HEGGEMANN

360 Years of Innovation

Isothermal hot forming of Titanium sheet metal
From parameter identification to customer parts

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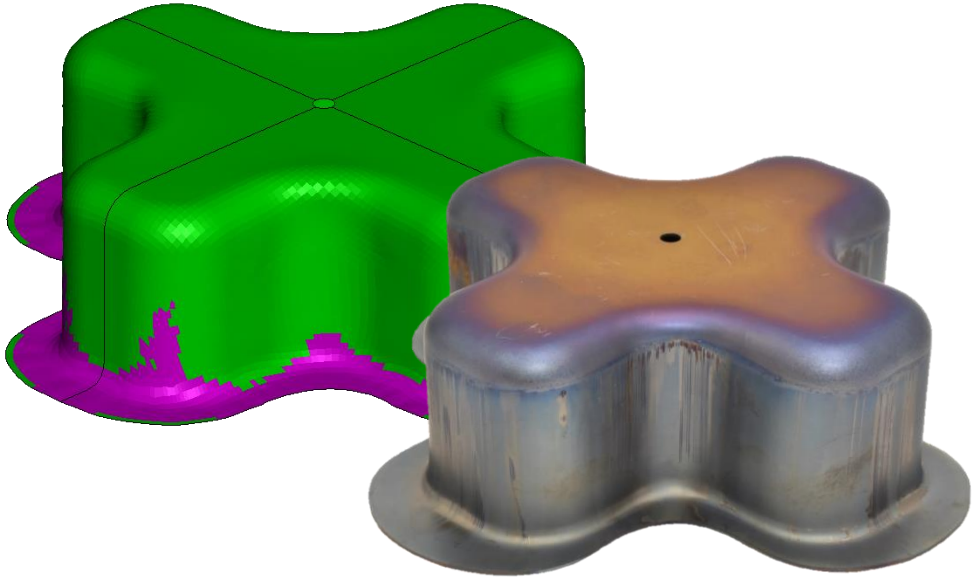
DYNAmore Infoday Automotive and Aerospace Applications, December 1, 2022 - Berlin

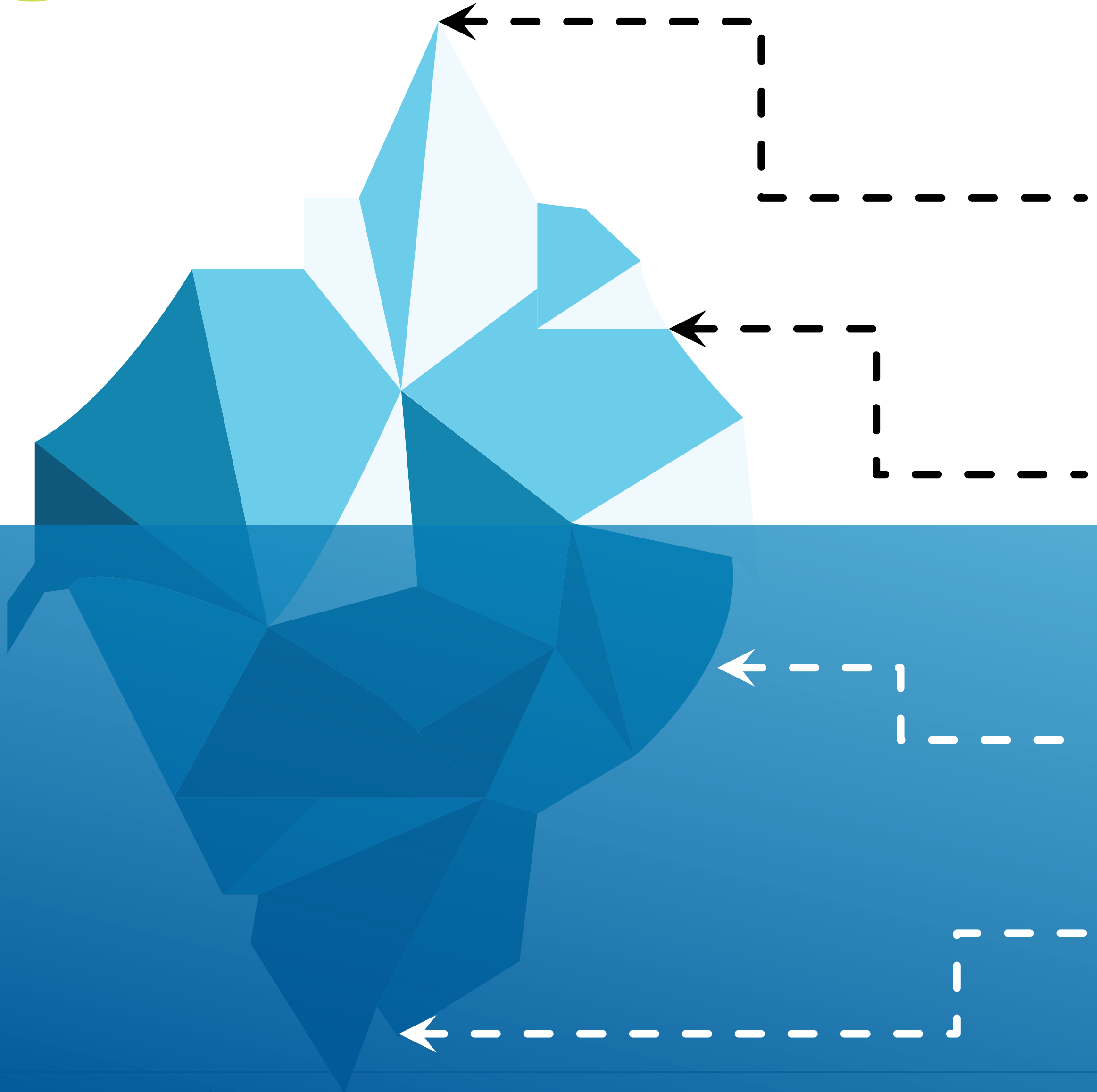
SCOPE

- Why numerical simulation in aerospace?
- Setup of simulation models
- Inhouse parameter identification
- Verification on technological specimen
- Validation on component-like specimen
- Summary & Outlook



In Cooperation with

Why numerical simulation in aerospace?



Drawing Requierments

Is forming the right technology for complex thin walled parts? Can hot forming by HEGGEMANN AG be a solution for the problem?

Drawing Ratio

What temperature range do we need to hit to achieve the largest possible drawing ratio?

Material Behavior

Does the component reaches the restrictions for permissible thinning? What is the degree of plastic deformation?

Geometric Behavior

Do we meet the customer specification in terms of shape and condition? How pronounced is the springback?

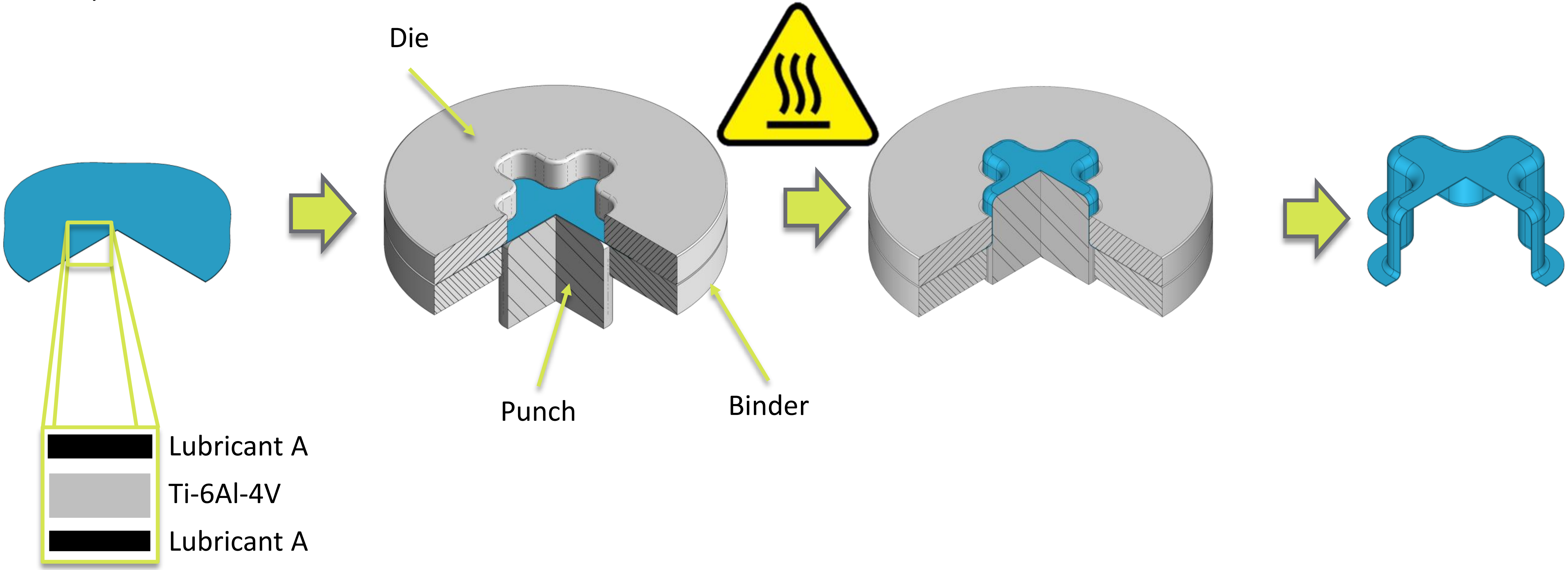
Hot Forming – Deep Drawing

Coated semi-finished product

Temperature-controlled deep-drawing process

ϑ = 25 °C – 850 °C

Formed part



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Numerical simulation – Methodical approach

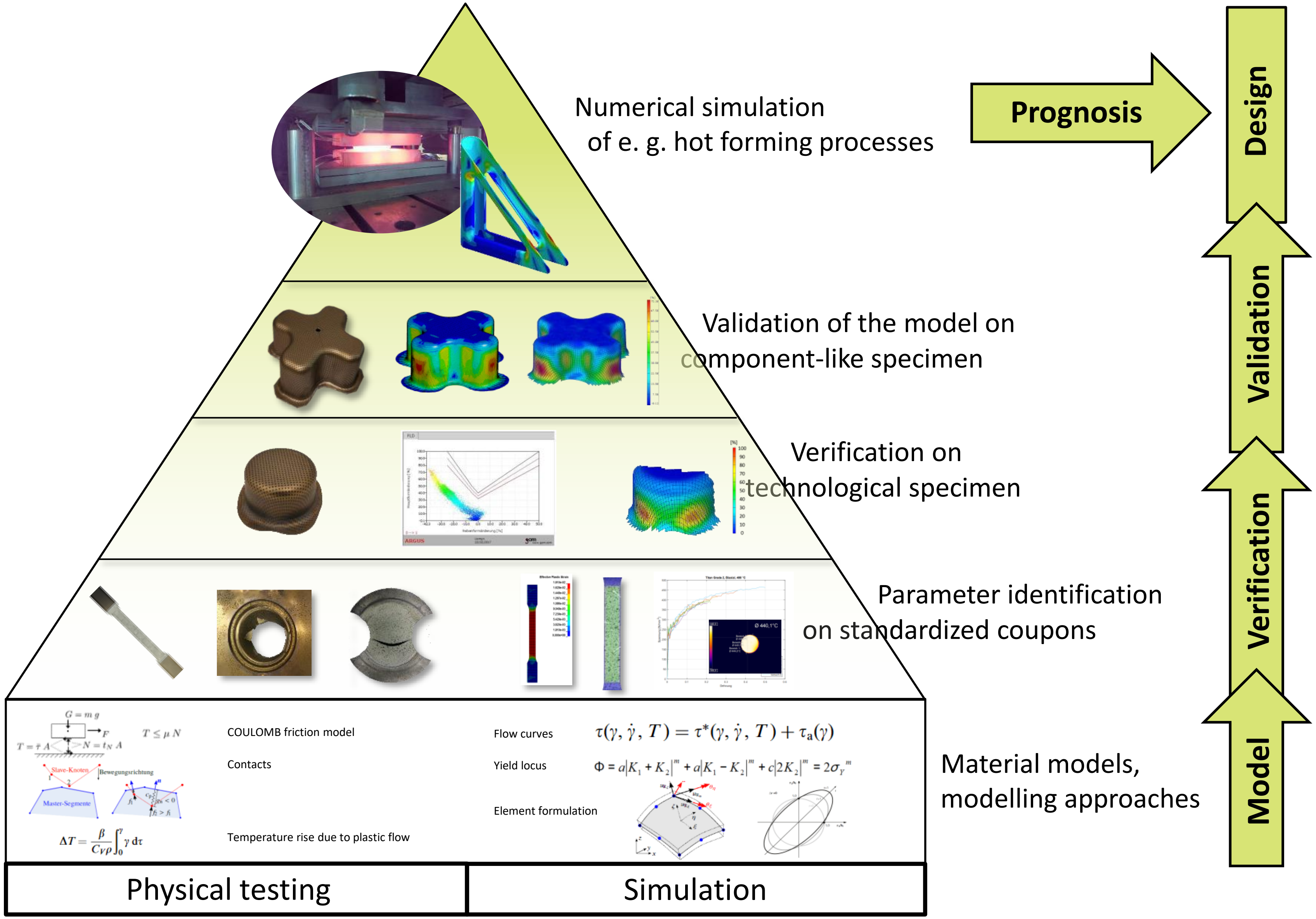


Illustration according to LWF University Paderborn; University Kassel

Numerical simulation – Methodical approach

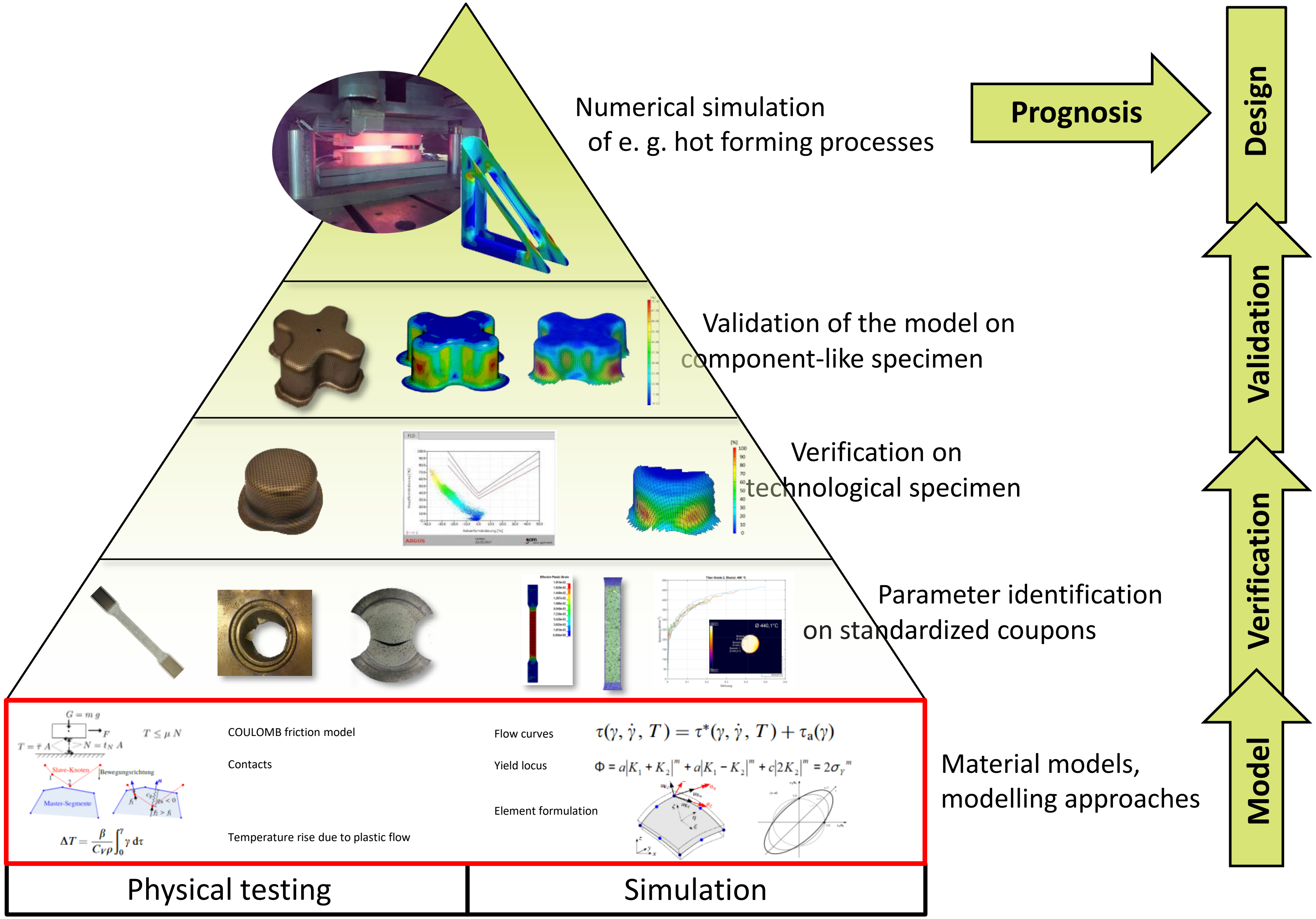
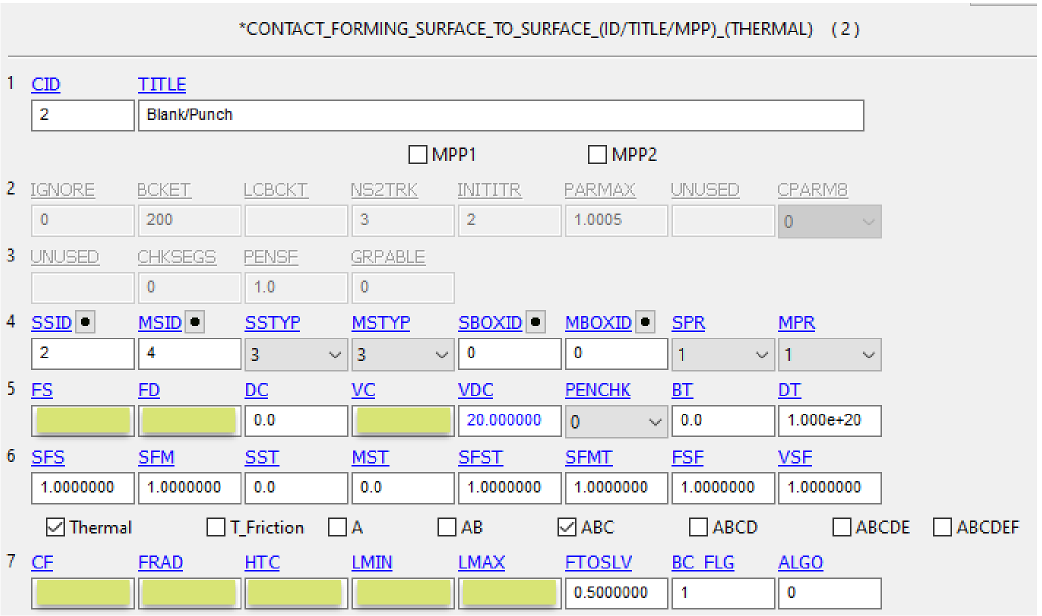
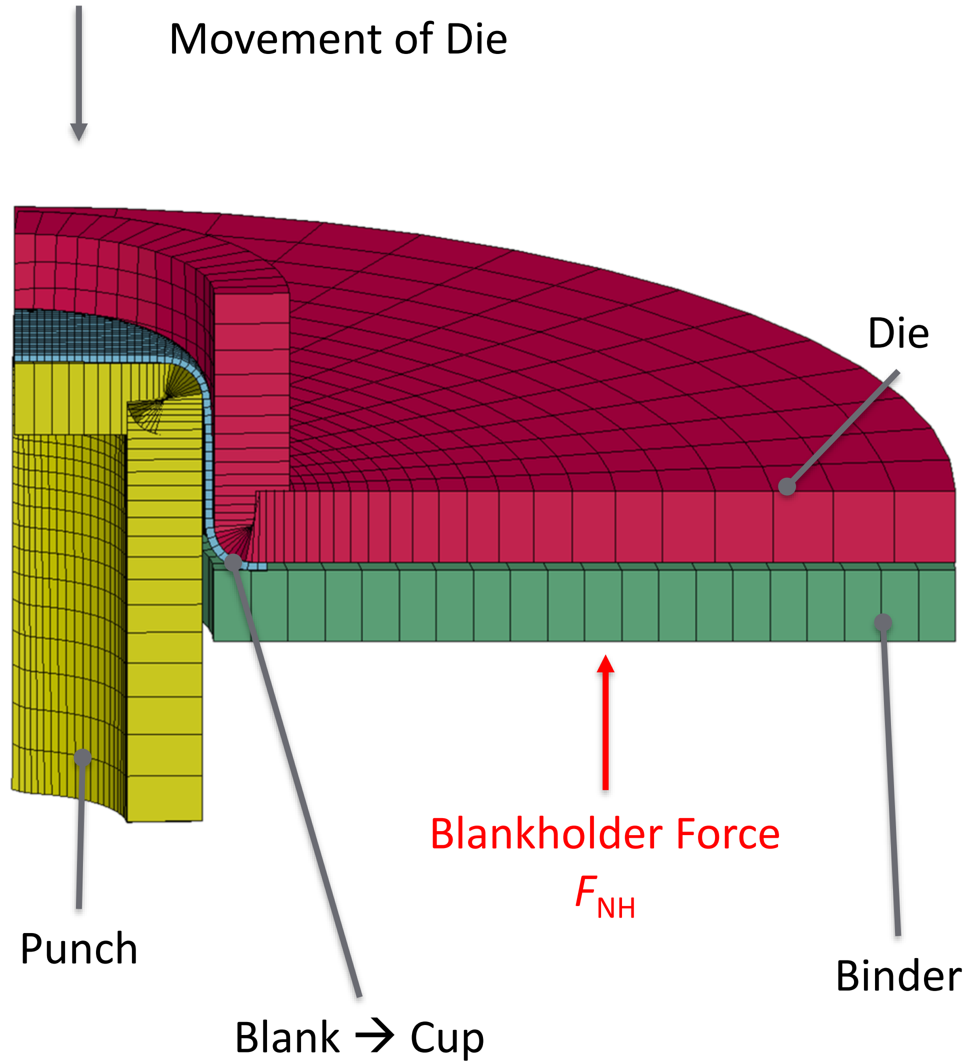


Illustration according to LWF University Paderborn; University Kassel

Structure of deep drawing simulation at HEGGEMANN AG

Contact definition	
Parameter	**Settings**
Element type	Shell element
Element formulation Tools	Belytschko-Lin-Tsay (ELFORM=2)
Element formulation Blanks	Fully-integrated (ELFORM=16)
Integration rule	Gauß-Lobatto-Integration
Element Size	1 mm – 1,5 mm
Thermal element formulation	Thermal thick shell





Structure of deep drawing simulation at HEGGEMANN AG

- **LS-Dyna Material cards**
  - Mat_036-3-Parameter_Barlat (BARLAT 89)
  - Mat_000-Add_Thermal_Expansion (Thermal expansion)
  - Mat_T10-Thermal_Isotropic (Conduction, Convection)
  - Mat_020_Rigid (Rigid bodies)

- **LS-Dyna Solver**
  - LS-Run R12.1.0

*MAT_3-PARAMETER_BARLAT_(TITLE) ((null)) (1)

TITLE

MAT_36_Ti64

1	MID	RO	E	PR	HR	P1	P2	ITER
	2	4.434e-09	1.151e+05		9.0	1.0000000	1.0000000	0.0
2	M	R00	R45	R90	LCID	E0	SPI	P3
					9900	0.0	0.0	0.0

```
*KEYWORD
*PARAMETER
$#   prmr1       val1      prmr2       val2      prmr3       val3      prmr4       val4
Rtem_blank20
R tem_tool500
R   Re_min468
R  t_blank1.05
R        SBC5.670E-11
R epsblank0.781655
R  epstool0.74711
R        sfa1
*PARAMETER_EXPRESSION
R  tem_air(tem_blank+tem_tool)/2
R         vcRe_min/1.732050808
R         cf-1.5e-8*tem_air*tem_air+7.2e-5*tem_air+0.02436
R      fradSBC/((1/epsblank)+(1/epstool)-1)
$=============================================================================$
$                                                                             $
$                                                                             $
$   _   _ _____ ____  ____ _____ __  __    _    _   _ _   _      _    ____    $
$  | | | | ____/ ___|/ ___| ____|  \/  |  / \  | \ | | \ | |    / \  / ___|   $
$  | |_| |  _|| |  _| |  _|  _| | |\/| | / _ \ |  \| |  \| |   / _ \| |  _    $
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$  |_| |_|_____\____|\____|_____|_|  |_/_/   \_\_| \_|_| \_| /_/   \_\____|   $
$                                                                             $
$=============================================================================$
$                                                                             $
$ Unit System: ton. mm. sec                                                   $
$                                                                             $
$ - Time Scaling with the parameter SFA                                       $
$           => SFA = 0                                                        $
$                                                                             $
$ Zu def. Parameter:tem_blank Anfangstemperatur Blech                         $
$                    tem_tool Anfangstemperatur Werkzeug                      $
$                      re_min Minimales Re des Werkstoffs bei t_tool          $
$                     t_blank Ausgangsblechdicke                              $
$                         SBC Stephan-Bolzmann Konstante                      $
$                    epsblank Emissionskoeffizient des Blechs (siehe Tabelle) $
$                     epstool Emissionskoeffizient der Werkzeuge (konstant)   $
$                         sfa Shift-Faktor für Fließkurven und thermische Seite$
$                                                                             $
$ Berechnette Parameter: tem_air Temperatur der Luft im Spalt                 $
$                             vc Schubfließgrenze des Materials               $
$                             cf Wärmeleitfähigkeit der Luft bei t_tool       $
$                           frad Strahlungskoeffizient der Luft               $
$=============================================================================$
```
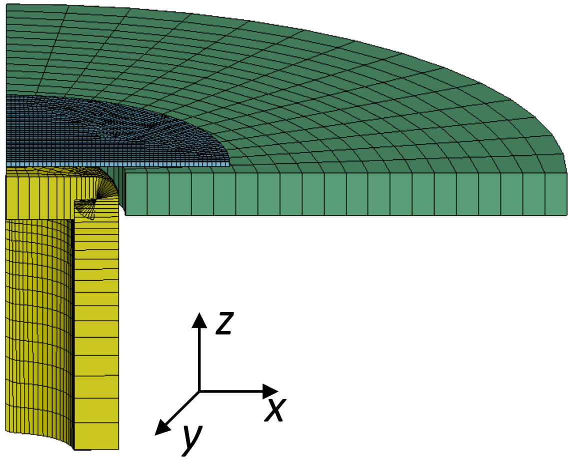
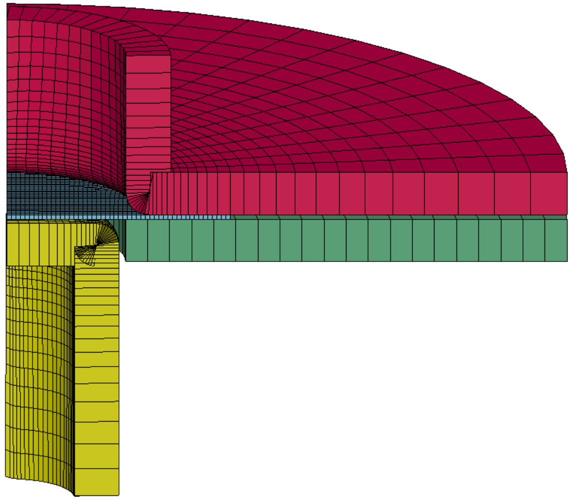

Operation procedure of the thermomechanic deep drawing simulation

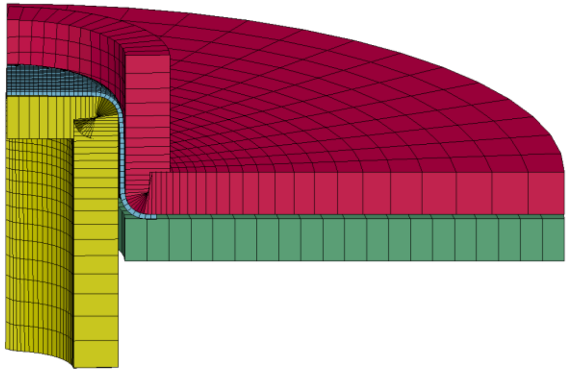
OP10: Positioning



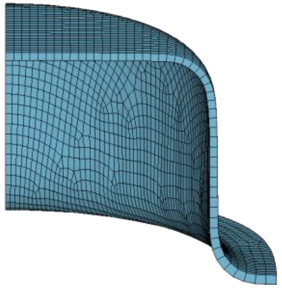
OP20: Closing of tools



OP30: Forming



OP40: Cooling & Springback



Attention: Shell thickness is just visualized! → No Solids

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Numerical simulation – Methodical approach

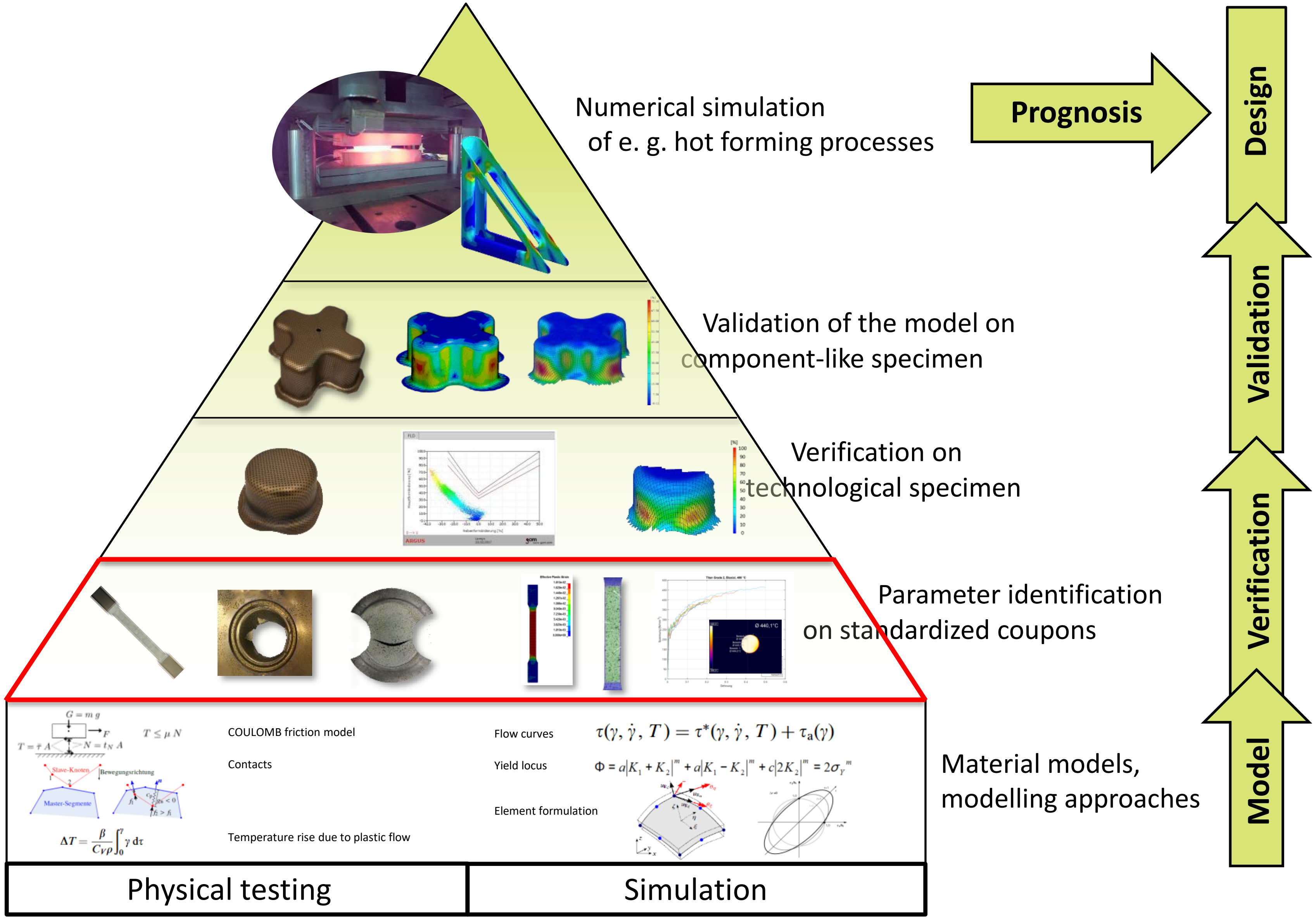
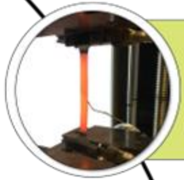


Illustration according to LWF University Paderborn; University Kassel

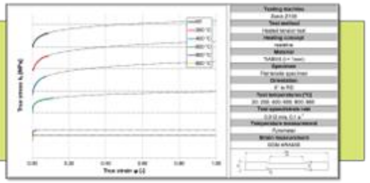
Advanced inhouse parameter identification

Determination of all parameters up to 850 °C



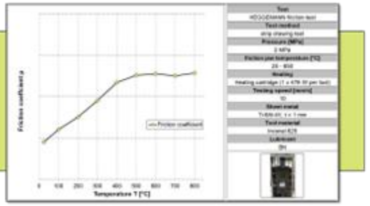
Flow curves

- Materials Testing Machine Zwick Z100
- Crosshead speed 0,0001 – 1500 mm/min
- Strain measurement by fine strain measurement or by GOM ARAMIS



Friction

- Contact pressure up to 50 MPa
- Heated or cooled tools
- Strip velocity up to 50 mm/s
- Sheet thickness < 3 mm

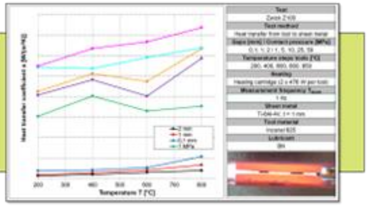


Forming test

- Cupping test (punch Ø 50 mm)
- Cross die test
- Heated or cooled tools
- Force-displacement curves

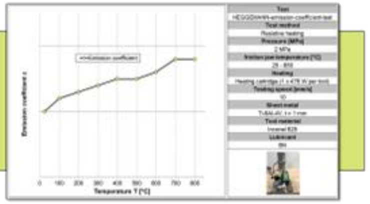
Heat transfer

- Contact pressure up to 50 MPa
- Heated or cooled tools
- Variable gap widths



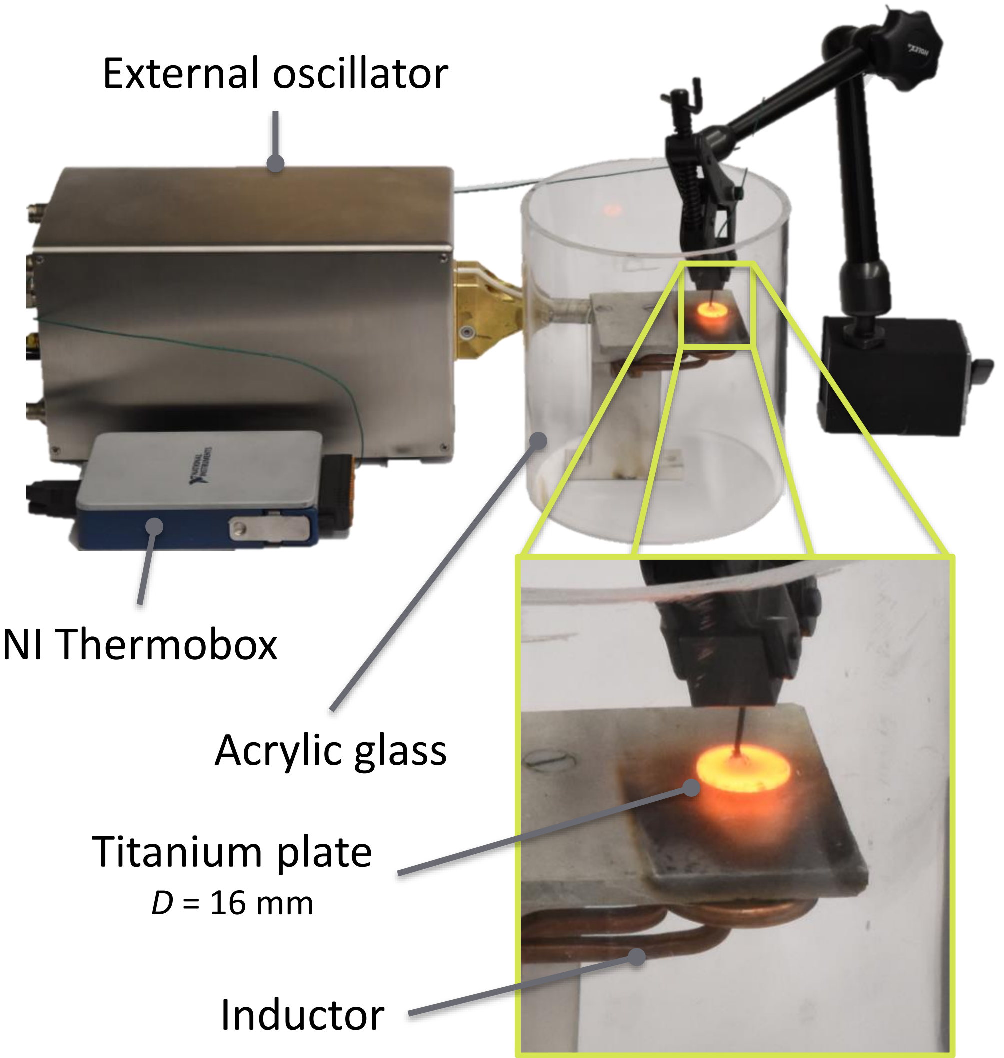
Emissivity

- Determination of emission coefficients
- Dry or lubricated surfaces
- Temperature measurement by pyrometer and themocouple



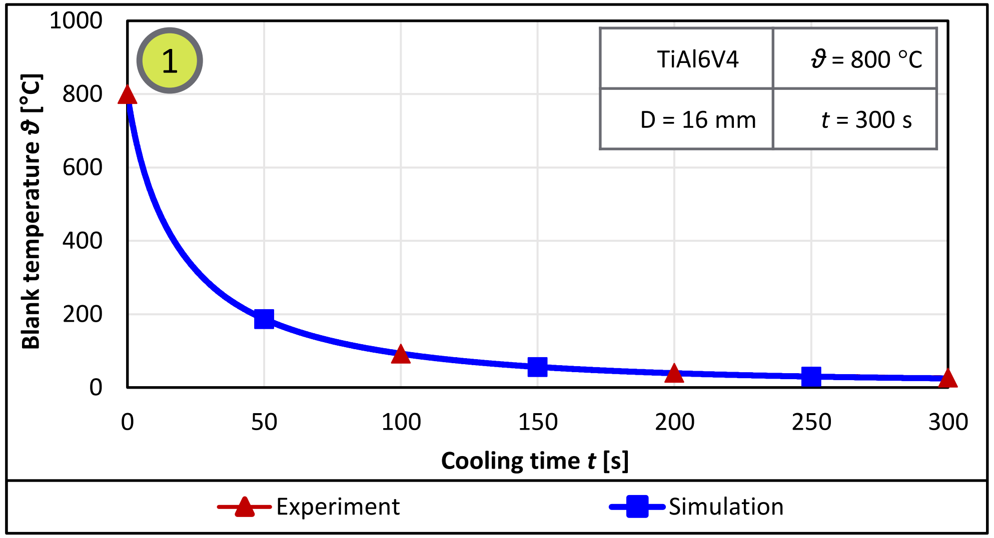
Inverse calculation of the convection coefficient

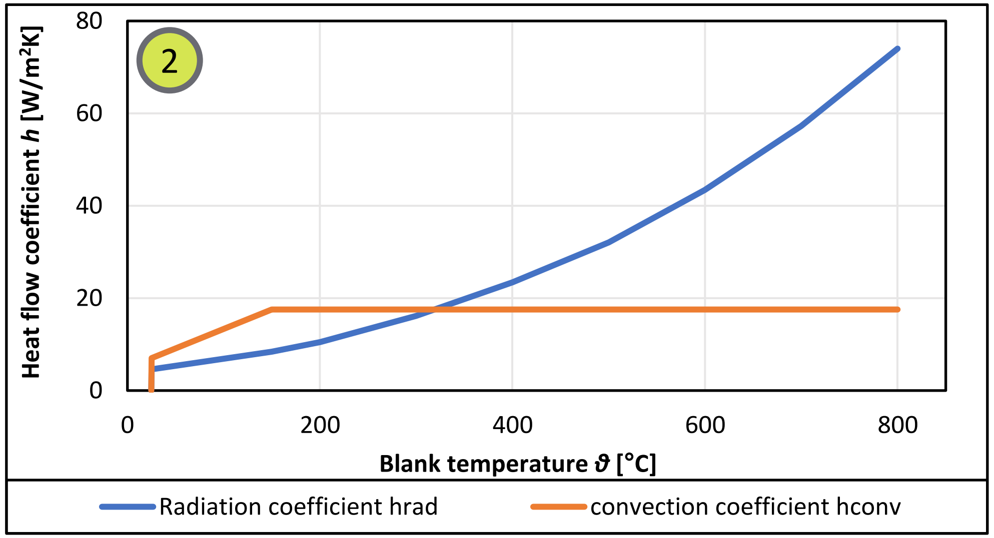
Experimental Setup



$$\dot{Q} = h * A * \Delta T$$

Evaluation





Numerical simulation – Methodical approach

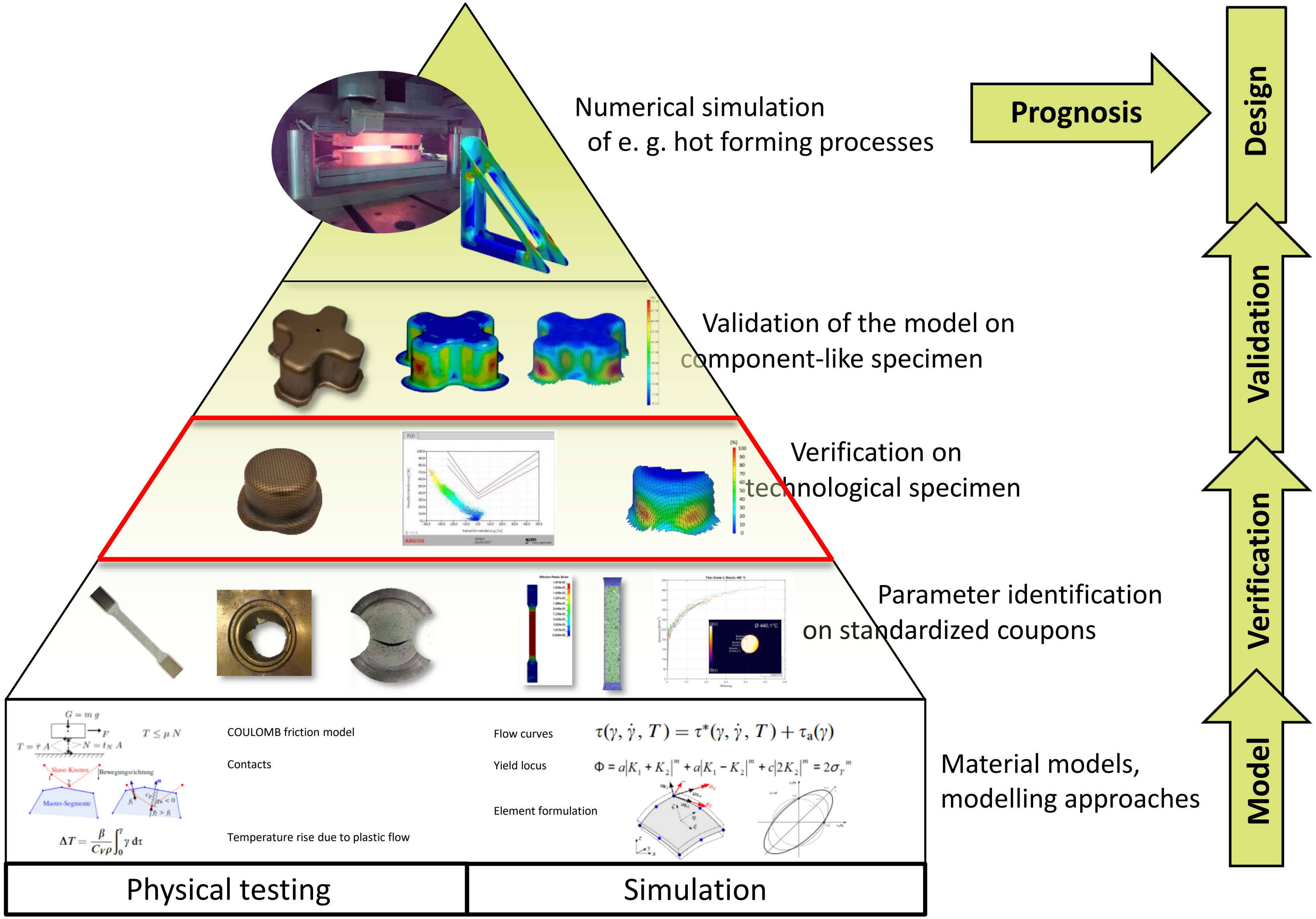
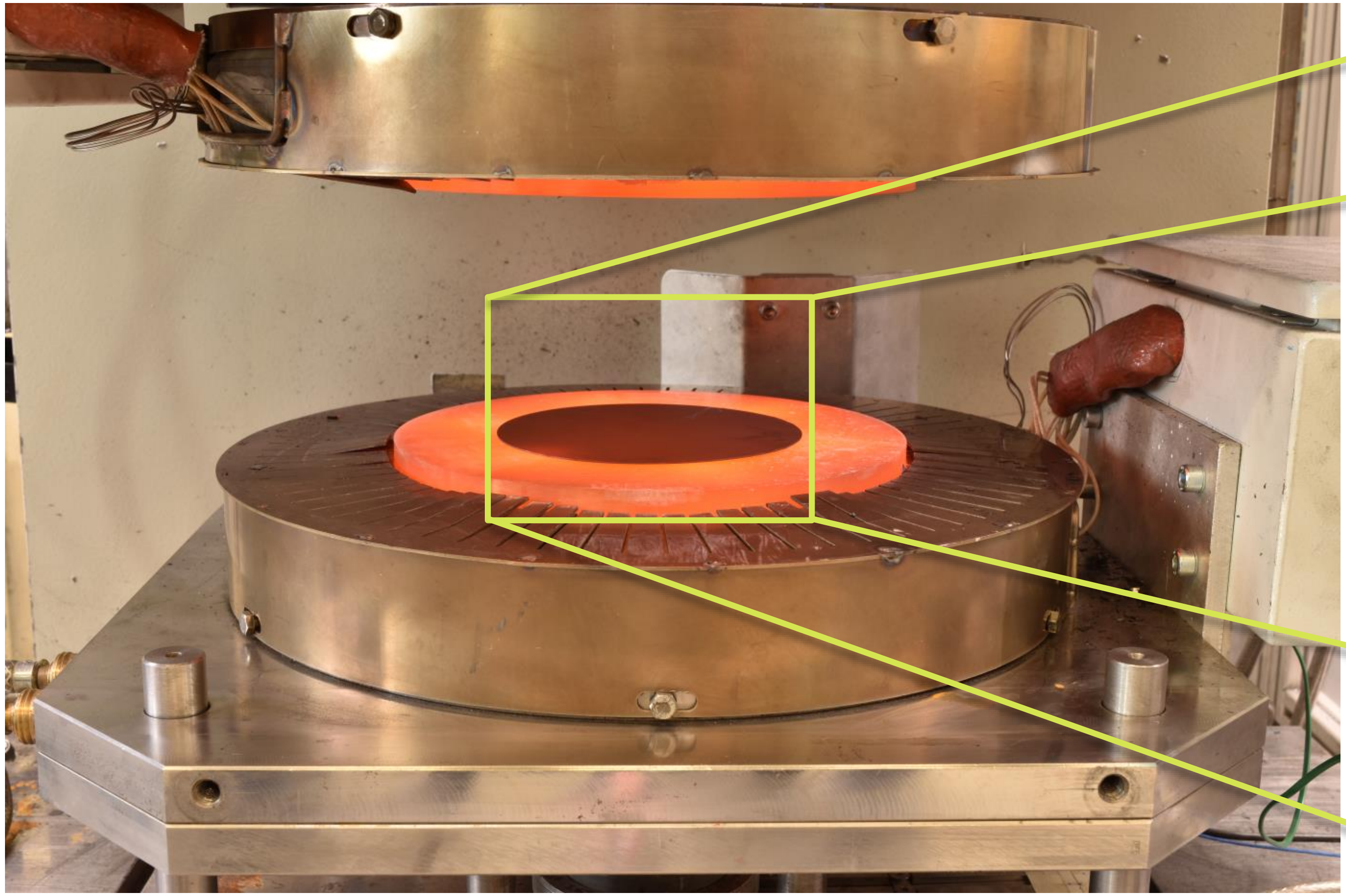
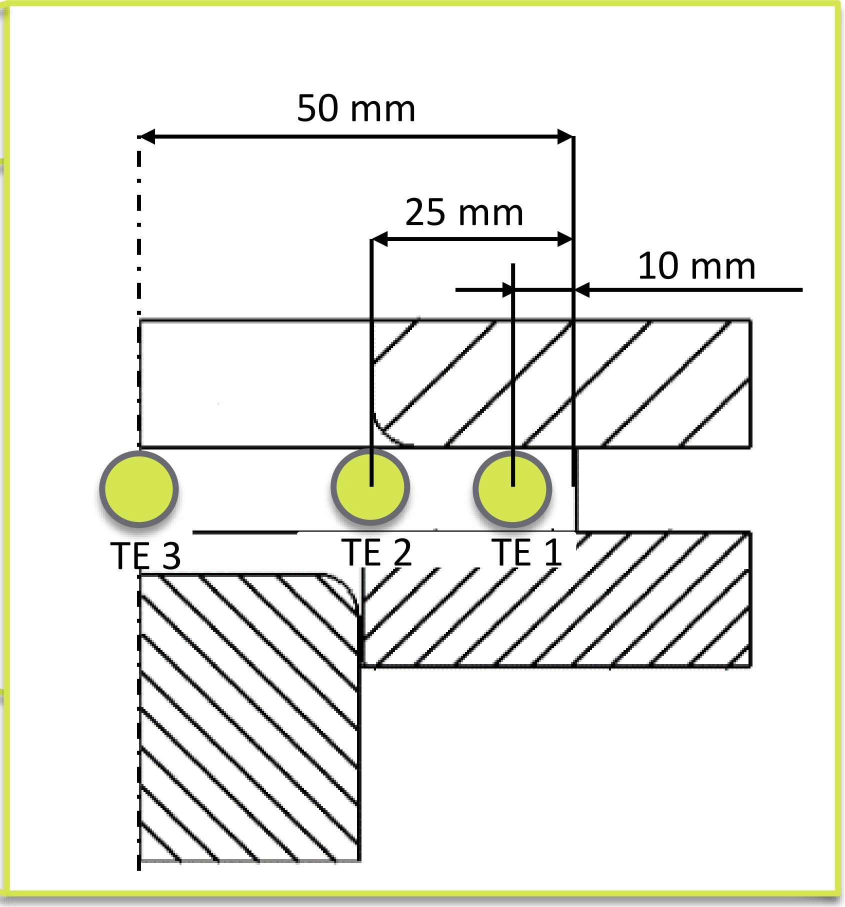


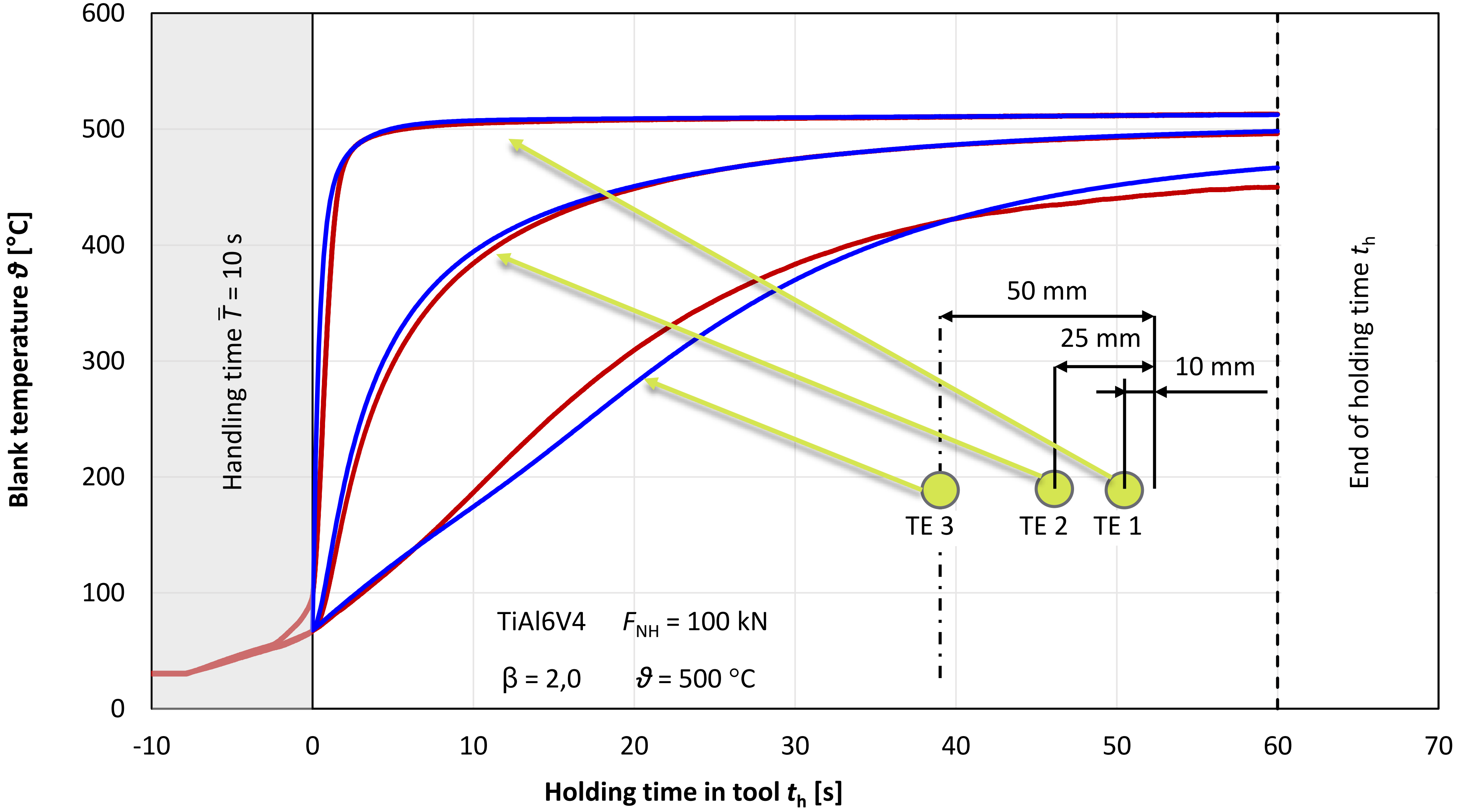
Illustration according to LWF University Paderborn; University Kassel

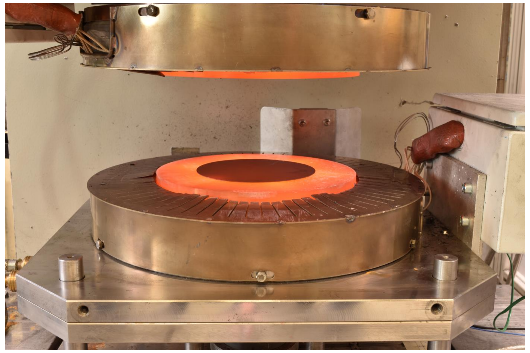
Determination of the temperature field





Verification of temperature distribution





Numerical simulation – Methodical approach

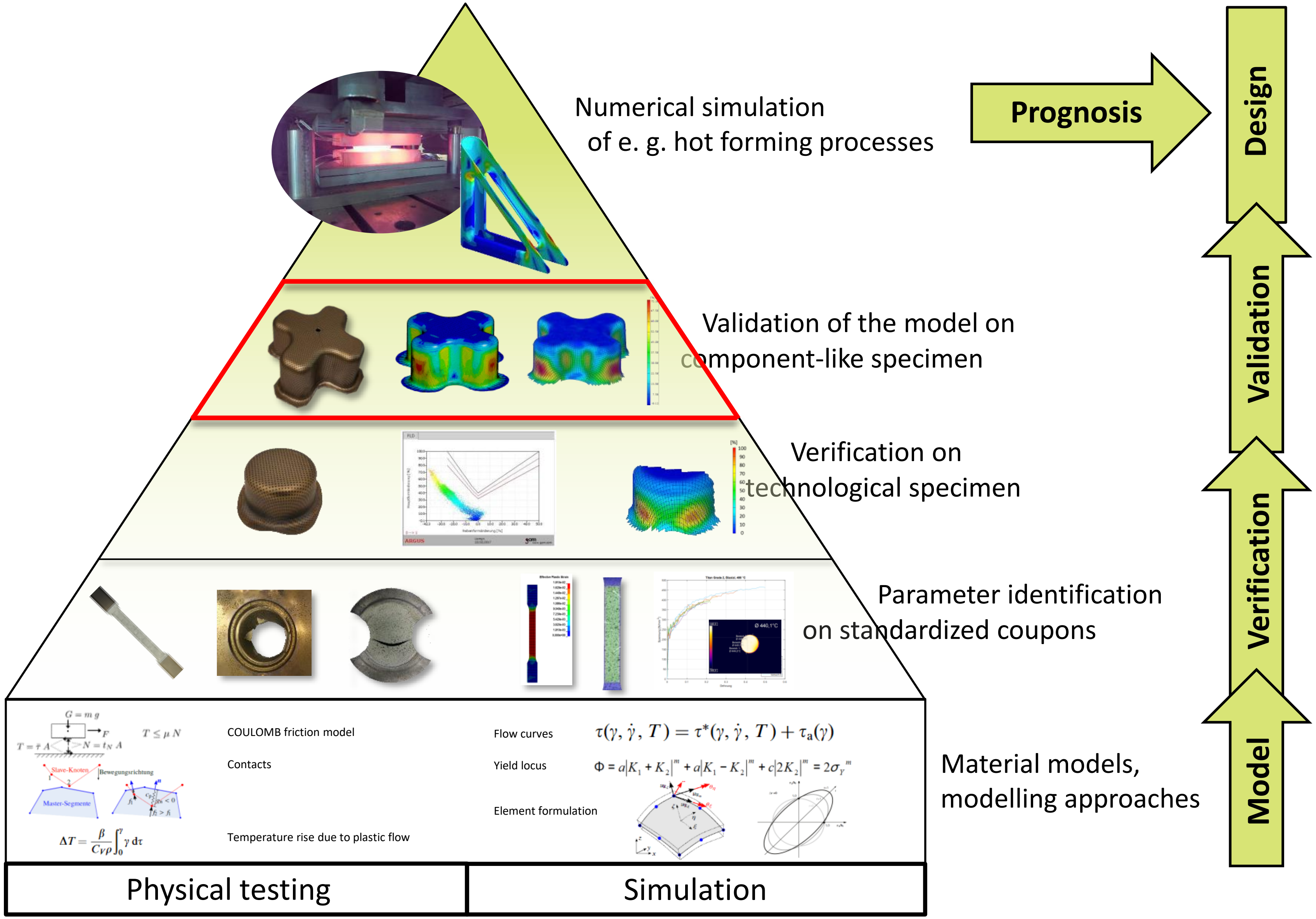


Illustration according to LWF University Paderborn; University Kassel

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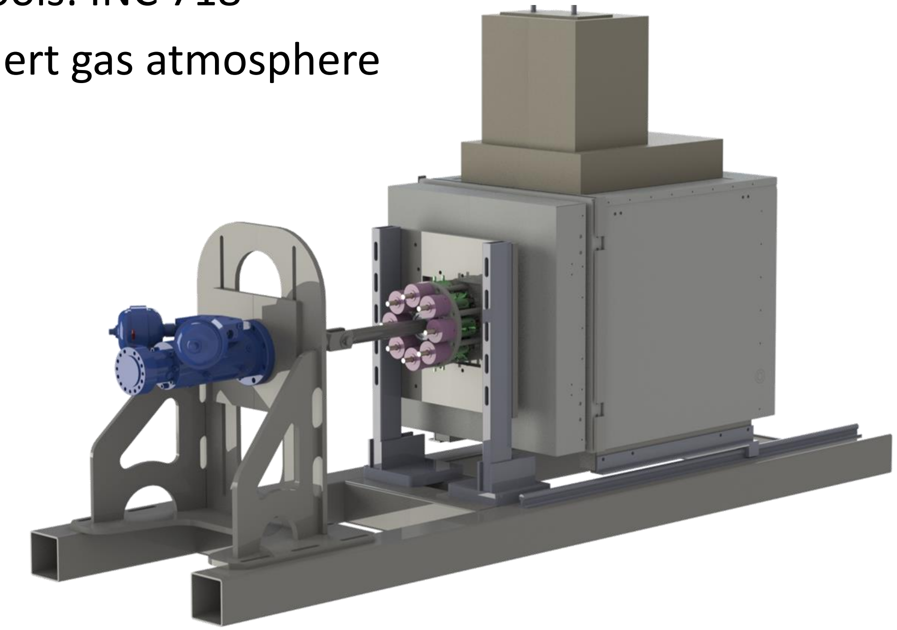
Unique High-Temperature Nakajima Teststand

- **Specifications:**
  - Punch diameter: 100 mm
  - Binder force: max. 8* 54 kN
  - Temperature range: max. 850 °C
  - Temperature distribution: ±10 °C
  - Evaluation: Optical by GOM Argus
  - Tools: INC 718
  - Inert gas atmosphere



LiA
www.Leichtbau-im-Automobil.de

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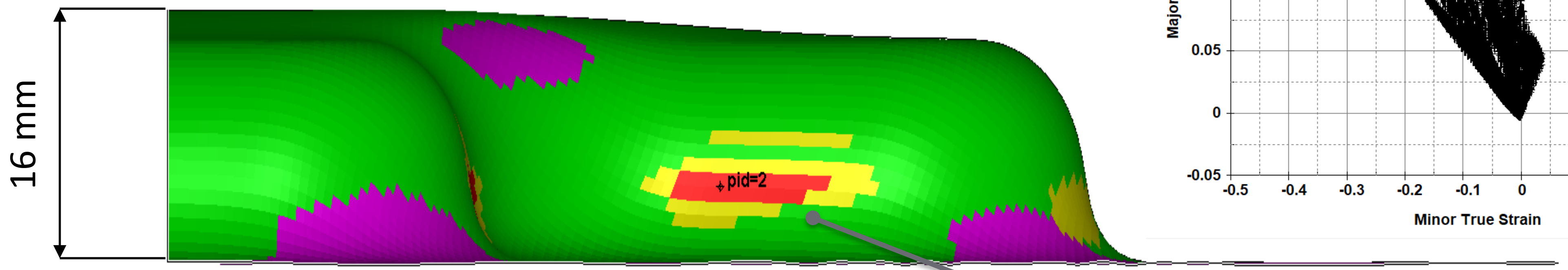
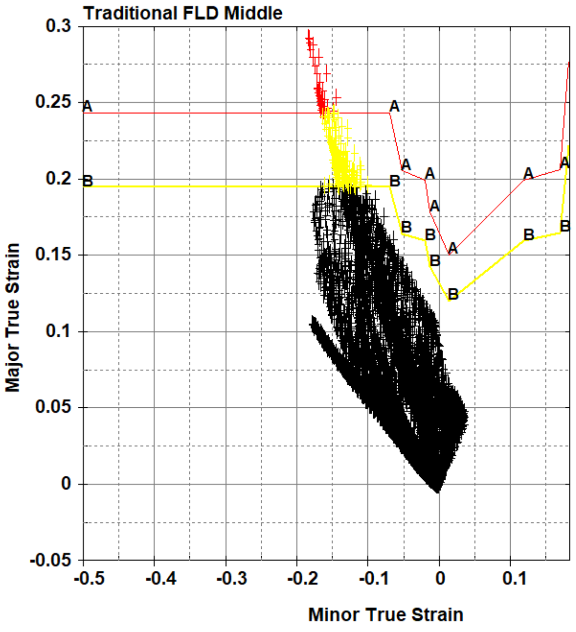
Process design for cross cup of Ti-6Al-4V

Temp. 1
TiAl6V4
β = 1,84
F_{NH} = -

Numerical forming result with FLC





Real forming result

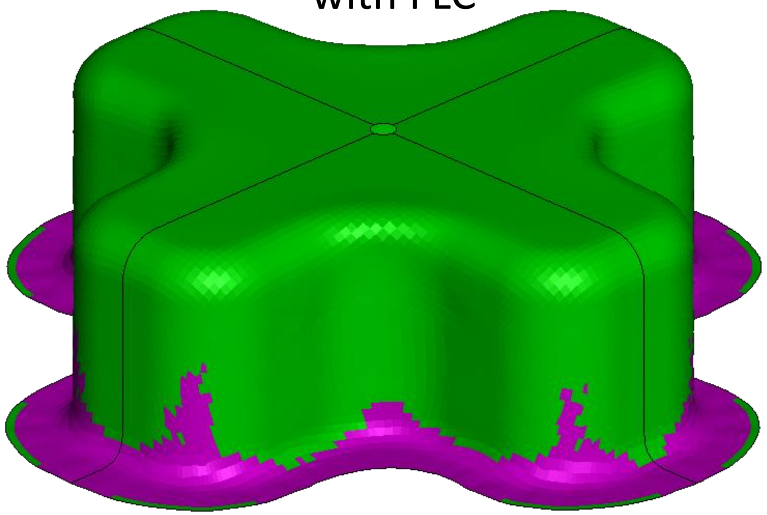
„S-shaped“ crack

(red)	Crack
(yellow)	Risk of Cracking
(green)	Correct
(purple)	Wrinkles

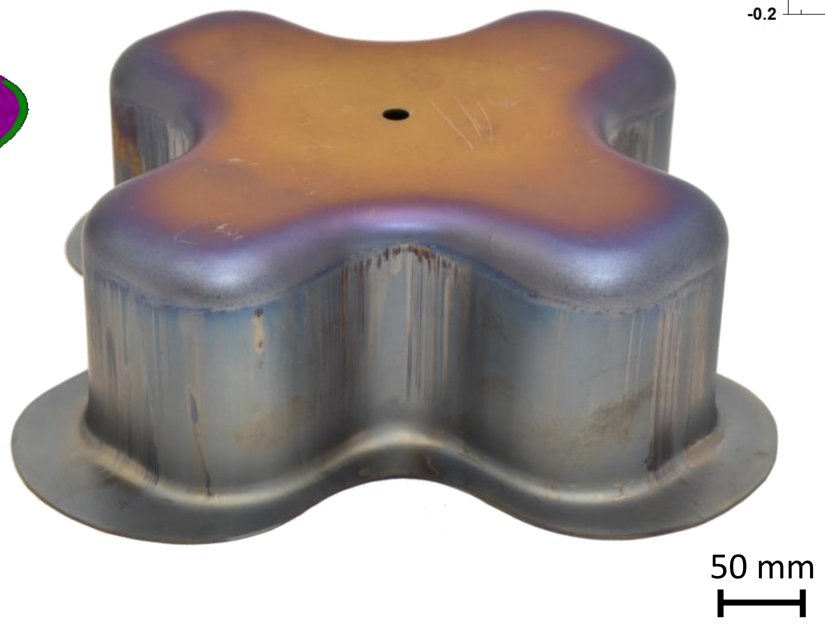
Process design for cross cup of Ti-6Al-4V

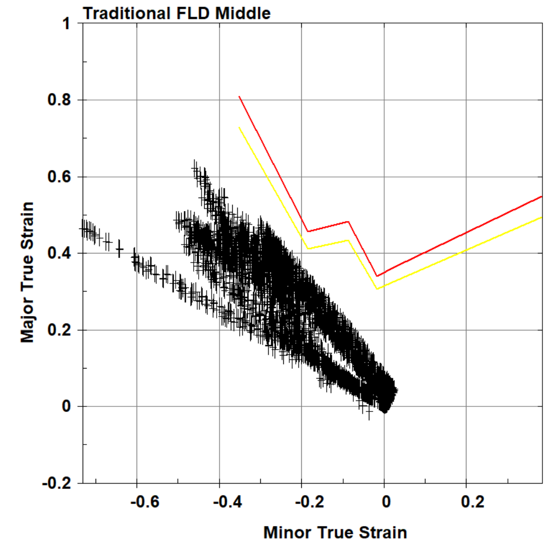
Temp. 2
TiAl6V4
β = 1,84
F_{NH} = -

Numerical forming result with FLC



Real forming result





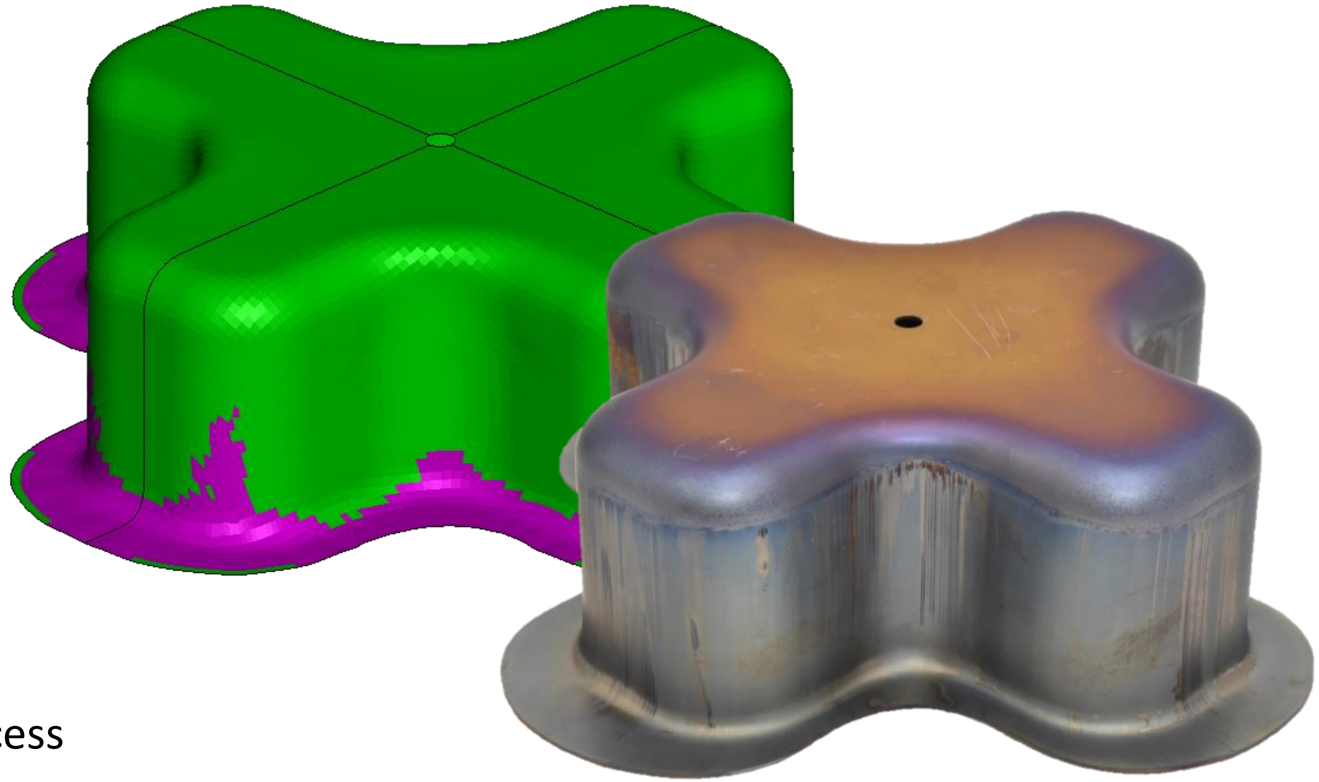
(red)	Crack
(yellow)	Risk of Cracking
(green)	Correct
(purple)	Wrinkles

Summary

- **HEGGEMANN AG inhouse testing**
  - Advanced Parameter identification up to 850 °C
  - Mechanical and thermal parameters

- **HEGGEMANN hot forming simulation**
  - Validated simulation models
  - High accuracy of applied models
  - Hot and cold forming

- **Advanced process evaluation**
  - Analysis of influencing factors
  - Construction and adaptation of the tool
  - LS-Dyna is an integral part of the development process



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Outlook

- **Permanent expansion of testing capacities for better process understanding**
  - E.g. Heat transfer coefficient
- **Permanent customer related optimization of simulation modells and validation**
- **Research efforts for sustainable process chains**
- **Further Implementation of LS-Dyna in HEGGEMANN AG**

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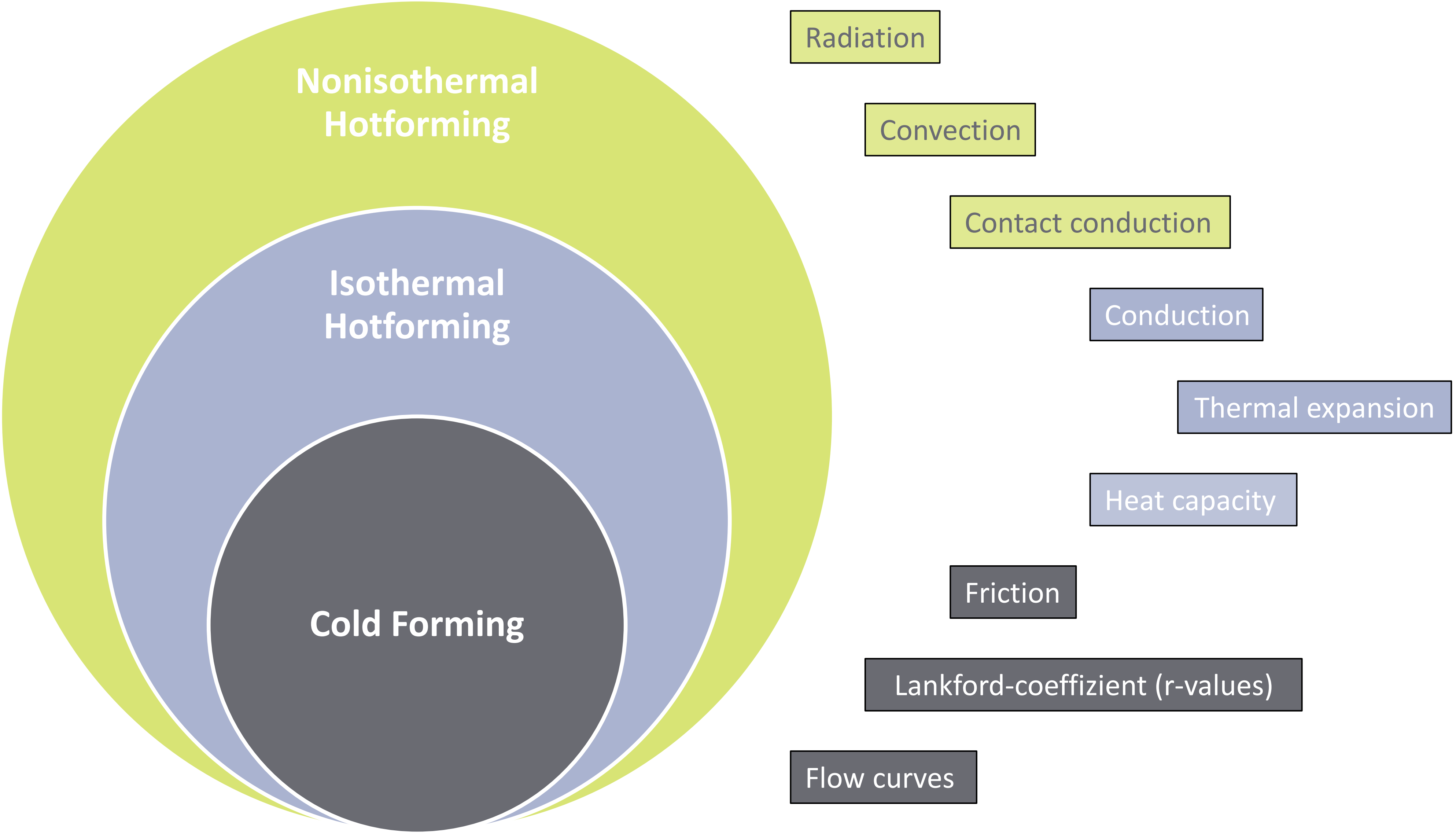
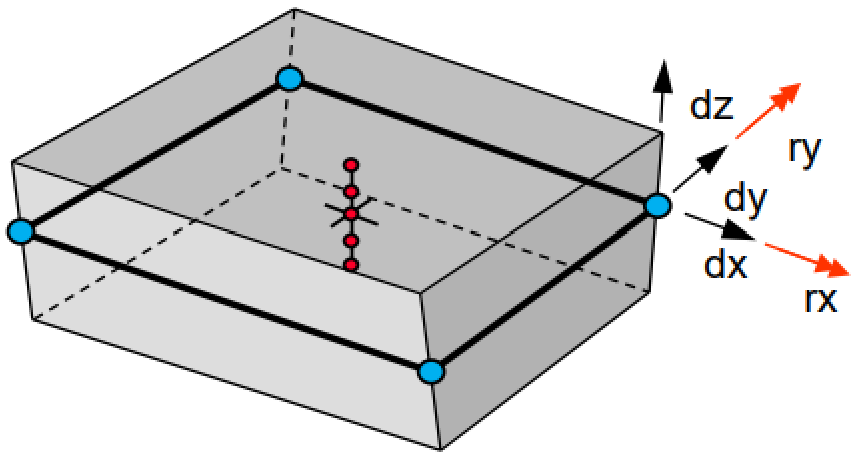
Your Development- and Manufacturing-Partner
for Customized Lightweight Design

Levels of simulation

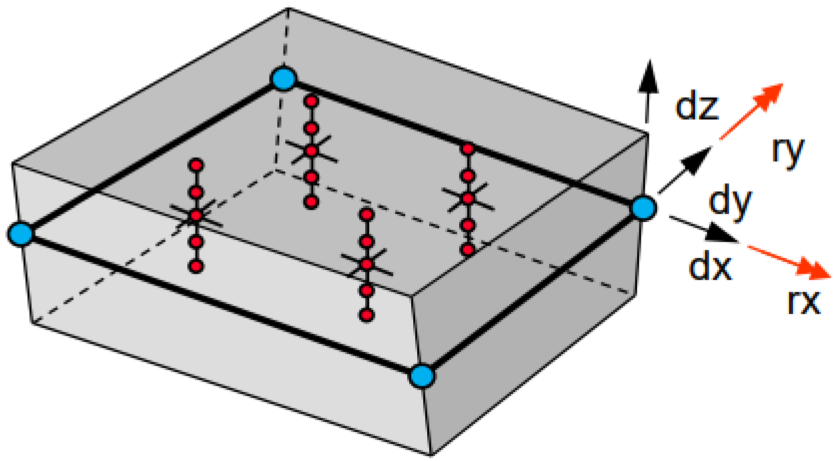


Element formulations

ELFORM=2



ELFORM=16



Belytschko-Tsay-Shell (Type 2)

- standard element with one point integration
- very fast
- problems in case of warping and large shear deformation
- very efficient: moderate accuracy (often sufficient) in combination with high speed
- Quality can be improved by:
  Belytschko-Wong-Chiang warping stiffness: *CONTROL_SHELL, bwc=1, proj=1
  (ca. 20% more CPU time)

→ Recommended shell element if speed is desired

Fully integrated shell (Type 16)

- fully integrated element with EAS-formulation and without Hourglass modes
- very fast for a fully integrated element (2.5 times more expensive than type 2)
- new standard element of Belytschko-Tsay group for increased accuracy
- Bathe/Dvorkin method for improvement of transversal shear
- behaviour of warped elements can be improved by
  *HOURGLASS, IHQ=8 (15% speed penalty)

→Recommended shell element if accuracy is desired

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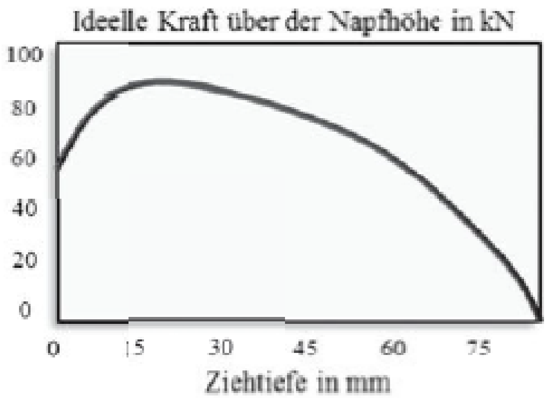
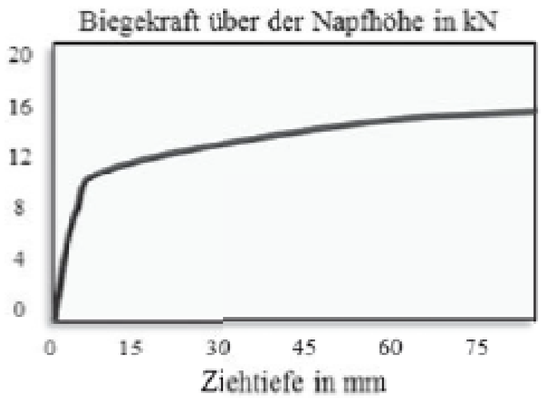
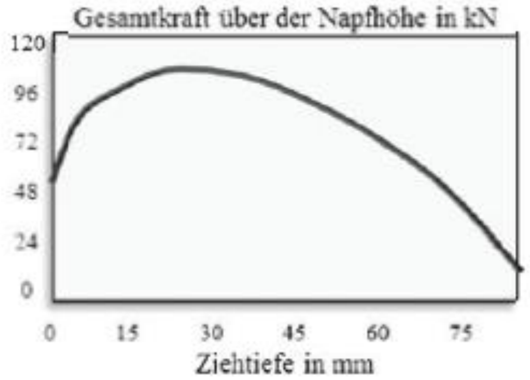
Superposition of the punch force curve



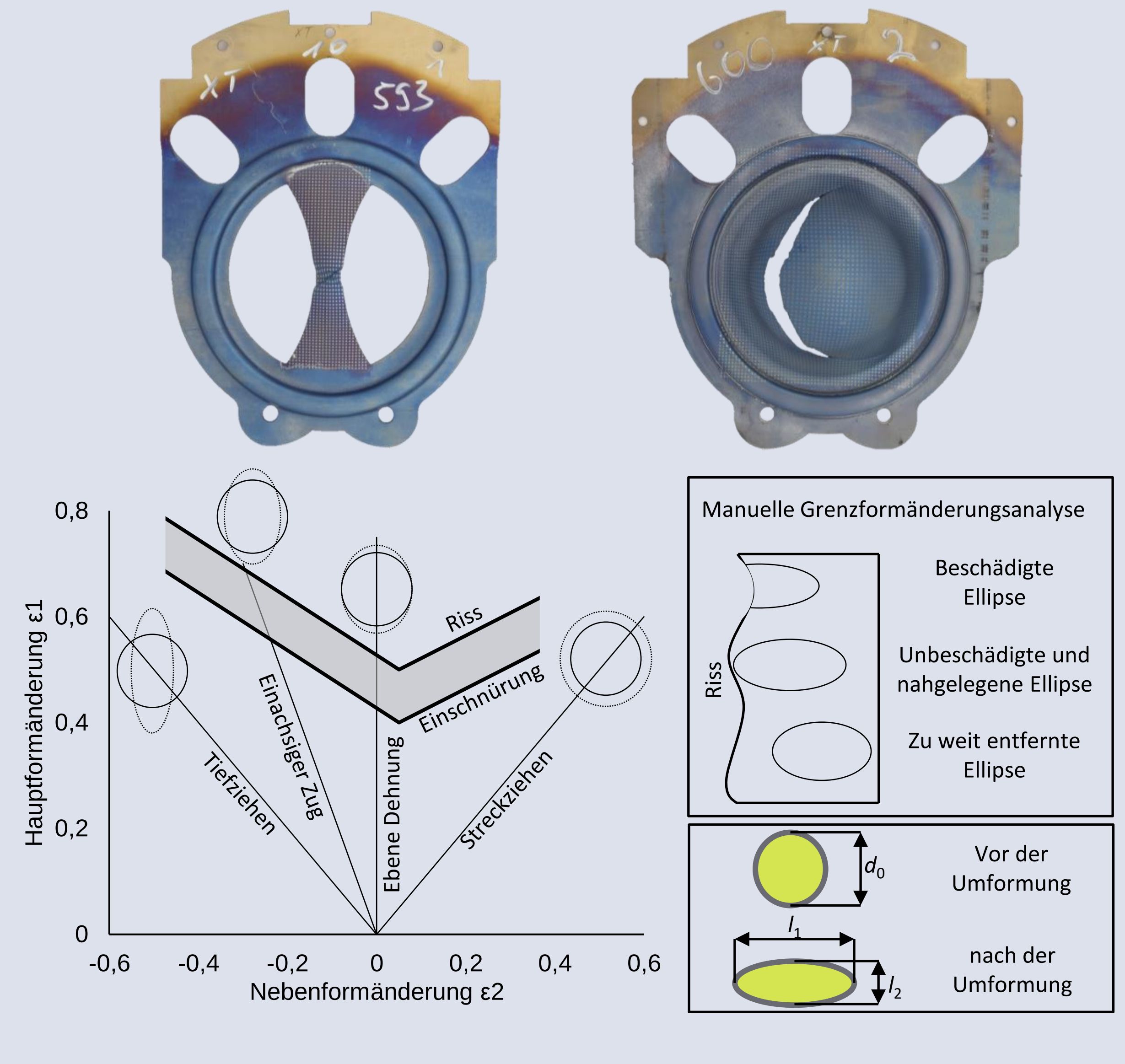


Quelle: [Sie15] Blechumformung



Determination of Forming Limit Curve (FLC)

1. Determination of major and minor deformation leading to failure according to DIN EN ISO 12004
    1. Constriction is considered a failure
    2. Four to seven supporting points for valid FLC
2. Formability of a material
    1. Strain paths
    2. Temperature
    3. Forming history
    4. etc.
3. Specimen geometry determines the strain paths
    1. Linear paths are necessary
    2. Subdivision into Hasek and Nakajima shape



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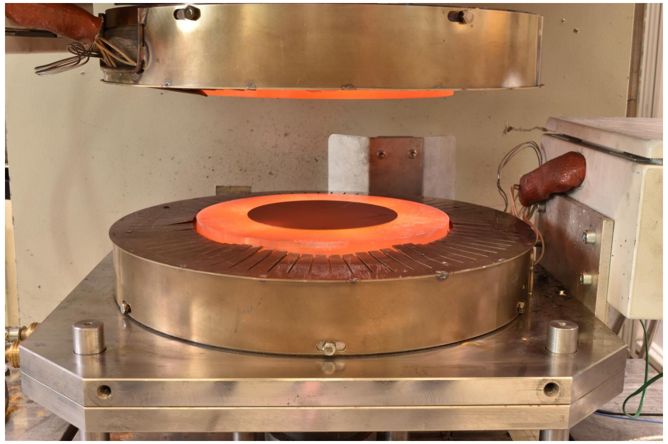
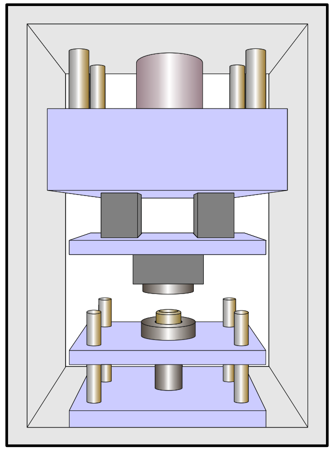
Validation parameters

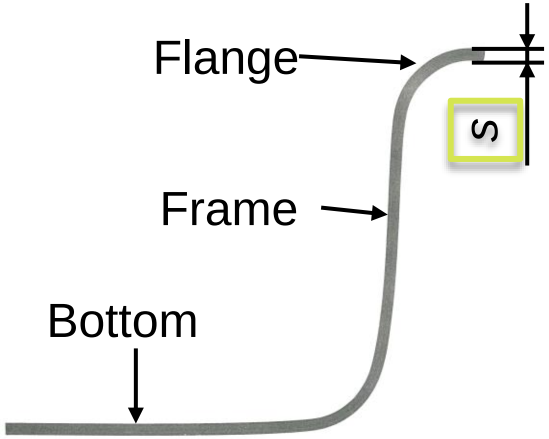
1. Temperature field



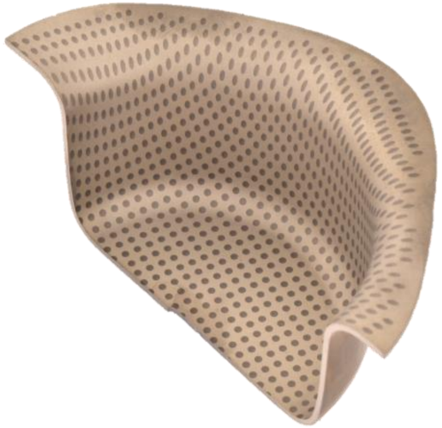
2. Punch force curve



3. Thickness

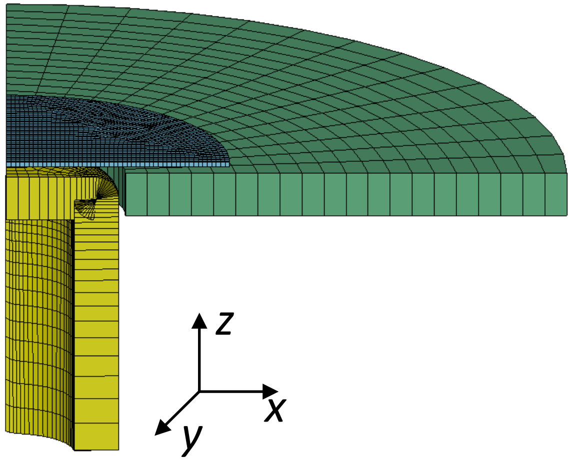


4. Major and minor strain



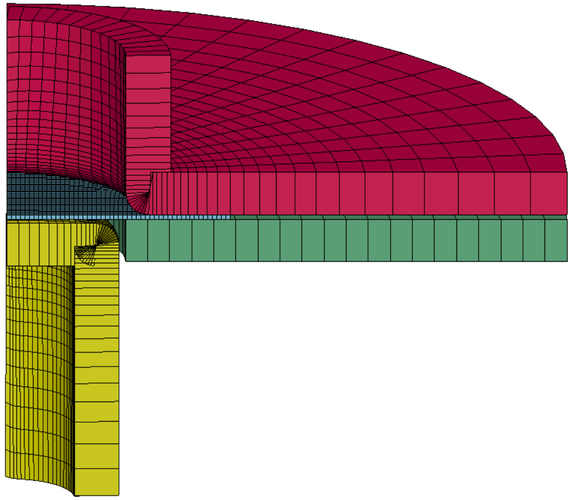
Operation procedure of the thermomechanic deep drawing simulation

OP10: Positioning



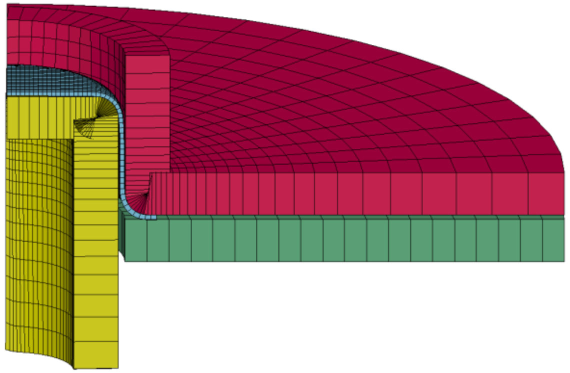
- Positioning of Blank by gravity
- Heating of blank
- Thermal expansion of blank
- Cooling of tools

OP20: Closing of tools



- Closing of die
- Heating of blank
- Thermal expansion of the blank
- Cooling of tools

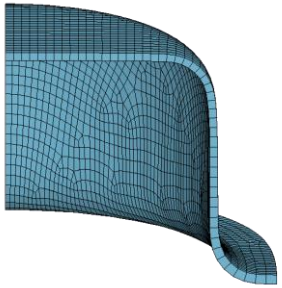
OP30: Forming



- Displacement controlled movement of die
- Force application on binder
- Heating of blank by deformation

→ Umformung der Ronde

OP40: Cooling & Springback



- Cooling of cup at room temperature
- Springback

Attention: Shell thickness is just visualized! → No Solids

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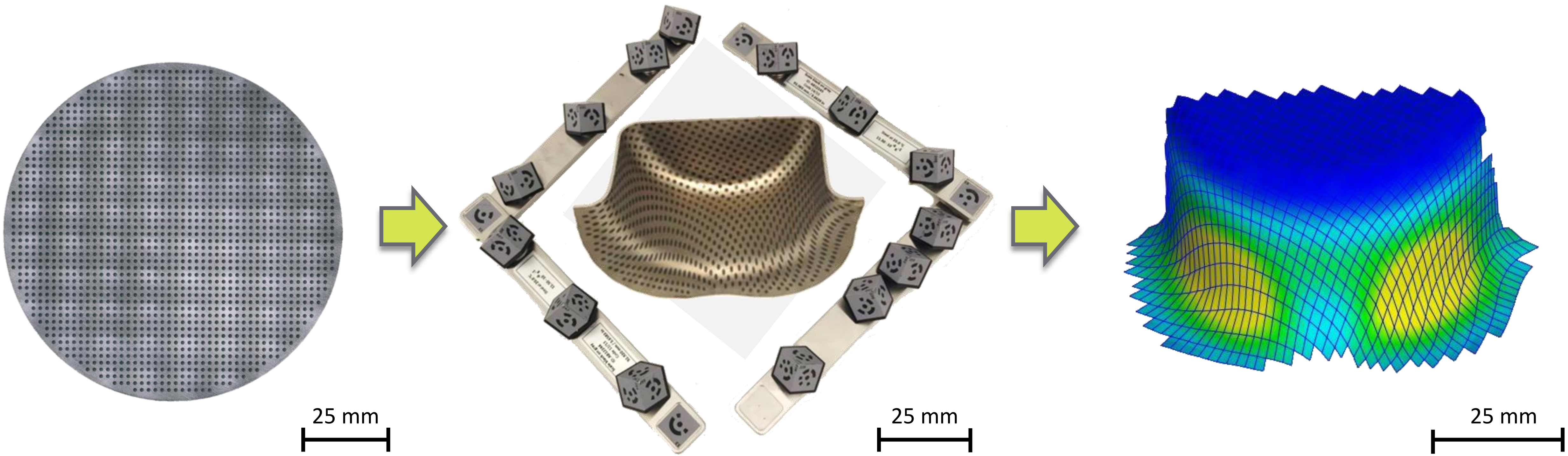
Mechanical verification

Unformed blank with GOM Argus pattern

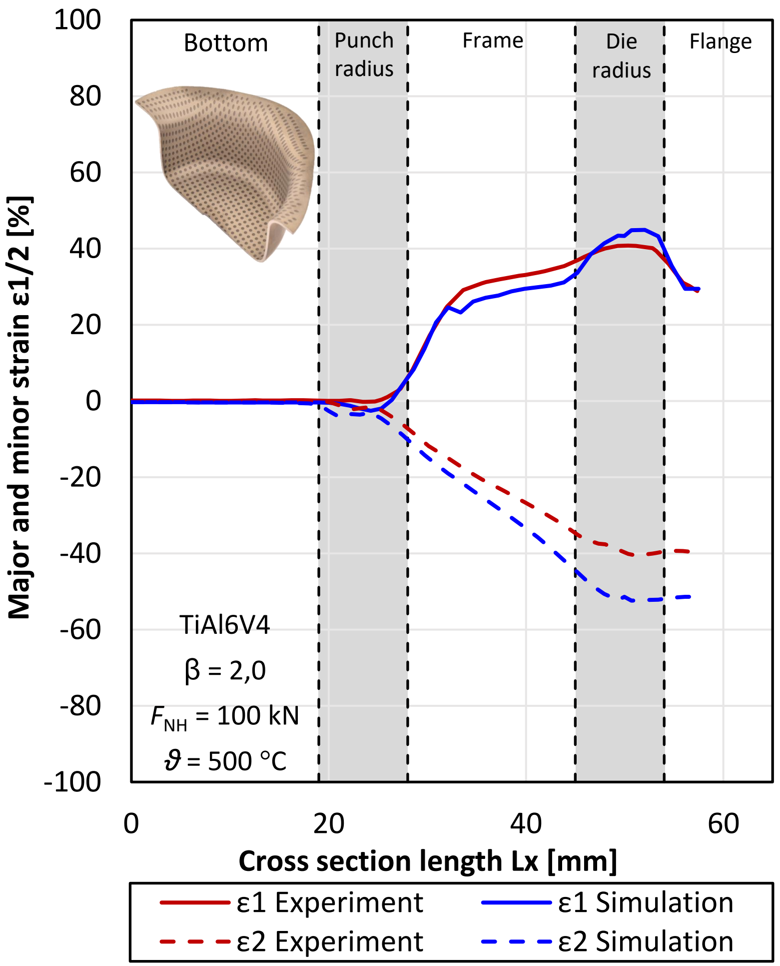
Formed blank with GOM Argus pattern

Calculated grid

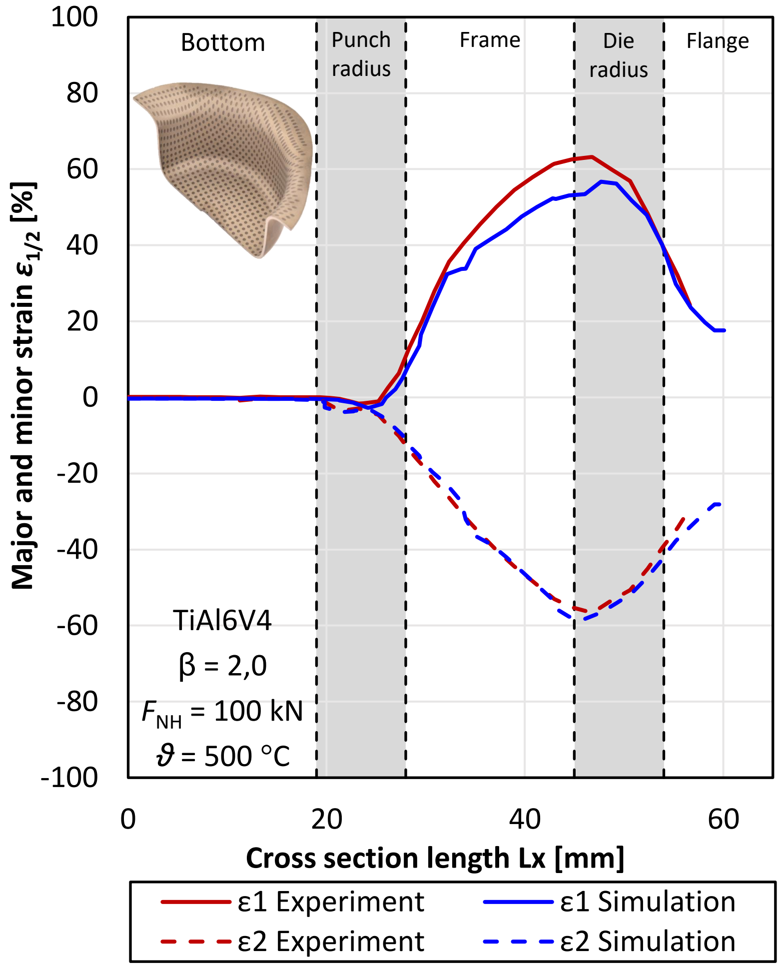


Verification of major and minor strain

0° RD



45° RD



90° RD