Activities of a material supplier to support the virtual manufacturing process with respect to forming simulations

Dr. Lutz Keßler, Dr. Jörg Gerlach

ThyssenKrupp Steel Europe

ThyssenKrupp

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Goals and requirements of modern material supplier

Material supplier

- Wide range of materials
- Continuous development
- Global material approach
- Application consulting
- Intensive cooperation with customers
- CO_2 friendly solution
- Multi-material competence

Part manufacturing is a material processing topic

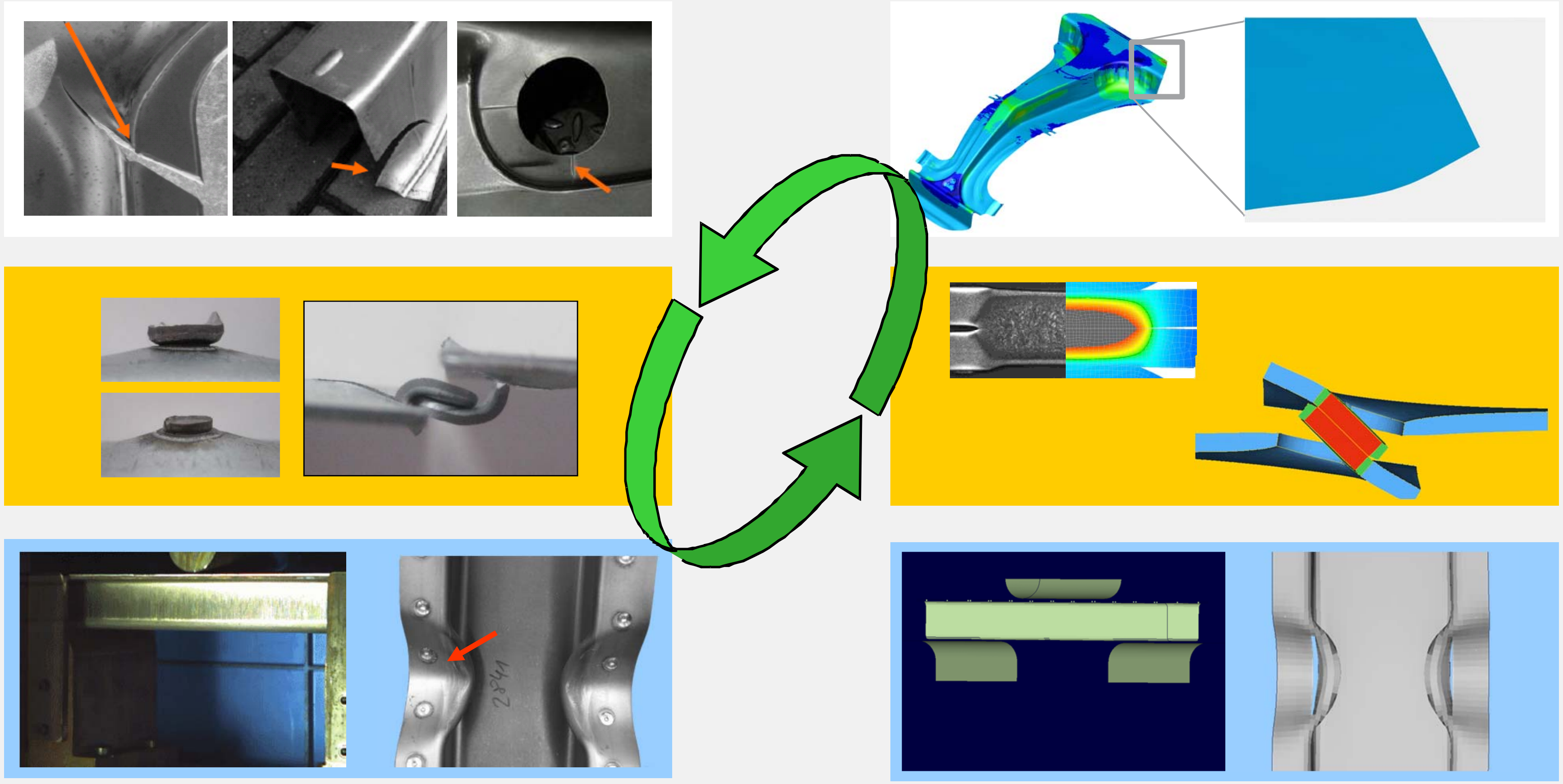
Why a material producer cares for the virtual customer process

The material is part of the complete process

ThyssenKrupp Steel Europe

The overall requirement of simulation application
To consider all necessary factors with sufficient impact

Real world | **Virtual space**



Consequent trends in industrial simulation
Minimization of virtual failure possibility with additional methods

- **Status of simulation in the 1990s**
  - Simulation with rough estimations
  - Use of simple material data
  - Use of simple numerical models
  - Hardly differentiation in between concept and final simulation

1990s
simple, few models

2010 +
professional, multiple models

- **Trends of recent years**
  - 100% simulation of all parts and processes
  - Differentiation between concept and final simulation
  - Process coupling, including advanced failure models
  - Production optimization based on simulation results
- **In parallel new material grades are continuously developed and introduced to the market**

Each solution of a problem is a new problem

Johann Wolfgang v. Goethe,

28.08.1749 - 22.03.1832

An exact optimization is never necessary, it is always too costly.

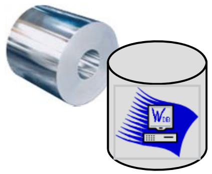
William Edwards *Deming*

14.10.1900 - 20.12.1993

Activities of a material supplier to support virtual manufacturing
with respect to robust forming simulations

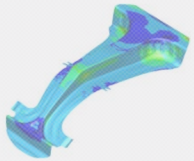
R&D activities at ThyssenKrupp Steel Europe

Material data and measurement



- Validation of measuring techniques for simulation purposes
- Data storage and simulation data support

Material hardening



- Material hardening
- Material modeling – yield locus
- Validation experiments

Material failure

- Instability
- Beyond instability (shear fracture)

Robustness and new Products

- Process stability and robustness
- Innovative material support for LITECOR®

From bare material to material model data and application

Conventional strategy to derive material cards

Material

1 of x

Laboratory

Testing 1:
- tensile

Testing 2:
- Bulge

Testing 3:
- Shear

Testing 4:
- FLC

Institute

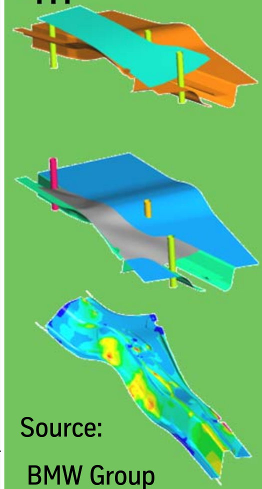
Modeling:
- yield curve

Modeling:
- yield locus
- (extrapolation)

Modeling:
- forming limit

Tool maker

Operation:
- part 01
- …



Source: BMW Group

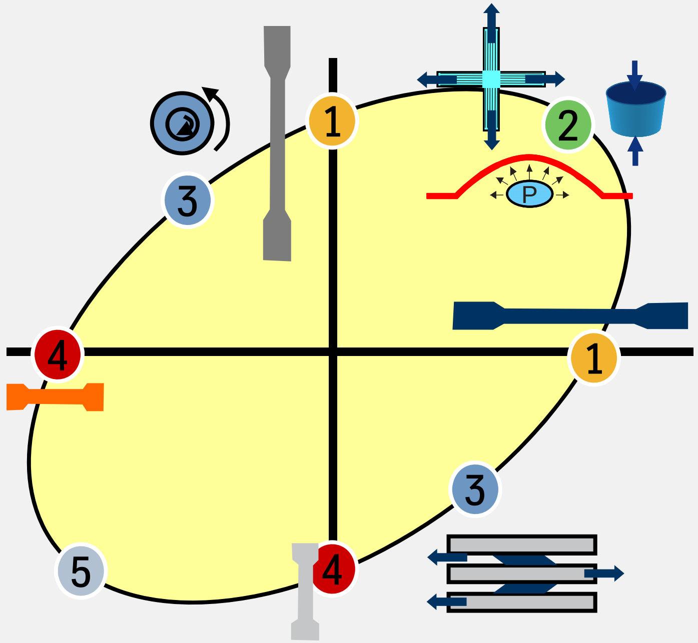
➔ A successful process setup when the modeling options are limited

Material data experiments are powered by simulation needs

An obstacle of exchangeability by missing standards

	Experiments used for yield locus parameter identification	Standard available	Useful strain range
1	Tensile test (0°, 45°, 90° …)	yes	0% → 25%
2	Hydr. Bulge	no *)	10% → 70%
	Stack compression	no	5% → 40%
	Biaxial cruciform test	no **)	0% → 10%
3	Shear test (Miyauchi)	no	5% → 30%
	In-plane torsion test	no	5% → 35%
4	Compression (in-plane)	no	0% → 10%
5	No test available	-	-

*) ongoing activities for ISO standardization by a GDDRG working group
**) ongoing activities for ISO standardization by a Japan working group



→ Most experiments for sophisticated models are undefined!

Material data and material testing for data base pushing

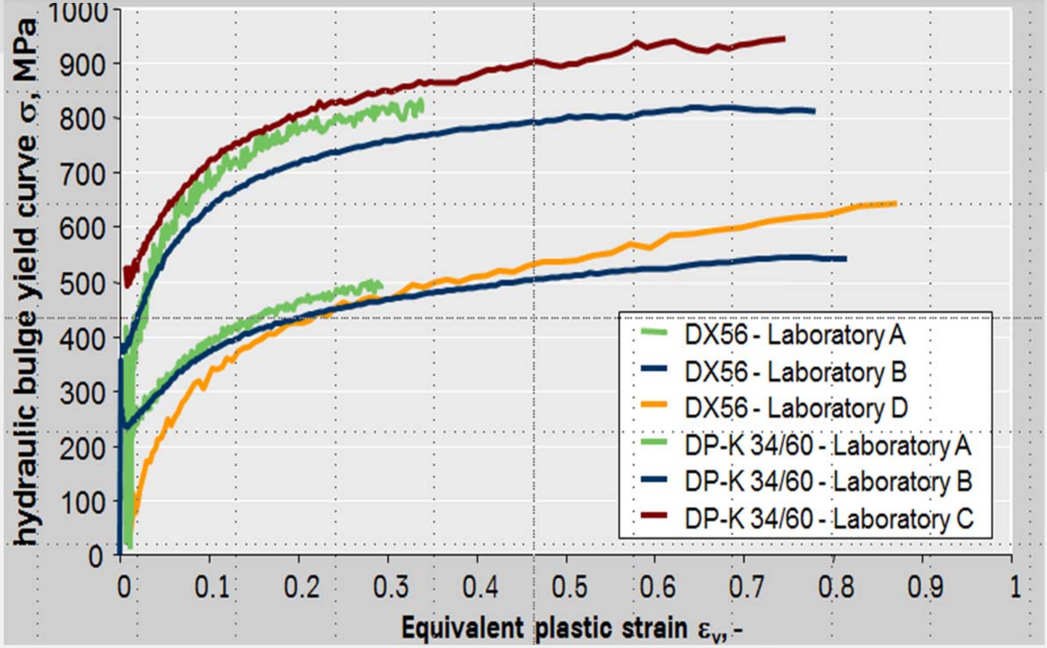
To assure quality and be aware of individual testing/evaluation methods

Analyze experiments for simulations modeling → Check for availability and reproducibility → Try to harmonize or set-up standards for measurement → Trustable and comparable material data from different laboratories

Material data and material testing for data base pushing
To assure quality and be aware of individual testing/evaluation methods

Analyze experiments for simulations modeling

ThyssenKrupp Steel Europe study for hydraulic bulge test orders in different laboratories in 2006



Trustable and comparable material data from different laboratories

Material data and material testing for data base pushing

To assure quality and be aware of individual testing/evaluation methods

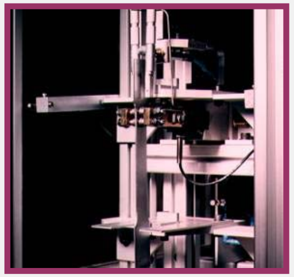
Analyze experiments for simulations modeling → Check for availability and reproducibility → Try to harmonize or set-up standards for measurement → Trustable and comparable material data from different laboratories

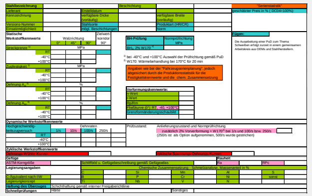
Example of activities:

- Member of the GDDRG working group for a standardization of the forming limit curve (ISO 12004-2)
- Member of the GDDRG working group for hydraulic bulge test standardization
- Member of the PuD and PuD-F group

→ ThyssenKrupp Steel Europe carefully analysis material model experiments

Material database for simulation purpose
Representative and documented material data for our customers



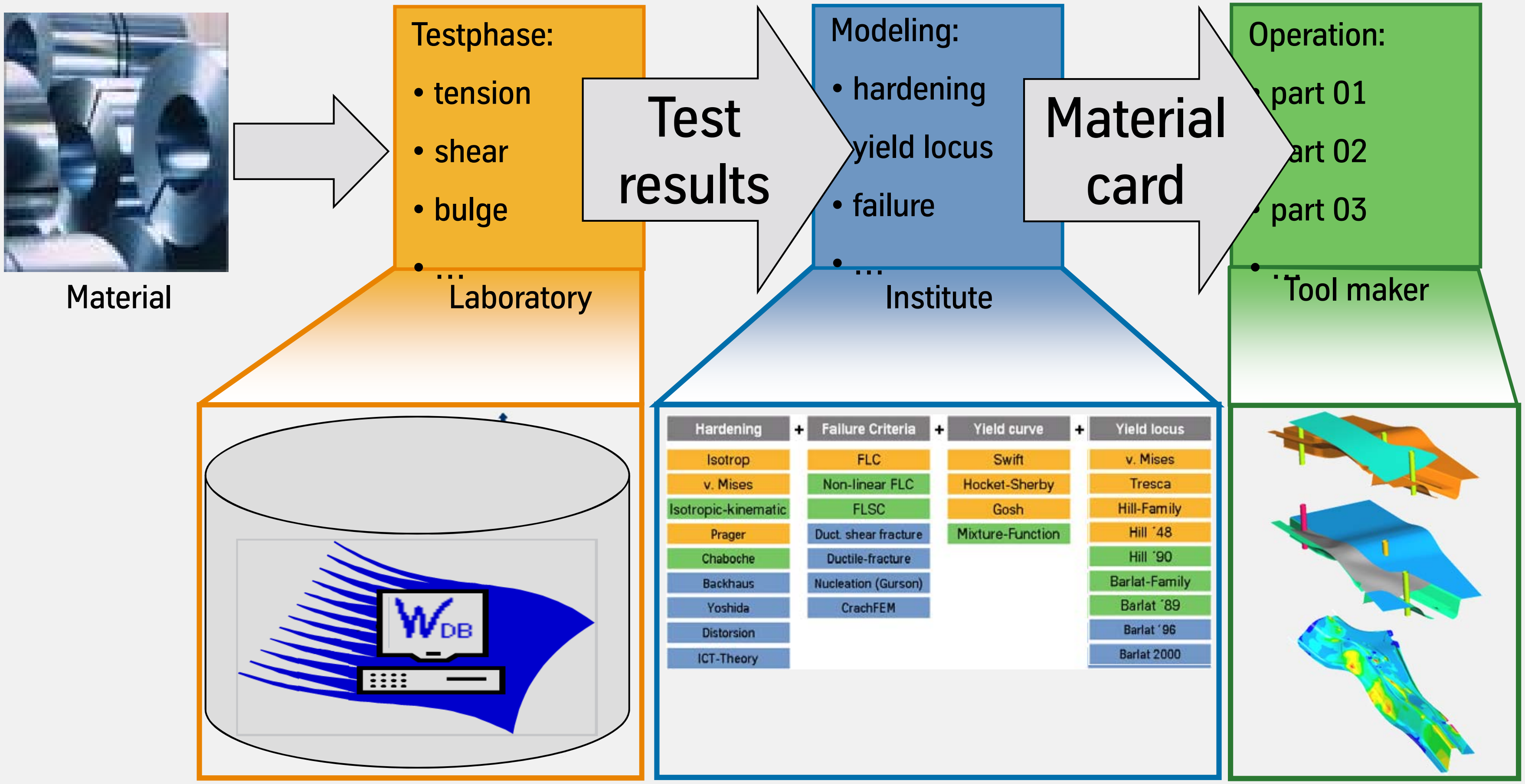

Measure	Collection	Database	Dissemination	Application
Measurement of representative material data	Data collection and validation with cross-comparison	Data provision, documentation and authorization concept	Database user interface and KISS for filtering and data export	CAE as construction, (crash, forming …)

- Standardized data measured by defined testing methods (SEP 1240).
- Availability according to PuD-steel (laboratory production, small series, …)
- Documented validation, approval and provision.

➔ Data are provided to the customers by the key accounts

Strategies for material model calibration

Standard process design for material setup in forming simulation

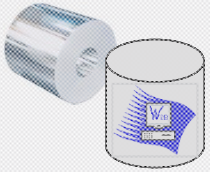


Hardening	Failure Criteria	Yield curve	Yield locus
Isotrop	FLC	Swift	v. Mises
v. Mises	Non-linear FLC	Hocket-Sherby	Tresca
Isotropic-kinematic	FLSC	Gosh	Hill-Family
Prager	Duct. shear fracture	Mixture-Function	Hill ´48
Chaboche	Ductile-fracture		Hill ´90
Backhaus	Nucleation (Gurson)		Barlat-Family
Yoshida	CrachFEM		Barlat ´89
Distorsion			Barlat ´96
ICT-Theory			Barlat 2000

Activities of a material supplier to support virtual manufacturing
with respect to robust forming simulations

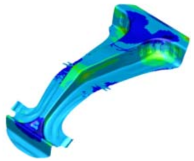
R&D activities at ThyssenKrupp Steel Europe

Material data and measurement



- Validation of measuring techniques for simulation purposes
- Data storage and simulation data support

Material hardening



- Material hardening
- Material modeling – yield locus
- Validation experiments

Material failure

- Instability
- Beyond instability (shear fracture)

Robustness and new Products

- Process stability and robustness
- Innovative material support for LITECOR®

Increased complexity is offered for a sufficient material modeling

A today's selection for material model options

Hardening	Failure Criteria	Yield curve	Yield locus
Isotrop	FLC	Swift	v. Mises
v. Mises	Non-linear FLC	Hocket-Sherby	Tresca
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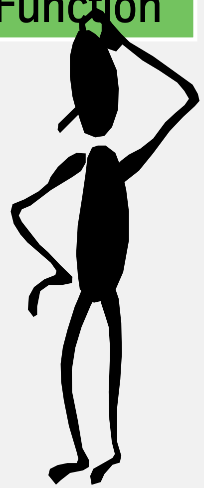
ICT-Theory			Barlat 2000
			Banabic 2005

- Level 01 = Standard (orange)
- Level 02 = Advanced (green)
- Level 03 = Complex (blue)



➔ To identify the best combination to meet the individual needs!

Increased complexity is offered for a sufficient material modeling

Activities for simplifying the yield curve extrapolation

Hardening	Failure Criteria	Yield curve	Yield locus
Isotrop	FLC	Swift	v. Mises
v. Mises	Non-linear FLC	Hocket-Sherby	Tresca
Isotropic-kinematic	FLSC	Gosh	Hill-Family
Prager	Duct. shear fracture	Mixture-Function	Hill ´48
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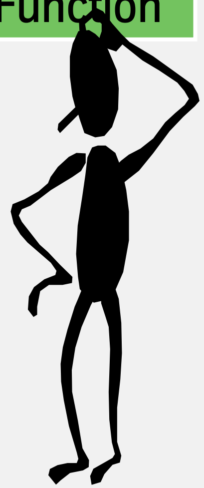
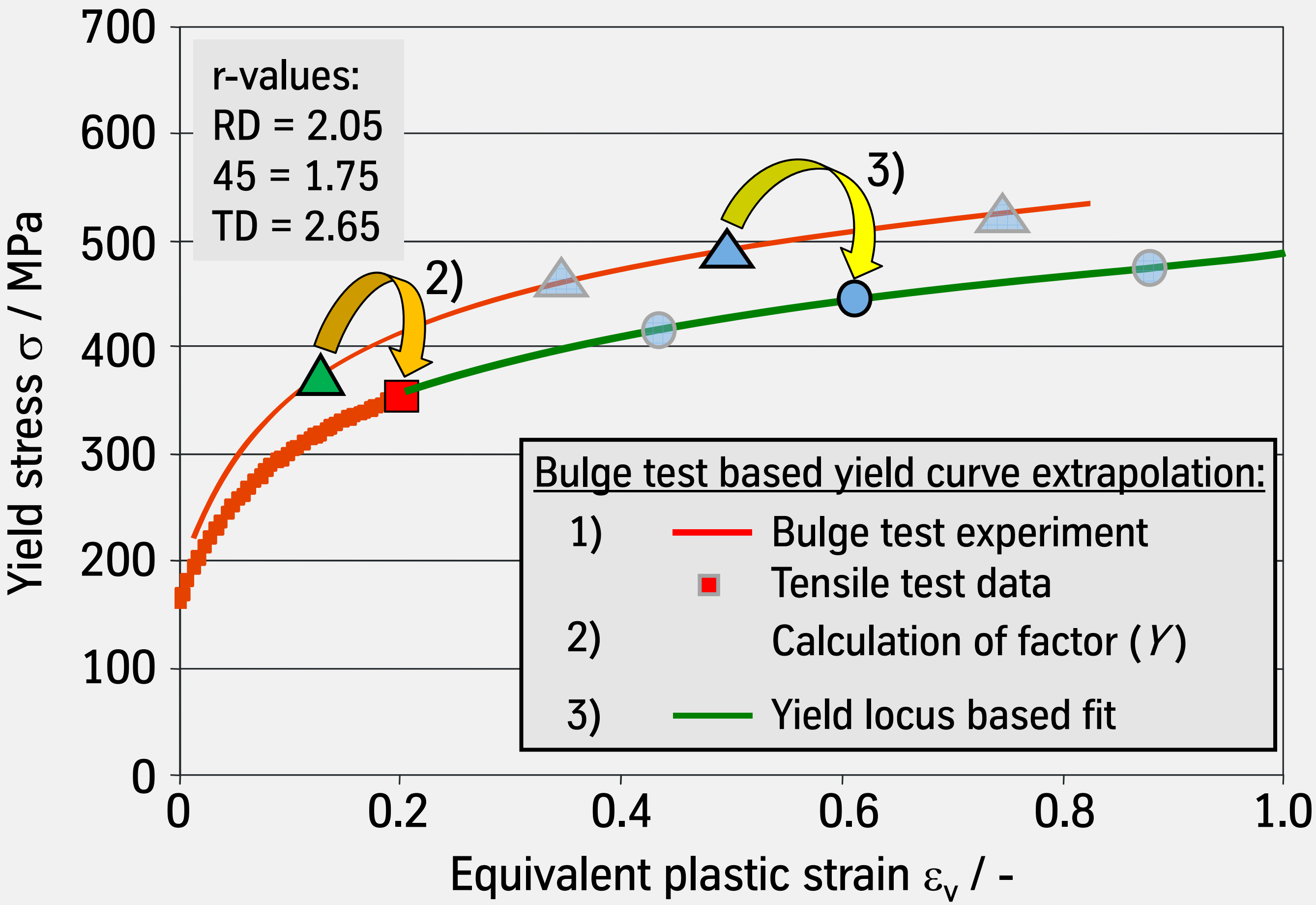
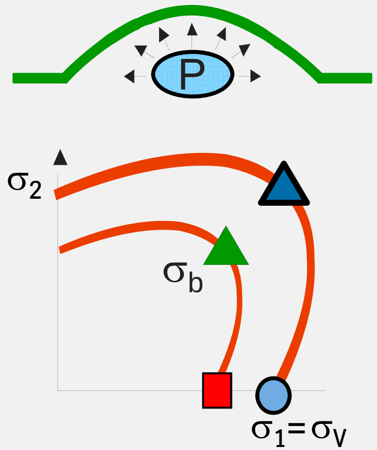


Yield curve extrapolation method

Calculation principle for a combined yield locus and hardening modeling





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

$$\varepsilon_V = \frac{\sigma_1\varepsilon_1 + \sigma_2\varepsilon_2}{\sigma_V}$$

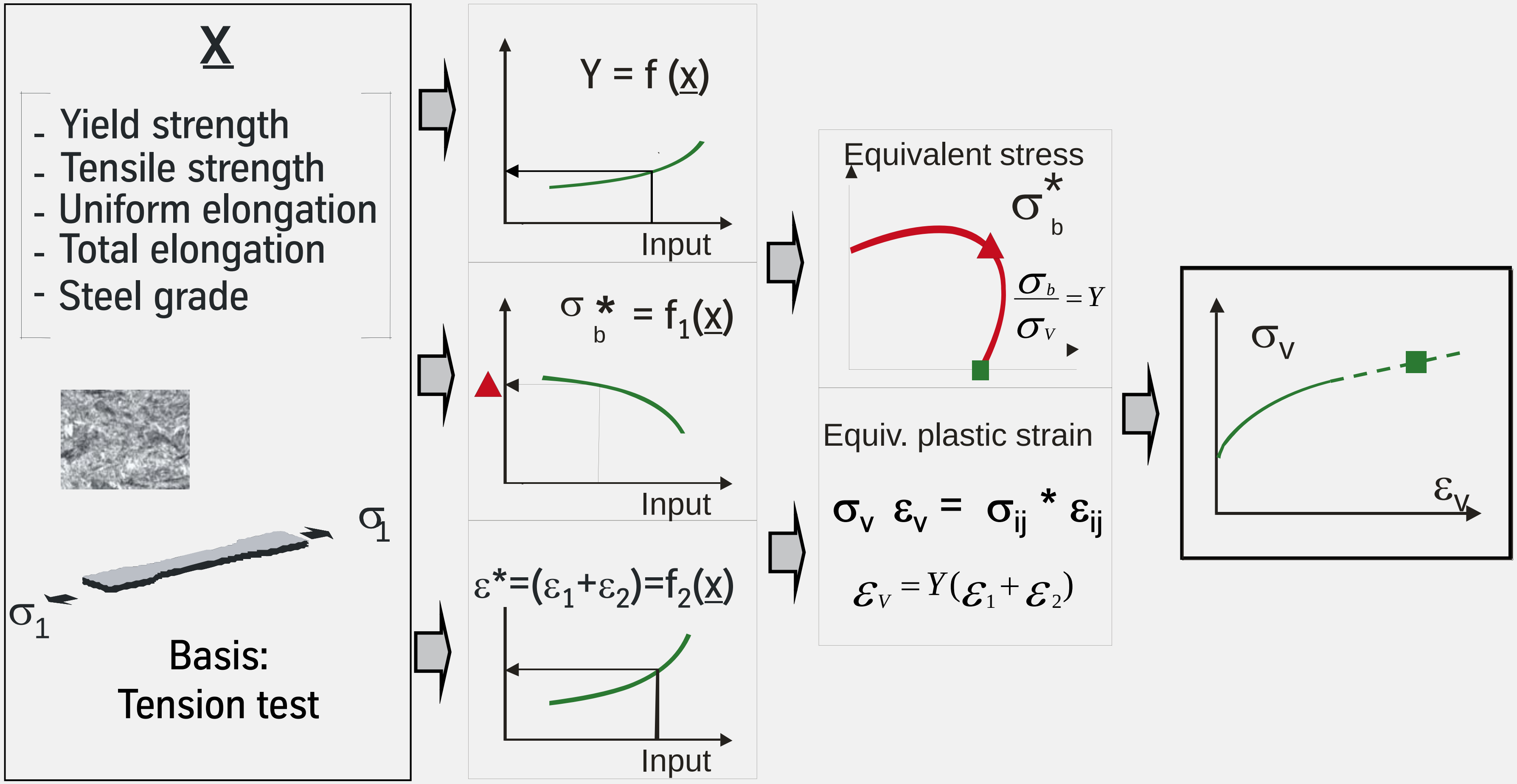
$$= \frac{\sigma_b}{\sigma_V}(\varepsilon_1 + \varepsilon_2)$$

$$= Y(\varepsilon_1 + \varepsilon_2)$$

Cost efficient extrapolation of the yield curve with TEM

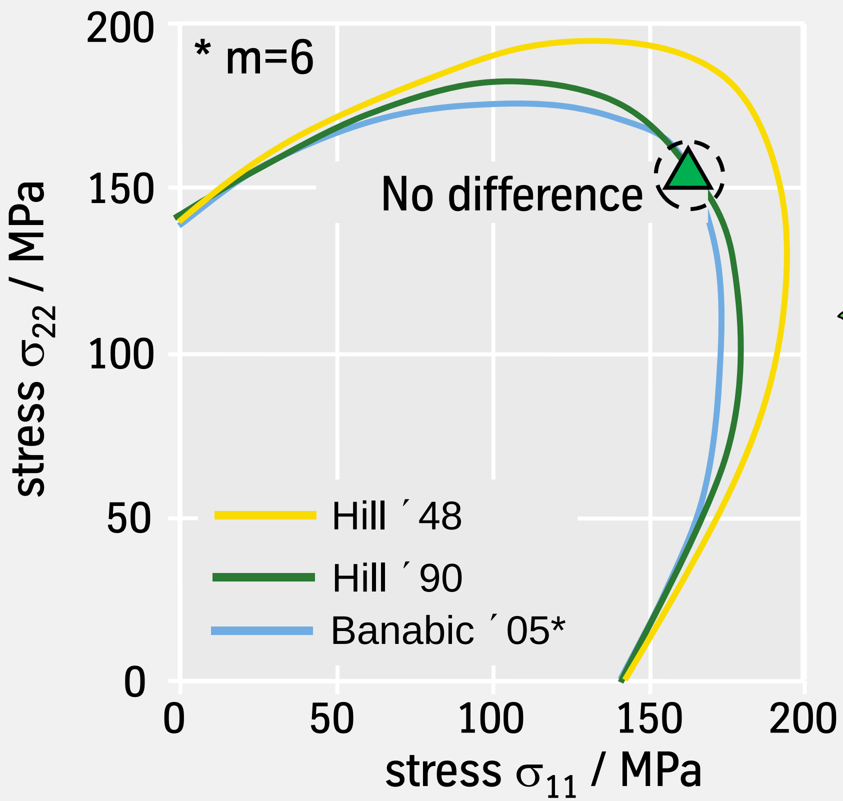
Basis for the extrapolation is a hydraulic bulge test

Start: Input values | Prediction | Transformation | Extrapolation



Increased complexity is offered for a sufficient material modeling

A focus on hardening and yield locus selection



Yield curve	Yield locus
Swift	v. Mises
Hocket-Sherby	Tresca
Gosh	**Hill-Family**
Mixture-Function	Hill ´48
	Hill ´90
	Barlat-Family
	Barlat ´89
	Barlat ´96
	Barlat 2000
	Banabic 2005

- Level 01 = Standard
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Advanced material model options need a validation phase

Especially developed experiments allow a fast check for general quality

<u>FEM-input (AutoForm):</u>

- ✓ r-values (0°, 45°, 90°)
- ✓ $\sigma_{0.2}$ (0°, 45°, 90°)
- ✓ biaxial stress point (bulge)
- ✓ extrapolation by bulge test
- ⚡ strain rate (SR=off)

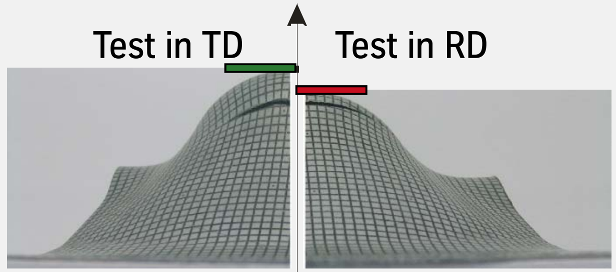
Hill´48

Hill´90

Barlat´89

Banabic 2005

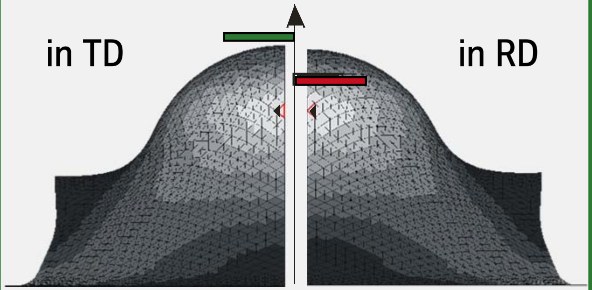
Experiment



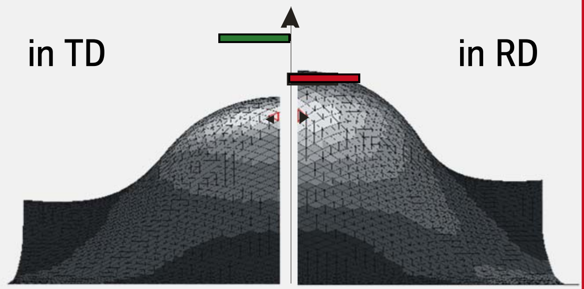
Major strain in TD | Major strain in RD

Barlat´89

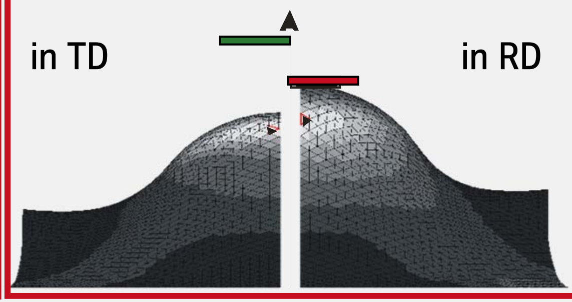
43.5 mm 35.7 mm



Banabic 2005, M=5



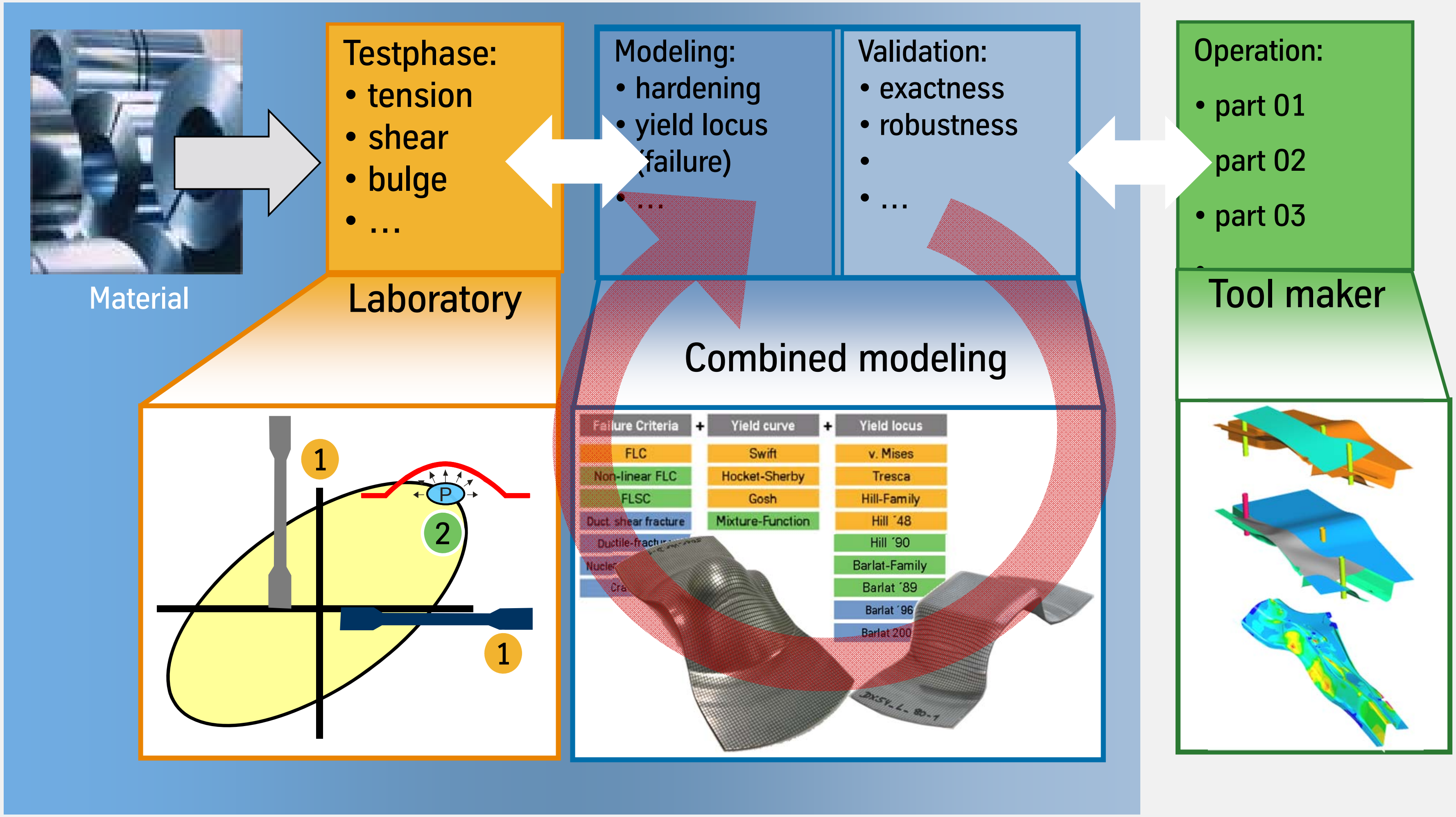
Banabic 2005, M=6



Depth experiment TD — Depth experiment RD — ▸ Critical Element FEM

Actual ThyssenKrupp Steel Europe strategy for material data

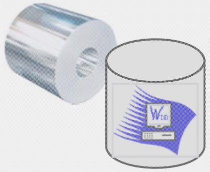
A new process design for material cards in forming simulations



Activities of a material supplier to support virtual manufacturing
with respect to robust forming simulations

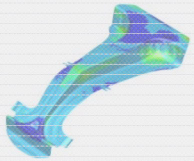
R&D activities at ThyssenKrupp Steel Europe

Material data and measurement



- Validation of measuring techniques for simulation purposes
- Data storage and simulation data support

Material hardening



- Material hardening
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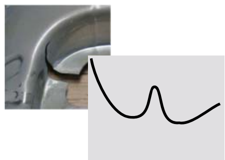
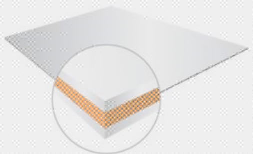
- Validation experiments

Material failure



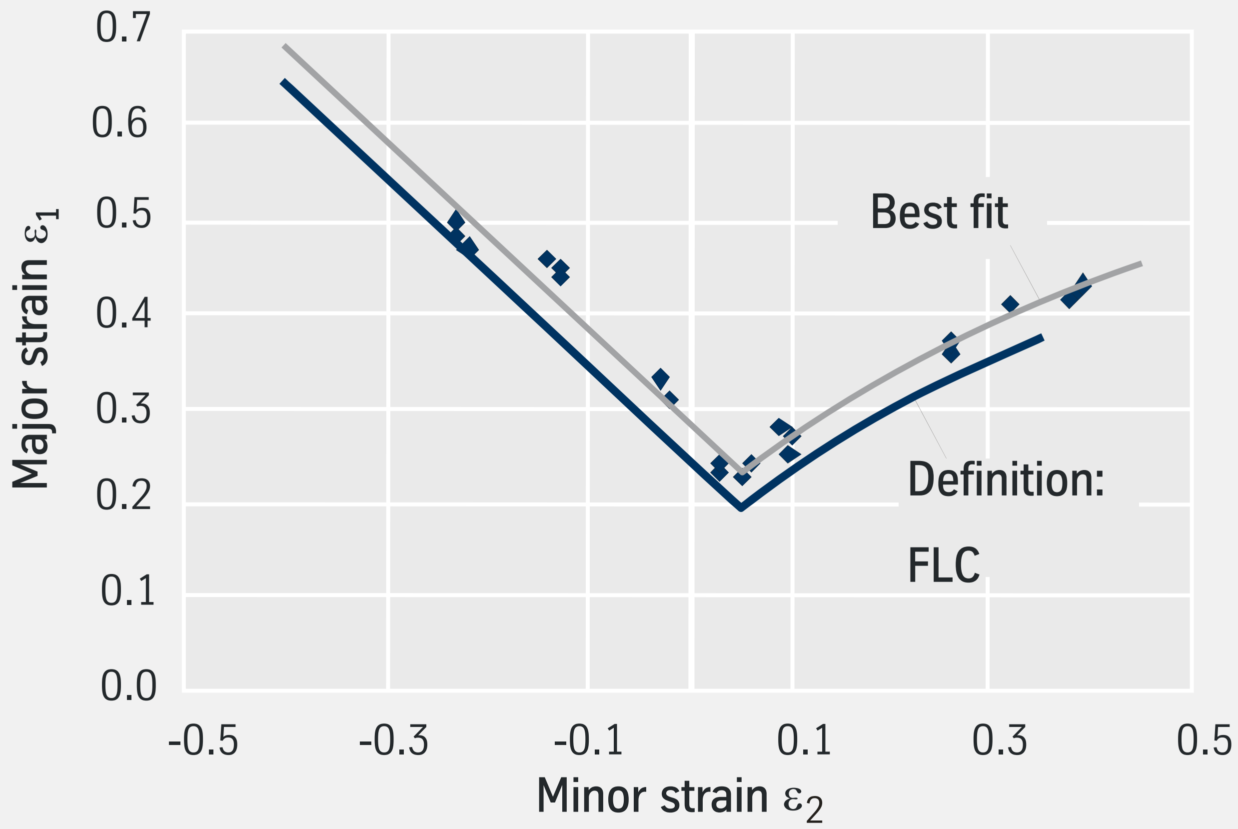
- Instability
- Beyond instability (shear fracture)

Robustness and new Products



- Process stability and robustness
- Innovative material support for LITECOR®

Deriving material models for industrial simulation
TKS definition of a forming limit curve (FLC)



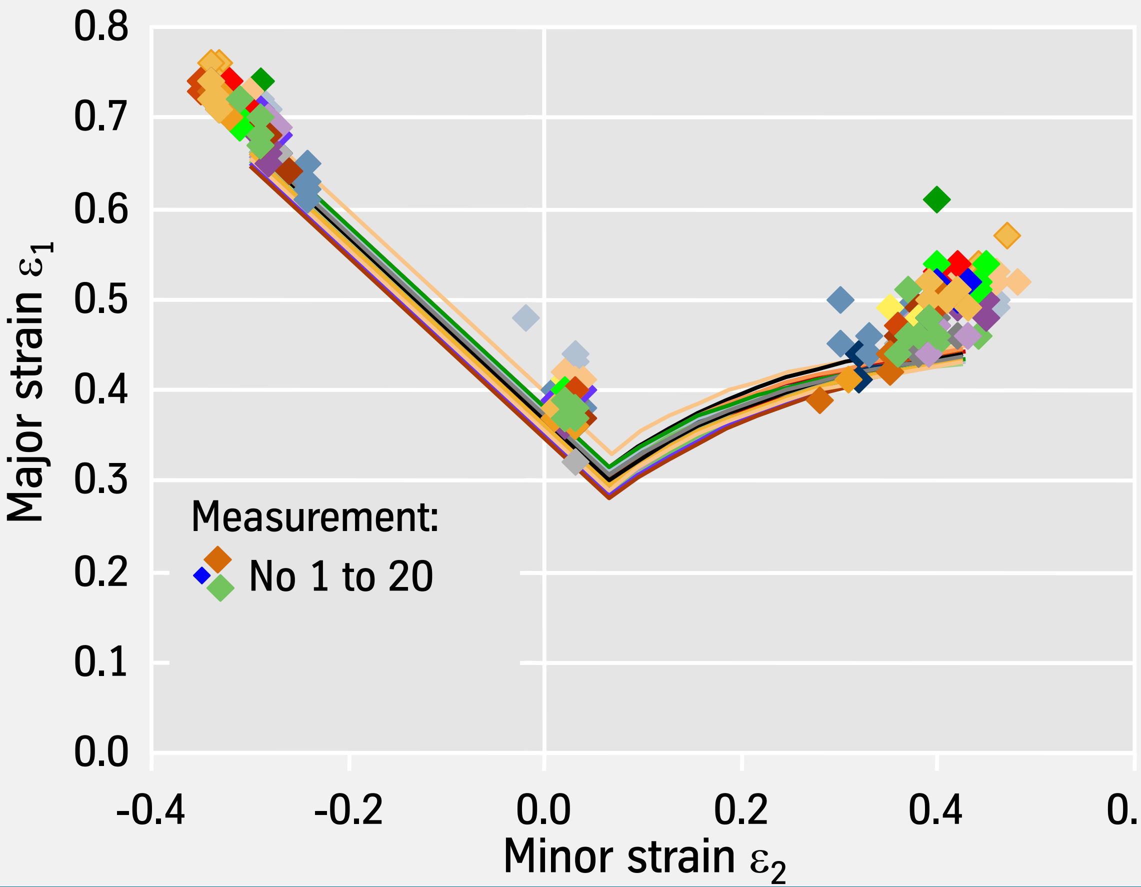
➔ The FLC at TK Steel Europe represents a no neck at 97.5% of all specimen!

Deriving material models for industrial simulation

FLC scatter and prediction for a larger number of coils

Number of coils

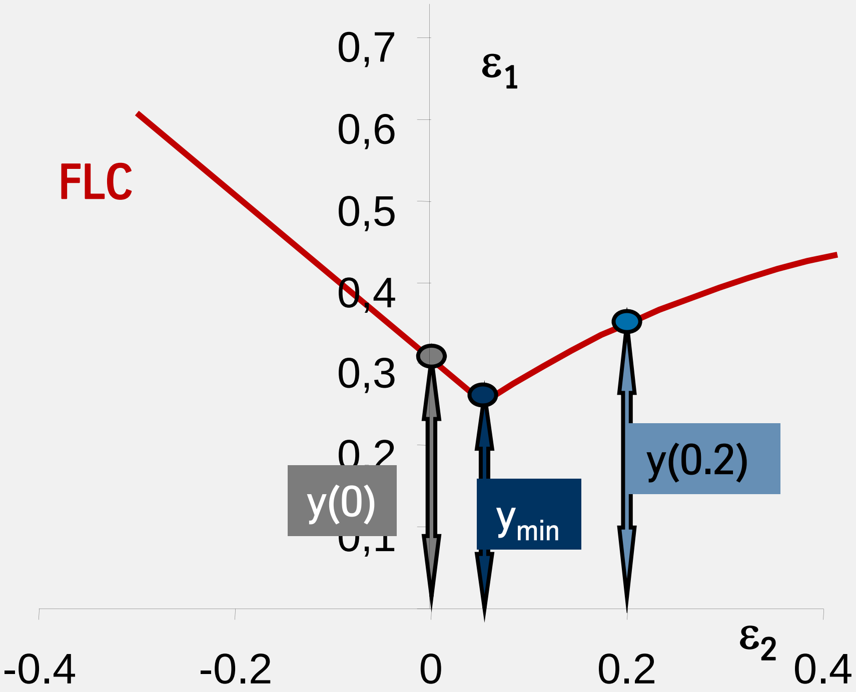
tested > 20



➔ The general scatter of FLC is limited, one FLC can represents a material sufficiently

Calculation of failure criteria – Forming Limit Curve (FLC)

Forming limit prediction by means of regression analysis



Approach:

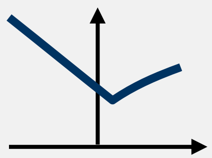
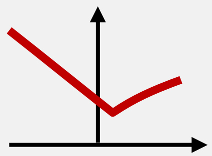
Approximation of the FLC using 3 strain points

These strain points are calculated by regression

y(0)
y_{min}
y(0.2)
} = f (mech. properties, thickness)

For each regression is valid: ✓

Coeff. of determination > 0.95 and stand. deviation < 0.022

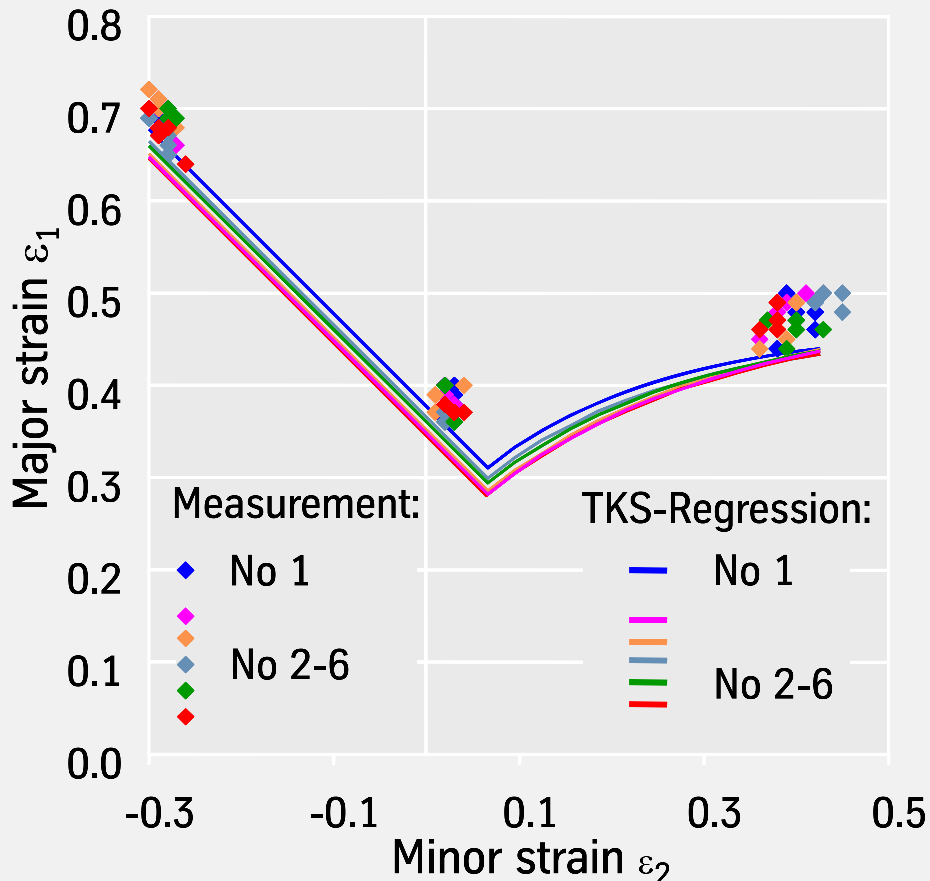
 +  =  or   FLC_{min}

Deriving material models for industrial simulation

Predicted scatter of the forming limit curve by a regression

Number of coils

tested = 6



➔ **A prediction with simple input parameters represents the scatter**

ThyssenKrupp Steel Europe

ThyssenKrupp

Increased complexity for a sufficient material modeling

A today's selection for material model options for fracture

Hardening	Failure Criteria	Yield curve	Yield locus
Isotrop	FLC	Swift	v. Mises
v. Mises	Non-linear FLC	Hocket-Sherby	Tresca
Isotropic-kinematic	FLSC	Gosh	Hill-Family
Prager	Duct. shear fracture	Mixture-Function	Hill´48
Chaboche	Ductile-fracture		Hill´90
Backhaus	Nucleation (Gurson)		Barlat-Family
Yoshida	CrachFEM		Barlat´89
Distorsion			Barlat´96
ICT-Theory			Barlat 2000
			Banabic 2005

- Level 01 = Standard
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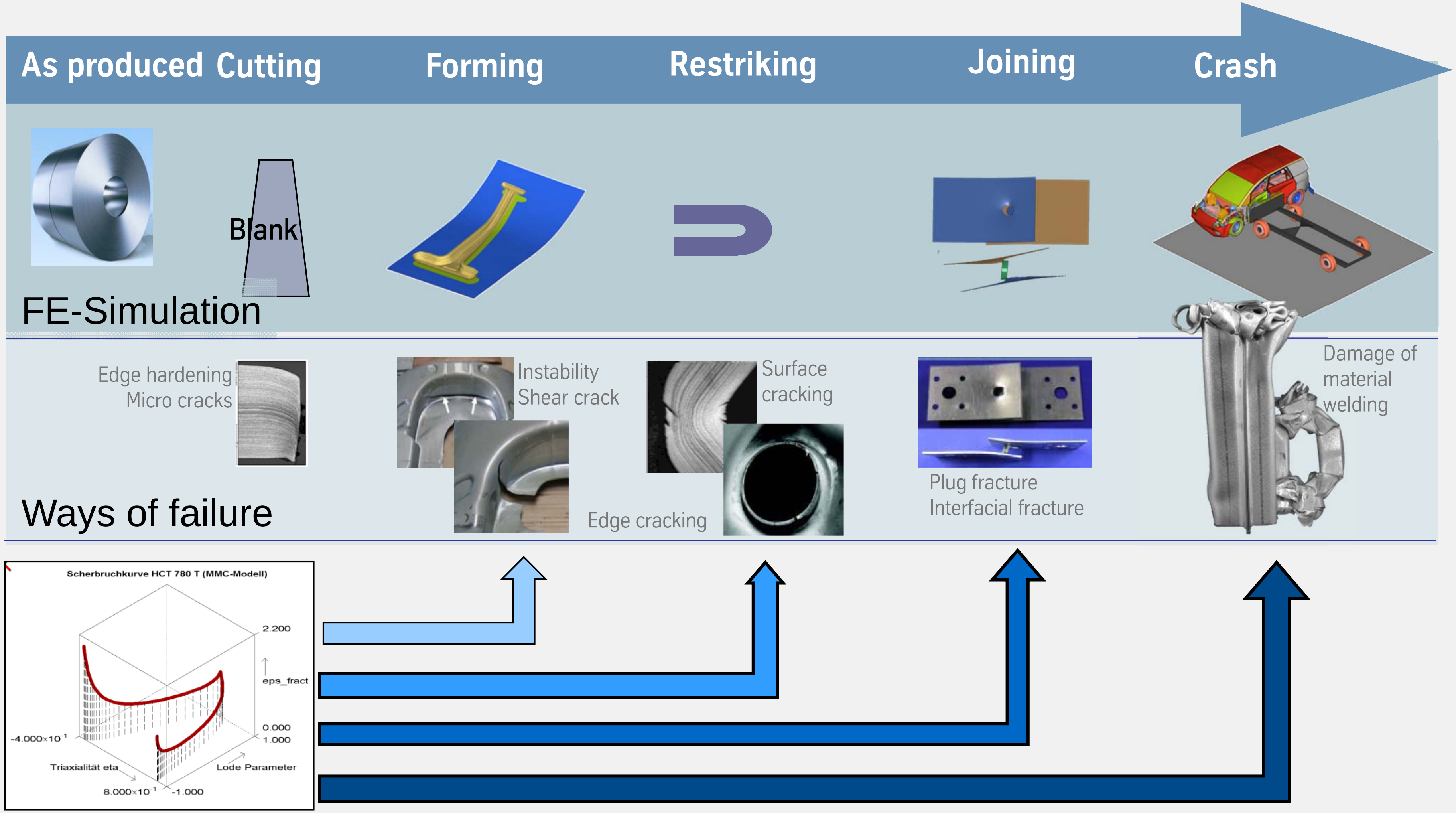
➔ All advanced fracture models need additional material parameter input!

Challenges for simulation techniques

To cover totally different failure modes with one model



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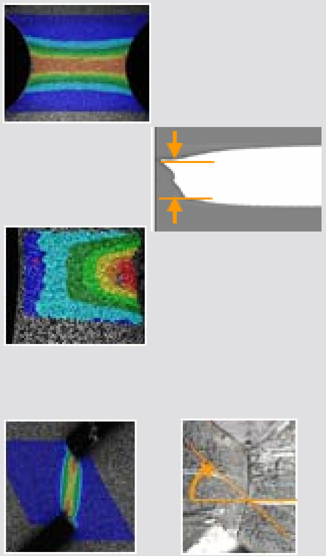
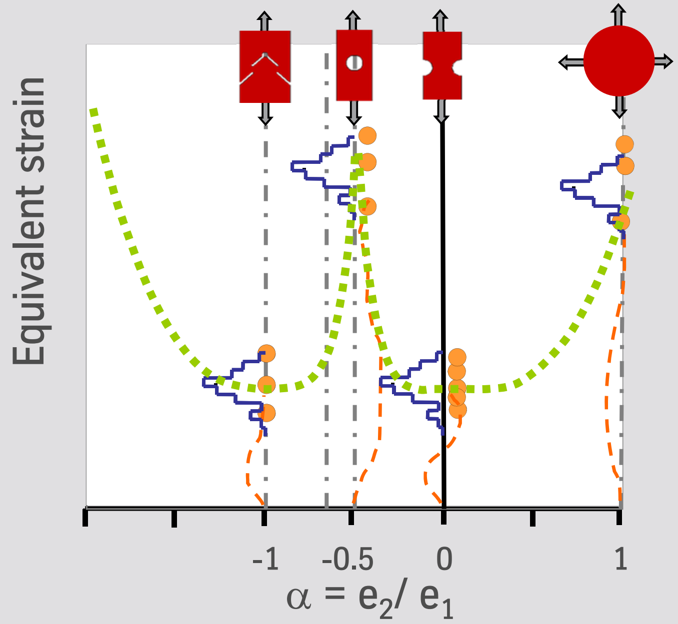
Beyond instability (fracture) for crash and forming simulations
The major steps for the determination of fracture data

Fracture Tests
for different stress states



Analysis of strain
and strain path



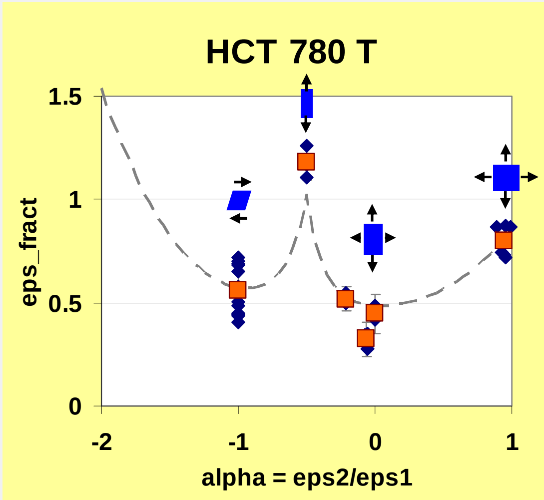
→ Stress dependent fracture data

- Determination of equivalent fracture strains and corresponding stress states
- Using optical strain measurement system to get strain path till fracture
- Evaluation of local fracture strain by additional methods (e.g. micrographs)
- Transformation of effective strain state to stress state for calibration of fracture models

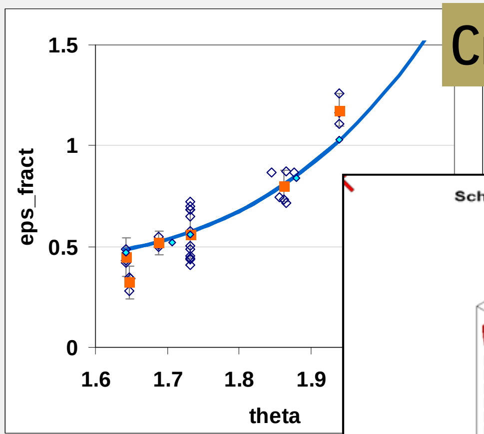
Modeling of fracture for high strength steel grades

To support the customers with advanced fracture data

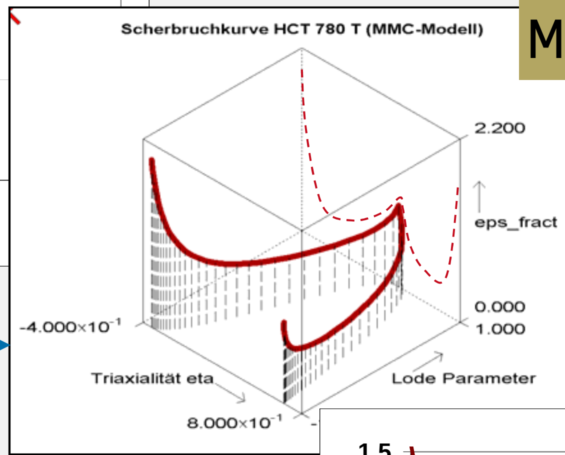
Experiment partly in-house
⇒ Basic fracture data



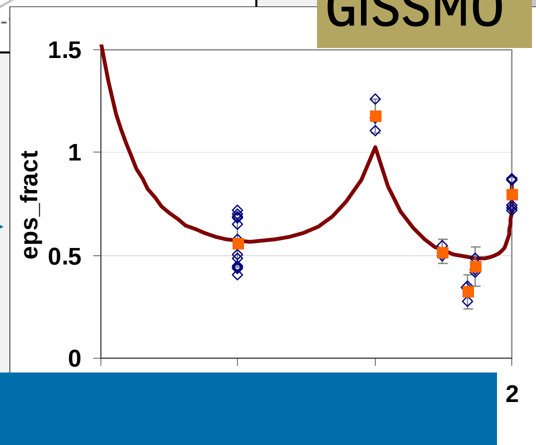
CrachFEM $\varepsilon_{SF} = f(\Theta)$



MMC/MIT $\varepsilon_{fract} = f(I_1, I_3)$



GISSMO



➔ To aspire model compatibility for fracture data

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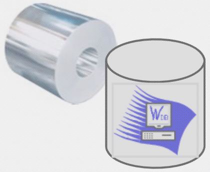
R&D activities at ThyssenKrupp Steel Europe

Material data and measurement



- Validation of measuring techniques for simulation purposes
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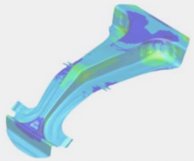
Material hardening



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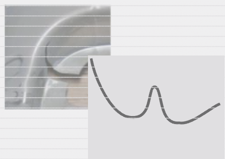
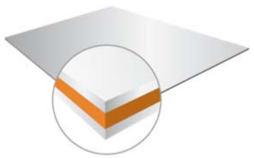
Material failure



- Instability
- Beyond instability (shear fracture)

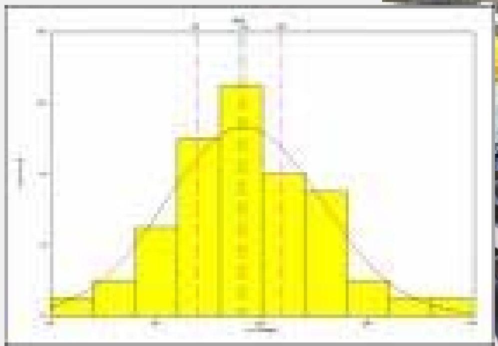
Robustness and new Products



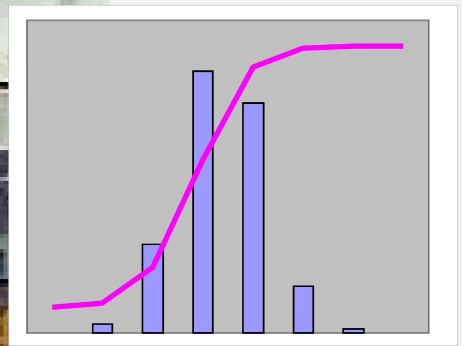
- Process stability and robustness
- Innovative material support for LITECOR®

Application of complex models for robustness simulation

A rough sketch with a selection of result impact parameters



Input



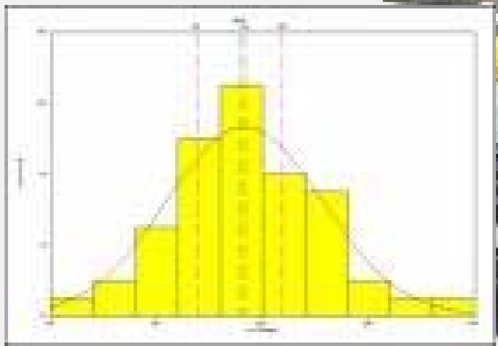
Output

Simple model (only tensile test)

Complex model (tensile test and more)

Application of complex models for robustness simulation

A rough sketch with a selection of result impact parameters



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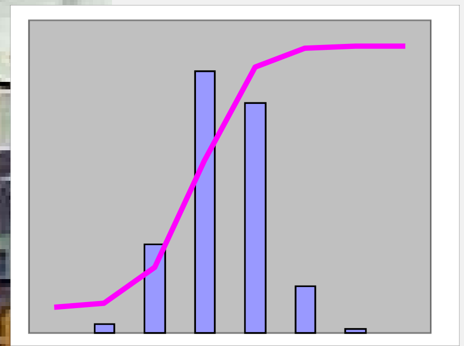


Output

Simple model (only tensile test)

TK-Moduls:

TEM, FLC-Regression

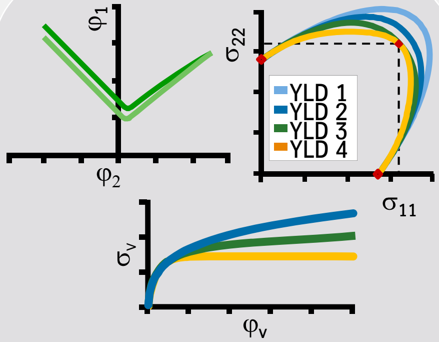
Complex model (tensile test and more)

Checking of material group simplifications for modeling

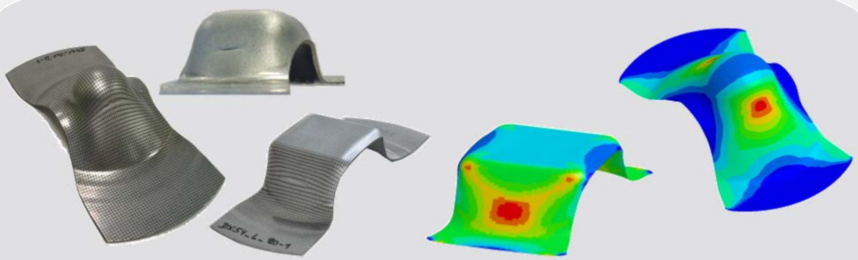
Family parameters for a group of steel grades

Various production runs different material grades

Model 1
Model 2
Model 3



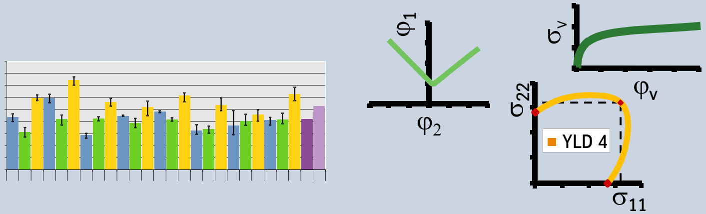
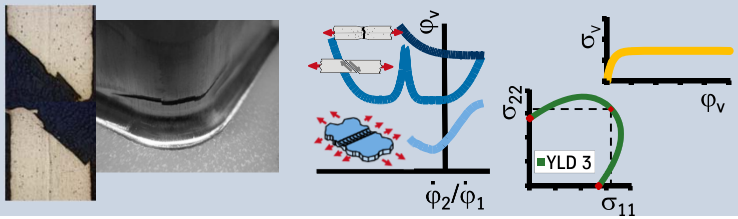
Material modelling components



Validation of exactness

Model 2

Model 3

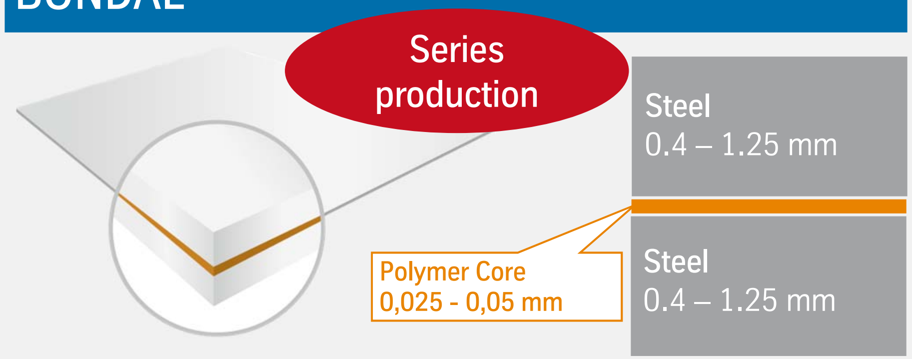
Material grade family A	Material grade family B	...
		

ThyssenKrupp Steel Europe

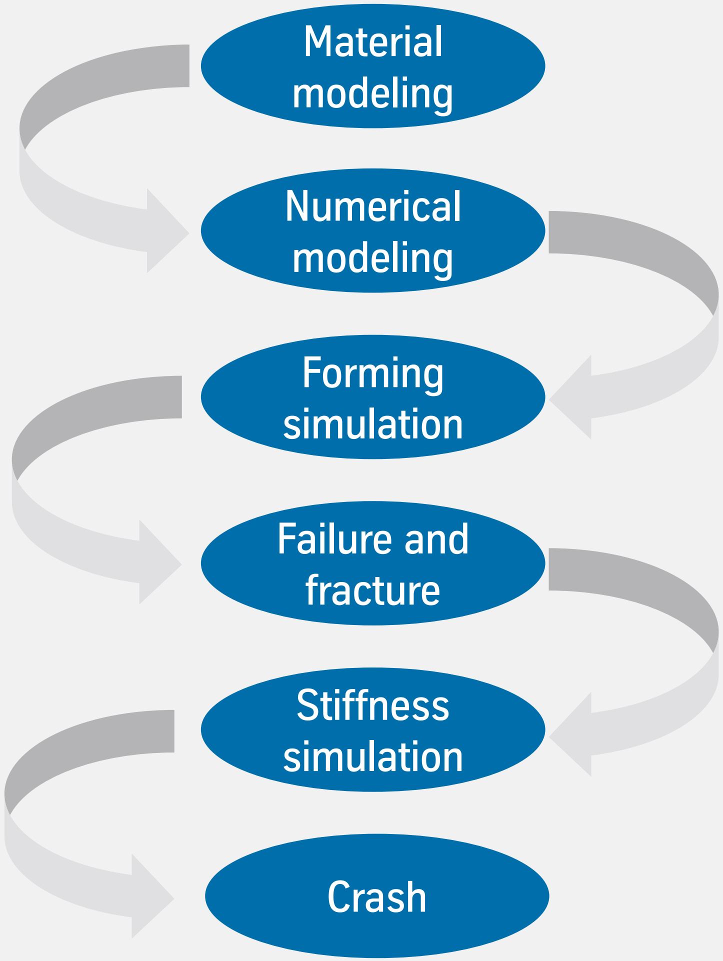
Expanded simulation support for sandwich materials (LITECOR®)

How to handle new products with reliable results in simulation?

BONDAL®



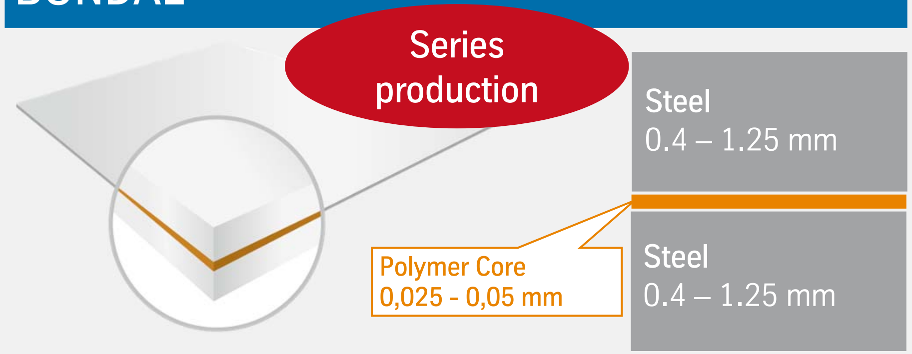
Sandwich LITECOR®



Expanded simulation support for sandwich materials (LITECOR®)

How to handle new products with reliable results in simulation?

BONDAL®



Sandwich LITECOR®

- Material modeling
- Numerical modeling
- Forming simulation

See also:

Session: Crash II – Composites 16:20 – 16:40

D. Pieronek, T. Böger, R. P. Röttger

Modellierungsansätze für Stahl-Polymer-Verbundbleche in der automobilen Crashsimulation

Conclusion and outlook

- The ambition to optimize the virtual production process leads to
  - a need of more and more material data
  - activities in order to generate standards for new experiments

- This process is accompanied by material producers with
  - activities of expanding the simulation data base
  - cross checking of typical simulation data
  - generating in-house measurement possibilities
  - a development of fast simplification methods to access modern modeling options
  - simplification methods to allow a carry over to robustness simulation

➔ We still have to remember, that material data is only a small part in simulation