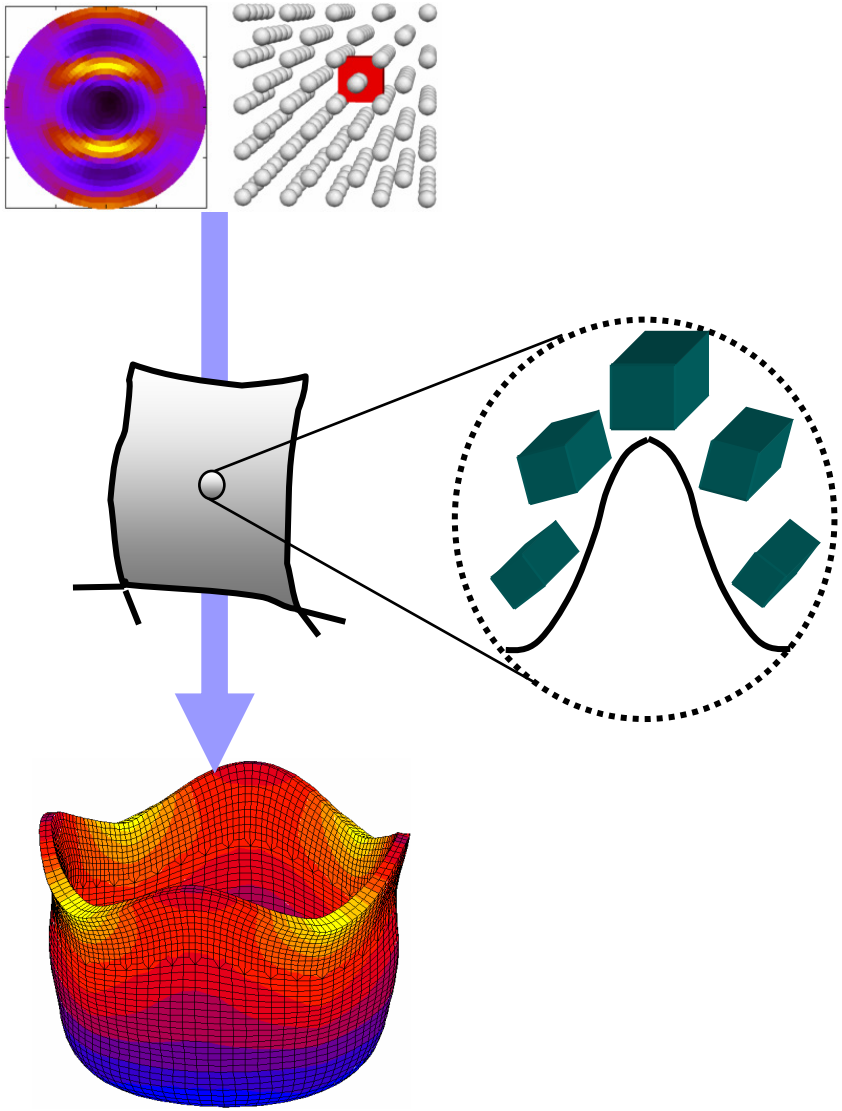
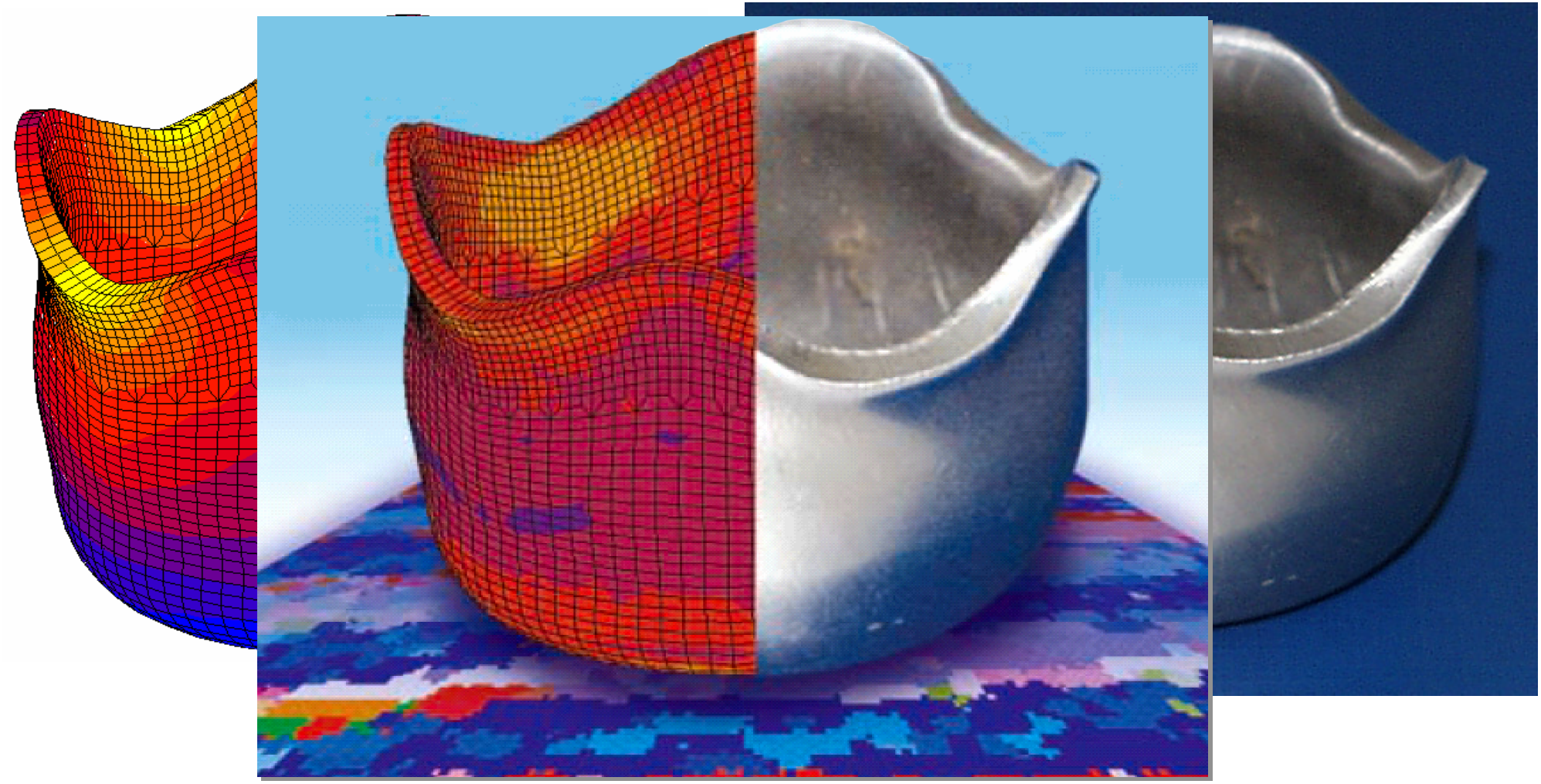


Crystal plasticity FEM

- Direct use of crystal plasticity in the forming simulation
- Texture representation by random sampling of texture components (peaks and fibers) at every integration point
- Homogenization at the integration point (multiple orientations – sampled components)
- Orientation samples differ from point to point – added level of homogenization
- Demonstrated by MPIE for (fcc) Aluminum
- High CPU and memory demands
- Limited to small stamping parts with few through-thickness layers

Application to deep drawing



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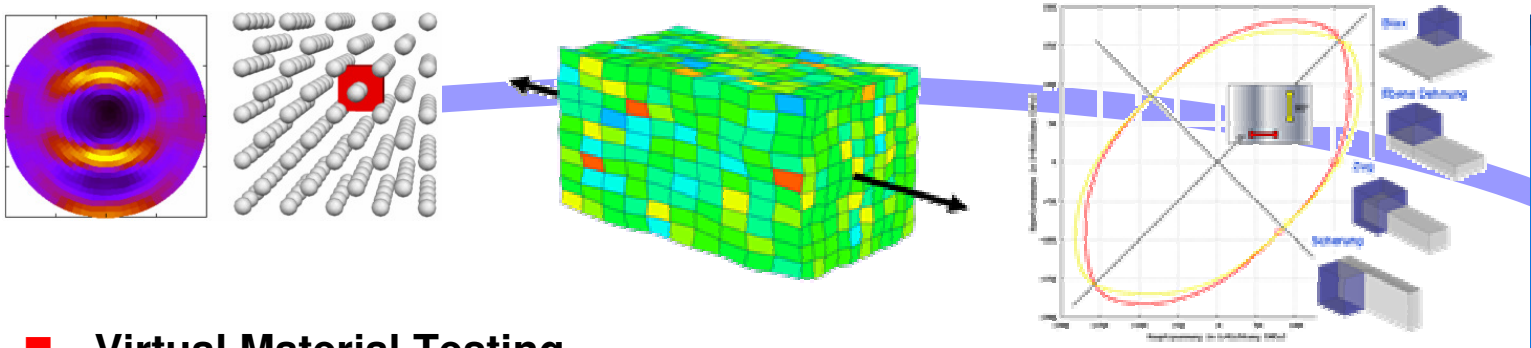
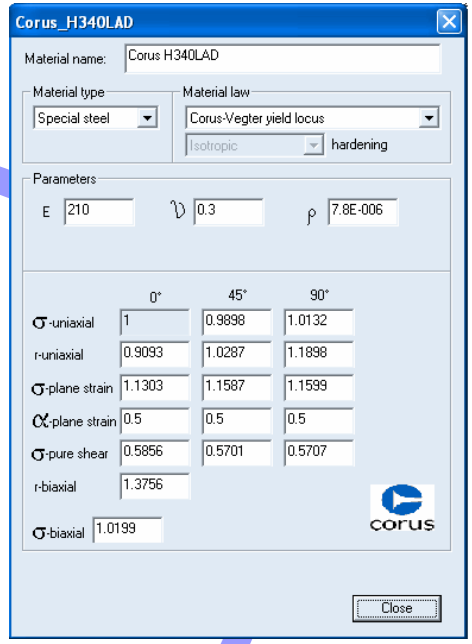
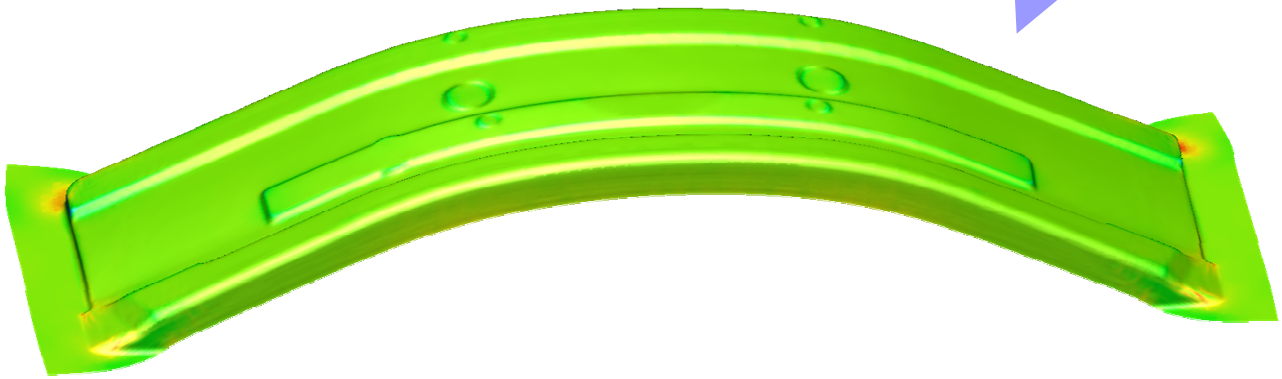
From Crystal Plasticity to Deep Drawing



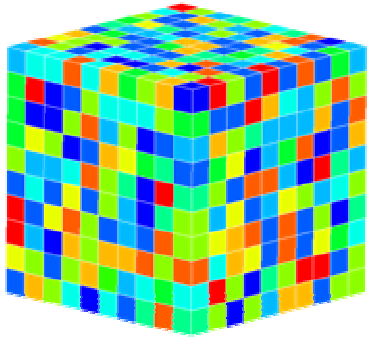


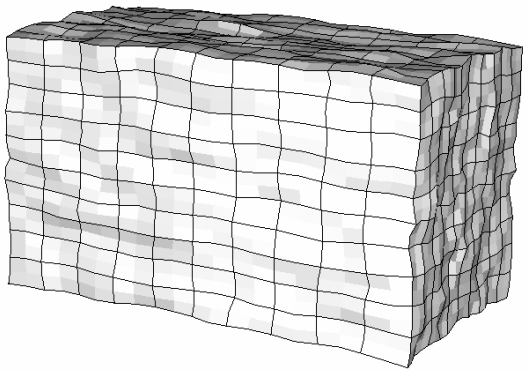
Vegter-Modell in PamStamp 2G

- **Virtual Material Testing**
  - Representative Volume Element
  - Virtual test program – extrapolation of calibration tests
  - Parameter fit of the macro material model
  - No performance loss compared to classical deep drawing simulation
  - Material behaviour limited to available models in commercial FE codes
  - Demonstrated by INPRO for (bcc) HSLA steel



- **Co-operation MPIE-INPRO**
  - Based on a cooperation between MPIE and INPRO
  - Crystal plasticity provided as black box ABAQUS UMAT by MPIE
  - RVE concept, implementation and testing by INPRO
- **Basic Features**
  - Trade-off between accuracy and speed
  - 1000 grains
  - 1 Element per grain
  - Cubic grain shape
  - Periodic boundary conditions for load application
  - Process(test) specification by piecewise constant velocity gradient





$$\mathbf{L}(t) \rightarrow \mathbf{F}(t) = \int \mathbf{L}(t)\,dt \rightarrow \mathbf{T}_0(t)$$

Velocity gradient

Deformation gradient

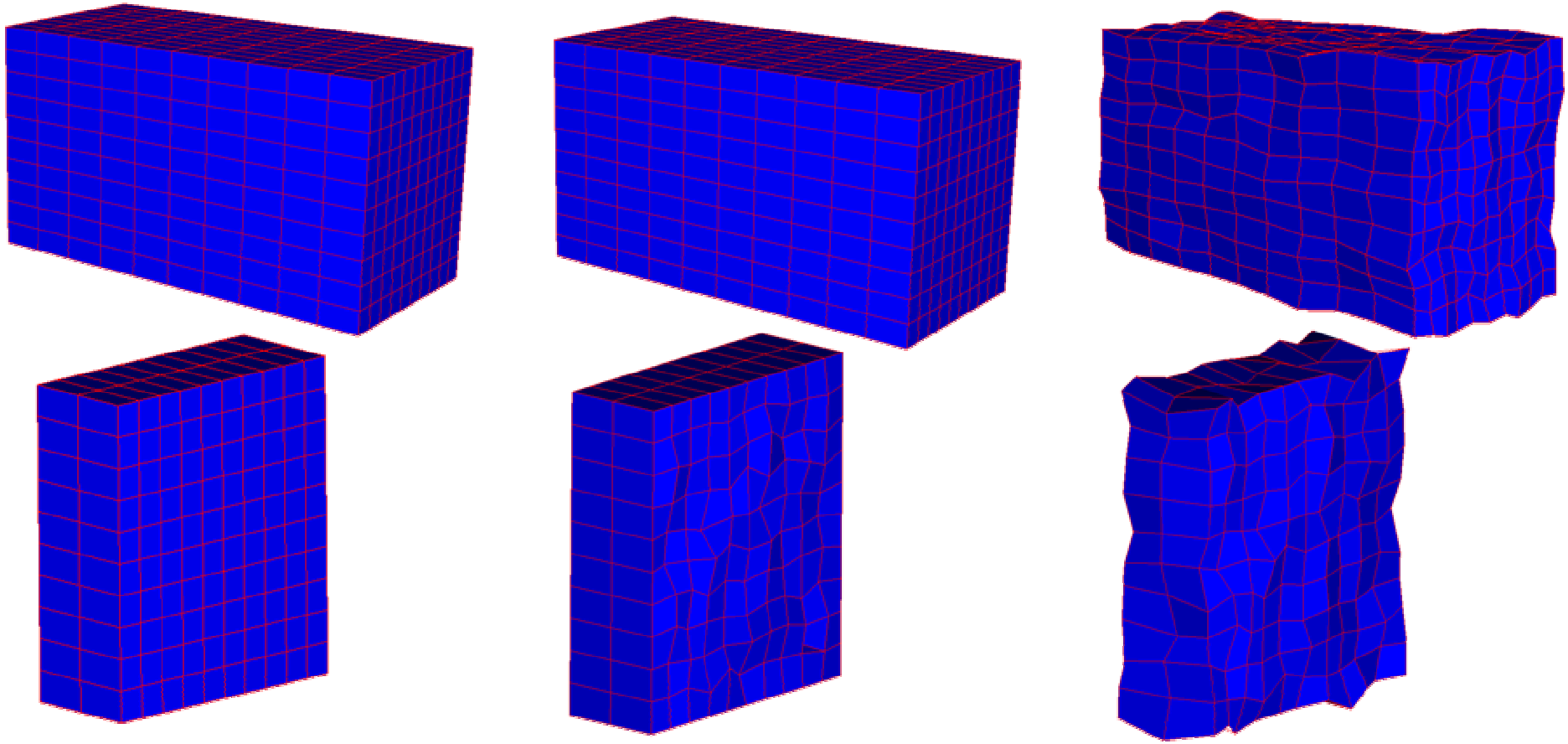
Nominal stress tensor (1PK)

Boundary Conditions

All nodal displacements prescribed (Taylor model)

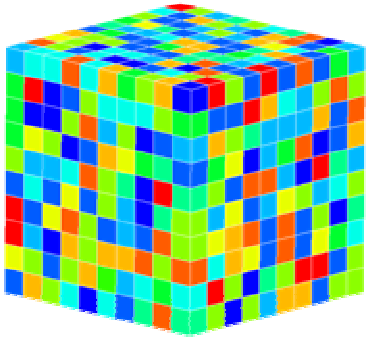
Only bundary node displacements prescribed

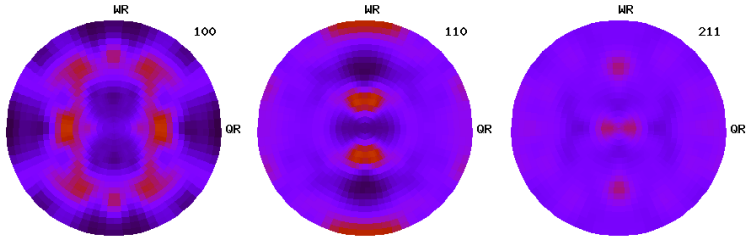
No direct specification except mean deformation and periodicity

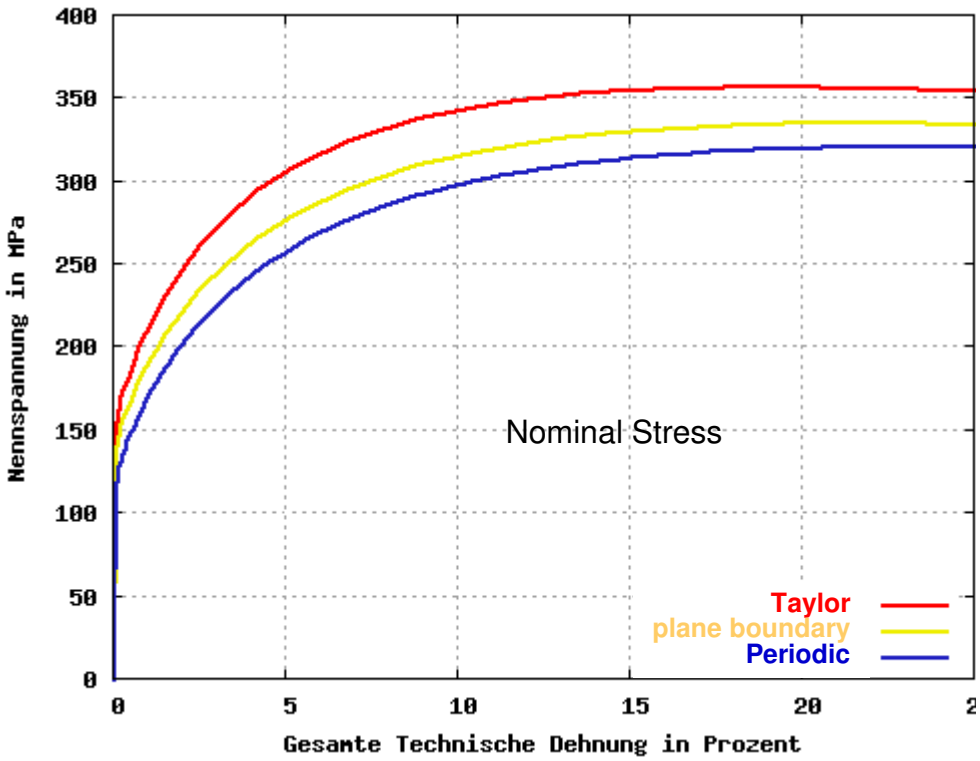


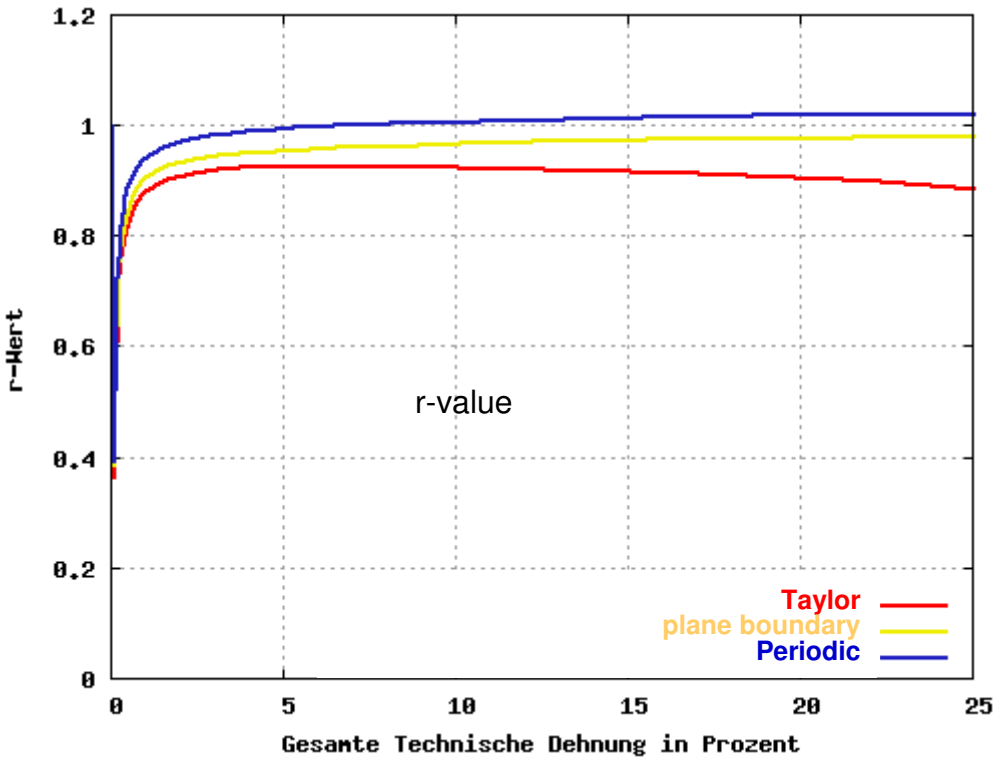
Boundary Influence

- 1000 grains based on sampled texture components (measured, DC04)
- Simulated tensile test

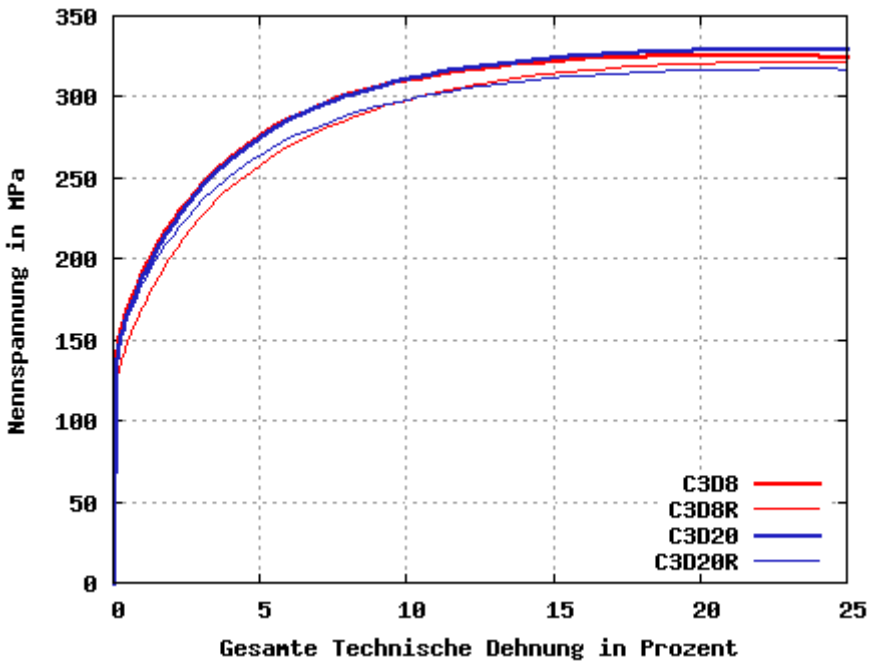


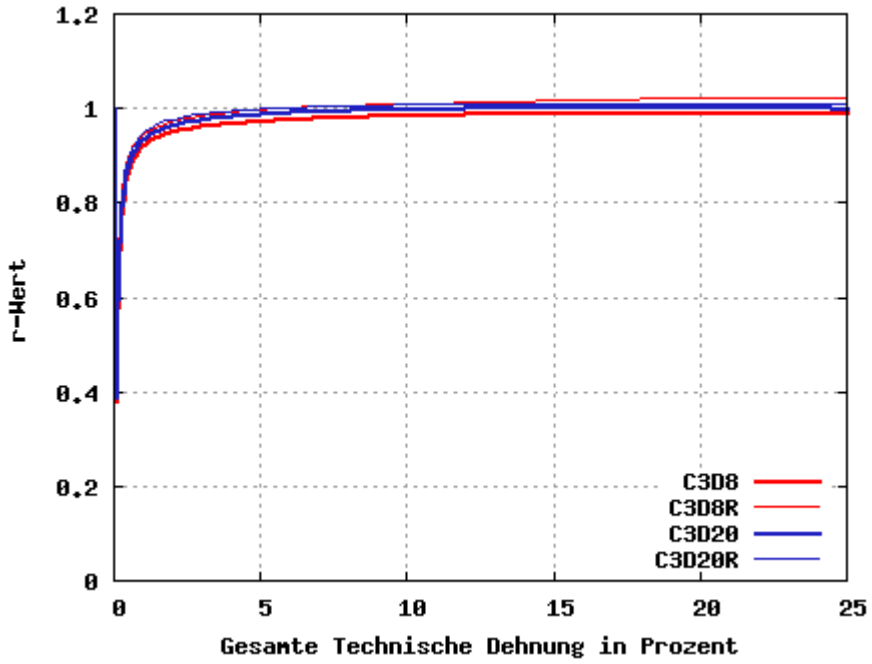




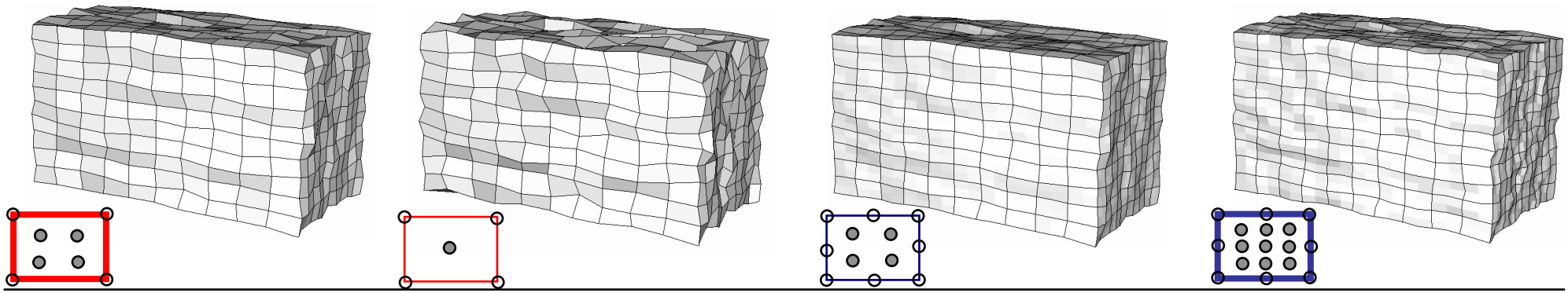


Influence of Element Type

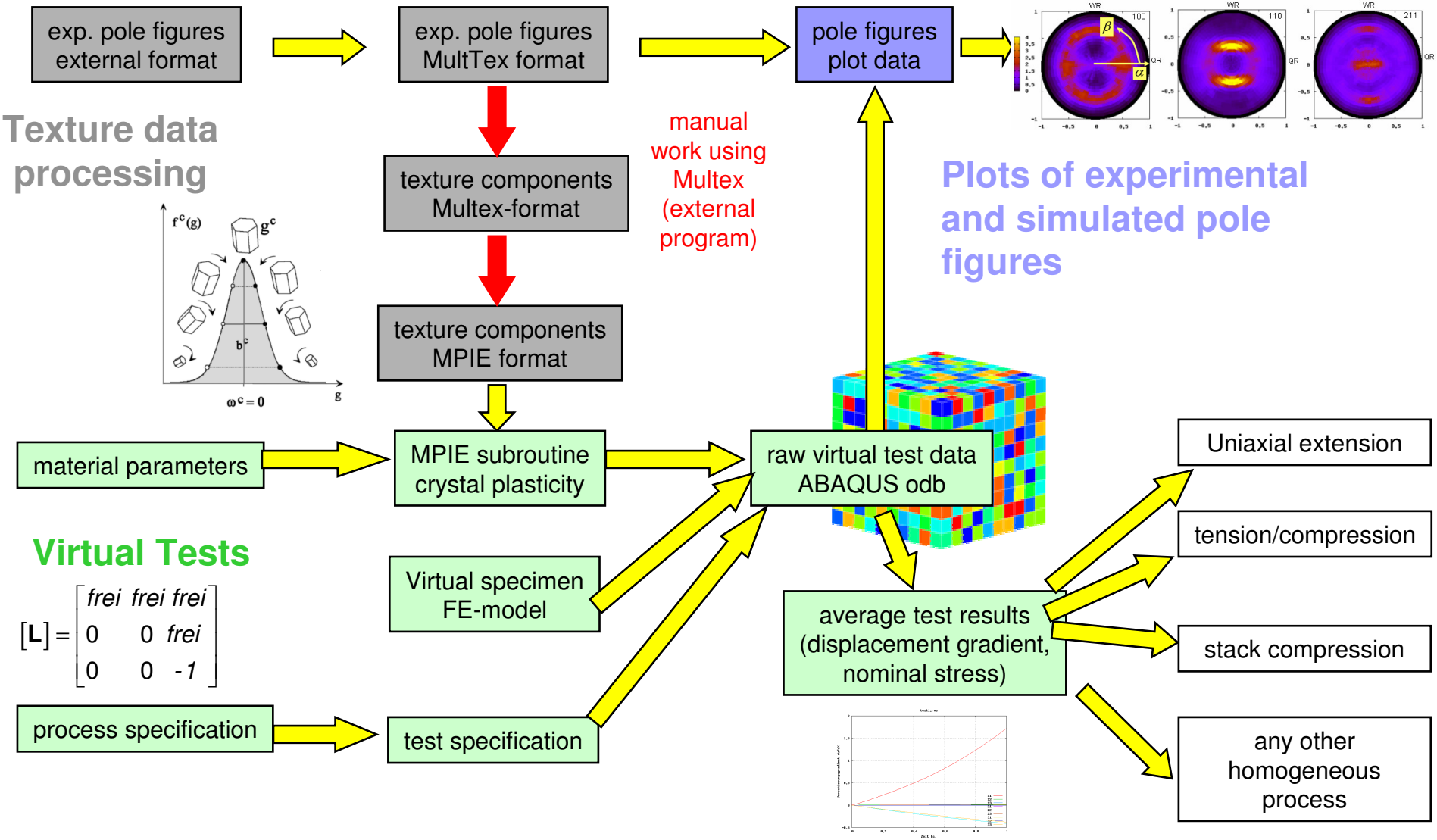




C3D8 C3D8R C3D20R C3D20



Virtual Specimen: Process Chain

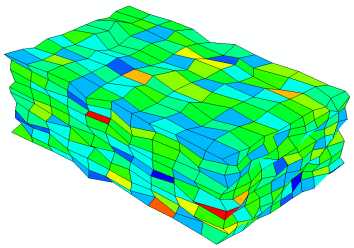


$$[\mathbf{L}] = \begin{bmatrix} frei & frei & frei \\ 0 & 0 & frei \\ 0 & 0 & -1 \end{bmatrix}$$

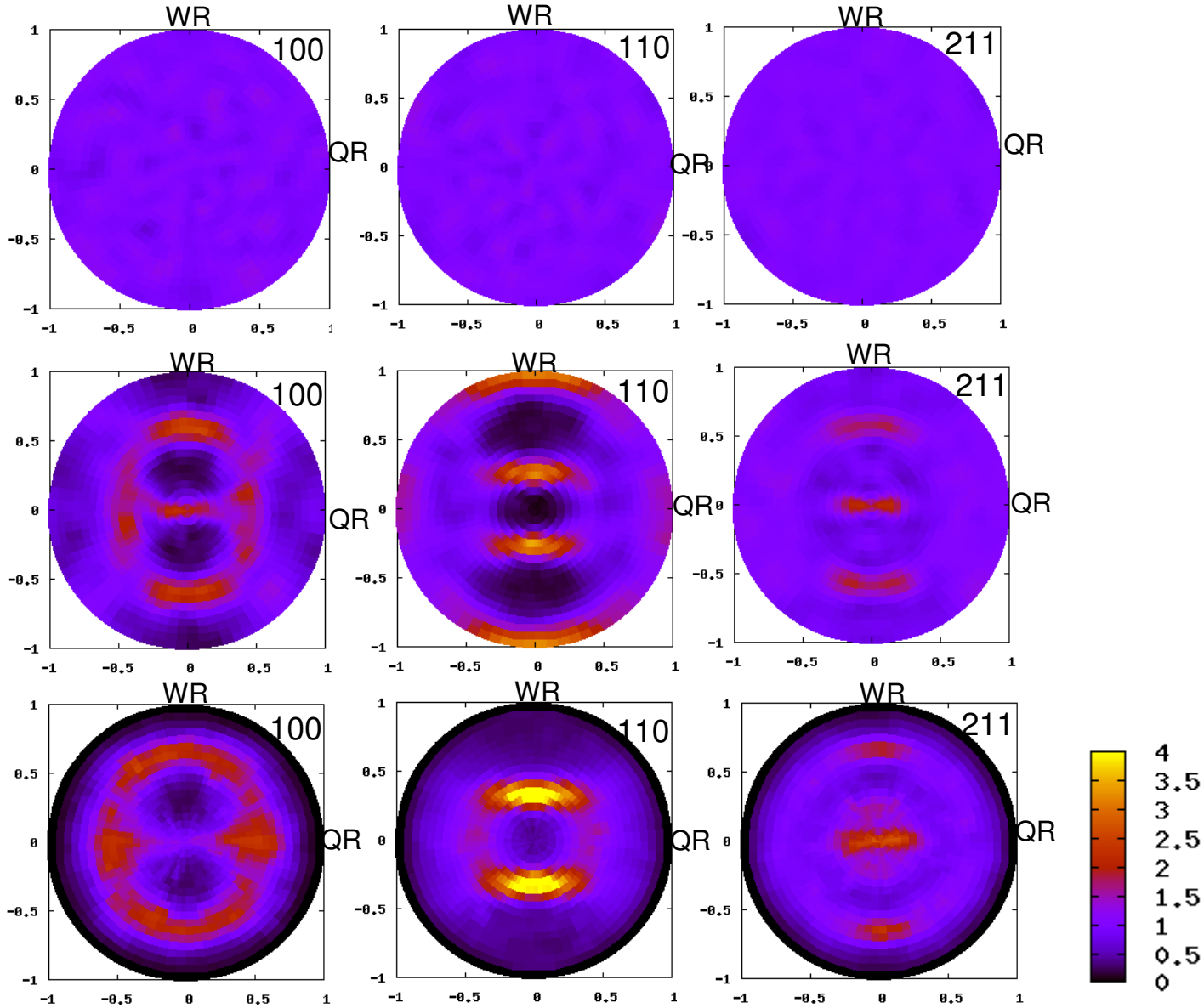
Deformation Induced Texture

Initial state (grey texture)

Simulated rolling texture (reduction by 40%)



Measured texture (DC04)



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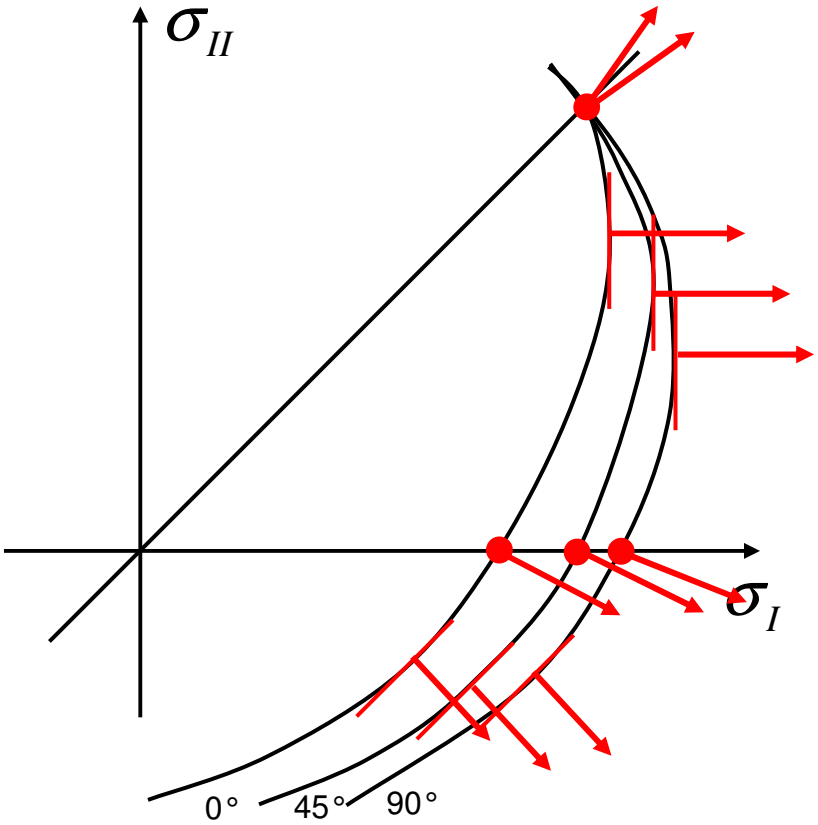
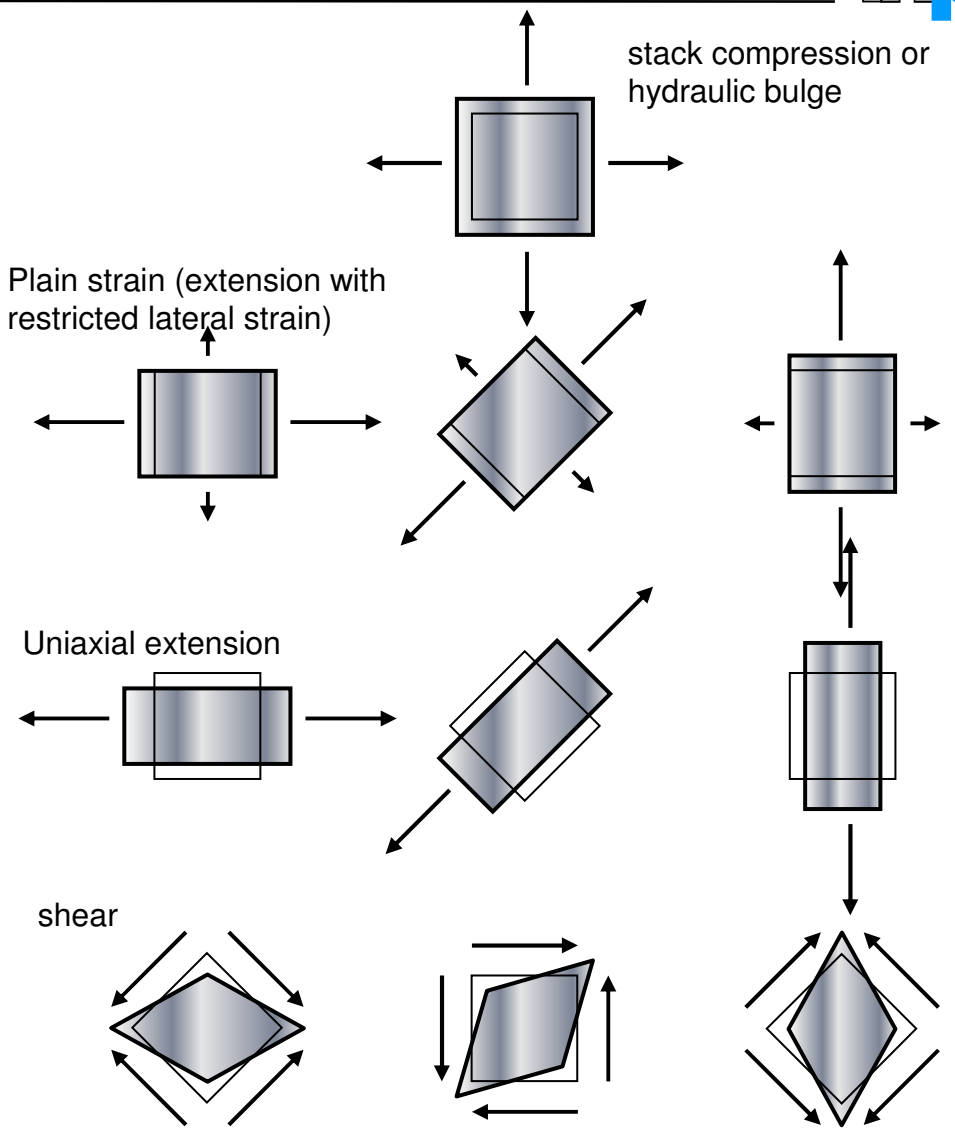
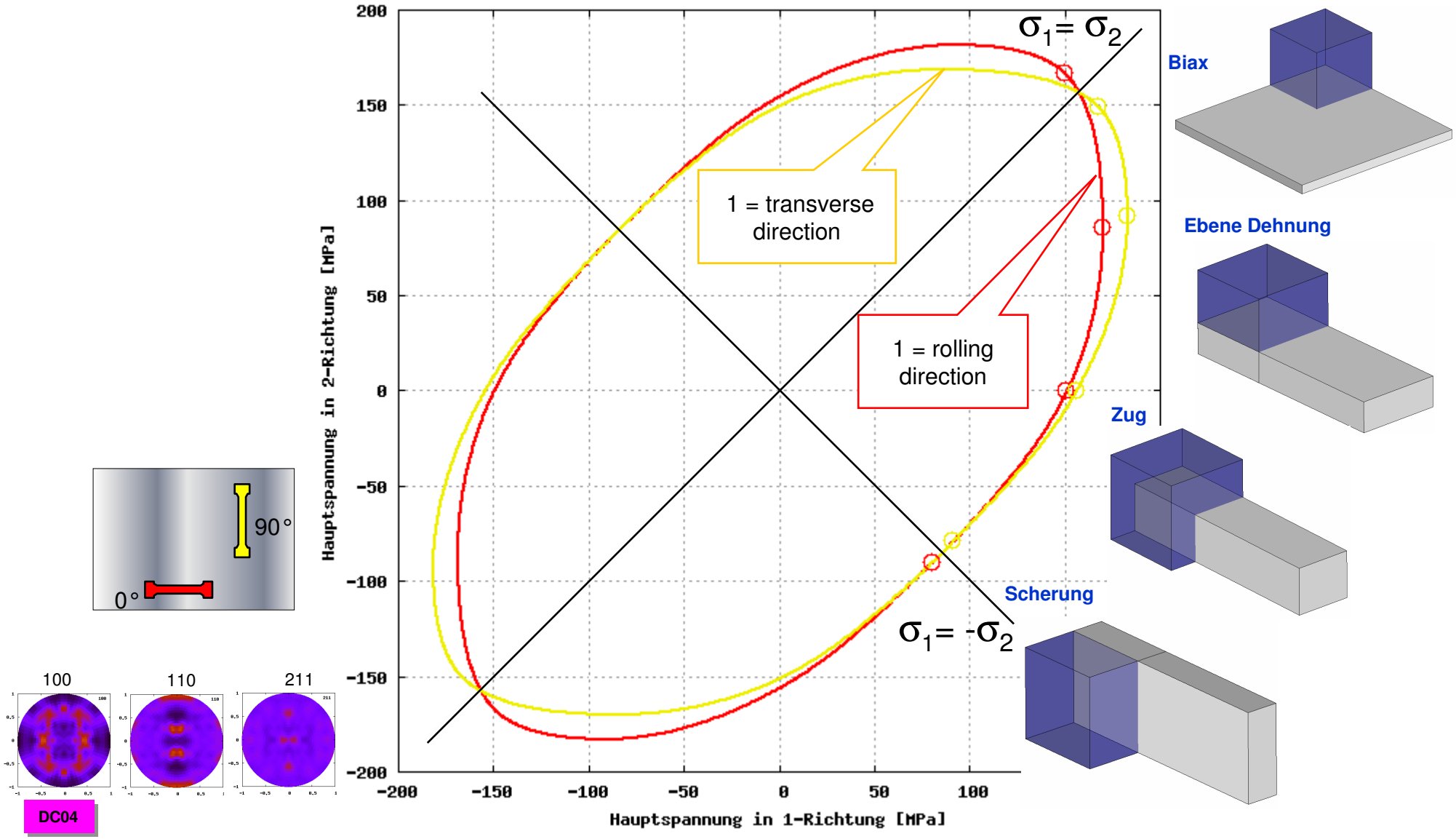
Vegter Yield Locus

- Direct interpolation of test data
- Suitable for steel, Al und Mg
- PAMSTAMP 2G implementation available
- High number of tests required



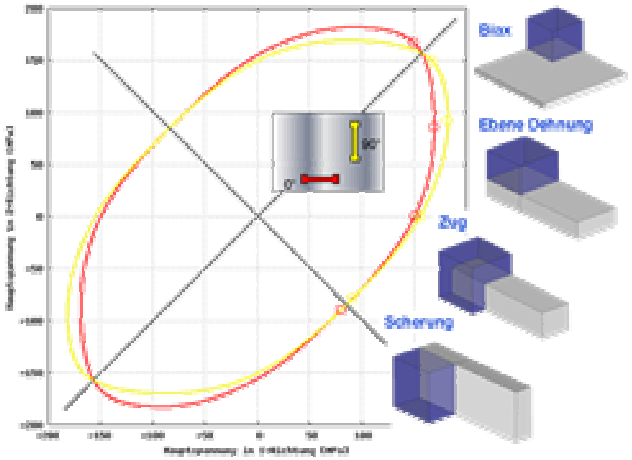


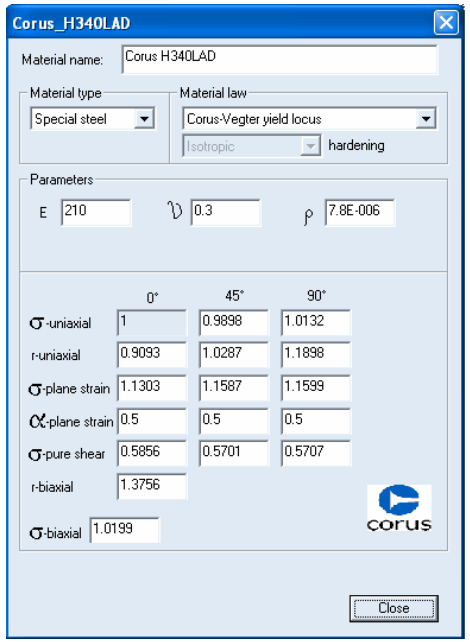
Vegter Yield Locus Based on Virtual Tests (DC04)

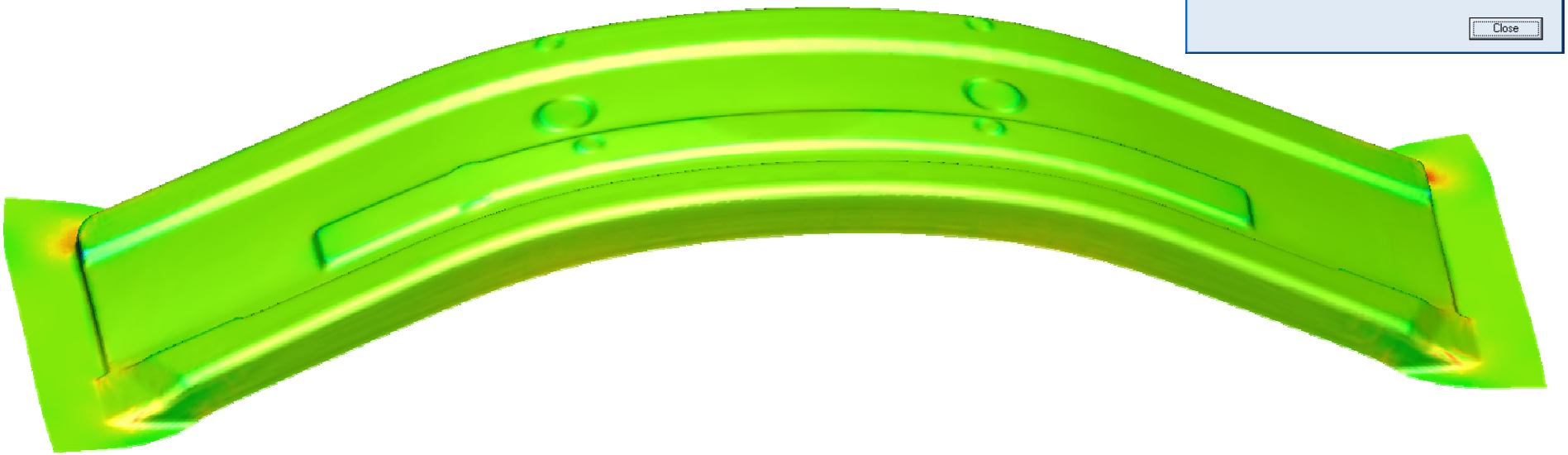


Deep Drawing Simulation (Vegter Model)

- Input data is directly extracted from the tests
- No fit procedure required







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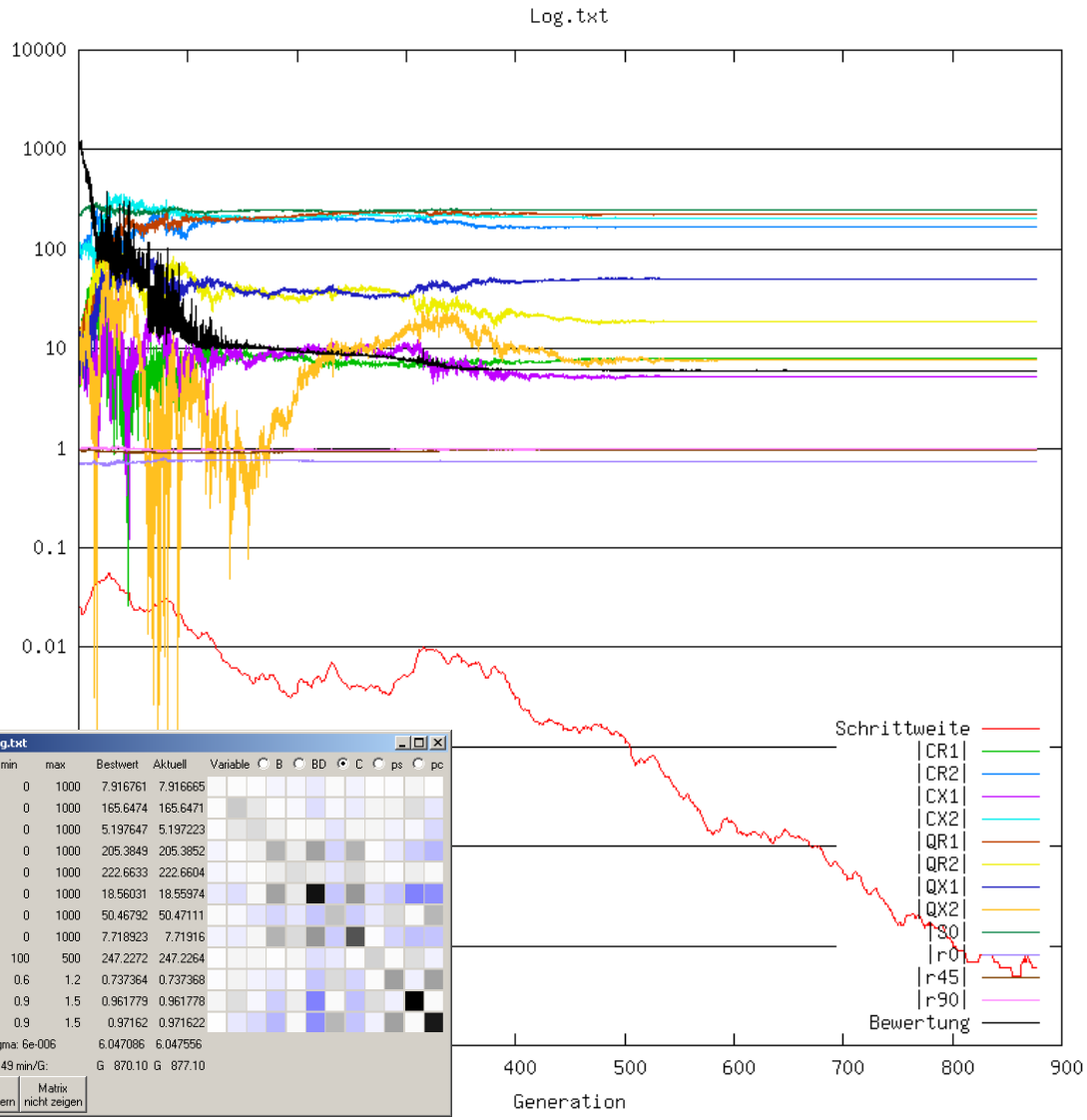
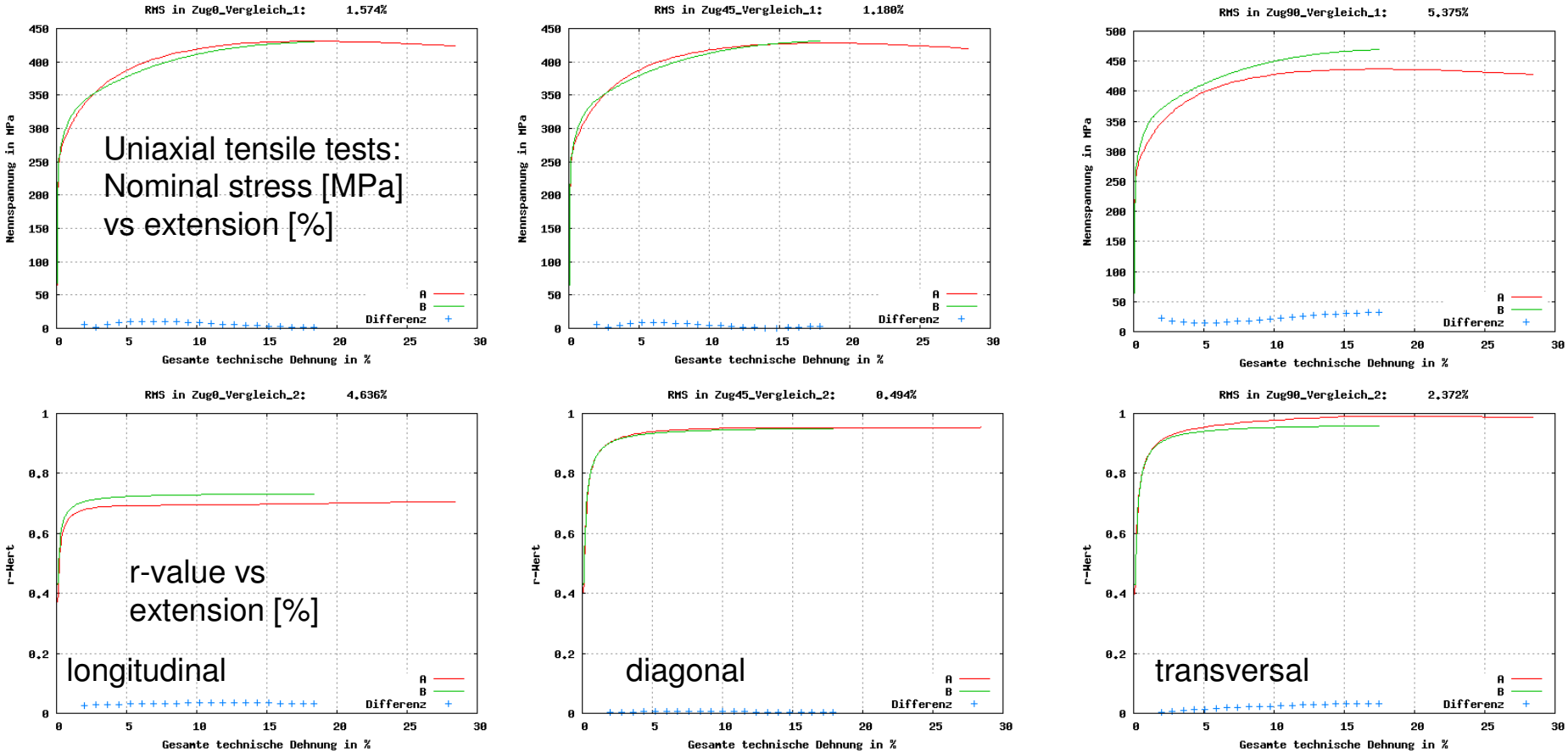
Example Fit

- **Material: H320LA**
- **Texture data: HMI**
- **Slip system calibration based on 0° yield curve**
- **Virtual tests:**
  - uniaxial tension 0, 45, 90°
  - uniaxial tension-compression 0°
  - stack compression test
- **Material model LS-Dyna 103**
  - Hill 48 yield locus (4 params)
  - 4 params for isotropic hardening
  - 4 params for kinematic hardening (2 back stress terms)
- **(10,1)-Evolution strategy**
  - mutation rate and covariance matrix adaptation



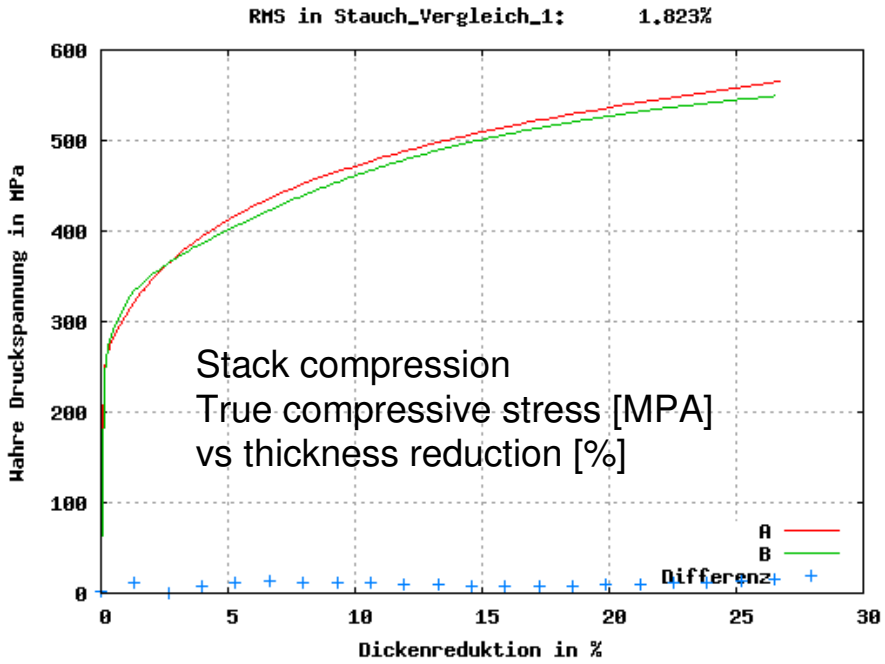
Fit Quality I

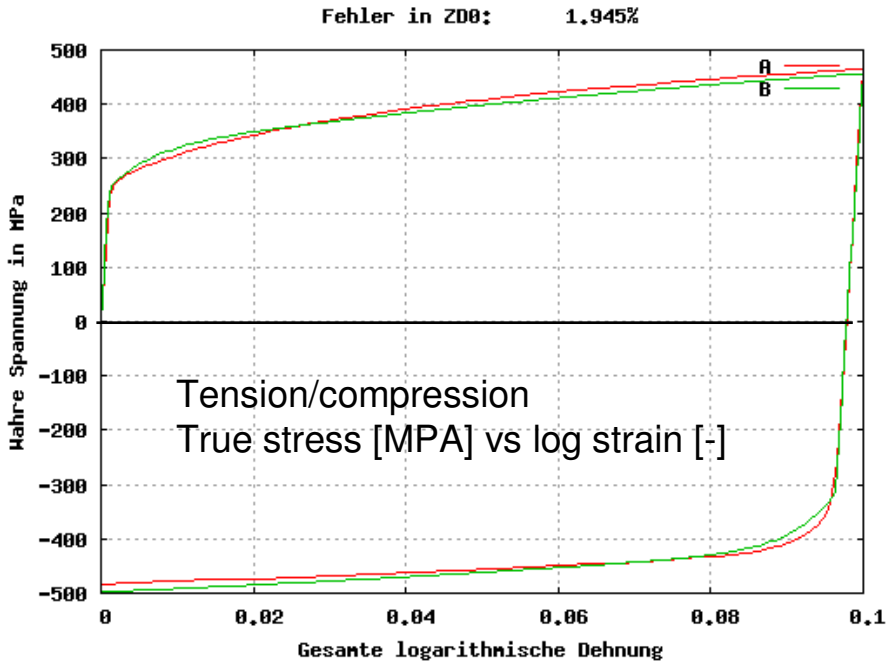


- Fit for r (0°) and stress (90°) is poor.
- Hill 48 cannot in general reproduce both yield curves and r-values

Virtual test
LS-Dyna fit

Fit Quality II





- Note: The slip system model has no backstress.
- Even so, the RVE shows a kinematic hardening fraction of approx 25%
- This is caused by internal stresses between and inside the grains

Virtual test
LS-Dyna fit

Summary

- **Microstructure based models can potentially improve the quality of deep drawing simulations**
- **Direct approach: Crystal Plasticity FEM:**
  - limited by computational resources and UMAT convergence
- **Indirect approach: Virtual Testing (RVE):**
  - in principle acceptable for application in the automotive industry (no performance loss)
  - limited by empirical models in the simulation codes
  - Texture sampling must be improved (hand work not acceptable, quality not sufficient for low numbers of grains)
  - Hardening parameters (latent vs self hardening) need further investigation (r-values differ from real testing)