Hot Stamping Experience and Tech Tour

November 29-30, 2023

Holland, MI

PRODUCED BY PMA PRECISION METALFORMING ASSOCIATION | MetalForming Magazine

Die Development & Process Simulation for Hot Stamping

Kidambi Kannan

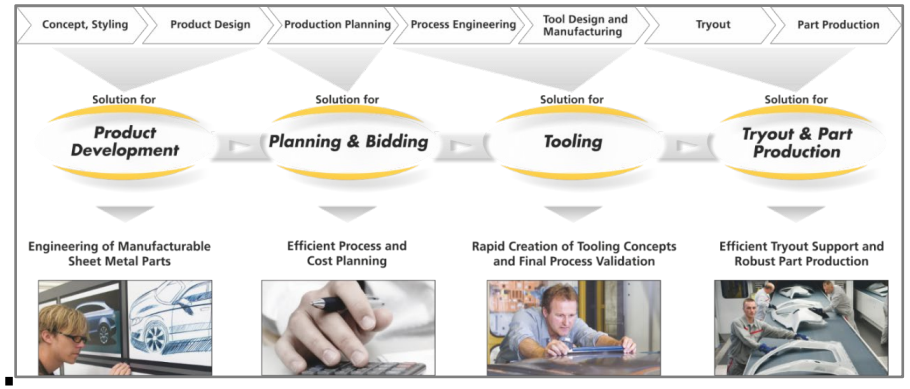
AutoForm Engineering USA, Inc.

Alper Guener

AutoForm Engineering GmbH

AutoForm Engineering – Who We Are

Development and Sales of Software Solutions for Sheet Metal Forming



- Product Manufacturability
- Tool and Material Cost Estimation
- Concept and CAD-quality Die Face Design
- Process Validation and Optimization
- Digital Support for Tryout and Part Production
- Assembly Validation and Component Countermeasures

AutoForm Engineering – Who We Are

Switzerland: Headquarters, software development, global marketing
Germany: Sales, support and training center, engineering services, software development
Other offices: Sales, support and training

- Zurich ’95
- Dortmund ’96, Munich ’03, Ravensburg ’08, Stuttgart ’14
- Detroit ’00, Grand Rapids ’17
- Barcelona ’00
- Aix-en-Provence ’01
- Rotterdam ’02
- Seoul ’03, Busan ’14
- Torino ’04,
- Hyderabad ’05
- Monterrey ’07
- Tokyo ’07, Ota ’11, Nagoya ’17
- Hong Kong ’08
- Brazil ’11

AutoForm Offices and Representatives
AutoForm Agents

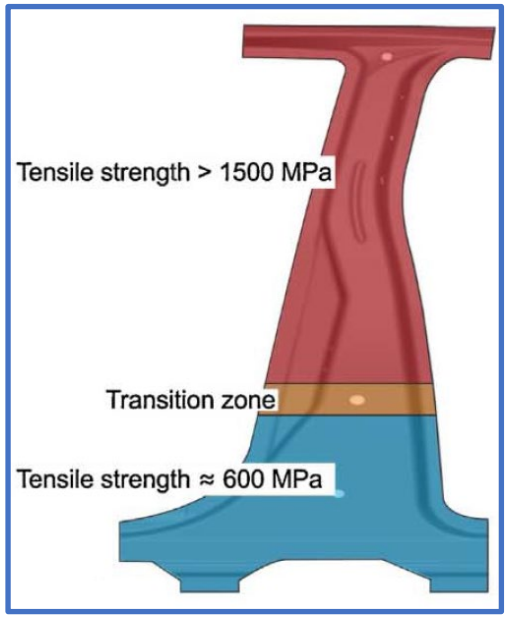
Recent Advances in Simulation Technology

- **Property Tailoring**
- **Material Modeling**
- **Tribology**
- **Aluminum Hot Forming**
- **Die Spotting**
- *Tool Wear…*

Simulation of Property Tailoring Applications

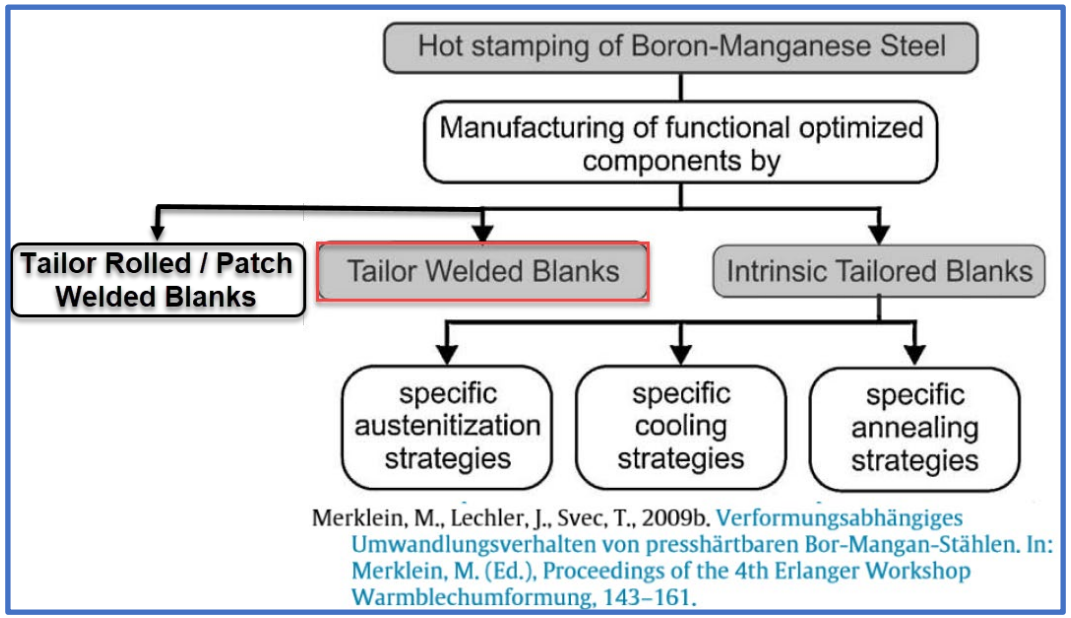
Property Tailoring

Development of locally differentiated mechanical properties on a single stamped component…



Common approaches in press hardening…

- Differential Cooling
- Tailored Products
- Partial Heating

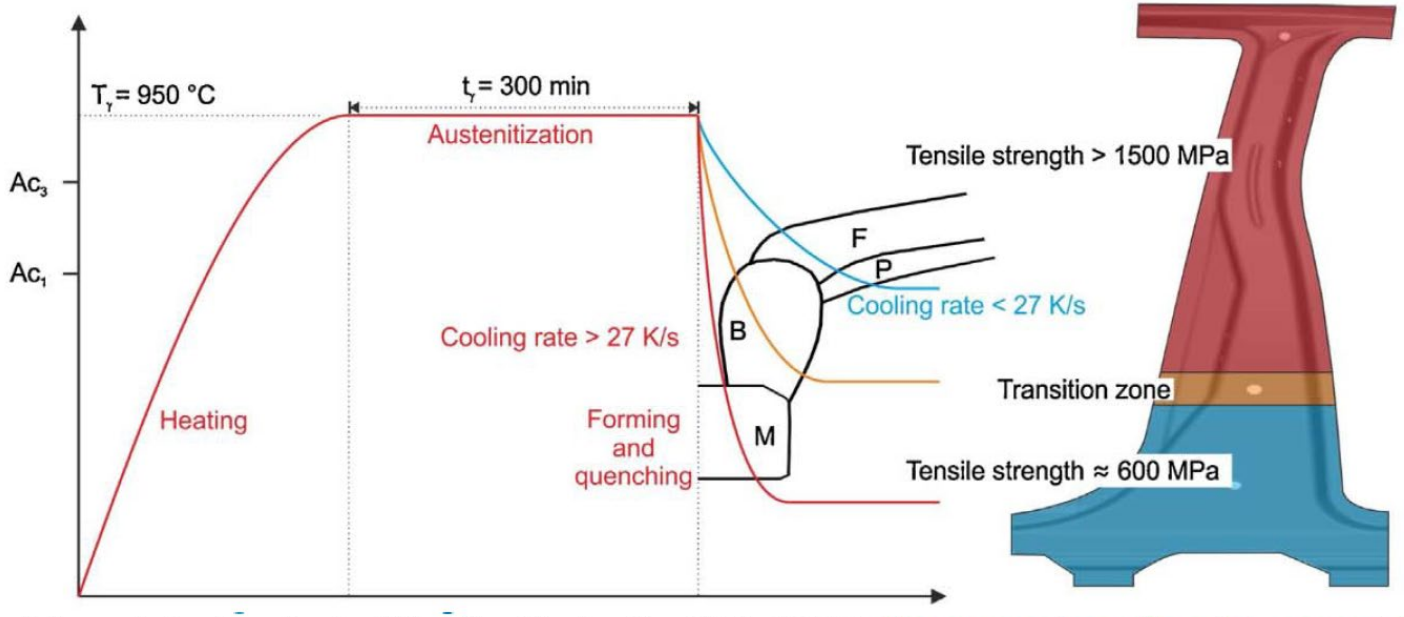


Merklein, M., Lechler, J., Svec, T., 2009b. Verformungsabhängiges Umwandlungsverhalten von presshärtbaren Bor-Mangan-Stählen. In: Merklein, M. (Ed.), Proceedings of the 4th Erlanger Workshop Warmblechumformung, 143–161.

Property Tailoring

Differential Cooling

=> Cooling rate control to develop desired phases and properties



Ademaj, A., Donis, A., Weidig, U., Steihoff, K., 2013. Hot stamping of multi-material composites. In: Oldenburg, M., Prakash, B., Steinhoff, K. (Eds.), Proceedings 4th International Conference Hot Sheet Metal Forming of High-Performance Steel—CHS². Luleå, Sweden, pp. 481–488.

Property Tailoring

Differential Cooling

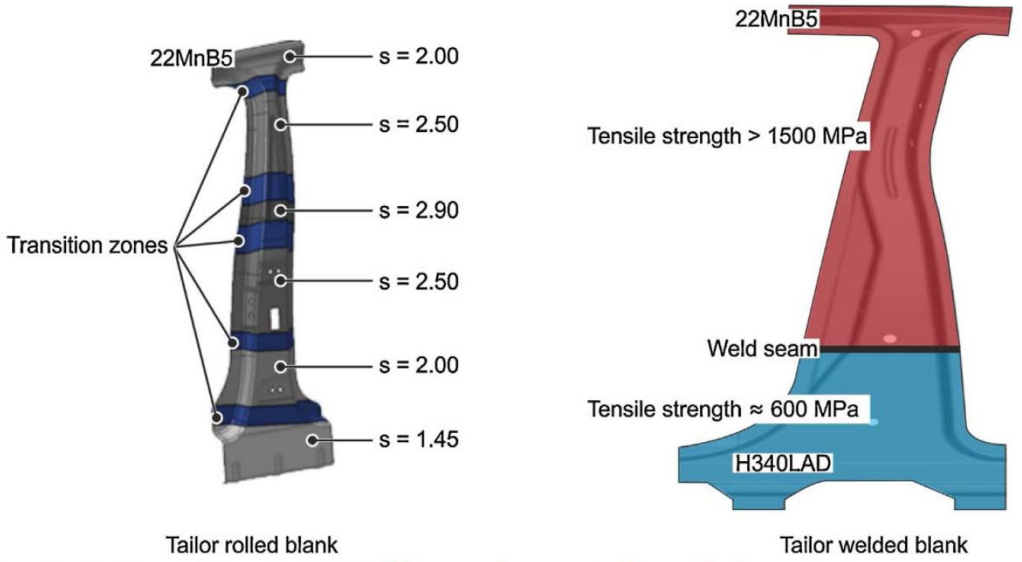
=> Cooling rate control to develop desired phases and properties

- “Tailored Tempering” – heated tool tailoring
- Thermal properties of tool materials
- Die relief

Hot Stamping of Boron Sheet Steels with Tailored Properties: A Review, Merklein et al, Journal of Materials Processing Technology 228 (2016), 11-24

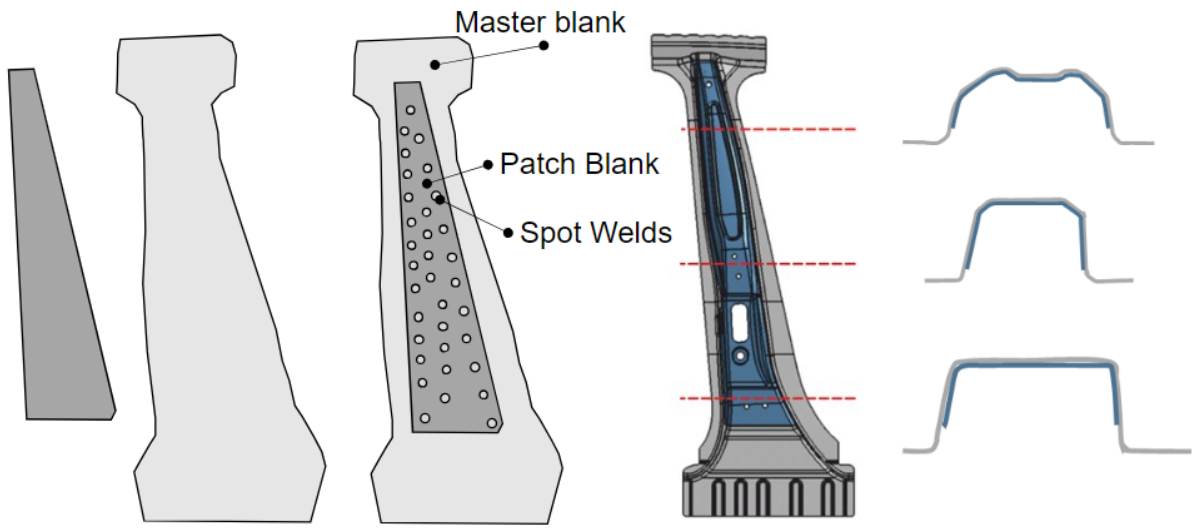
Property Tailoring

Tailored Products



Brecht, J., Goeddeke, B., 2013. Warmgeformte tailor rolled products, Funktionsoptimaler Leichtbau für die Fahrzeugkarosserie. In: Merklein, M. (Ed.), Proceedings of the 8th Erlanger Workshop Warmblechumformung. Erlangen, Germany, pp. 85–94.

Merklein, M., Geiger, M., Kerausch, C., Lechler, J., 2010a. Presshärten von Tailor Welded Blanks—Final Report of the Research Project P709. Forschungsvereinigung Stahlanwendung: Forschung für die Praxis, Verlags und Vertriebsgesellschaft, Düsseldorf.



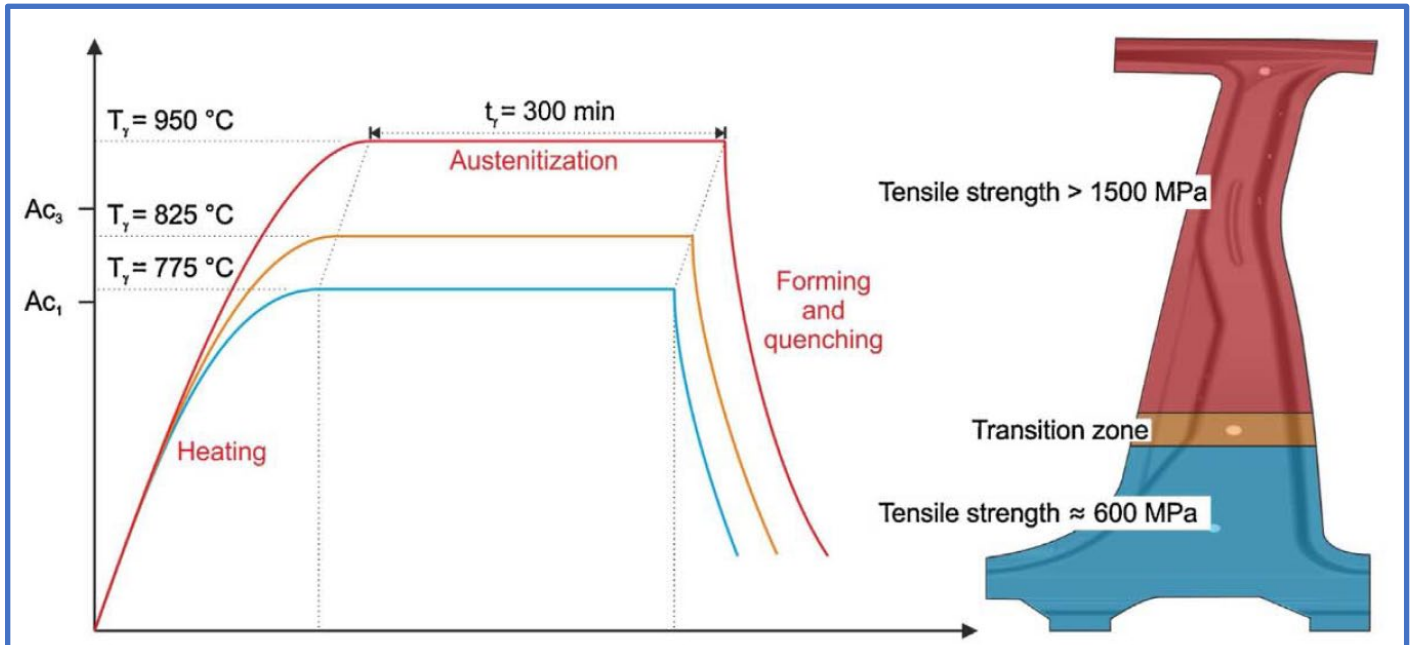
B-14. E. Billur, Ed., "Hot stamping of ultra high-strength steels: From a Technological and Business Perspective," Springer, 2019, ISBN 978-3-319-98870-2.

L-52. C. Lei, Z. Xing, W. Xu, Z. Hong and D. Shan, "Hot stamping of patchwork blanks: modelling and experimental investigation," The International Journal of Advanced Manufacturing Technology, vol. 92, pp. 2609-2617, 01 9 2017 doi.org/10.1007/s00170-017-0351-9.

Property Tailoring

Partial Heating

=> Selective austenitization in areas requiring high strength / hardness through quenching to Martensite



Merklein, M., Svec, T., Stöhr, T., Wieland, M., 2010c. Maßgeschneidert – Funktionsoptimierte Strukturbauteile im Presshärteprozess. Lightweight Des. 5, 52–57.

Property Tailoring

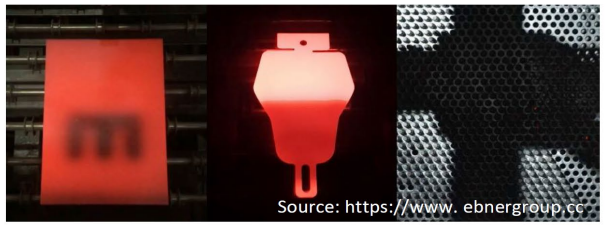
Partial Heating

=> Selective austenitization in areas requiring high strength / hardness through quenching to Martensite

- Separate furnace chambers
- Radiant heaters
- Masks
- Absorption masses / thermal shielding
- Forced air cooling
- (AP&T) TemperBox®

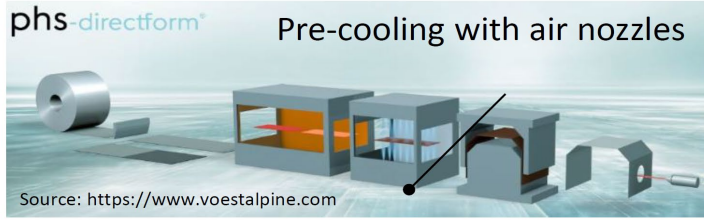
New Process Routes

- TemperBox (AP&T)
- Thermal Printing (schwartz)
- PHS DirectForm (Voestalpine)
- PACC-Module (Ebner)



Main Principle

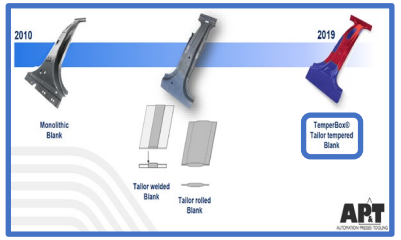
- After full austenitization (first furnace), the blank goes to a tempering station.
- The common feature of these technologies is a convectional cooling operation before forming where the blank is cooled down to a specific temperature within a defined duration.

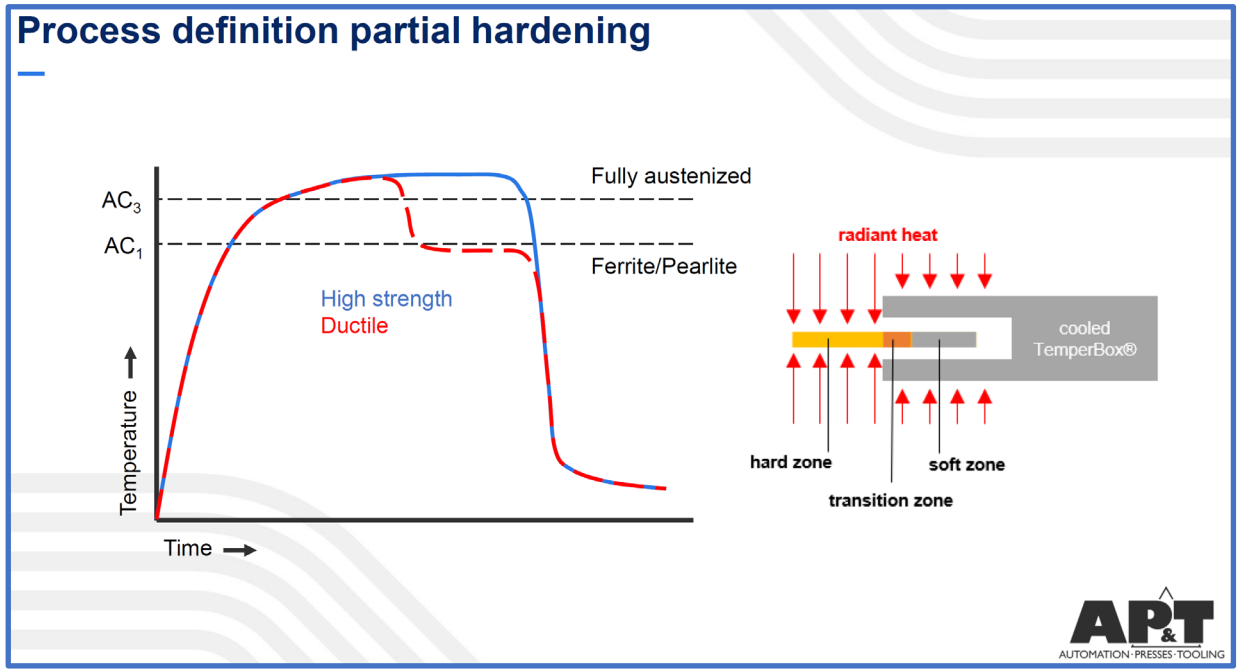


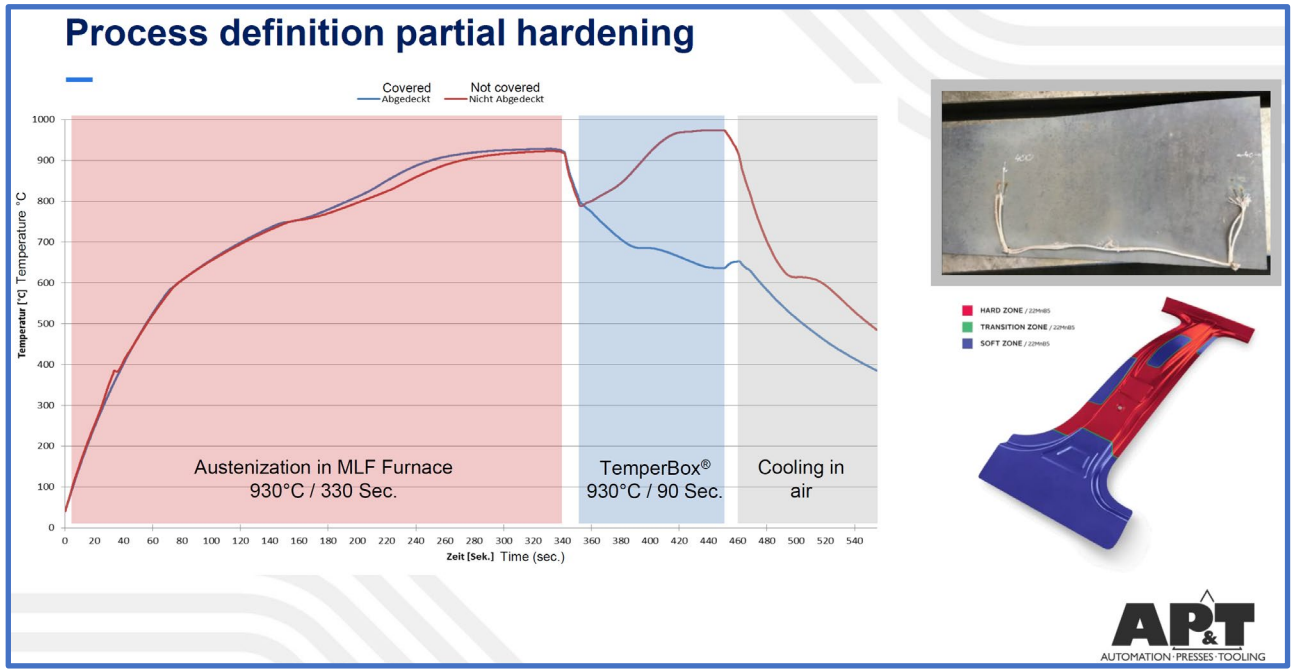
Property Tailoring

Partial Heating

(AP&T) TemperBox®







Property Tailoring

(AP&T) TemperBox® - Experimental and Simulation Studies

"Analysis of process limits for partial hot stamping with controlled pre-cooling by radiation exchange", *A Reihani et al 2023 IOP Conf. Ser.: Mater. Sci. Eng. 1284 012004*

A Reihani[1], L Donat[1], S Heibel[1], T Schweiker[1], M Gienger[2], A Güner[2], M Winderlich[3] and M Merklein[4]

[1]**Mercedes-Benz AG**, Béla-Barényi-Straße 1, 71063, Sindelfingen, [2]**AutoForm Engineering** Deutschland GmbH, [3]**GEDIA Gebrüder Dingerkus** GmbH, Röntgenstraße 2-4, 57439 Attendorn, [4]**Institute of Manufacturing Technology**, Friedrich-Alexander Universität Erlangen-Nürnberg

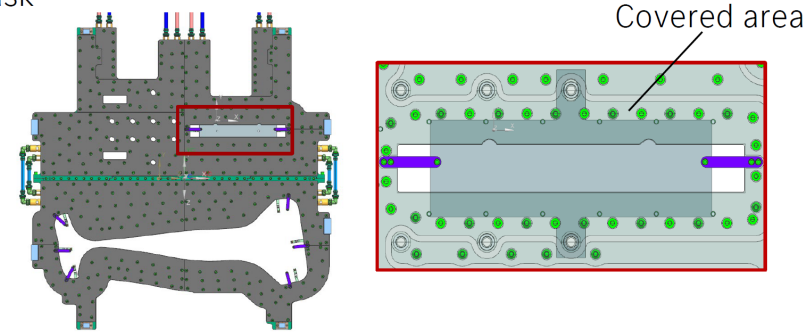
Investigation methods
- Experimental trials
- FE-simulation with AutoForm®R10

Materials
- 22MnB5 AS150
- 8MnB7 AS150
- Blank 8MnB7 and patch 22MnB5

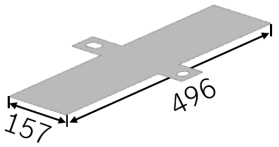
Parameter
- Sheet tickness t_0
- Partial pre-cooling time $t_{pre\text{-}cooling}$

Objectice
Simulative and experimental analysis of **phase transformation** and **hardness** using different **sheet thicknesses and materials**
⇨ Elaboration of possible process limits

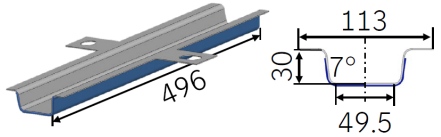
Mask



Blank



Patched-hat profile

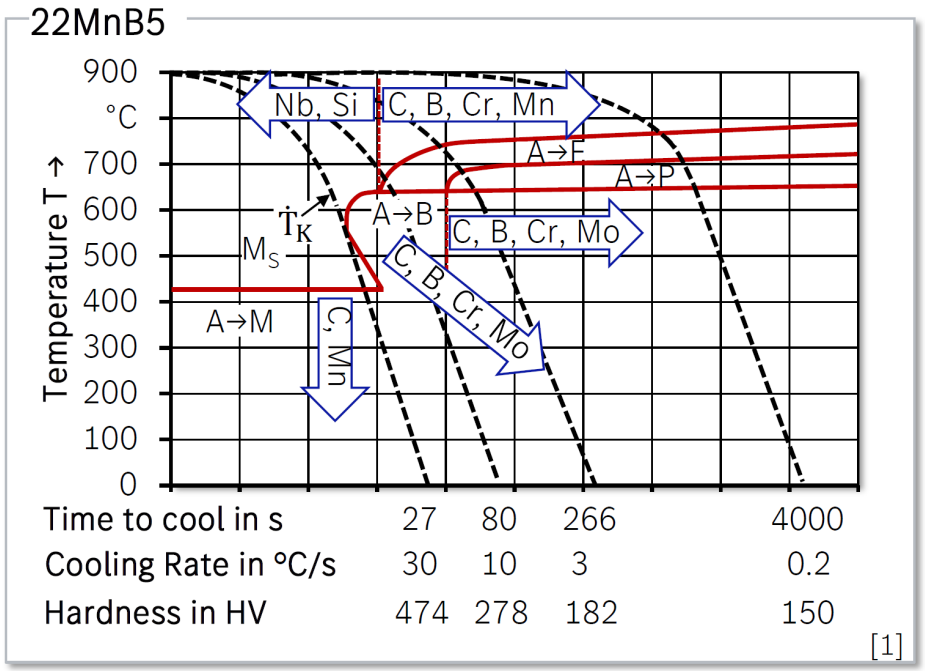


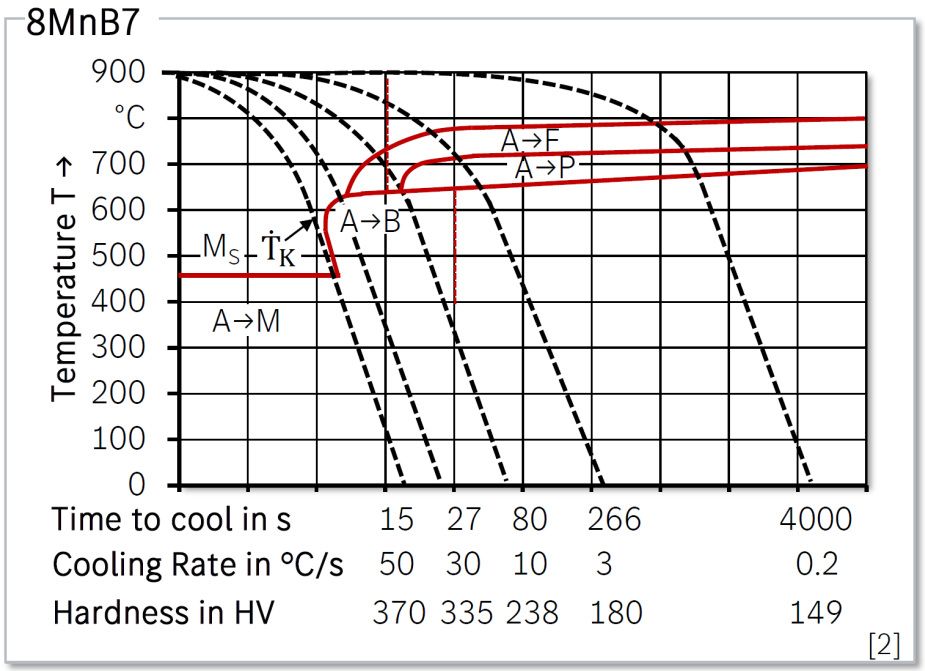
Property Tailoring

(AP&T) TemperBox® - Experimental and Simulation Studies

CCT-Diagram of 8MnB7 and 22MnB5

Shifting phase transformation areas due to chemical composition





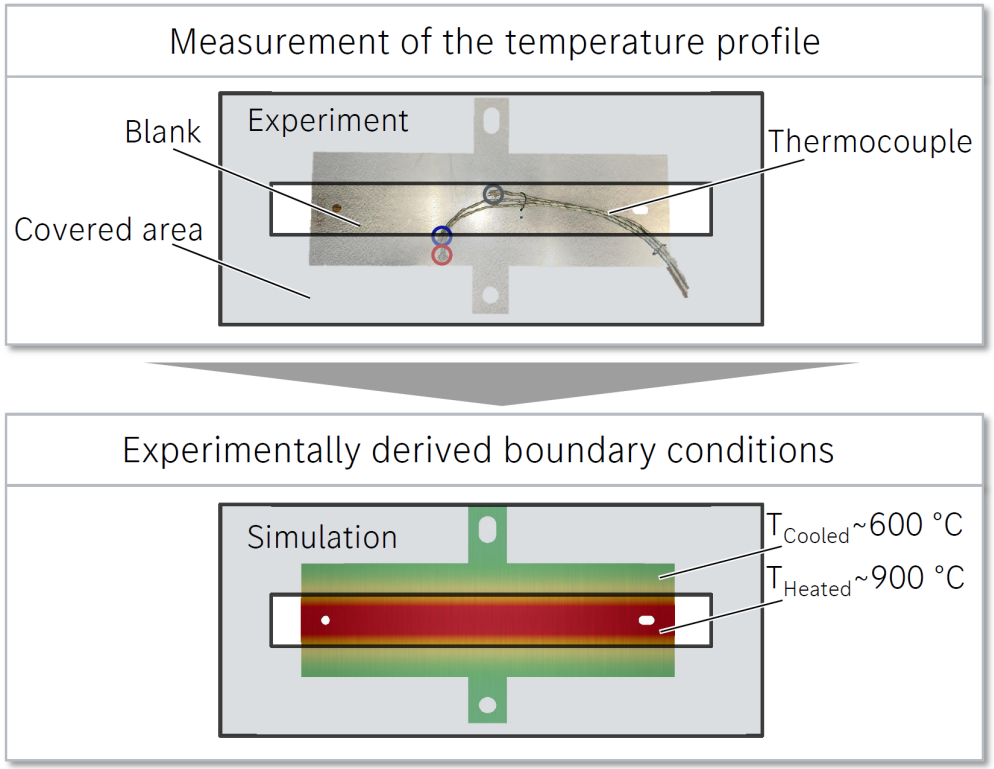
A: Austenite B: Bainite F: Ferrite P: Perlite M: Martensite M_S = Martensite Start Temp.

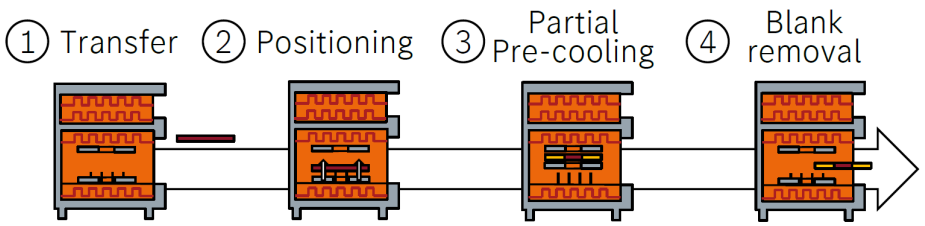
Property Tailoring

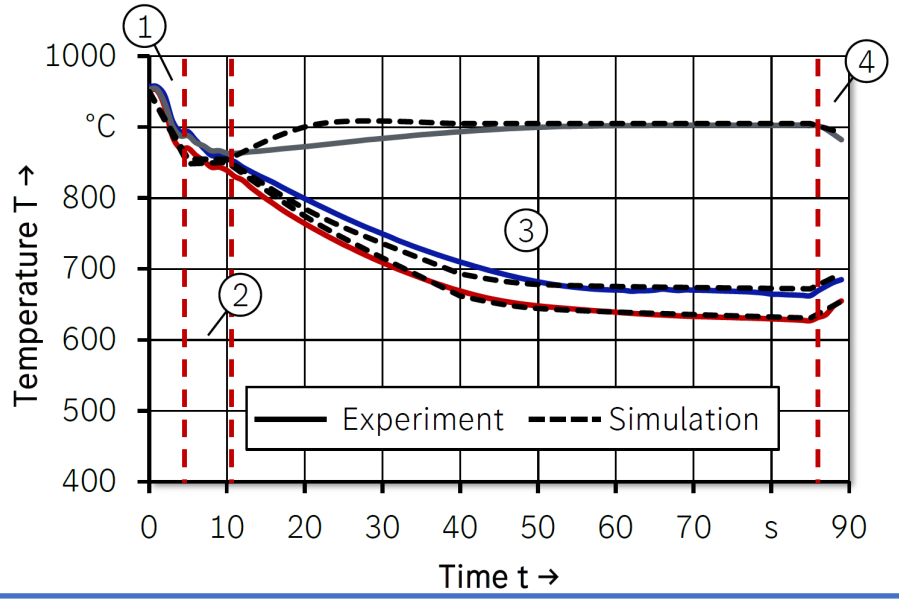
(AP&T) TemperBox® - Experimental and Simulation Studies

Temperature measurements and simulation of partial pre-cooling

Temperature-input for the simulation is derived from experimental measurements



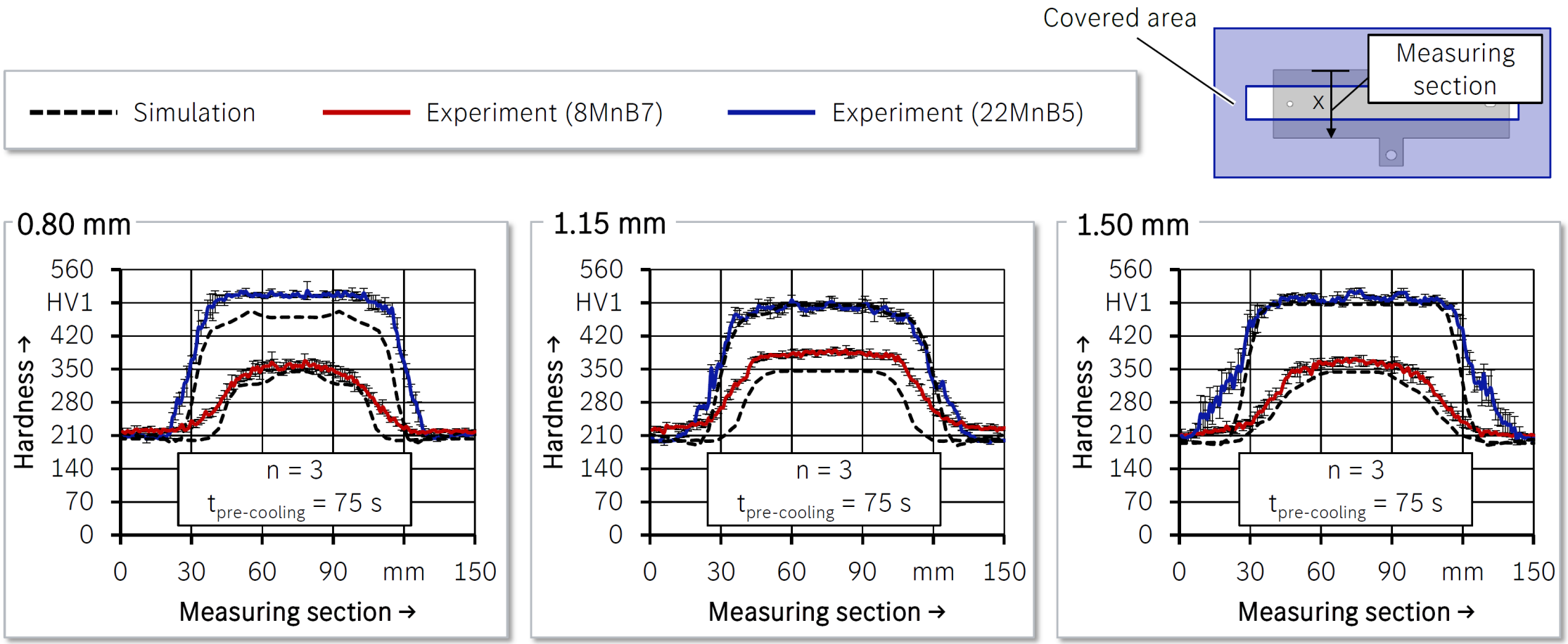




Property Tailoring

(AP&T) TemperBox® - Experimental and Simulation Studies

Sheet thickness influences the formation of soft, transition and hard areas

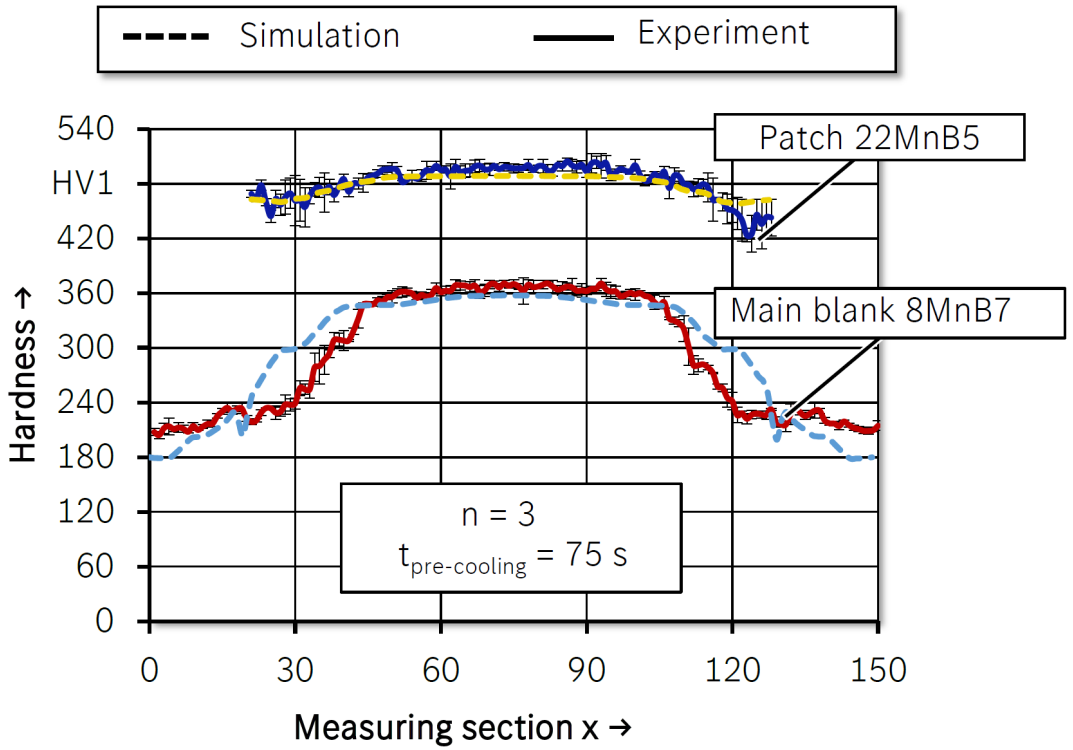


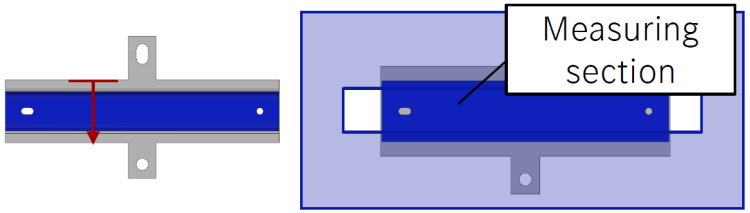
Property Tailoring

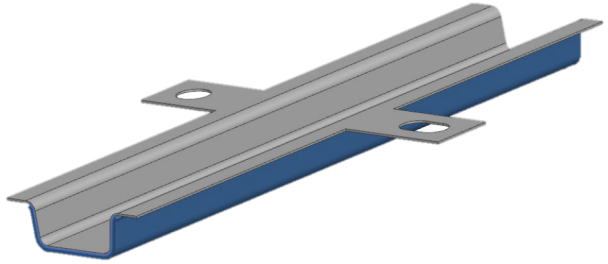
(AP&T) TemperBox® - Experimental and Simulation Studies

Patched-hat profile

TemperBox® process affects hardness of the patch





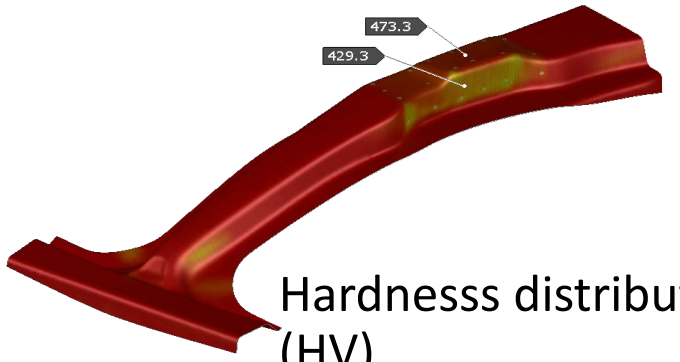


Modeling of Press Hardening Materials

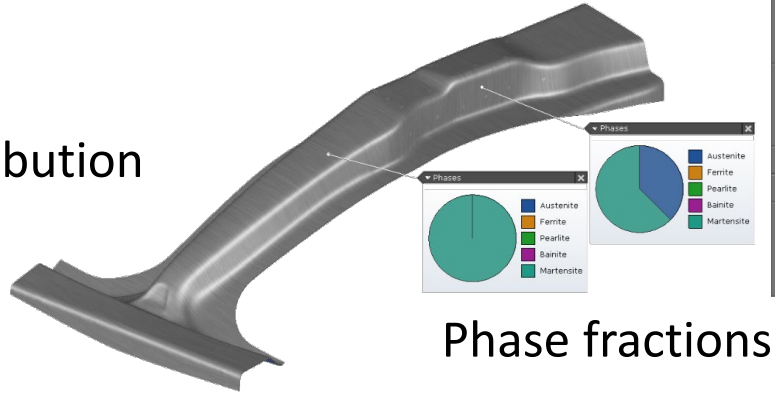
Material Modeling

22MnB5:hot stamping steel for applications with high hardness/intrusion resistance requirements

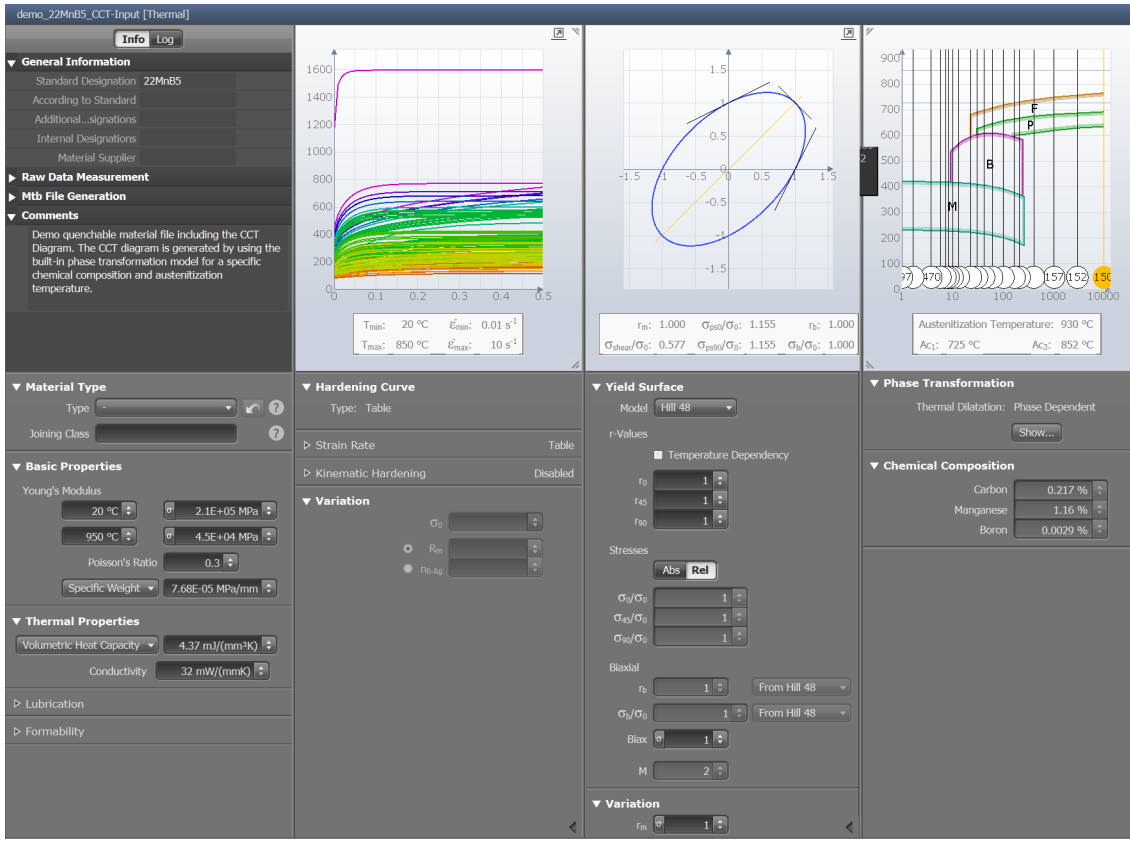
- Flow curves
- Phase transformation using CCT
- ***Phase fractions, strength & hardness***



Hardnesss distribution (HV)



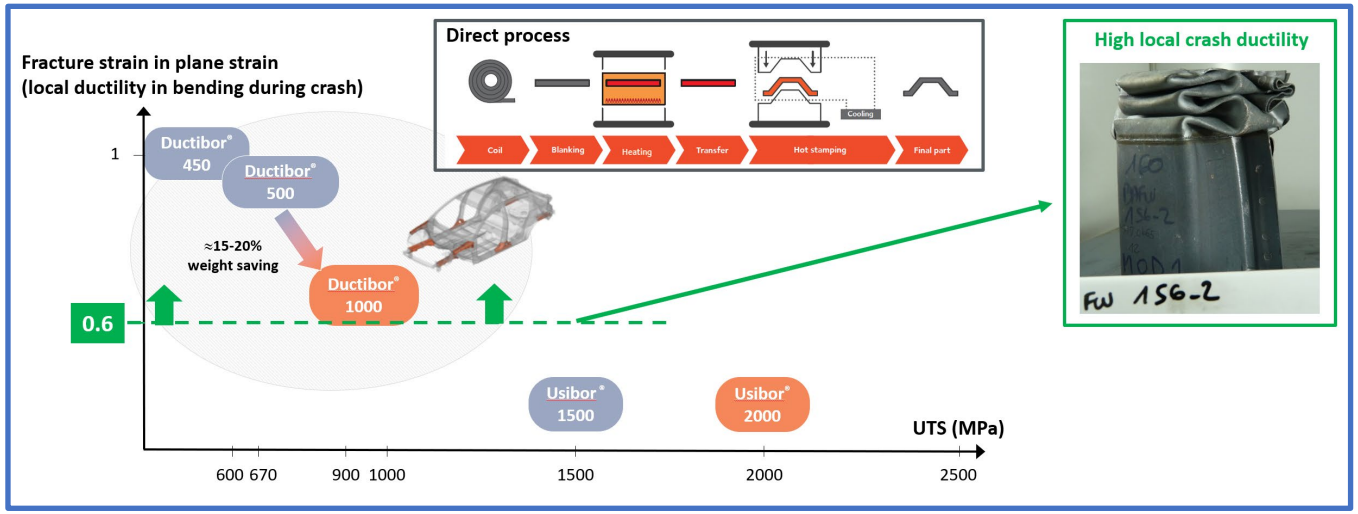
Phase fractions

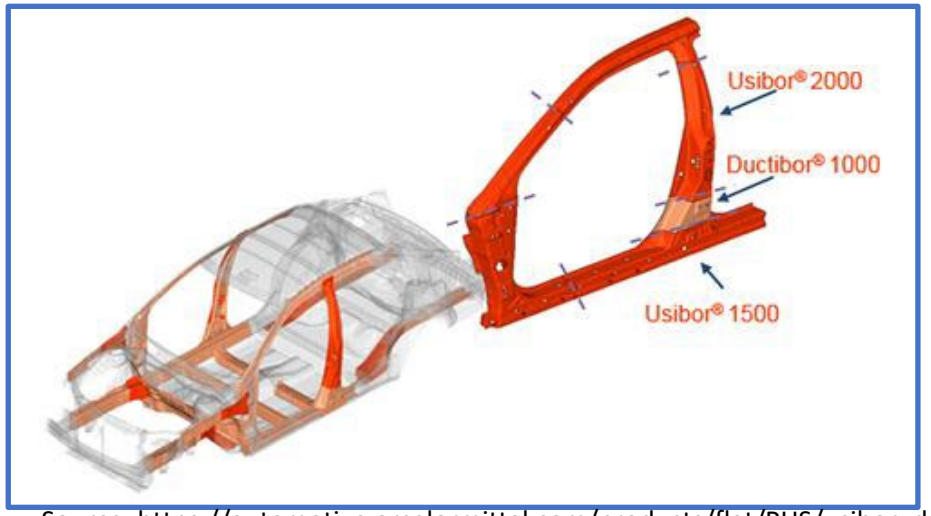


Material Modeling

Increasing demand for materials with higher strength or with higher crash ductility for more energy absorption

- **Ductibor® 1000 AS** offers compromise between higher crash ductility in bending and tensile strength





Source: https://automotive.arcelormittal.com/products/flat/PHS/usibor_ductibor

Material Modeling

Experimental and Numerical Investigation of Final Product Properties of Ductibor® 1000 AS Under Different Process Conditions

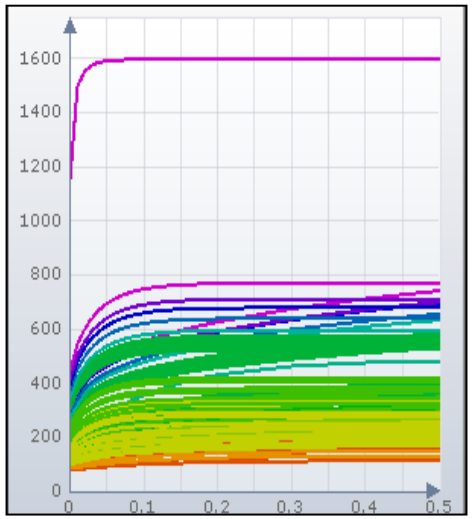
Alper Güner[1], Maximilian Sonntag[1], Clement Philippot[2], Jacques Bittendiebel[2], Benjamin Sarre[3], Ludovic Dormegny[4], Alborz Reihani[5] and Sebastian Heibel[5]

(CHS2 – 2022 Barcelona)

[1] AutoForm Engineering GmbH; [2, 3, 4] ArcelorMittal; [5] Mercedes-Benz

I. Develop Hot Stamping Material Model for **Ductibor® 1000 AS**

- Basic properties:
  - Temperature-dependent modulus of elasticity
  - Density, Heat capacity, Conductivity
- Flow curves: Temperature and strain rate dependency for each phase
- CCT-Diagram:
  - ***Resulting hardness and phase composition for cooling rates from 0.5 – 200 °C/s***



Material Modeling

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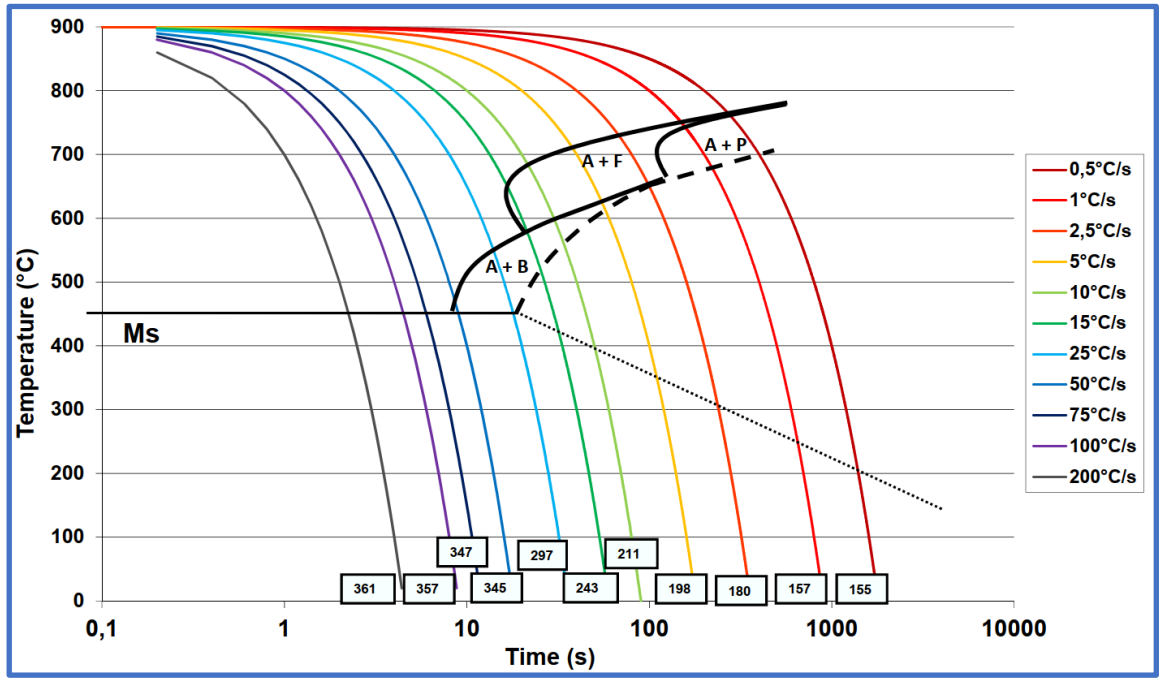
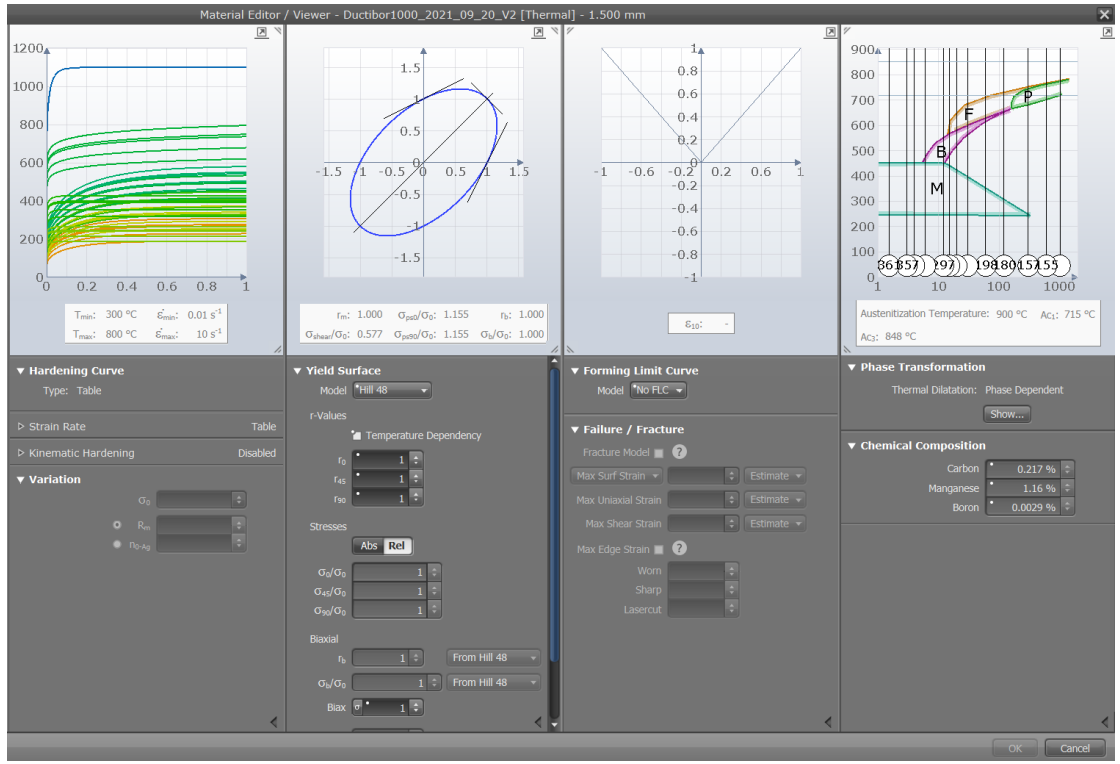
- CCT-Diagram:

Resulting hardness and phase composition for cooling rates from 0.5 – 200 °C/s



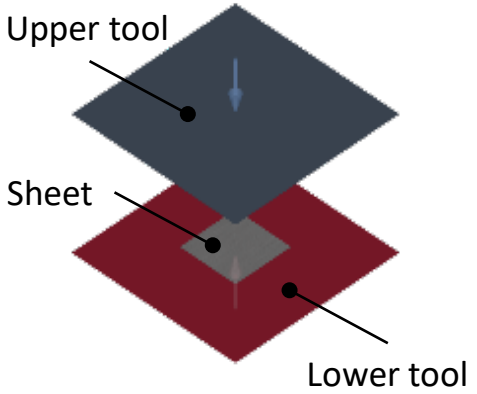


Material Modeling

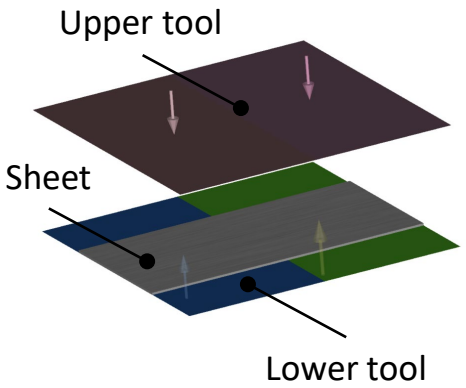
II. Validate Material Model through Experimental and Numerical analysis of four different tools

- Variation of process parameters (e.g. contact pressure, transfer time, tool temperature)

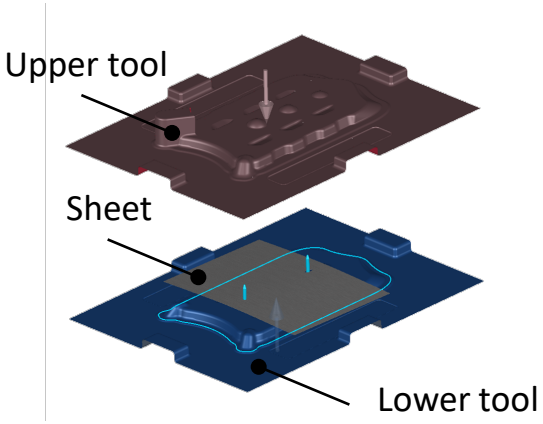
Flat tool



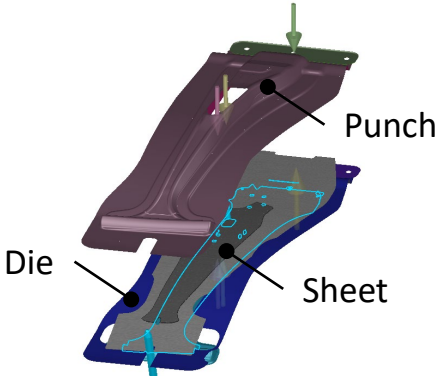
Flat tool with cooled and heated sides



Demonstrator Part

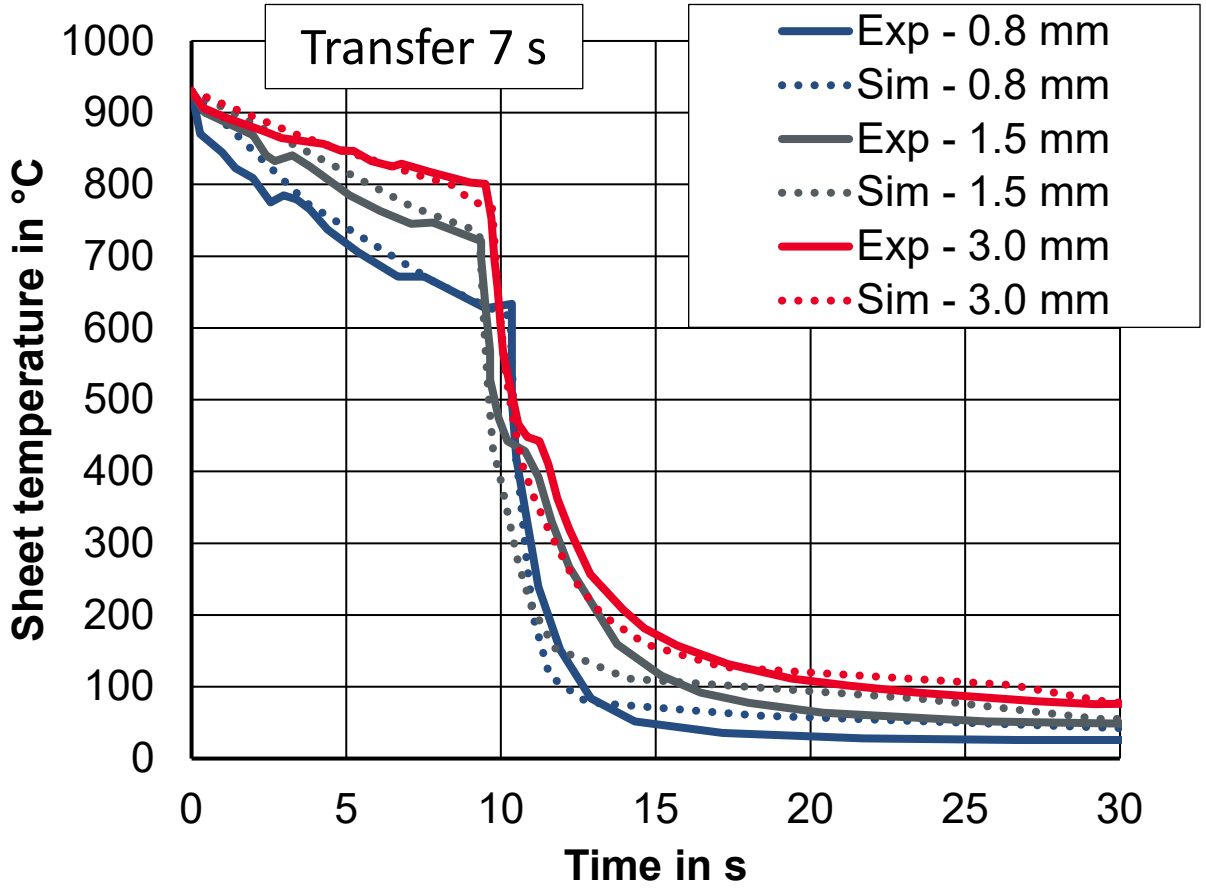


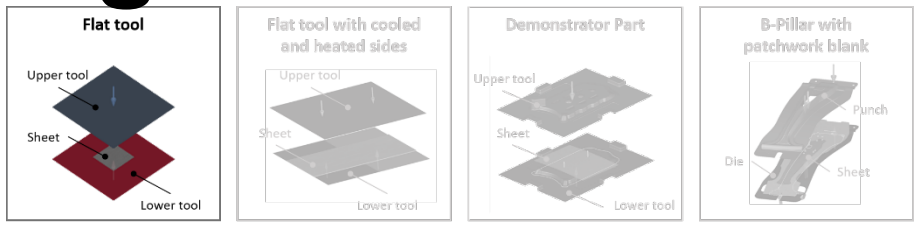
B-Pillar with patchwork blank

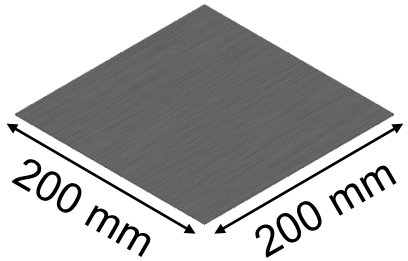


Material Modeling

Model Validation – Experimental and Numerical Temperature History







Furnace temperature
- 930 °C

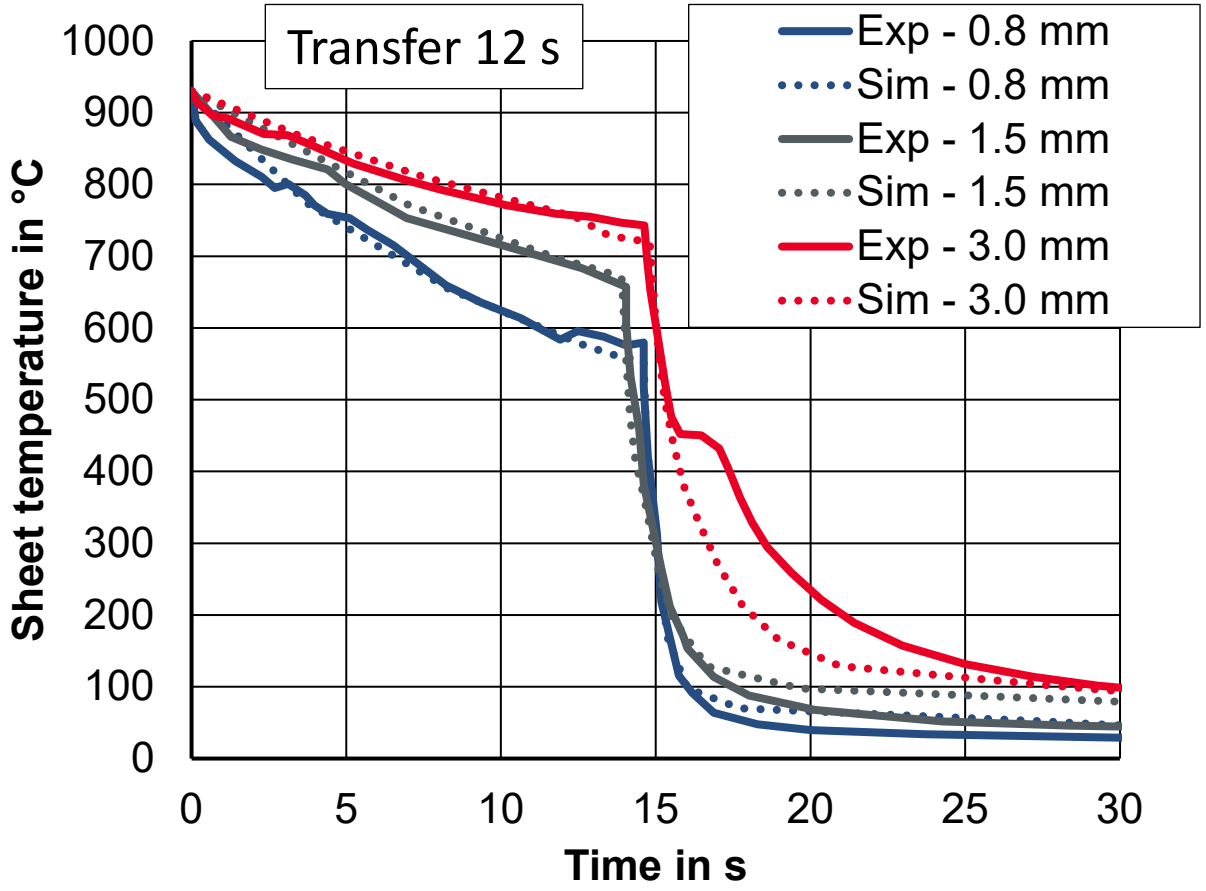
Transfer time
- 7 s
- 12 s

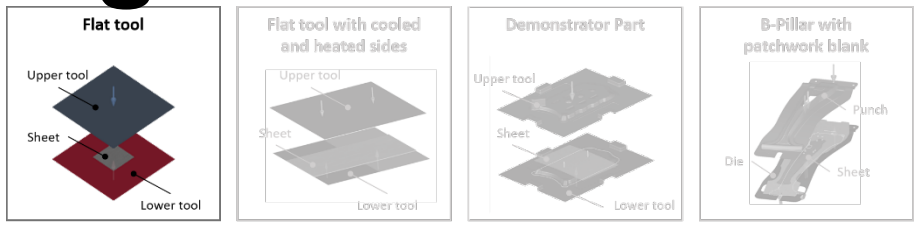
Blank thickness
- 0.8 mm
- 1.5 mm
- 3.0 mm

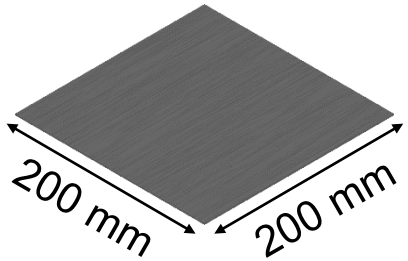
Quenching pressure
- 15 MPa

Material Modeling

Model Validation – Experimental and Numerical Temperature History







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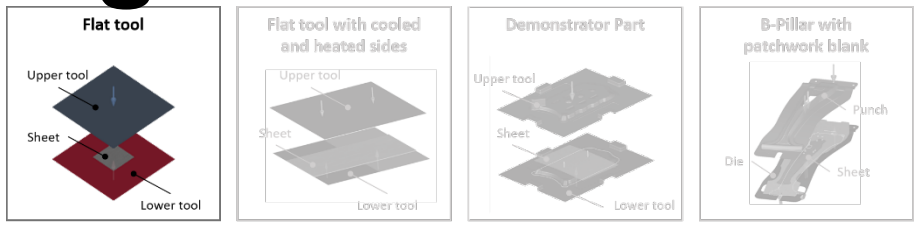
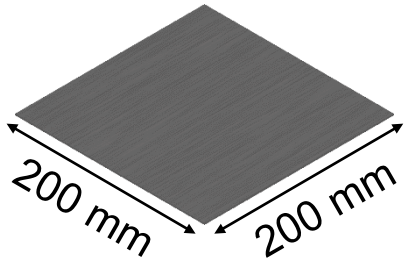
Material Modeling

Model Validation – Experimental and Numerical Hardness Values



Thickness [mm]	Transfer [s]	Experimental Hardness (mean) [HV]	Numerical Hardness [HV]
0.8	7	360.1	343.7
	12	364.8	323.0
1.5	7	357.6	360.0
	12	364.5	347.0
3.0	7	358.6	357.7
	12	354.1	353.0



Furnace temperature
- 930 °C

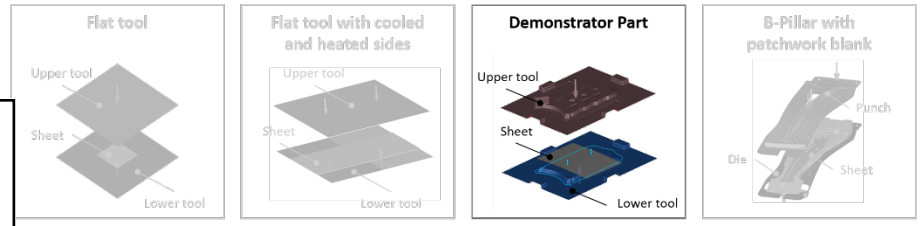
Transfer time
- 7 s
- 12 s

Blank thickness
- 0.8 mm
- 1.5 mm
- 3.0 mm

Quenching pressure
- 15 MPa

Material Modeling

Model Validation – Demonstrator Part



Furnace temperature
- **930 °C**

Time in air
- **11 s**

Tool Temperature
- **25 °C**

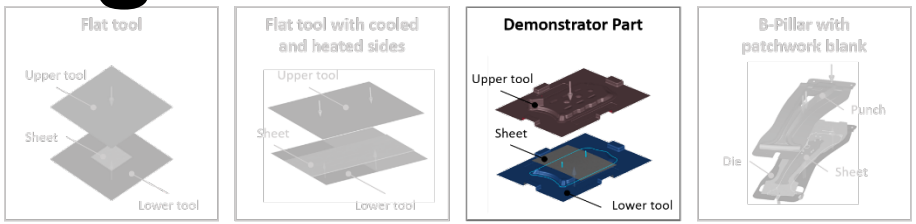
Quenching pressure
- **15 MPa**

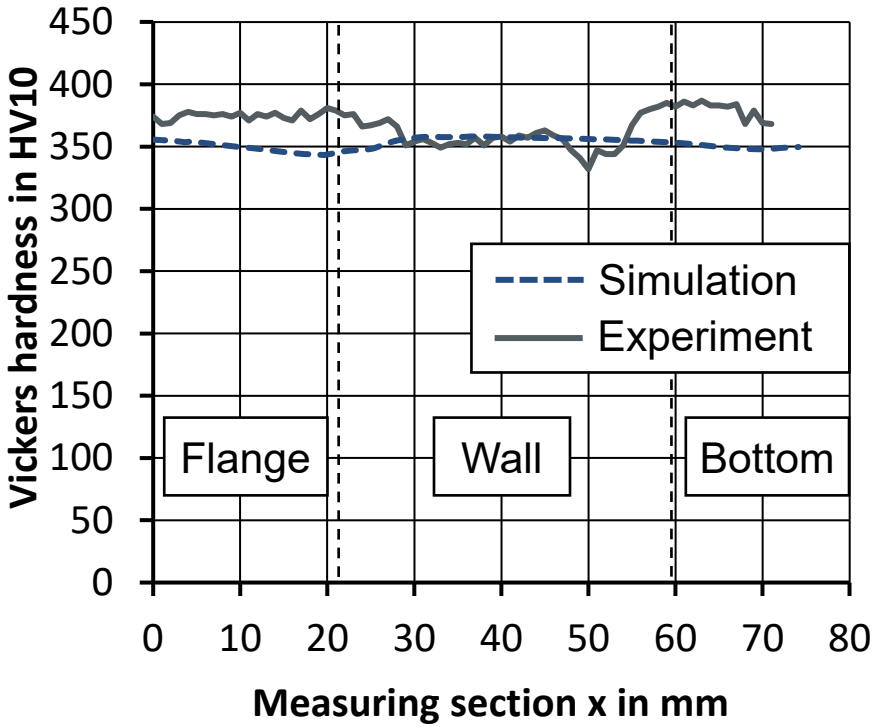
Quenching duration
- **15 s**

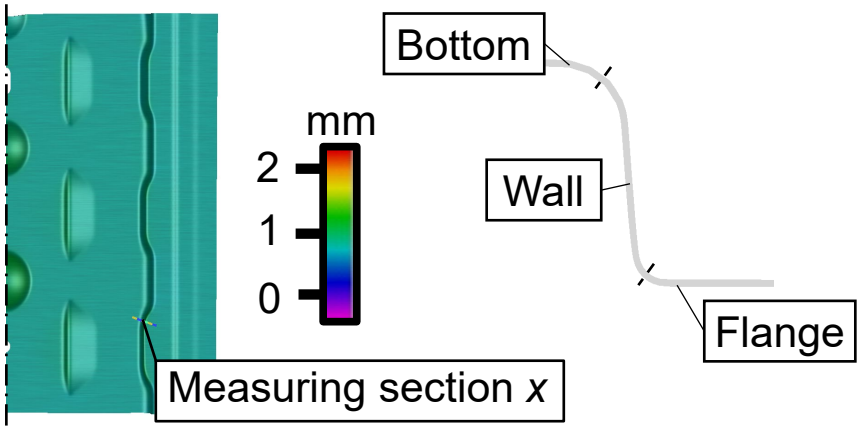
Press force
- **1250 kN**

Material Modeling

Model Validation – Demonstrator Part







Furnace temperature
- 930 °C

Time in air
- 11 s

Blank thickness
- 1.5 mm

Tool Temperature
- 25 °C

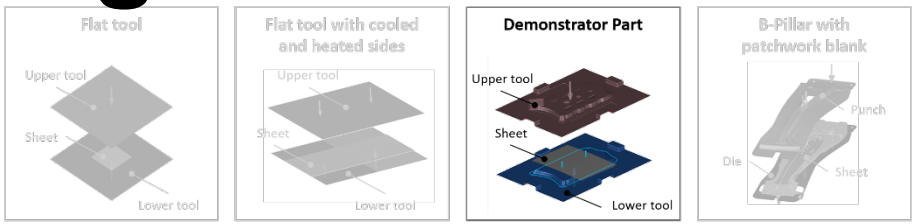
Quenching pressure
- 15 MPa

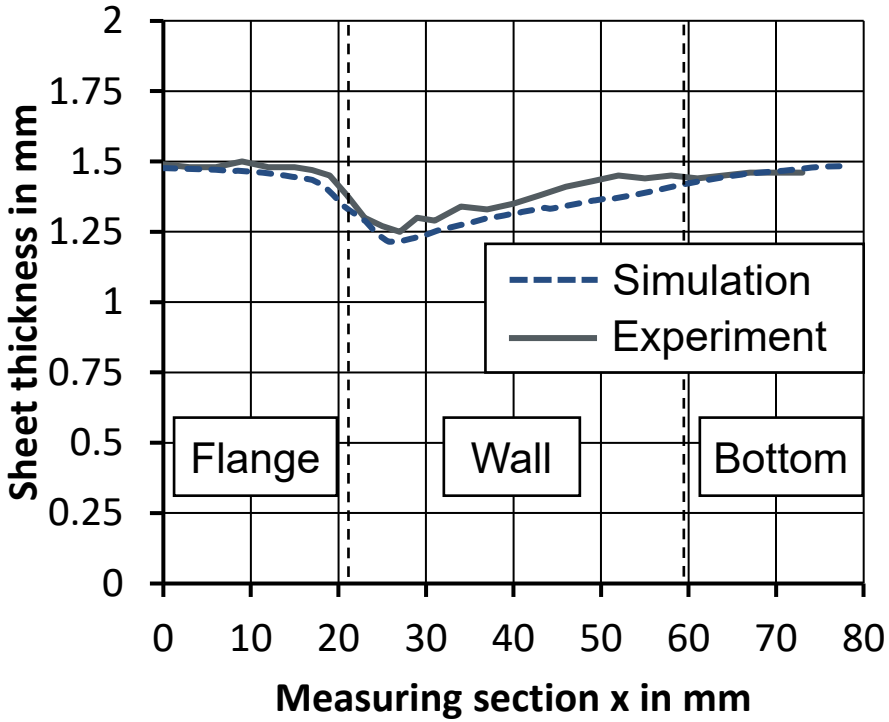
Quenching duration
- 15 s

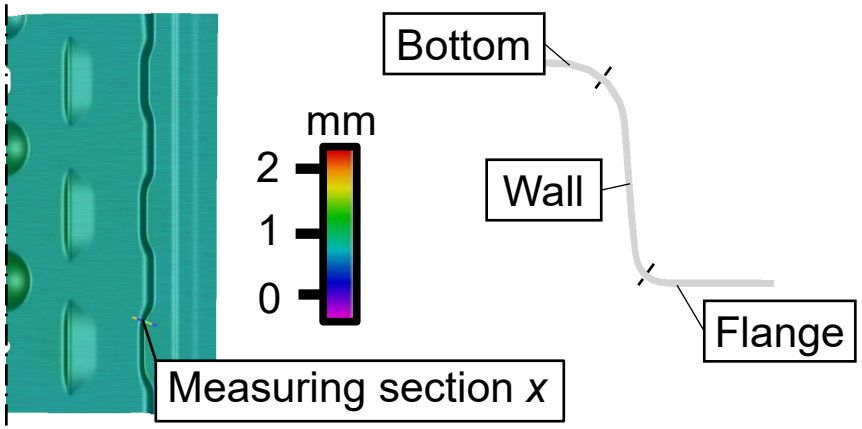
Press force
- 1250 kN

Material Modeling

Model Validation – Demonstrator Part







Furnace temperature
- 930 °C

Time in air
- 11 s

Blank thickness
- 1.5 mm

Tool Temperature
- 25 °C

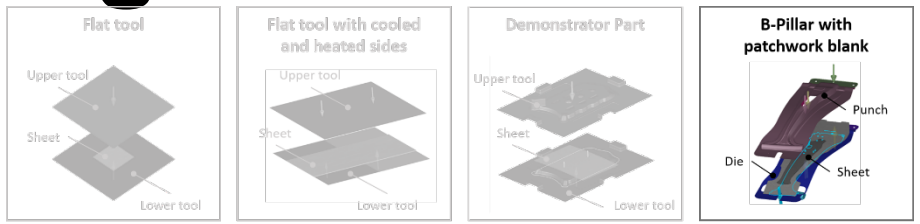
Quenching pressure
- 15 MPa

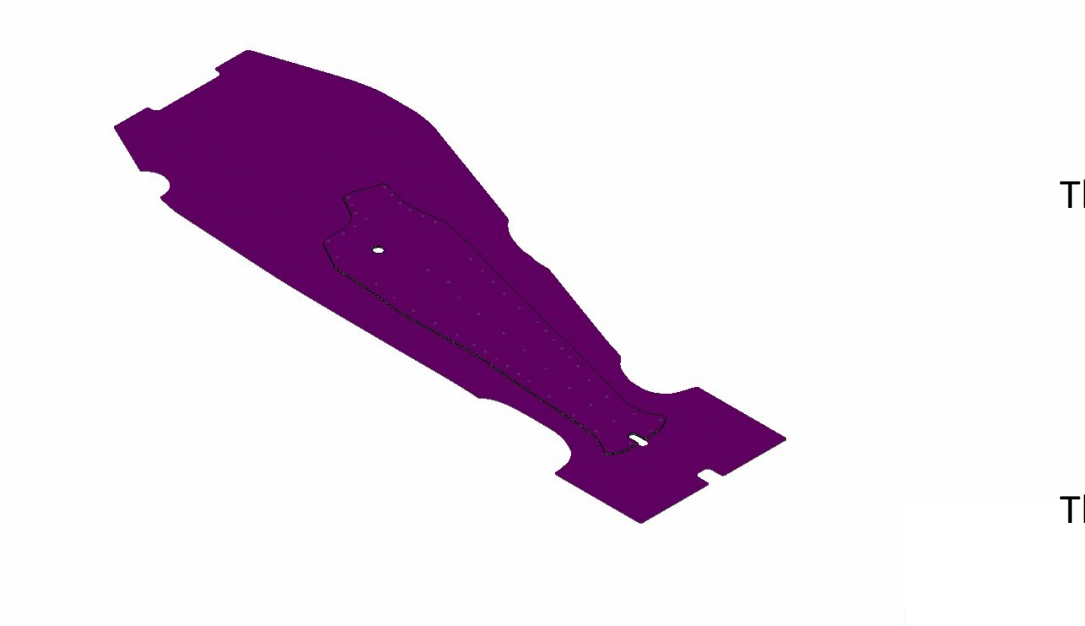
Quenching duration
- 15 s

Press force
- 1250 kN

Material Modeling

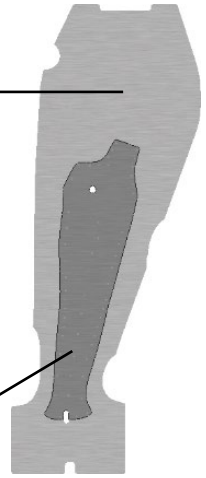
Model Validation – B-Pillar with Patch





Main blank
Ductibor® 1000
Thickness: 1.5 mm

Patch
Usibor® 1500
Thickness: 2.5 mm



Furnace temperature
- 950 °C

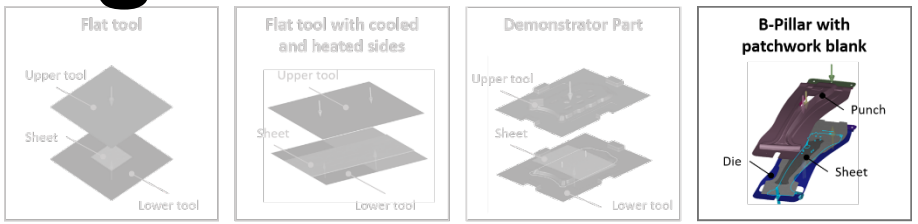
Time in air
- 11 s

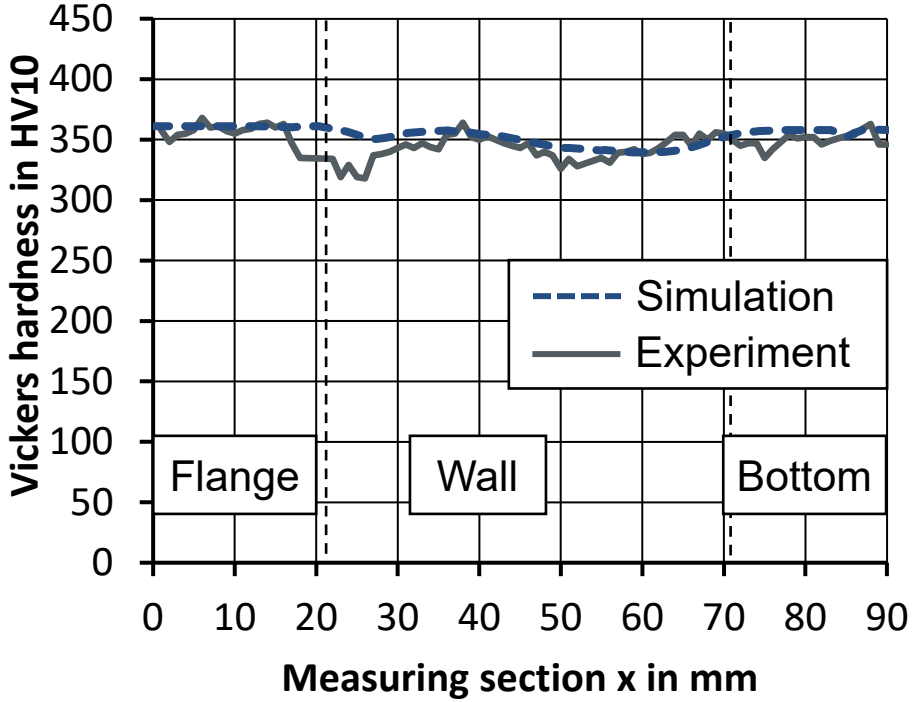
Quenching duration
- 25 s

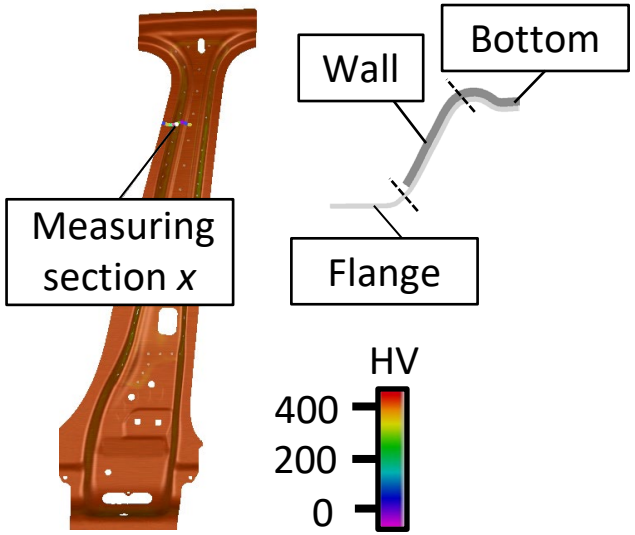
Press force
- 8000 kN

Material Modeling

Model Validation – B-Pillar with Patch







Furnace temperature
- 950 °C

Time in air
- 11 s

Blank thickness

Main blank (Ductibor® 1000)
- 1.5 mm

Patch (Usibor® 1500)
- 2.5 mm

Quenching duration
- 25 s

Press force
- 8000 kN

Material Modeling

Experimental and numerical investigations on tailored product properties of BIW parts using MBW®1200+AS and MBW®1900+AS Pro

Michael Firus[1], Maik Winderlich[1], Tim Scharfenberg[1], Stéphane Graff[2], Melanie Dinter[3], Fabian Dobrowolski[4], Alper Guener[4]

(CHS2 – 2024 – Nashville, TN)

Abstract

… In a first step, phase transformation, hardening and flow behaviour of the materials have been characterized. In a second step, advanced material cards were developed, to allow a reliable description of the phase transformation and resulting mechanical properties of these steels for both the stamping processes with and without tempering technology. Finally, obtained simulation results were compared with laboratory scale experiments for varying temperatures and transfer times, as well as non-continuous temperature histories. In order to generate reliable process knowledge and ensure final product properties, the material cards and simulation setup were verified with demonstrator B-Pillar geometry.

Affliations

1 Gedia Dinkergus GmbH, *2, 3* thyssenKrupp Steel Europe AG, *4* AutoForm Engineering GmbH

Handling Friction / Tribology in Press Hardening Simulations

Tribology

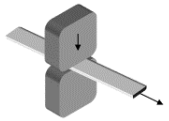
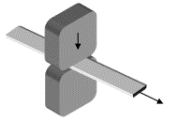
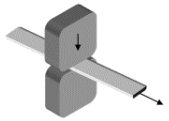
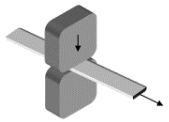
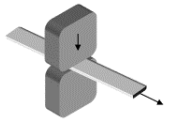
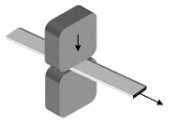
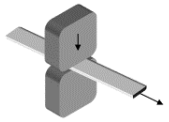
- Flow curves
- Heat transfer
- Phase transformation
- r-Values (T)
- FLD (T)
- Patchwork-Blanks
- Modelling of cooling channels
- **Friction: Modelled as constant (μ=0.45)**

Application of an advanced friction model in hot stamping simulations: A numerical and experimental investigation of an A-Pillar reinforcement panel from Volvo Cars; **IDDRG 2021**

A. Güner[1], J. Hol[2], J. Venema[3], M. Sigvant[4], F. Dobrowolski[5], A. Komodromos[5] and A. E. Tekkaya[5]

[1] AutoForm Engineering GmbH, [2] TriboForm Engineering BV, [3] Tata Steel, Research & Development, Netherlands, [4] Volvo Cars, Sweden, [5] Institute of Forming Technology and Lightweight Components, Germany

Tribology

Reference \ μ depending on	Temperature	Contact Pressure	Sliding Velocity
Yanagida and Azushima (2009) 	μ ↑ (600 °C, 700 °C & 800 °C)		
Kondratiuk and Kuhn (2011) 		μ - (12.5 MPa & 20 MPa)	
Tian et al. (2012) 	μ ↑ (500 °C, 600 °C & 700 °C)		μ ↓ (25 mm/s & 50 mm/s)
Vilaseca et al. (2014) 	μ ↓ (550 °C & 800 °C)		
Mozgovoy et al. (2018) 		μ ↓ (7 MPa & 21 MPa)	μ - (10 mm/s & 100 mm/s)
Venema (2019) 	< 600 °C: μ ↓ > 600 °C: μ ↑		
Schwingenschlögl (2020) 	< 600 °C: μ ↓ > 600 °C: μ ↑	μ ↓ (2.5 MPa, 5 MPa & 7.5 MPa)	μ ↓ (10 mm/s - 120 mm/s)

Positive Correlation

Negative Correlation

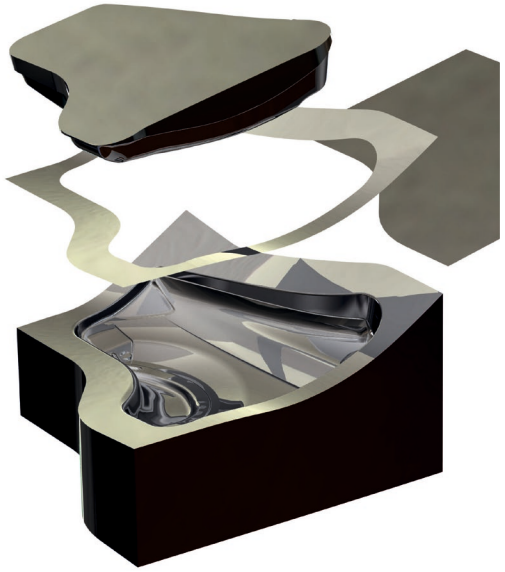
No clear correlation

Tribology in Hot Stamping

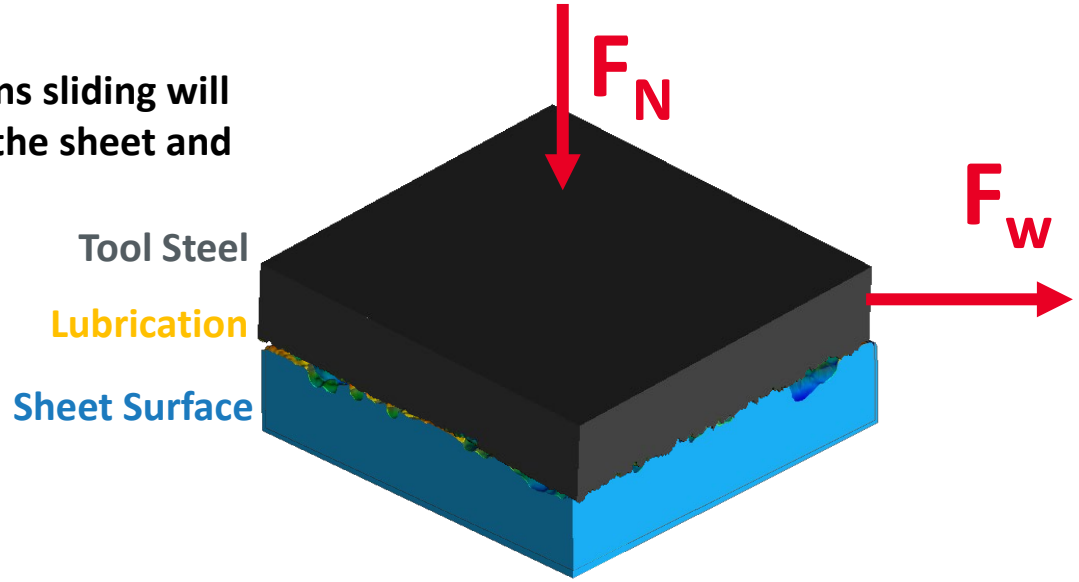
The Coefficient of Friction (COF) is often described by the Greek symbol μ

μ is often assumed constant during metal forming simulations

μ describes the ratio between frictional force and normal force (Coulomb's law)



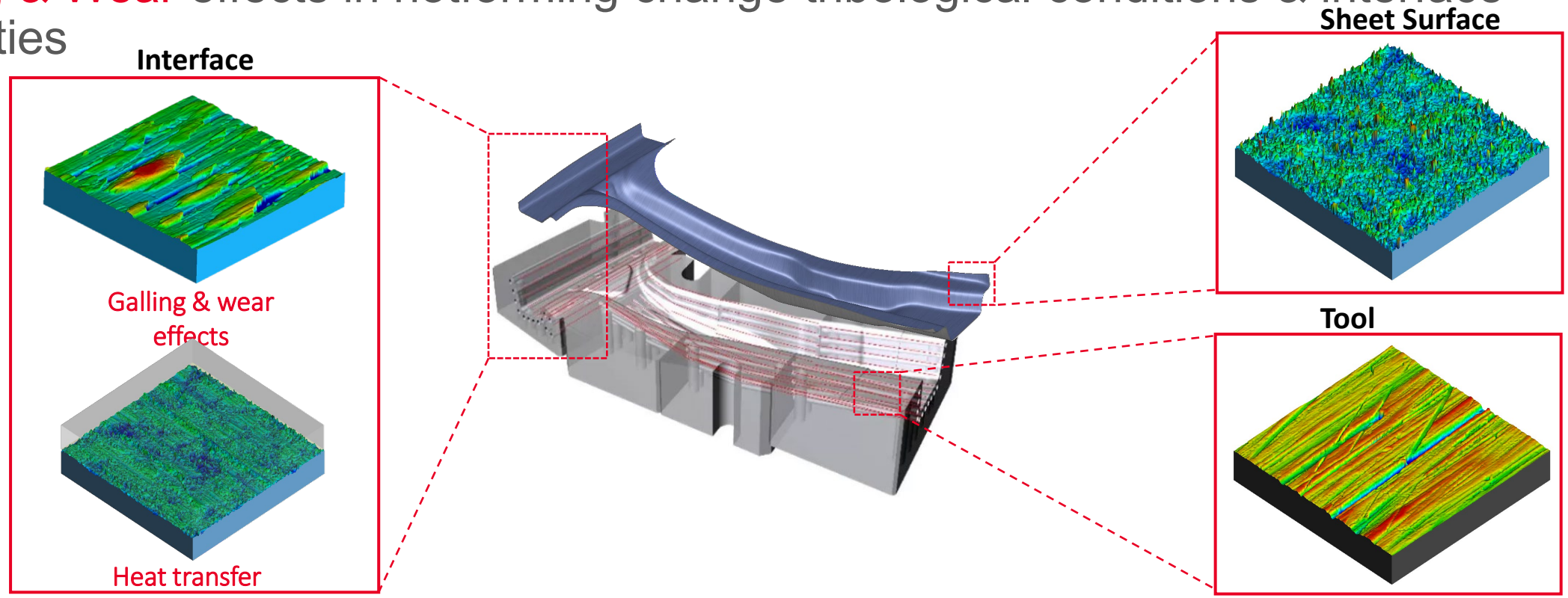
In contact regions sliding will occur between the sheet and contacting tool:



Coulomb's law → $\mu = \frac{F_w}{F_N}$ (Friction Force) / (Normal Force)

Tribology in Hot Stamping

- Where is friction coming from?
  - The surfaces of the blank and tooling are not flat!
  - All surfaces have a roughness; this roughness plays an important role in tribology.
  - Galling & Wear effects in hotforming change tribological conditions & interface properties



Tribology in Hot Stamping

- Where is friction coming from?
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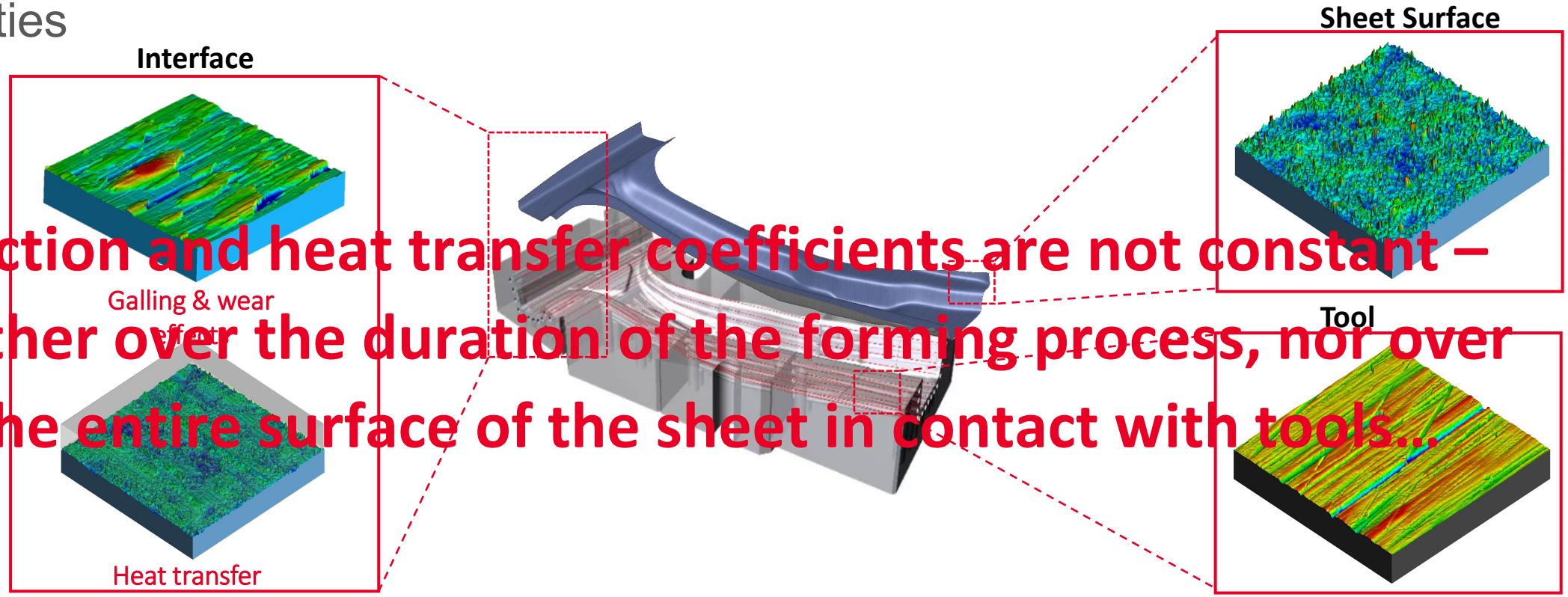
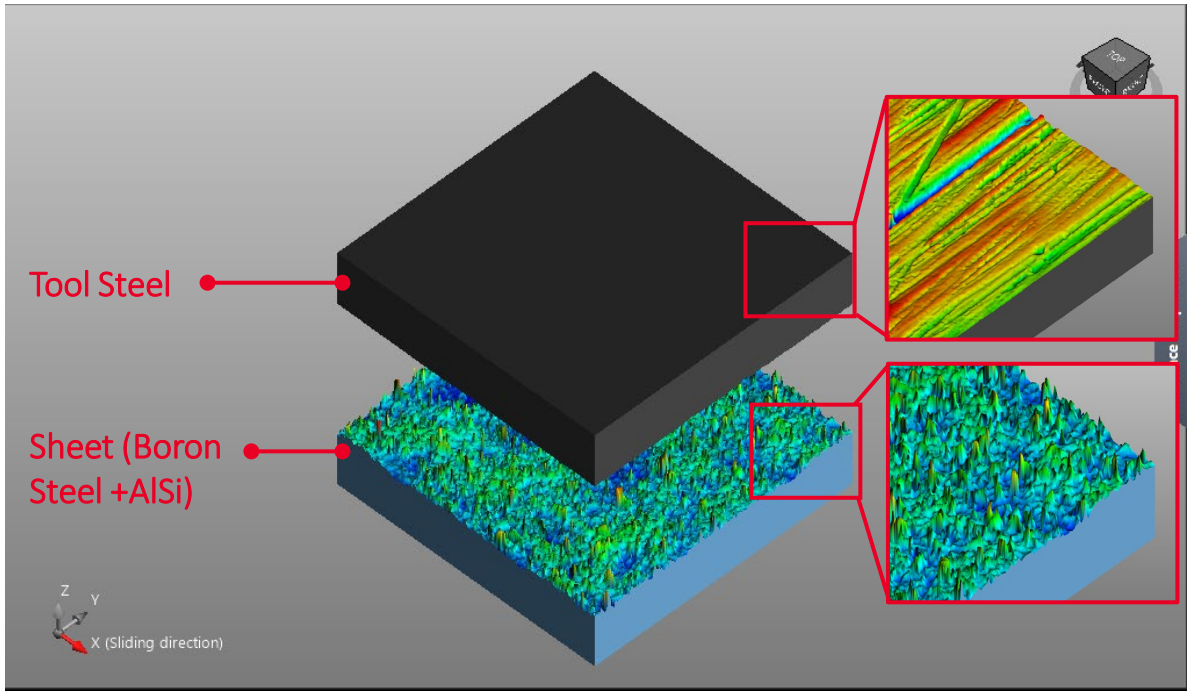
  - All surfaces have a roughness; this roughness plays an important role in tribology.
  - Galling & Wear effects in hotforming change tribological conditions & interface properties

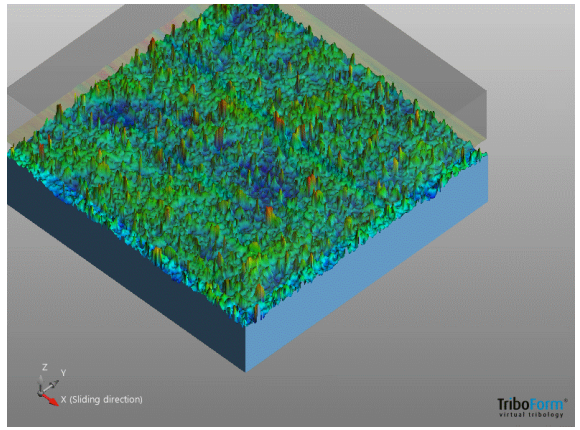


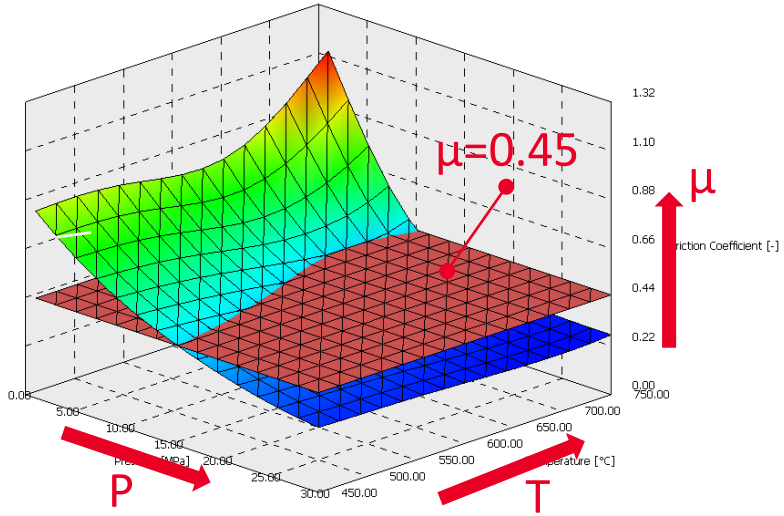
Friction and heat transfer coefficients are not constant – neither over the duration of the forming process, nor over the entire surface of the sheet in contact with tools…

Advanced friction modelling (TriboForm)

- μ ≠ constant → μ (TriboForm) = f (pressure, strain, velocity, temperature)

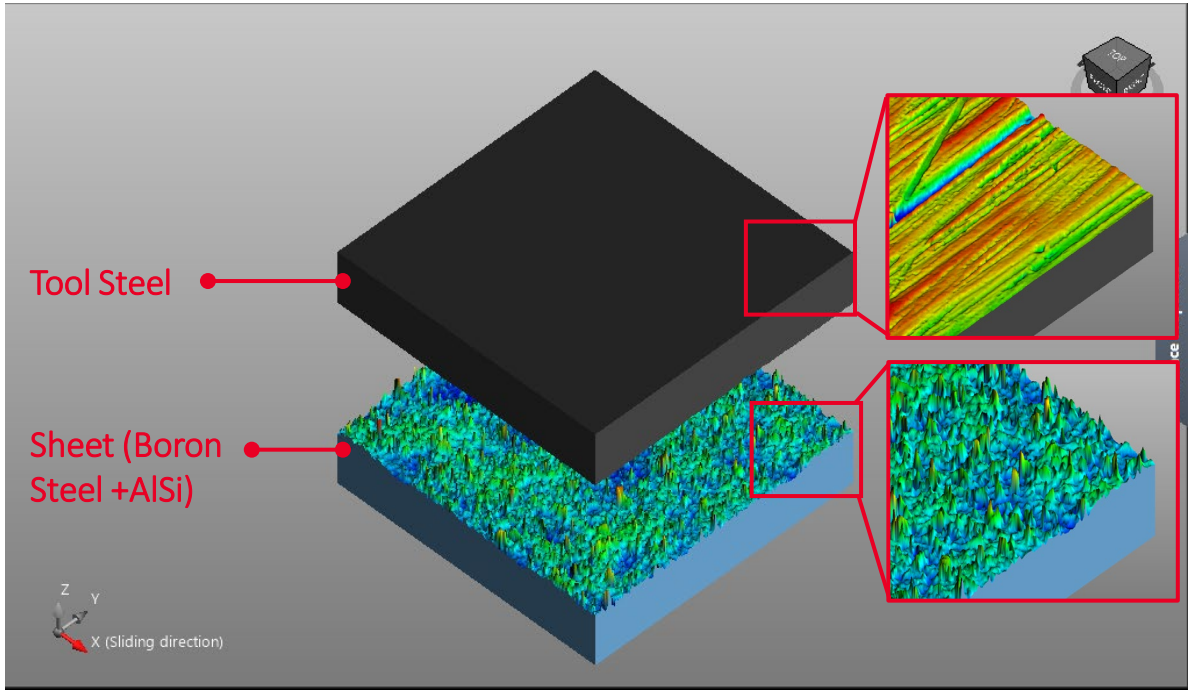


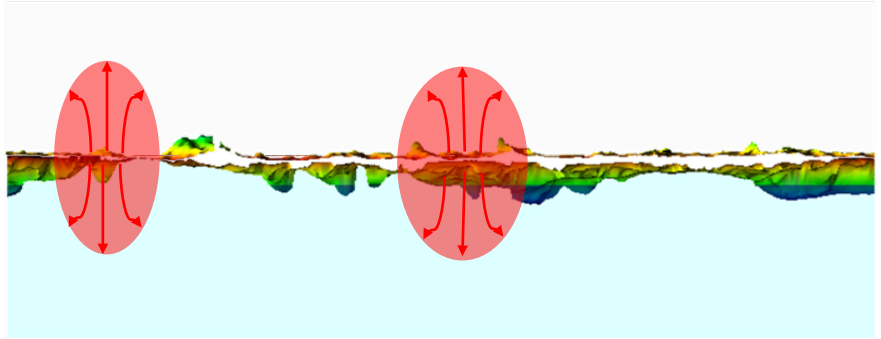


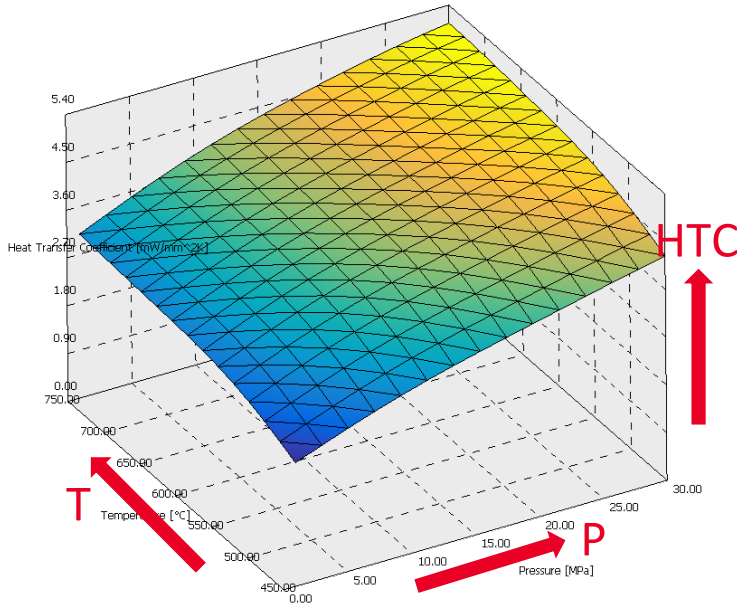


Advanced friction modelling (TriboForm)

- Interface HTC as a function of Temperature, Contact Pressure...



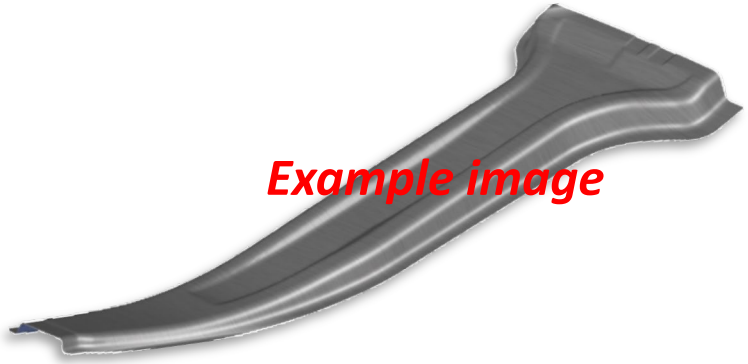




Advanced friction modelling (TriboForm)

A-Pillar Reinforcement

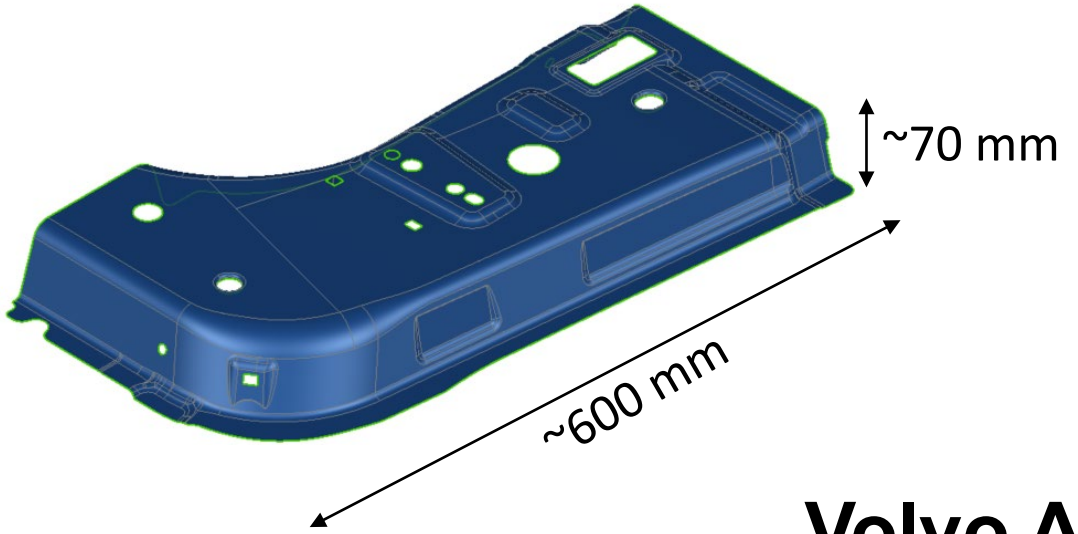
B-Pillar Reinforcement

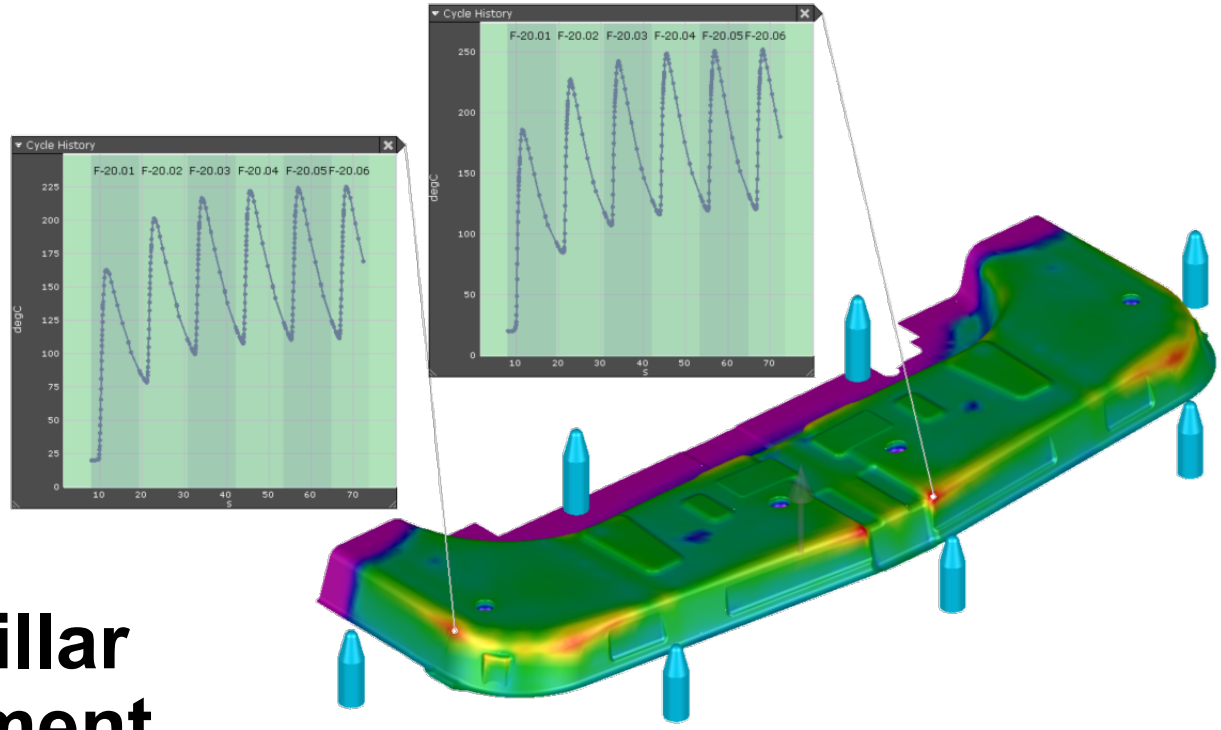


Industrial application cases

Advanced friction modelling (TriboForm)

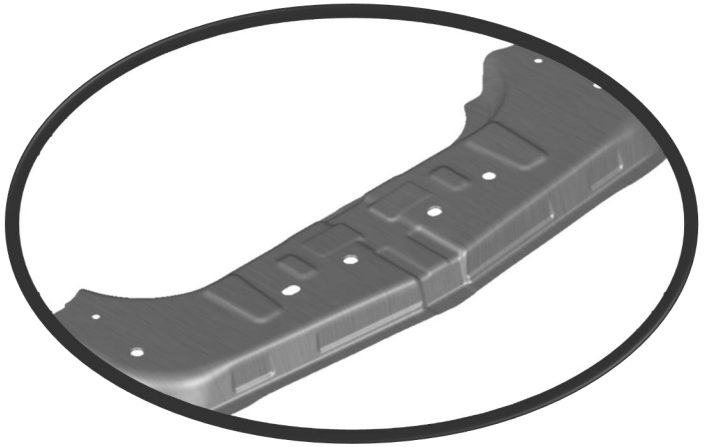
- Material: 22MnB5, t=1.20 mm
- With temperature dependent r-Values
- Modelling of cooling channels with 3D heat conduction





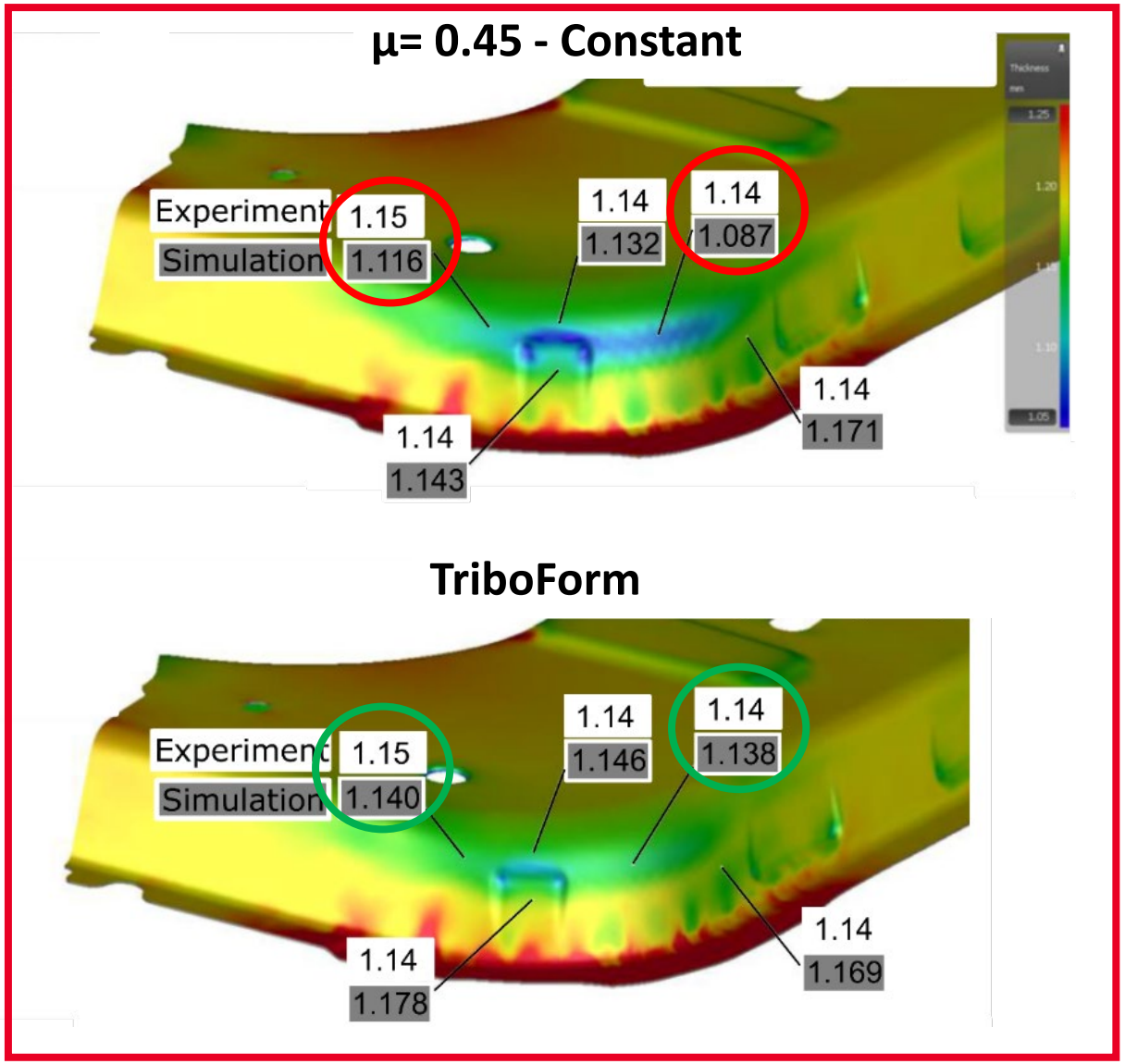
Volvo A-Pillar Reinforcement

Advanced friction modelling (TriboForm)



Volvo A-Pillar Reinforcement

Thickness comparison



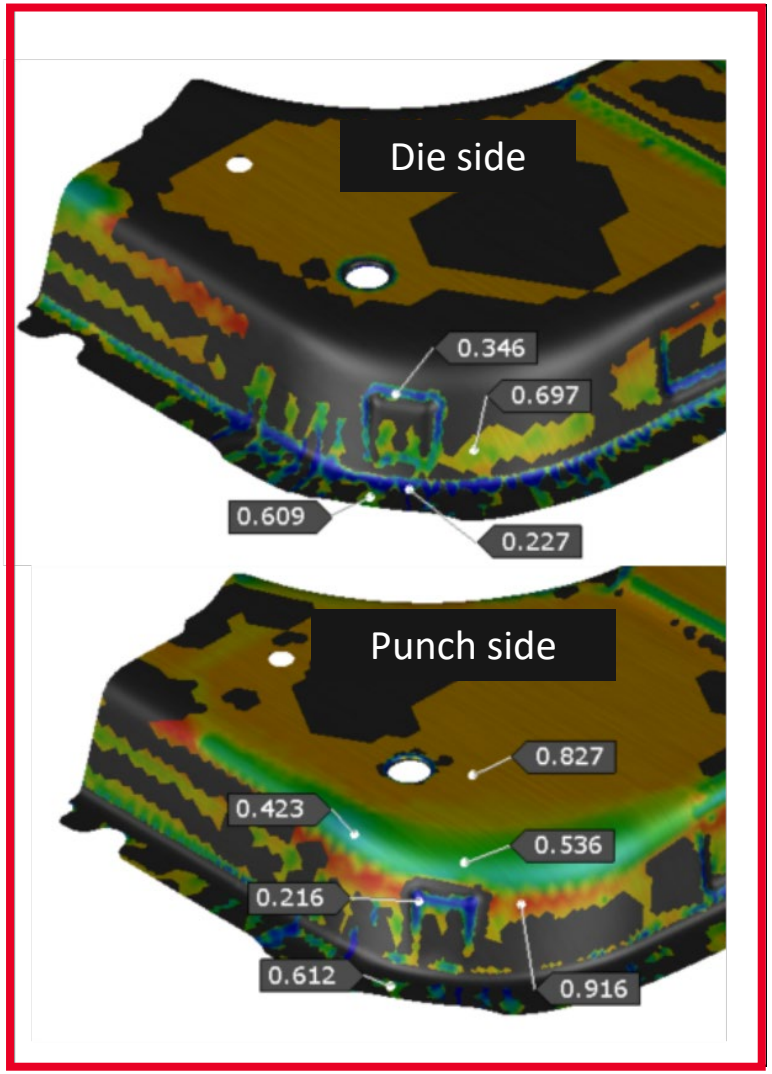
Advanced friction modelling (TriboForm)

- Friction coefficient changes through the process

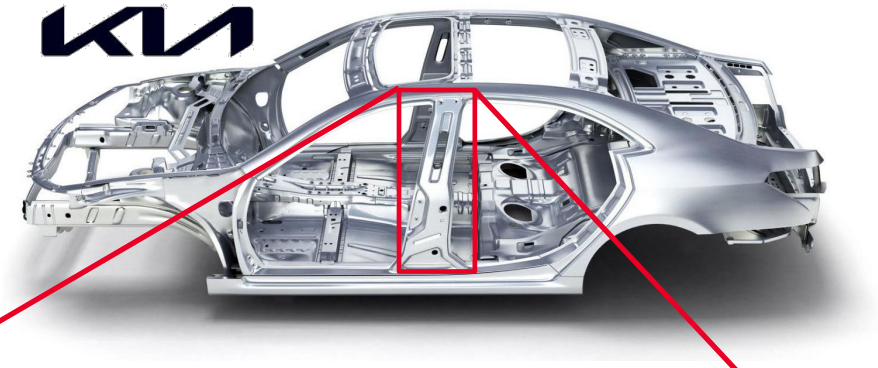
- Considered dependencies:
  - Surface topography
  - Contact pressure
  - Temperature
  - Strain
  - Sliding velocity

Volvo A-Pillar Reinforcement

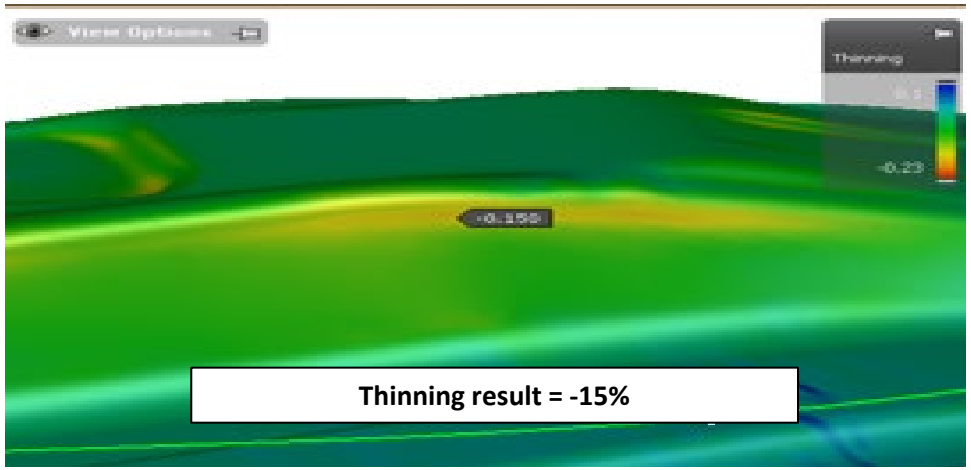
Distribution of friction coefficient



Advanced friction modelling (TriboForm)



- Material: 22MnB5, t=1.60 mm



KIA B-Pillar

Simulation + constant (Coulomb) friction:

Not critical

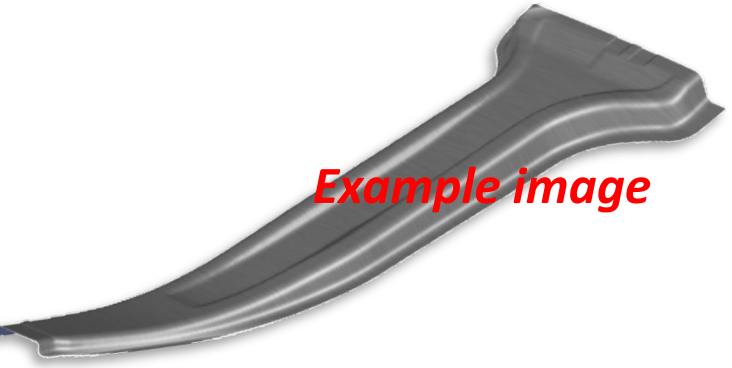
≠

?

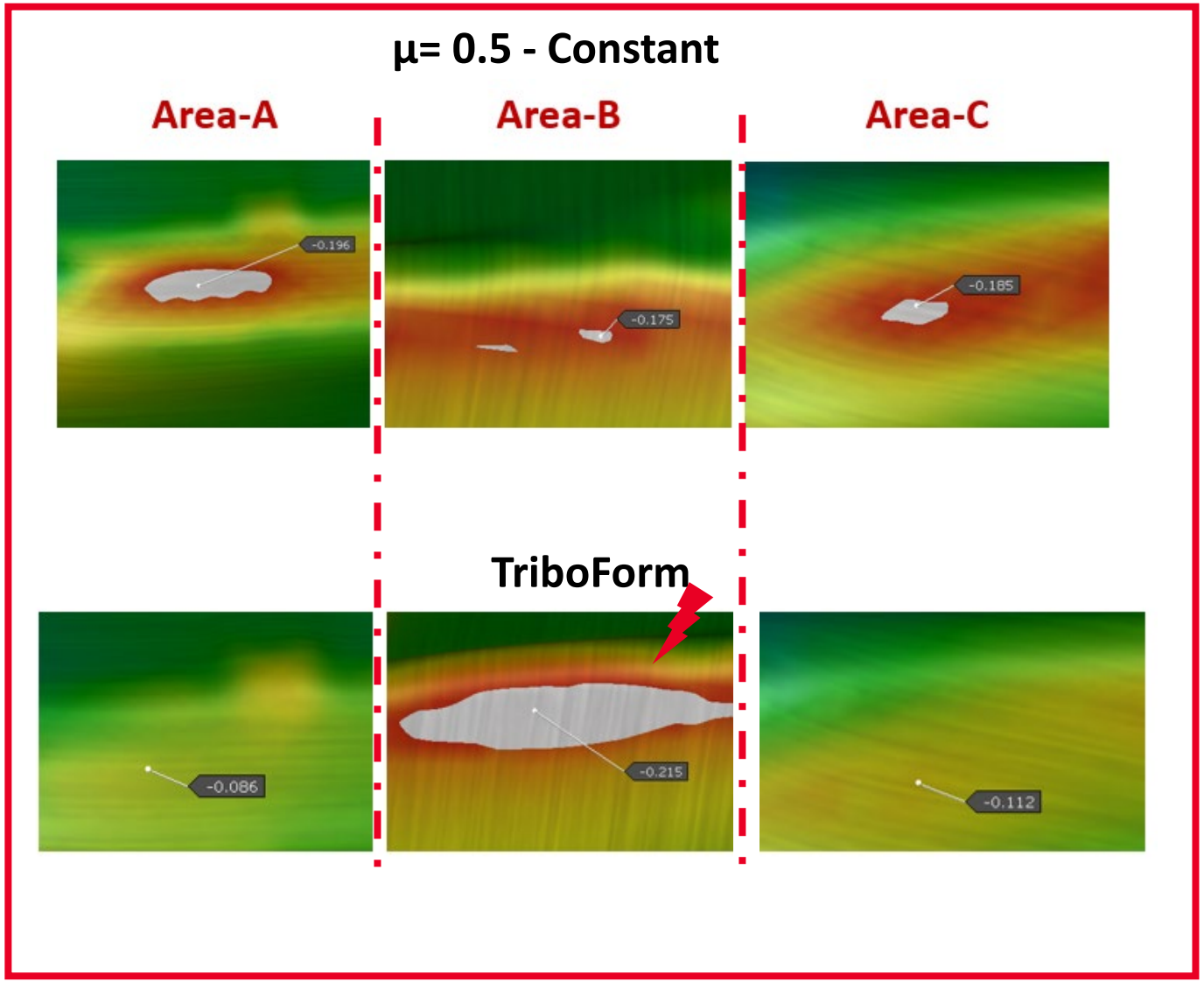
First press trial:

Necking

Advanced friction modelling (TriboForm)



Thickness comparison



KIA B-Pillar

Advanced friction modelling

- Flow curves
- Heat transfer
- Phase transformation
- r-Values (T)
- FLD (T)
- Patchwork-Blanks
- Modelling of cooling channels

- **Interface Sheet-Tool:**
  - Advanced friction modelling
  - Heat transfer coefficient
  - ***Galling and Wear***

Advanced friction modelling

Tribological modelling in hot stamping processes: Prediction of tool wear and tool lifetime on industrial scale

Ciska van der Veen[1], Johan Hol [1], Mats Sigvant[2,3]*

[1] TriboForm Engineering, Hengelosestraat 500, 7521 AN, Enschede, the Netherlands
[2] Volvo Cars Dept. 81110 Strategy Development, Olofström, Sweden
[3] Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden

CHS2 – 2024 (Nashville, TN)

Abstract: ….More recently an advanced friction model for hot stamping processes has been introduced to accurately describe frictional behavior of 22MnB5-AlSi. This study aims to further extend the advanced friction model of 22MnB5-AlSi into an abrasive wear prediction tool by evaluating a number of abrasive wear models. 3D tool scans of industrial parts are used to calibrate the abrasive wear models. This resulted in a multi-dimensional abrasive wear model as a function of temperature, pressure, strain and also on the relative sliding distance in contact between the tool and the sheet. Finally, the abrasive wear distribution and tool lifetime predictions are evaluated based on a number of industrial parts from Volvo Cars. The abrasive tool wear locations are properly identified on the tools. However, the evolution of abrasive wear over time should be further investigated to increase the prediction capability of tool lifetime.

Hot Forming of Aluminum

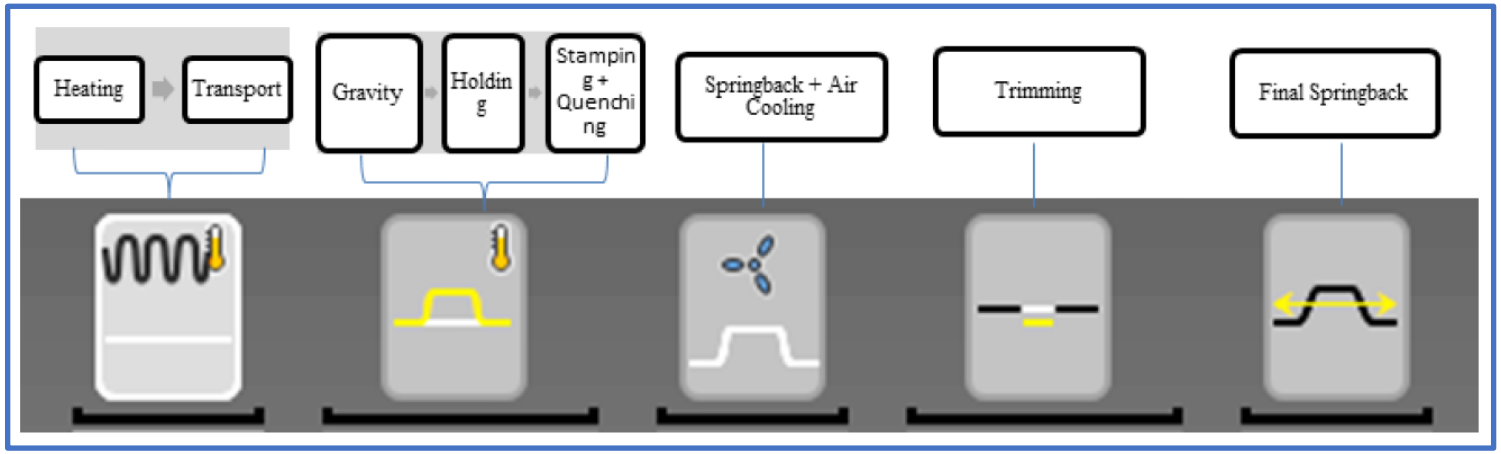
Aluminum Hot Forming

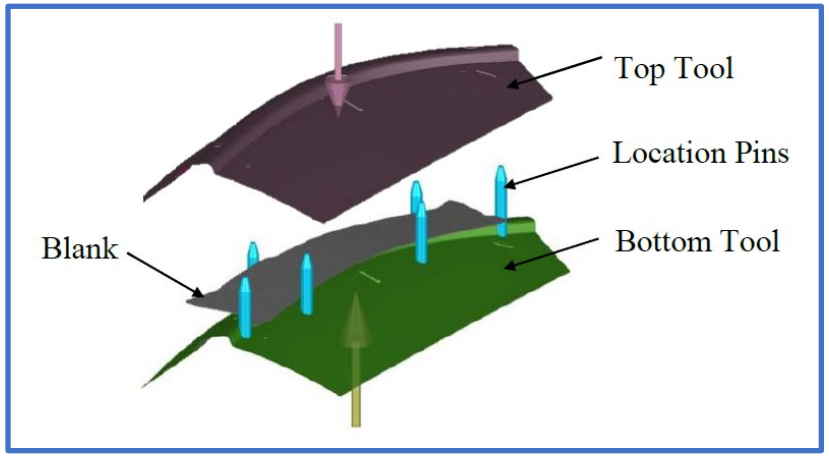
- Aluminum hot forming requires heating of Aluminum sheet to above or near its solutionizing temperature; typically applied to high-strength, heat-treatable grades of Aluminum – 6xxx, 7xxx
- **HFQ™** – Hot Form Quench – involves forming the heated blank in cooled dies, simultaneously quenching the formed component
  - Non-isothermal process; involves complex thermo-mechanical effects, similar to press hardening of steels
  - Simulation-based engineering and optimization of process are essential to producing acceptable and dimensionally compliant parts

Process optimisation and robustness analysis for HFQ process
M Mohamed[1], D Szegda[1], J Swift[1], O Gaines[1], D Ling[2], M Sonntag[3] and A Güner[3]
[1] Impression Technologies Limited, Coventry, CV5 9PF, UK, [2] AutoForm Engineering B.V., Netherlands, [3] AutoForm Engineering, Germany
42nd Conference of the International Deep Drawing Research Group (IDDRG 2023)

Aluminum Hot Forming

- The following hot forming process was defined in simulation in detail





- Process conditions, as well as thermal and mechanical characteristics of the forming system were carefully represented:
  - ambient temperature, heat transfer coefficients, tool temperatures, press speeds, press forces, and time delays within the tool for robot automation, material model, etc.

Aluminum Hot Forming

HFQ Process Trials

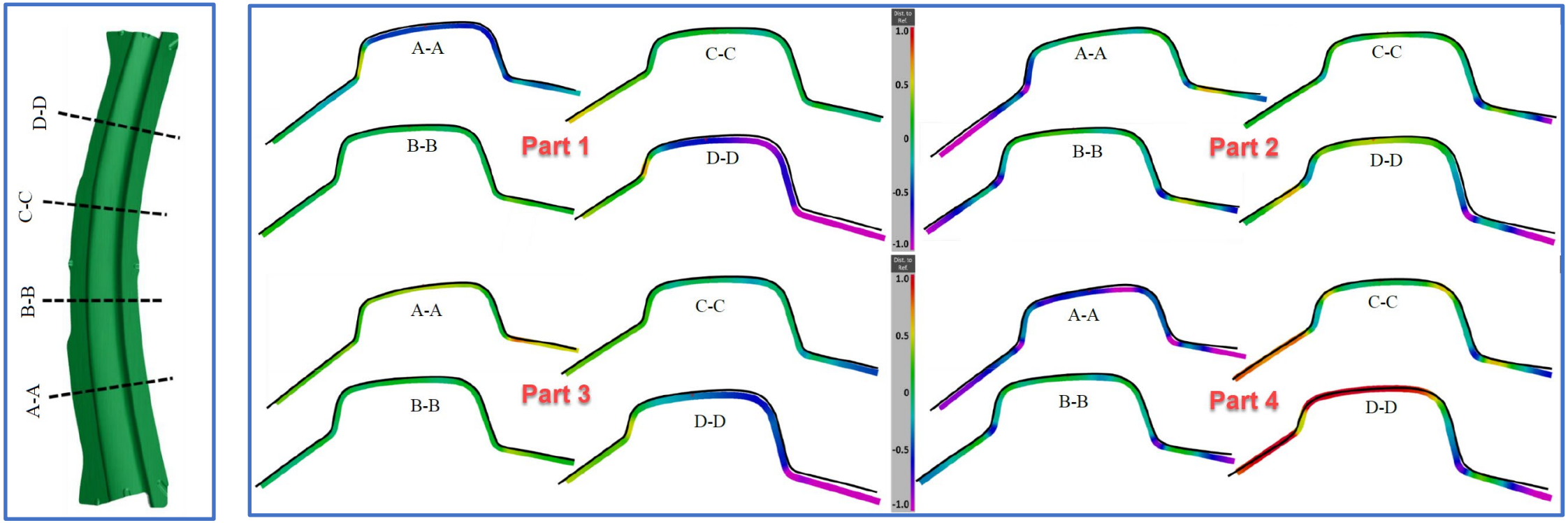
DOE over selected process parameters for an A-pillar formed out of AA6082

- **Group A** panels used to validate simulation capability
- **Group B** panels used to evaluate the influence of selected process conditions on panel distortion using simulation

Part No		Temperature (°C)	Speed (mm/sec)	Quenching-Force (ton)	Quenching - Time (sec)
Group A	1	525	250-79	250	8
	2	525	79-79	50	30
	3	460	250-79	50	8
	4	460	79-79	50	30
Group B	5	525	250-79	250	30
	6	525	79-79	50	2
	7	460	250-79	250	30
	8	460	79-79	50	2

Aluminum Hot Forming

Group A panels – Validation of HFQ Process Simulation

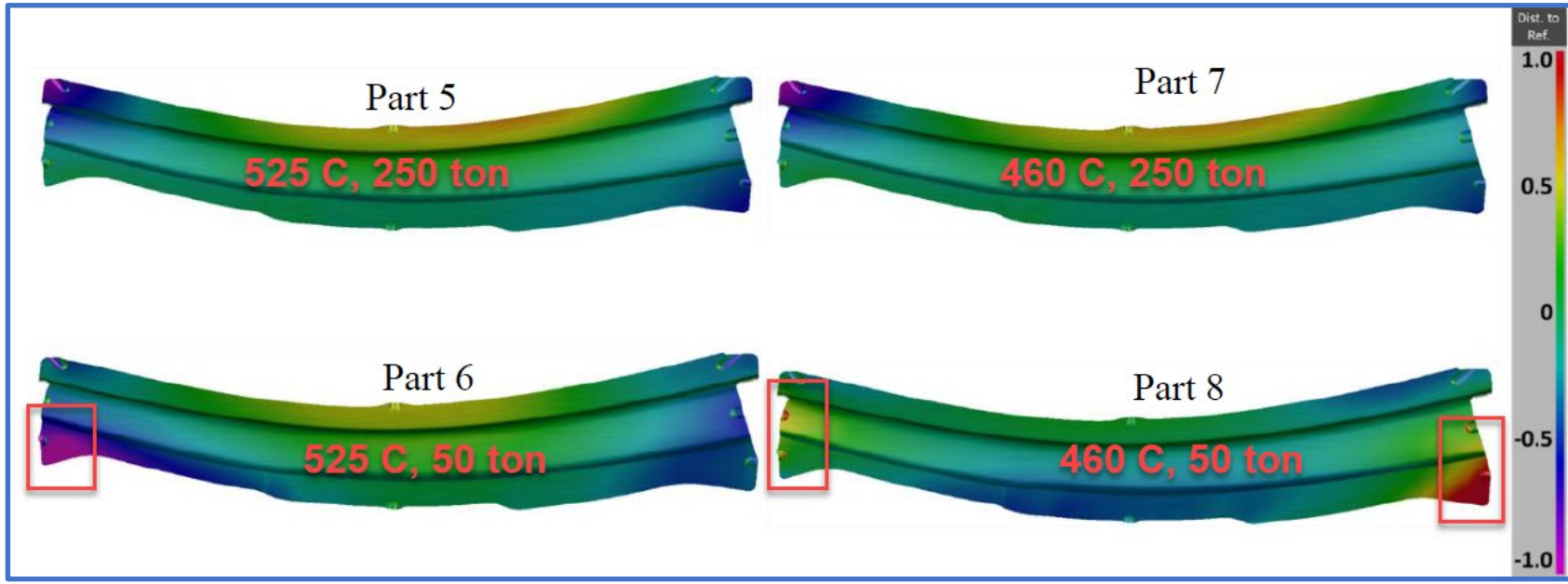


Comparison of physical and simulated panel shapes

Aluminum Hot Forming

Group B panels – Numerical evaluation of the influence of process parameters on panel distortion

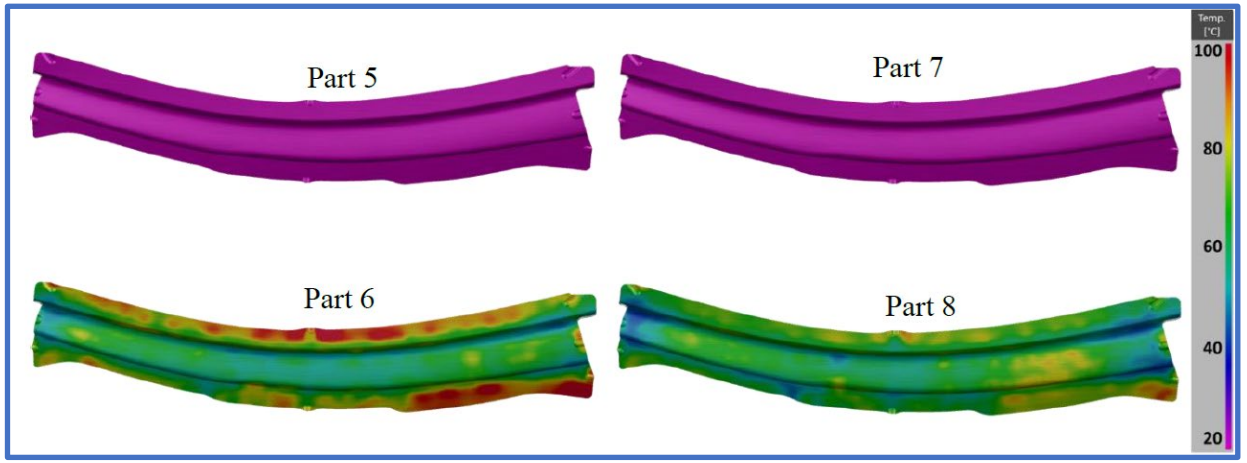
- Blank heating temperature
- Quenching force
- (Quenching / hold time)

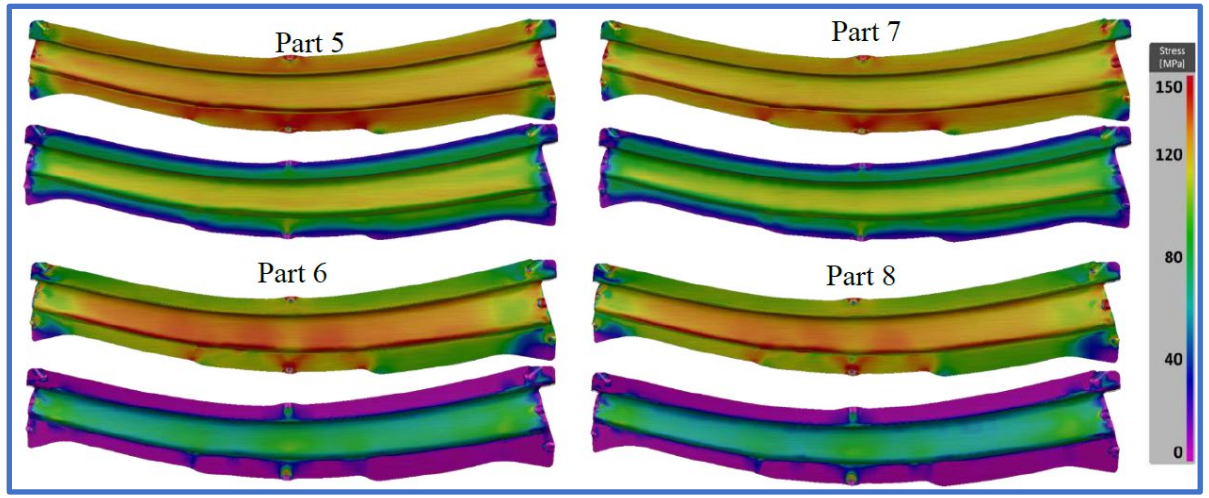


=> Quenching force influence on distortion is greater than Blank heating temperature…

Aluminum Hot Forming

Group B panels – Numerical evaluation of the influence of process parameters on panel distortion…



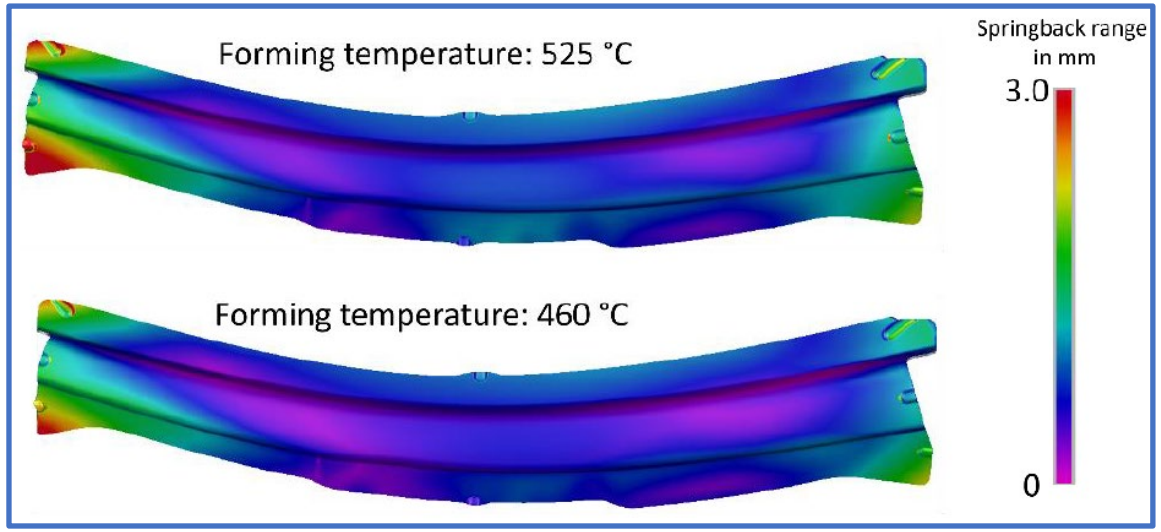


Post-quench distributions of temperature and Major / Minor stresses observed to show more variation associated with lower quenching force…

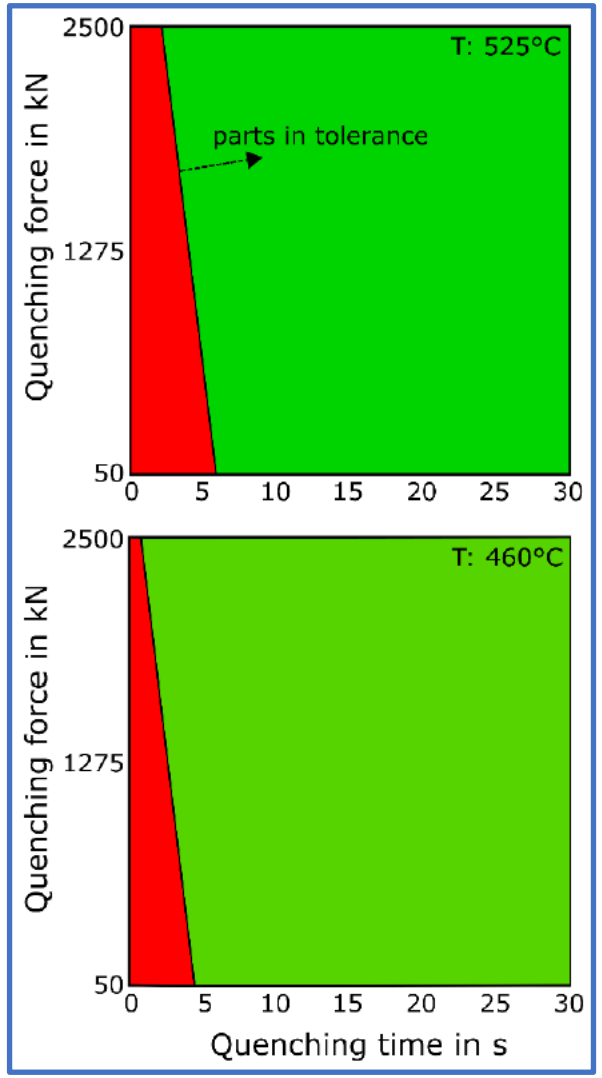
Aluminum Hot Forming

Sensitivity study using AutoForm-Sigma

- For each of the temperatures **460 C**, and **525 C**
  - Quenching Force varied **50 – 2500 kN**
  - Quenching Time varied **0 – 30 s**



Anticipated range of panel springback

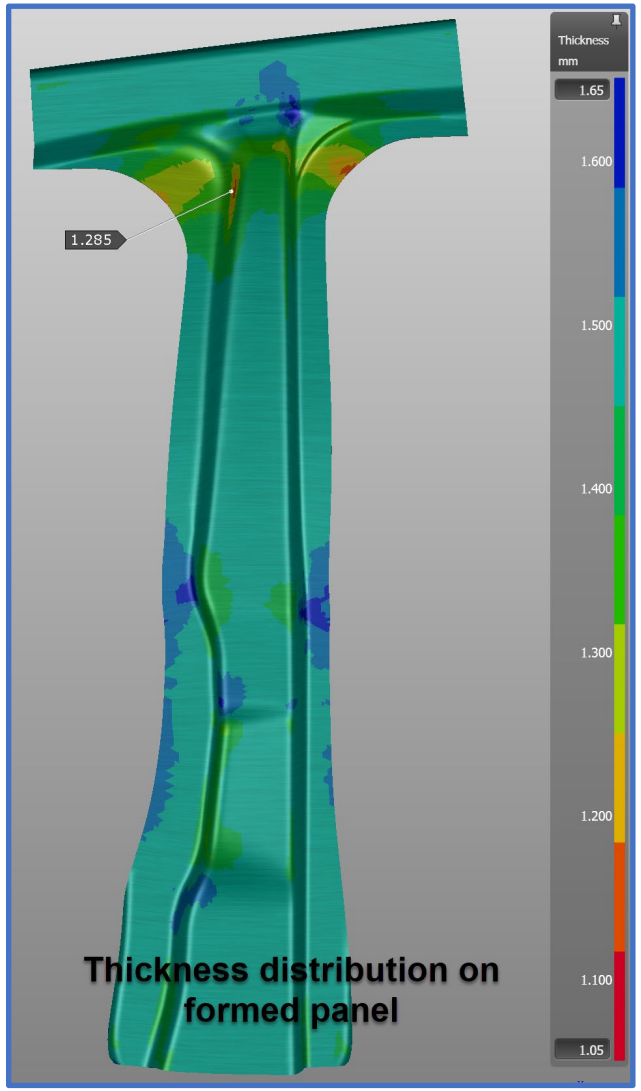


Die Spotting

Die Spotting

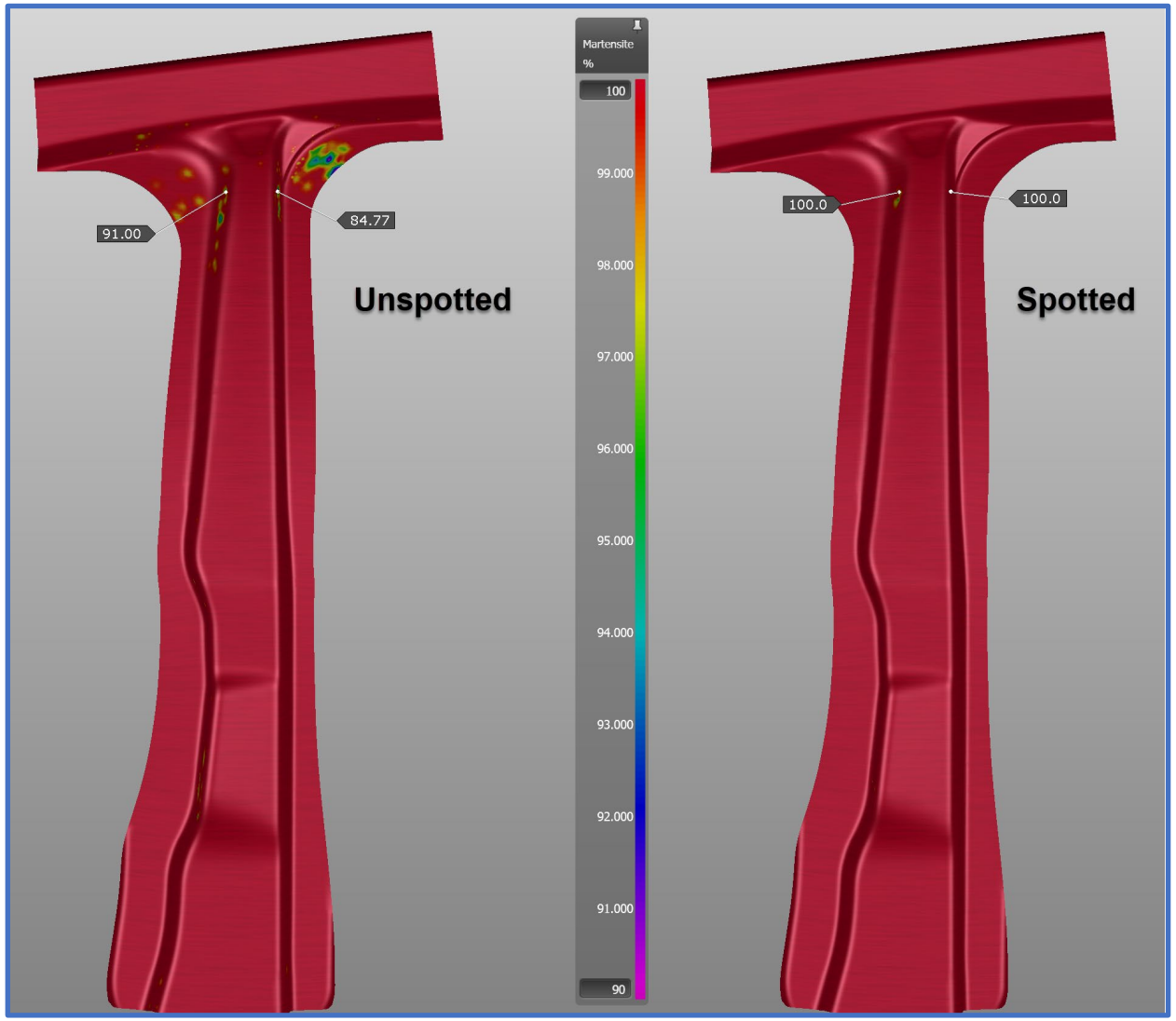
Hot Stamping…

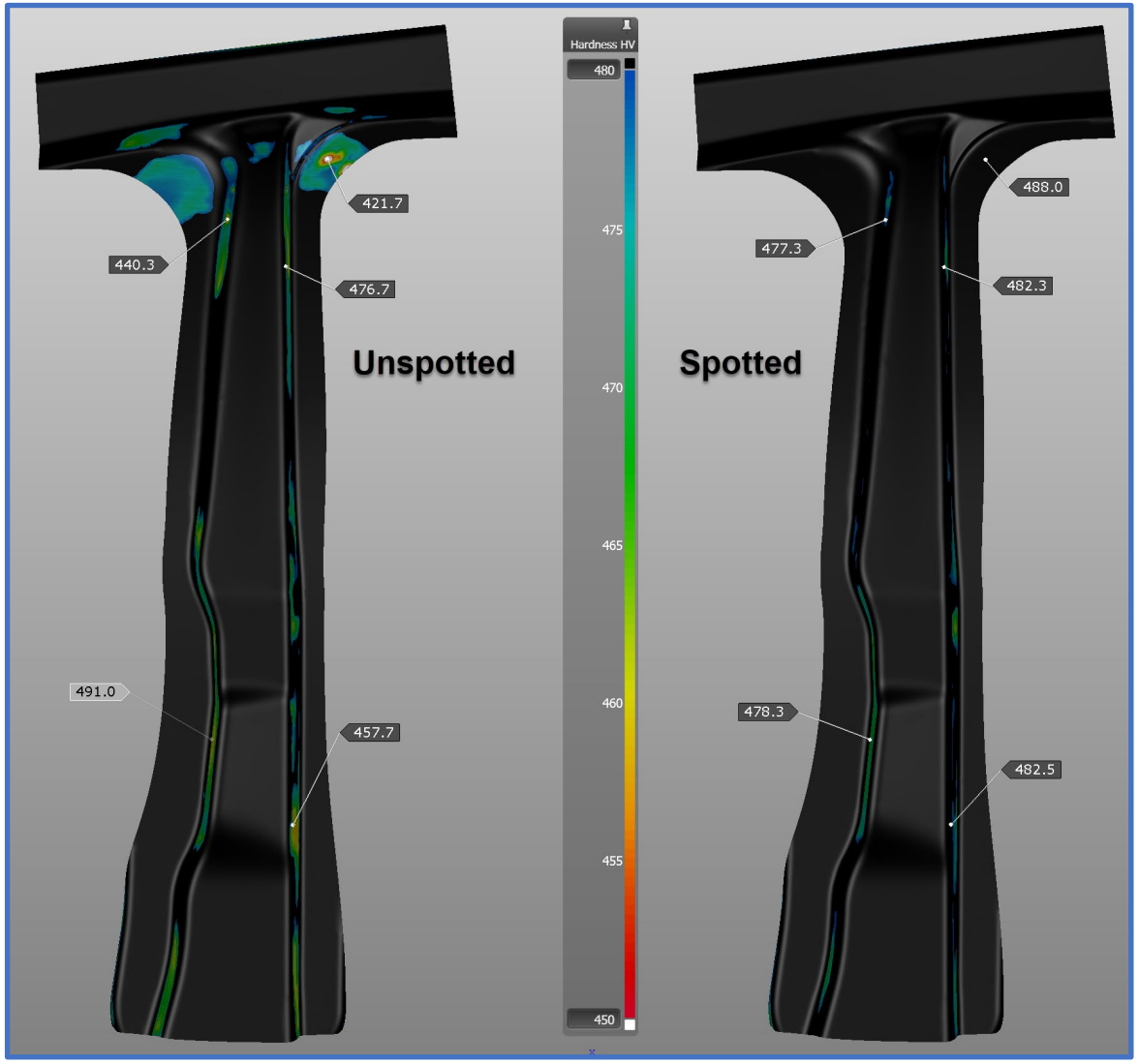
- Ensure consistent and uniform contact between tool and sheet surfaces
  - Compensate for thin outs on panel
- Sufficient cooling rate during quenching to develop Martensite
- Eliminate / minimize hot spots
- Digitally validated die spotting:
  - Reduce cost / time associated with physical spotting effort



Thickness distribution on formed panel

Die Spotting





Thank You!

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