GREAT DESIGNS IN STEEL

An Advanced Tribological Model for Accurate Press Hardening Simulation

Kidambi Kannan

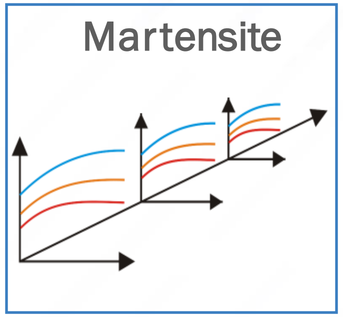
AutoForm Engineering USA, Inc.

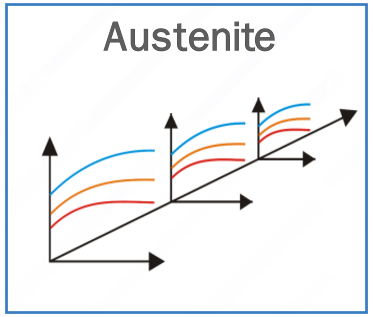
AutoForm Forming Reality

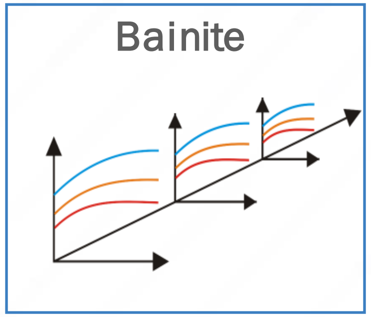
Advances in Modeling of Press Hardening

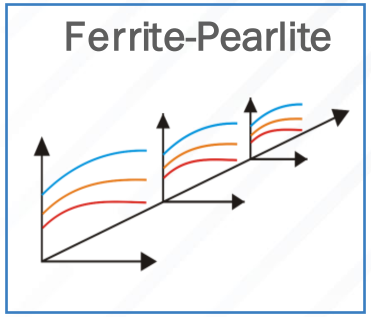
GDIS

Phase Dependent Flow Curves



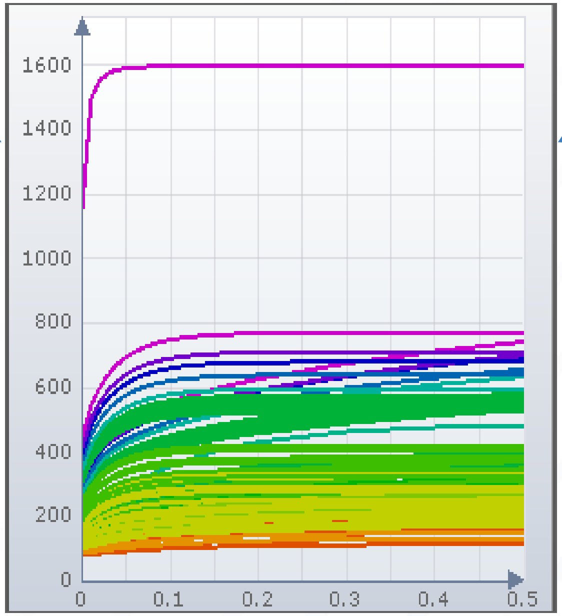






Essential for the accurate prediction of:

- Forming outcomes based on temperature history, and the resulting volume fractions of different phases



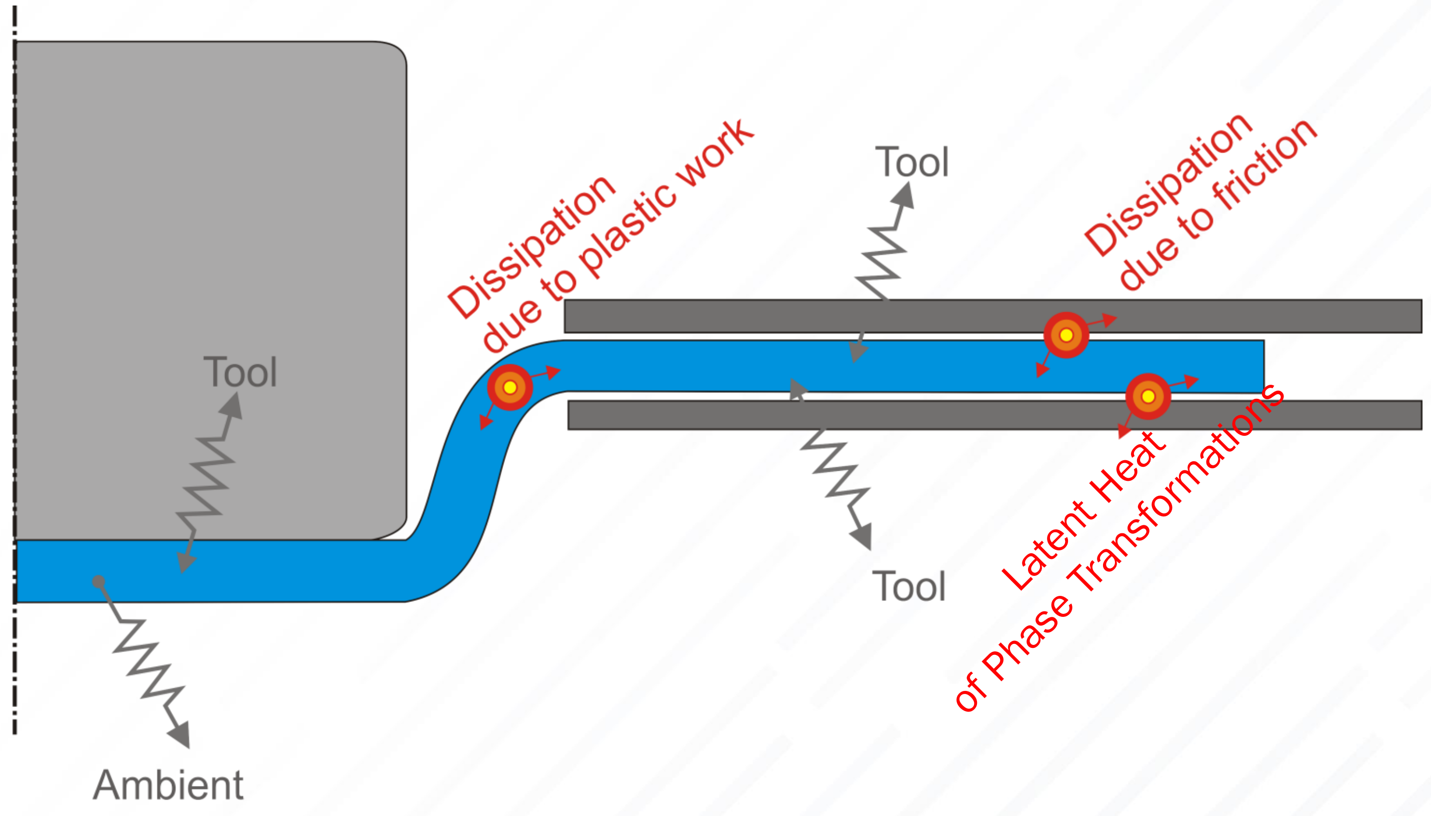
+ Temperature-dependent Youngs Modulus

Advances in Modeling of Press Hardening

Phase Dependent Flow Curves

Heat transfer

Heat Generation, Heat Exchange



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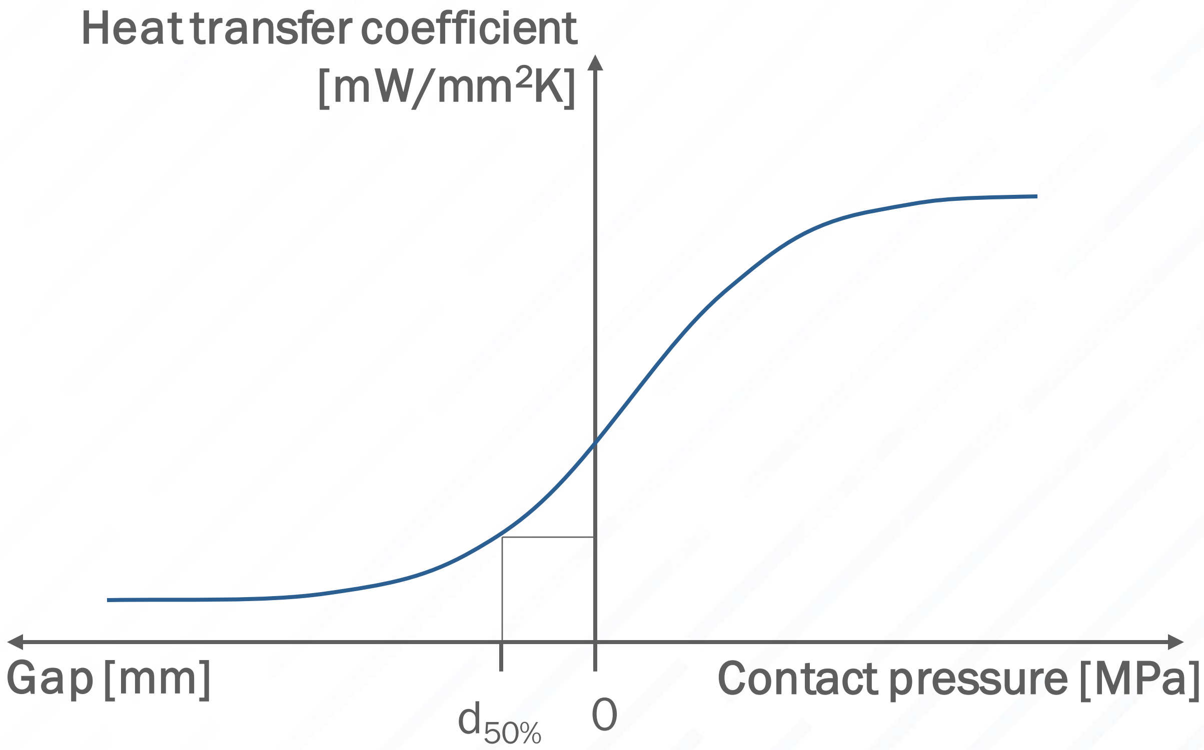
Phase Dependent Flow Curves

Heat transfer

Heat Exchange:

- Sheet <-> Tool
- Sheet <-> Ambient



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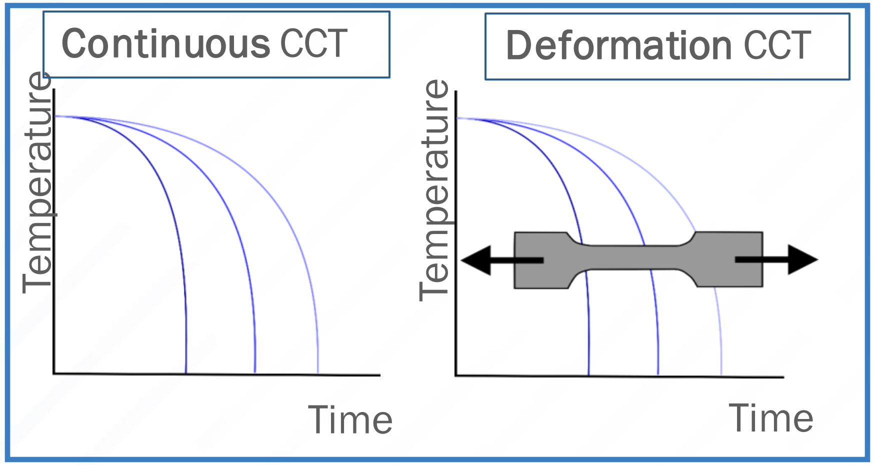
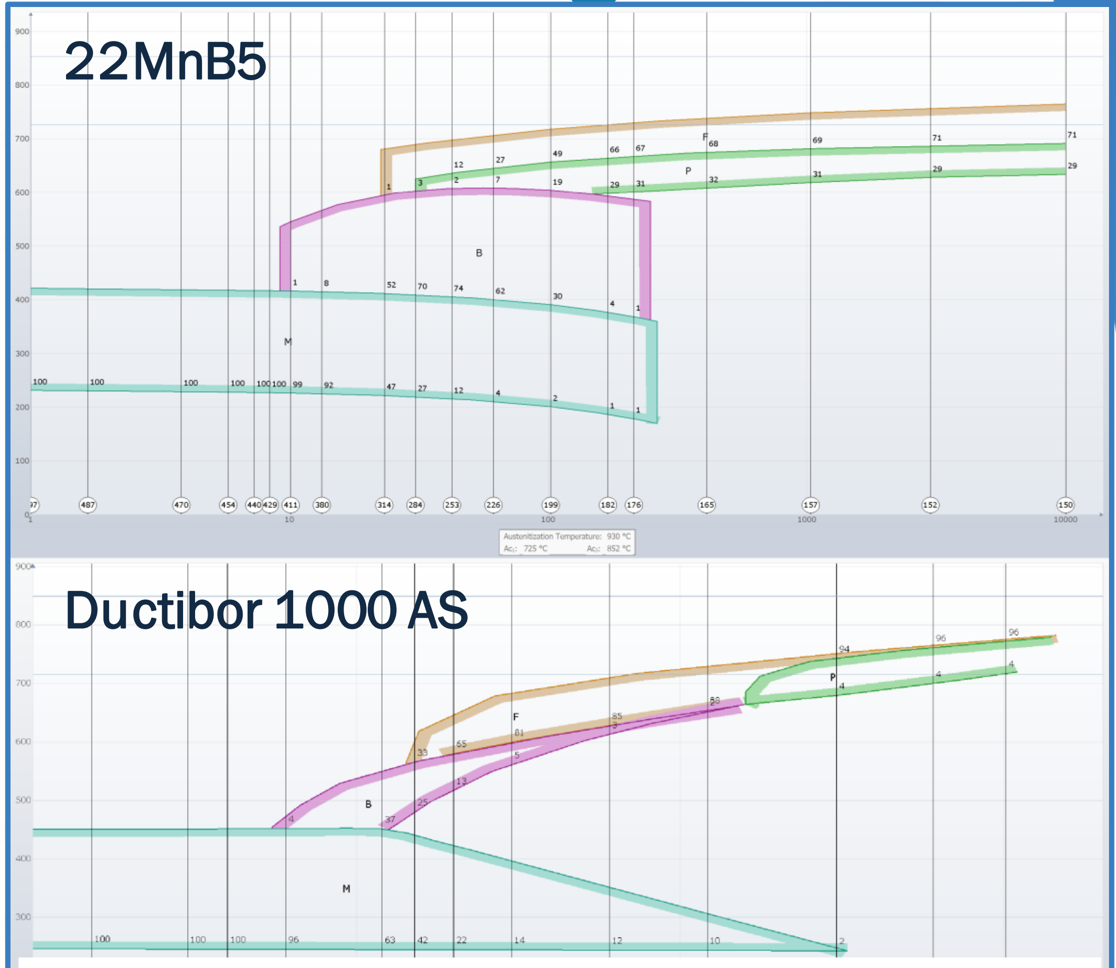
Phase Dependent Flow Curves

Heat transfer

Phase transformation

Evolution of Phase Fractions during Forming & Quenching





Experimental and Numerical Investigation of Final Product Properties of Ductibor® 1000 AS Under Different Process Conditions; CHS2 – 2022 Barcelona
AutoForm Engineering GmbH; ArcelorMittal; Mercedes-Benz

Essential for the accurate prediction of:

- Phase Transformations
- Phase Fractions and Mechanical Properties
- Panel Distortion

Advances in Modeling of Press Hardening

Phase Dependent Flow Curves

Heat transfer

Phase transformation

r-Values (T)

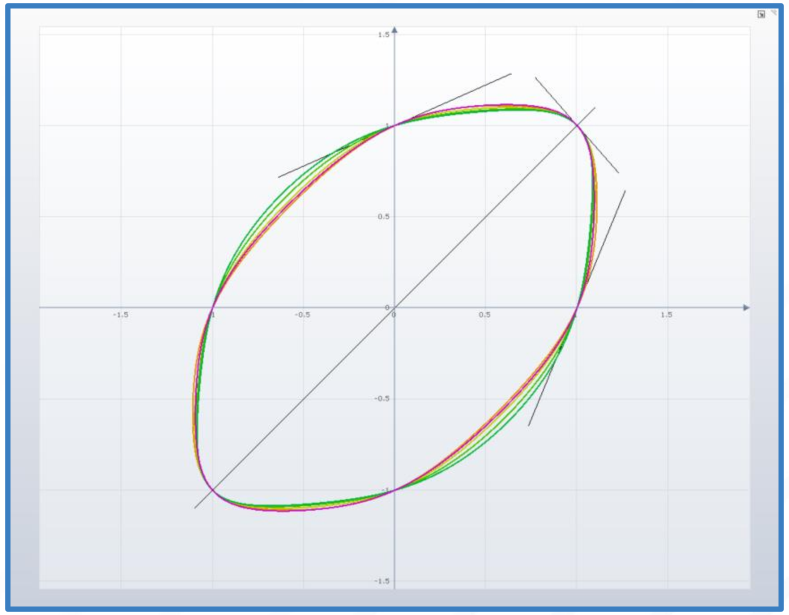
Temperature Dependent r-Value Table

Temperature	r_0	r_{45}	r_{90}	r_b
20.00 °C	0.700	0.900	0.800	0.875
500.00 °C	0.400	0.400	0.400	1.000
600.00 °C	0.500	0.500	0.500	1.000
700.00 °C	0.650	0.650	0.650	1.000
800.00 °C	0.850	0.850	0.850	1.000

Insert Table Entry

OK Cancel

Temperature dependent yield loci



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Phase Dependent Flow Curves

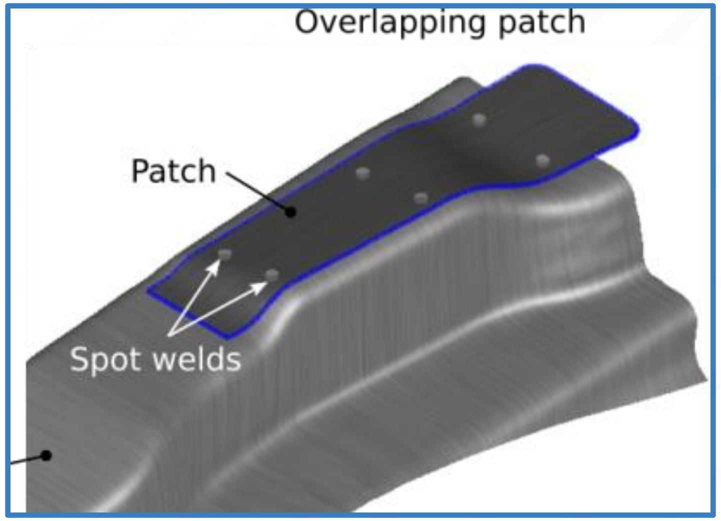
Heat transfer

Phase transformation

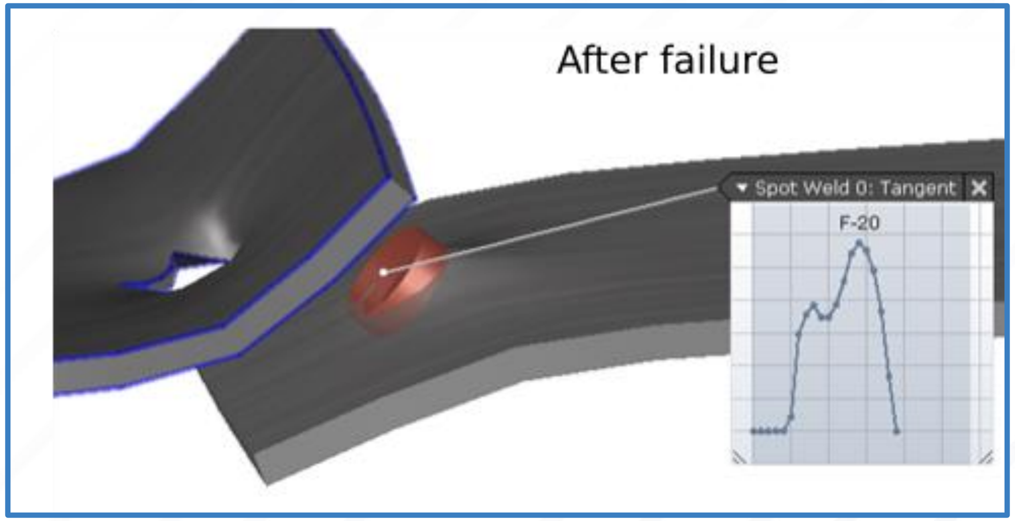
r-Values (T)

FLD (T)

Patchwork and Tailor Welded Blanks



- Patch-Base contact and separation
- Patch weld optimization and integrity…



Advances in Modeling of Press Hardening

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Phase Dependent Flow Curves

Heat transfer

Phase transformation

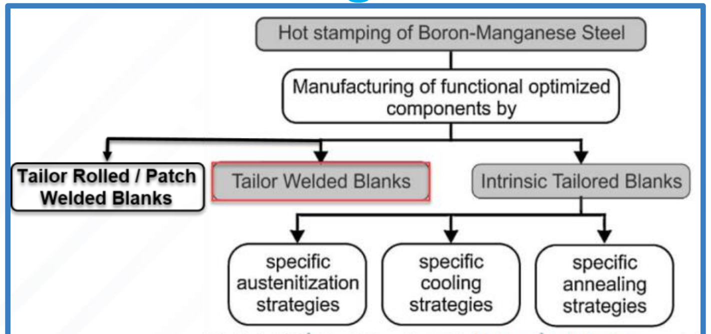
r-Values (T)

FLD (T)

Patchwork and Tailor Welded Blanks

Property Tailoring

- 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.

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

"Analysis of process limits for partial hot stamping with controlled pre-cooling by radiation exchange" *(IDDRG 2023)*

Mercedes-Benz AG, **AutoForm Engineering**, **GEDIA Gebrüder Dingerkus**, **Institute of Manufacturing Technology** (Friedrich-Alexander Universität Erlangen-Nürnberg)

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

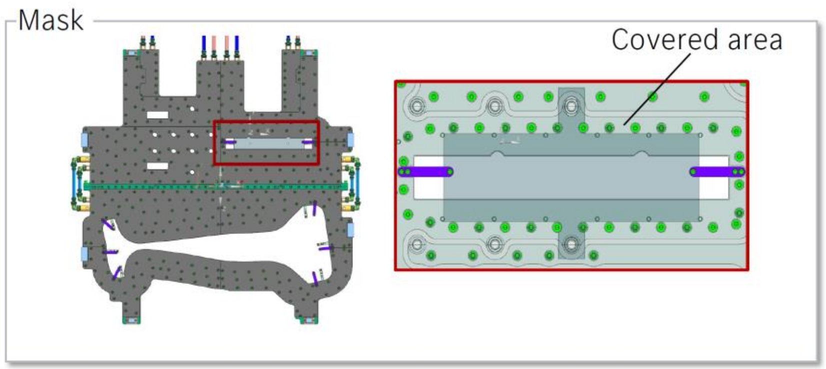
Materials
- 22MnB5 AS150
- 8MnB7 AS150
- Blank 8MnB7 and patch 22MnB5

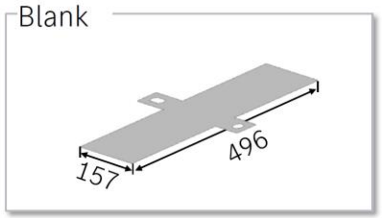
Parameter
- Sheet tickness t_0
- Partial pre-cooling time $t_{pre\text{-}cooling}$

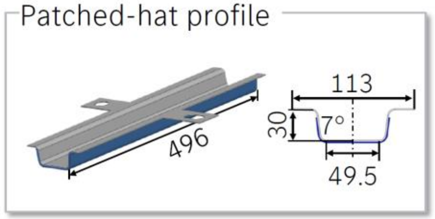
Objection

Simulative and experimental analysis of phase transformation and hardness using different sheet thicknesses and materials

⇨ Elaboration of possible process limits







Advances in Modeling of Press Hardening

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Phase Dependent Flow Curves

Heat transfer

Phase transformation

r-Values (T)

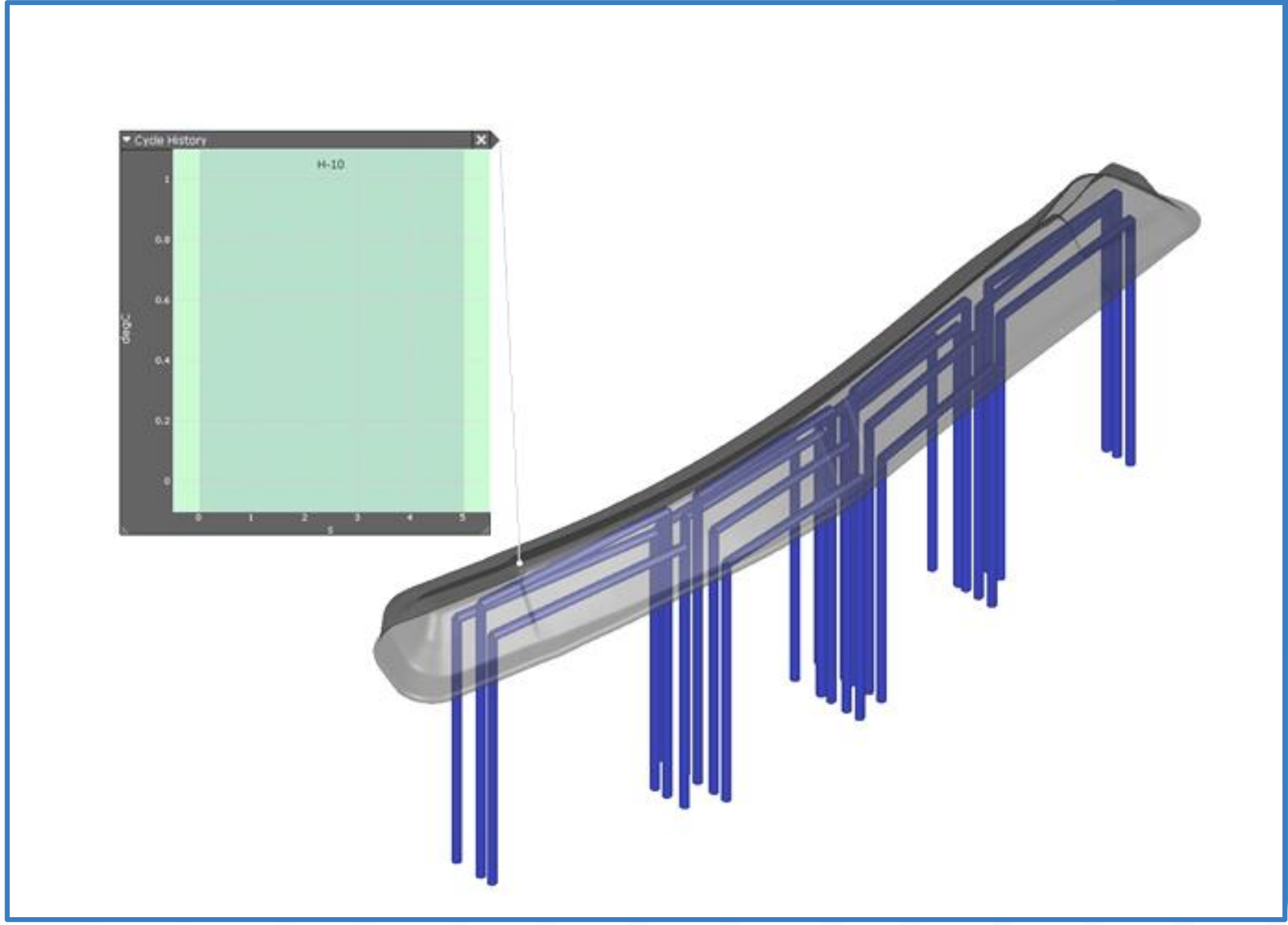
FLD (T)

Patchwork and Tailor Welded Blanks

Property Tailoring

Modelling of cooling channels & Thermal cycling

- Steady-state Temperatures for Sheet and Tools
- Hot Spots on Tool Surfaces ...



Advances in Modeling of Press Hardening

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Phase Dependent Flow Curves

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r-Values (T)

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Patchwork and Tailor Welded Blanks

Property Tailoring

Modelling of cooling channels

Tribological conditions?

Friction

Heat Transfer Coefficient

Experimental investigations

Reference \ μ depending on	Temperature	Sliding Velocity
Yanagida and Azushima (2009)	μ ↑ (600 °C, 700 °C & 800 °C)	
Kondratiuk and Kuhn (2011)		
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 - (10 mm/s & 100 mm/s)
Venema (2019)	< 600 °C: μ ↓ > 600 °C: μ ↑	
Schwingenschlögl (2020)	< 600 °C: μ ↓ > 600 °C: μ ↑	μ ↓ (10 mm/s - 120 mm/s)

Positive Correlation

Negative Correlation

No clear correlation

Friction in Press Hardening

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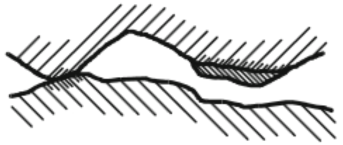
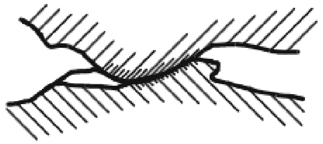
Adhesive Effects



- Defined by the forces to overcome adhesion

Abrasive Effects



- Defined by the forces for the deformation of asperities

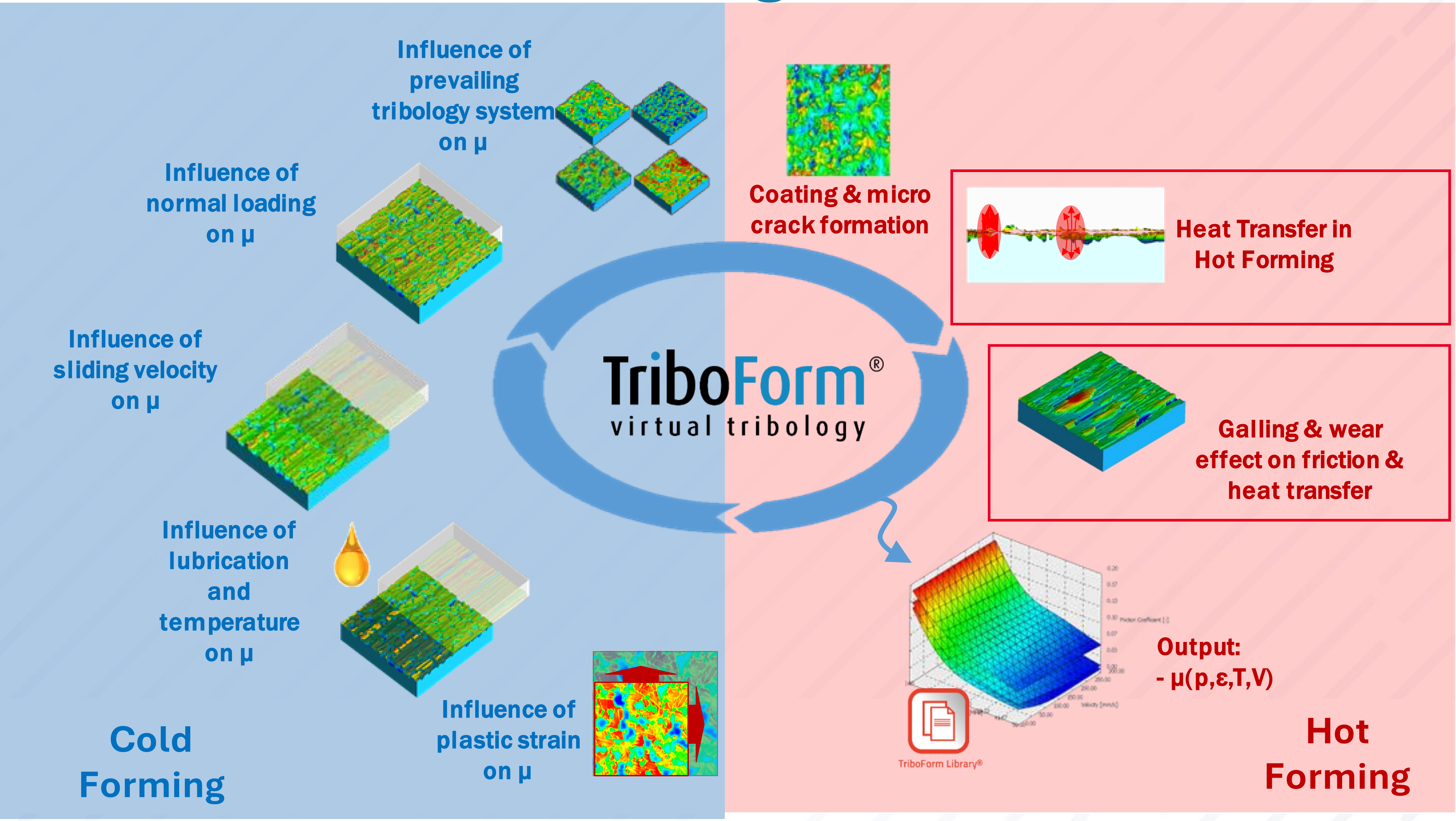
Coating, Contact Pressure, Temperature, Sliding Velocity, Sliding Distance / History have an influence on friction mechanisms

Effective Friction Coefficient is a function of prevailing conditions at the sheet-tool interface:

- Temperature
- Contact Pressure
- Sliding Velocity
- Strain

(Reference: Hardell, 2009)

Friction in Press Hardening



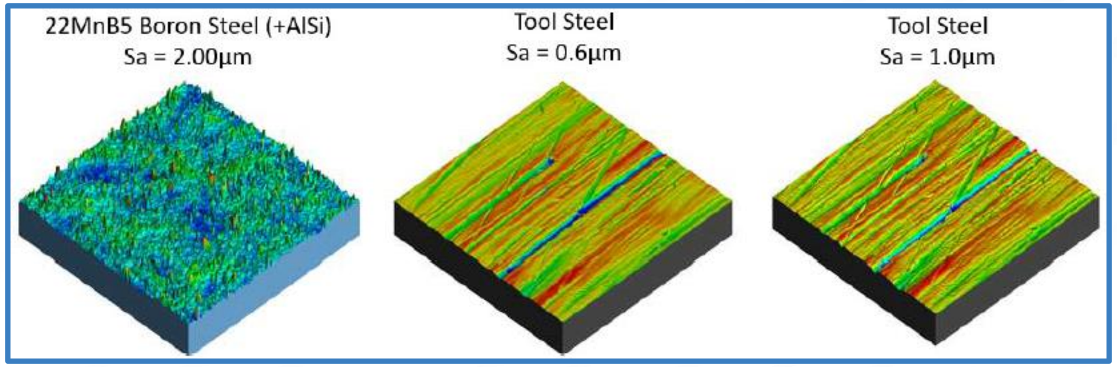
Friction in Press Hardening – Building the Model

Multi-scale Friction Model

- Friction Force = f(Asperity Deformation, Coating Fracture, Ploughing / Abrasion between Asperities)
- Friction Coefficient = f(Temperature, Sliding Velocity, Contact Pressure, Strain)

Tribological System

- Sheet: 22MnB5 with AlSi Coating
- Tool Steel



Experimental Model Calibration

- Required calibration data
- Sheet samples heated to 930 ^{o}C: activate coating diffusion; cooled down for topography measurements
- Additional experiments for calibration

Friction in Press Hardening

Multi-Scale Friction Modeling

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Multi-scale friction modeling for sheet metal forming: The mixed lubrication regime Tribol. Int. 85 (2015) 10–25; Hol J, Meinders V T, Geijselaers H J M and Van Den Boogaard A H

Multi-scale friction modeling for sheet metal forming: The boundary lubrication regime Tribol. Int. 81 (2015) 112-128; Hol J, Meinders V T, de Rooji M B, and Van Den Boogaard A H

Friction and wear mechanisms during hot stamping of AlSi coated press hardening steel

J. Venema [a,b*], D.T.A. Matthews [a,c], J. Hazrati [b], J. Wörmann [a], A.H. van den Boogaard [b]

[a] *Tata Steel, Research & Development, PO BOX 10000, 1970 CA IJmuiden, The Netherlands*
[b] *Nonlinear Solid Mechanics, Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands*
[c] *Laboratory for Surface Technology and Tribology, Faculty of Engineering Technology, University of Twente, Enschede, The Netherlands*

Wear380-381(2017)137-145

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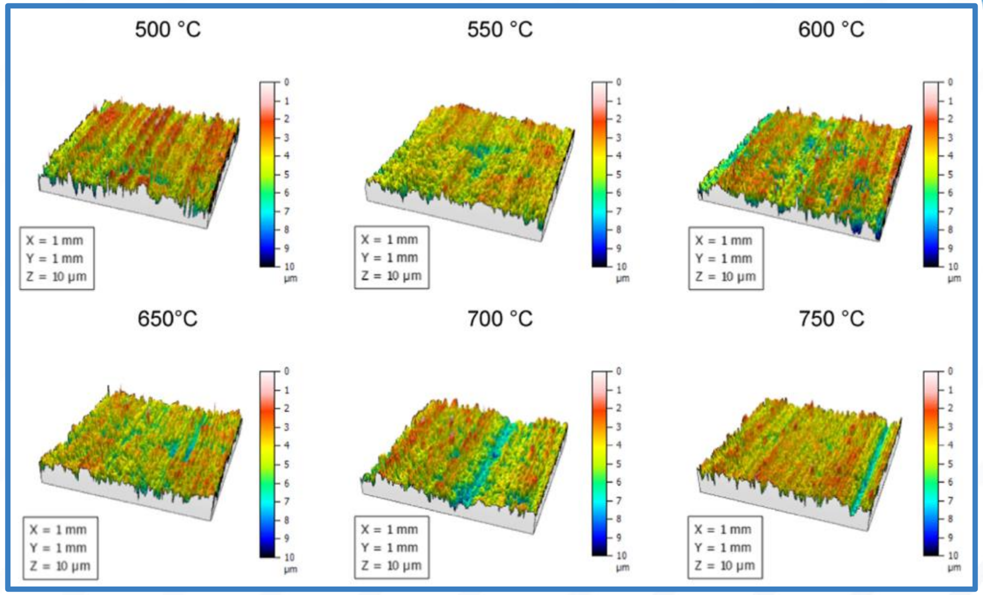

Friction in Press Hardening – Building the Model

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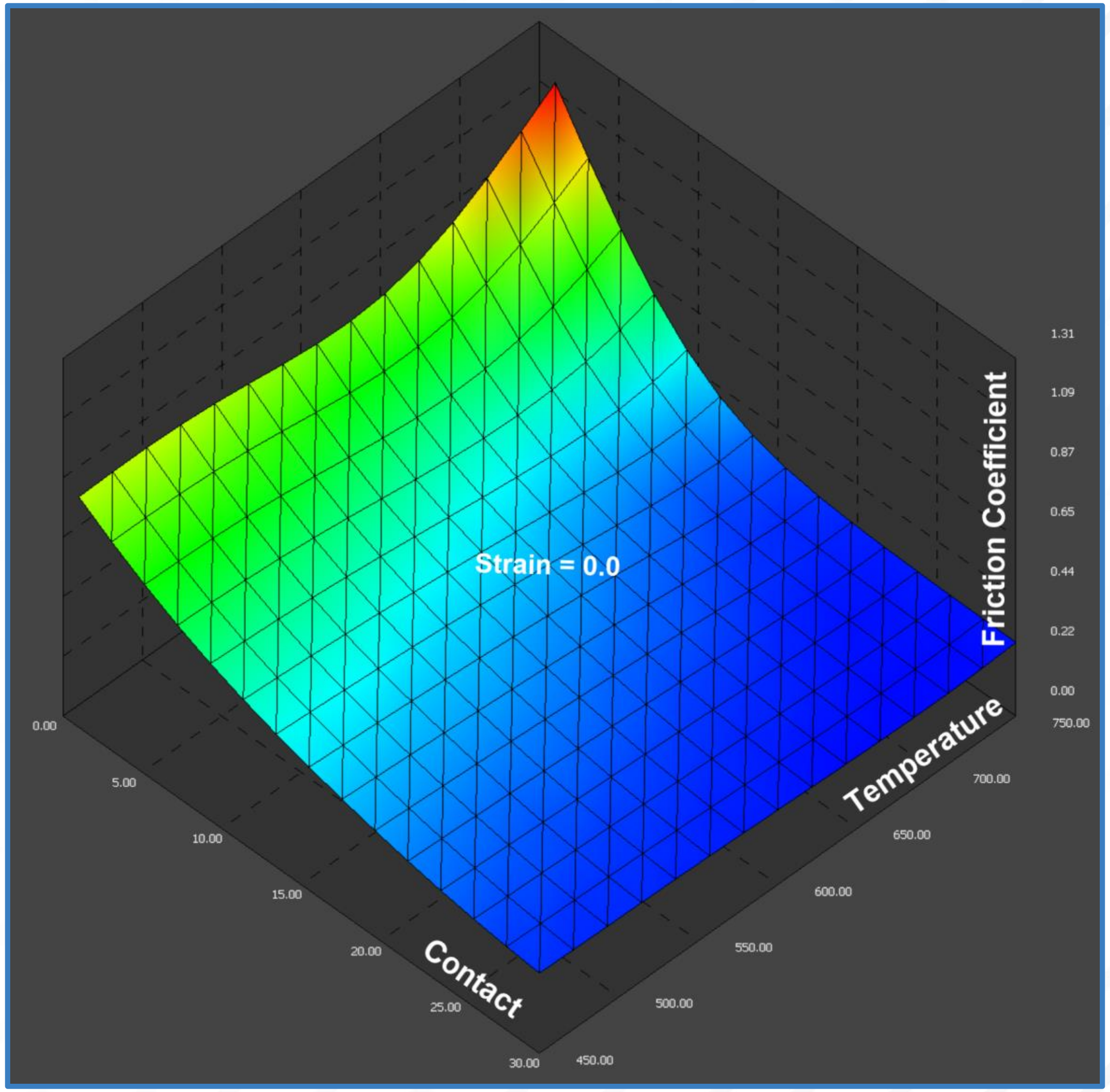
TriboForm Friction Model

- 22MnB5 + AlSi Coating; Tool Steel
- Temperature Range: 450-750 ^{o}C
- Contact Pressure Range: 1-30 MPa
- Plastic Strain Range: 0-0.4
- Sliding Velocity Range: 1-300 mm/s



Validation for Press Hardening

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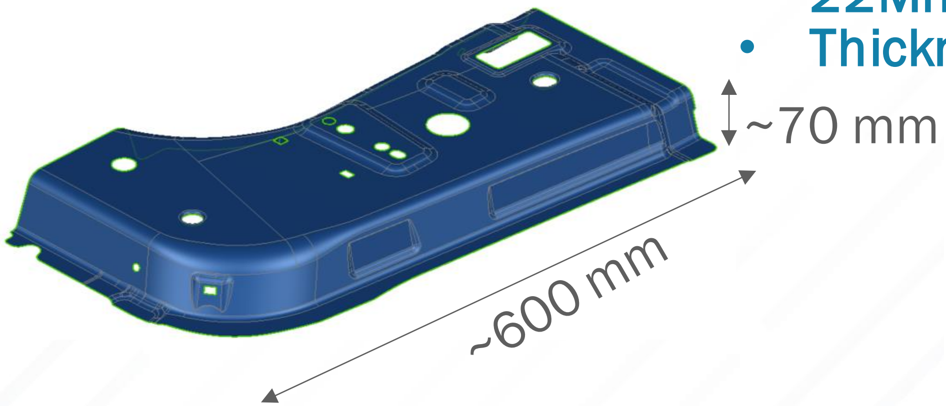
Application of an Advanced Friction Model in Hot Stamping Simulations: A Numerical and Experimental Investigation of an A-Pillar Reinforcement Panel from Volvo Cars

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

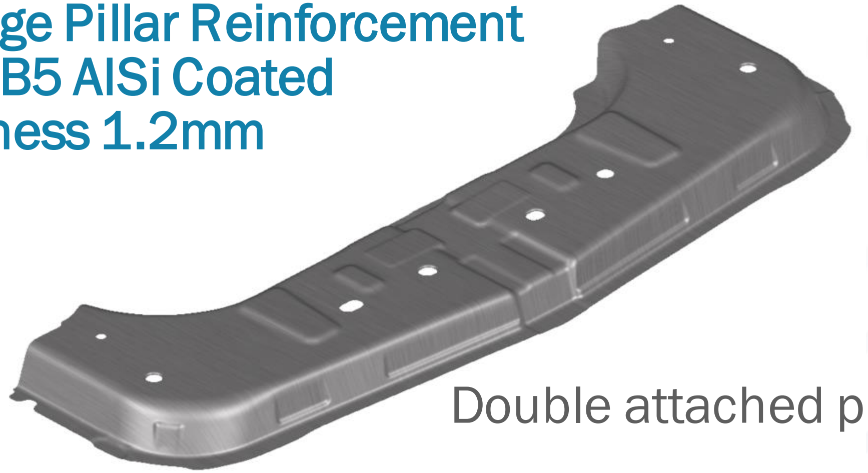
[1] AutoForm Engineering Deutschland, Dortmund, Germany
[2] TriboForm Engineering B.V., Enschede, Netherlands
[3] Tata Steel, Research & Development, IJmuiden, Netherlands
[4] Volvo Cars, Olofstrom, Sweden
[5] Institute of Forming Technology and Lightweight Components, TU Dortmund University, Dortmund, Germany

40th International Deep-Drawing Research Group Conference (IDDRG 2021)
IOP Conf. Series: Materials Science and Engineering 1157 (2021) 012020



Volvo Hinge Pillar Reinforcement

- 22MnB5 AlSi Coated
- Thickness 1.2mm



Double attached production

Volvo Hinge Pillar Reinforcement

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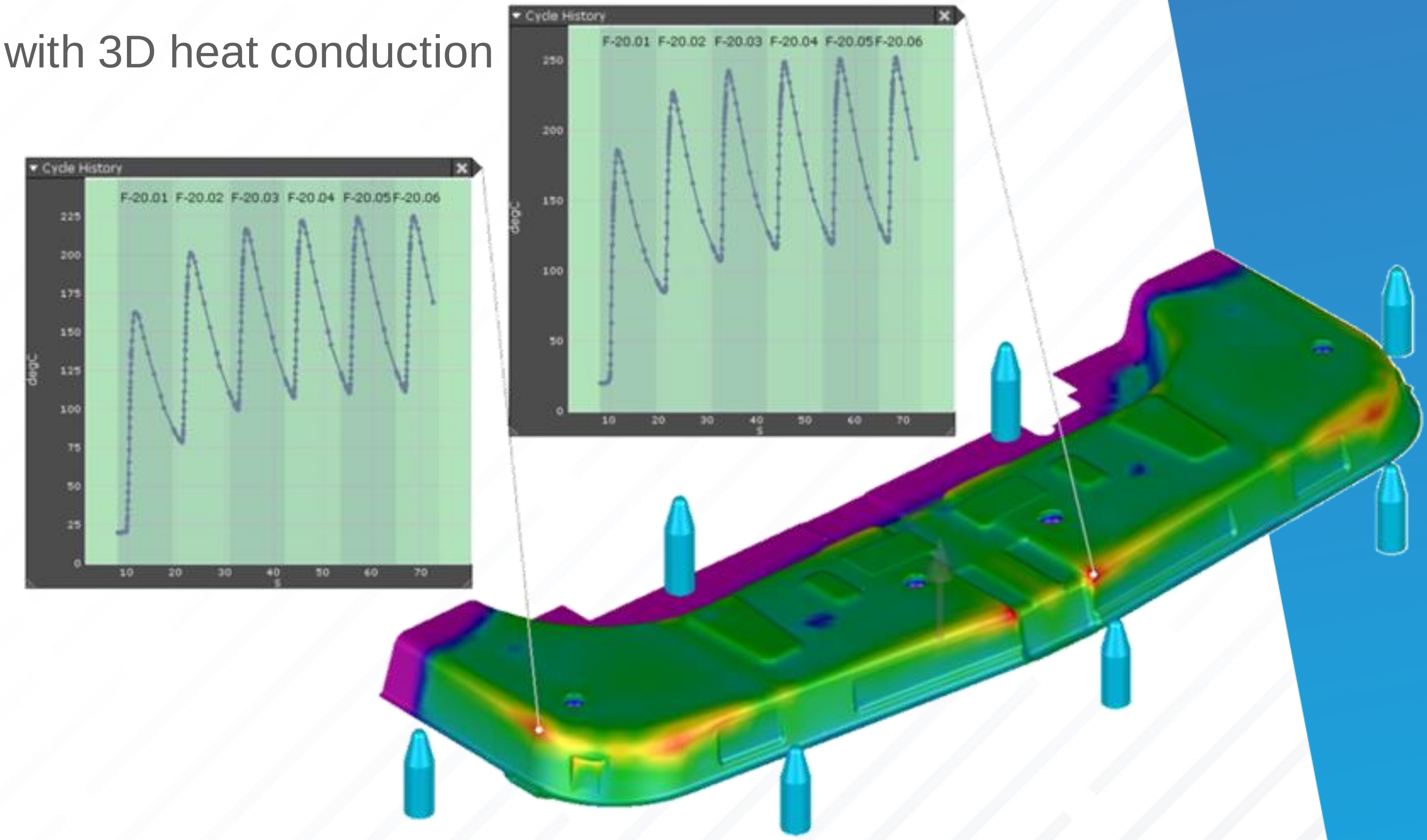
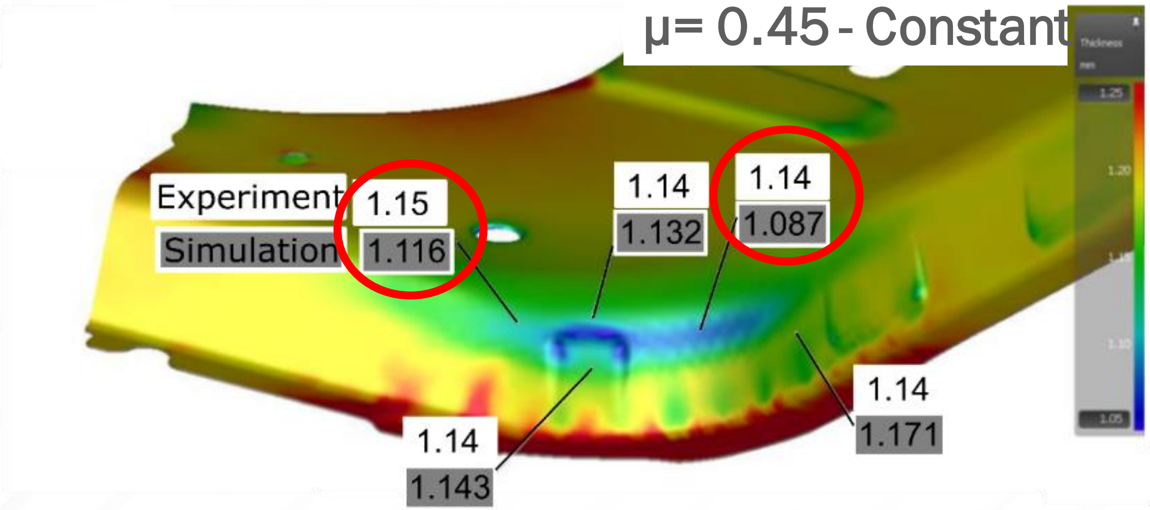
Material: 22MnB5, t=1.20 mm

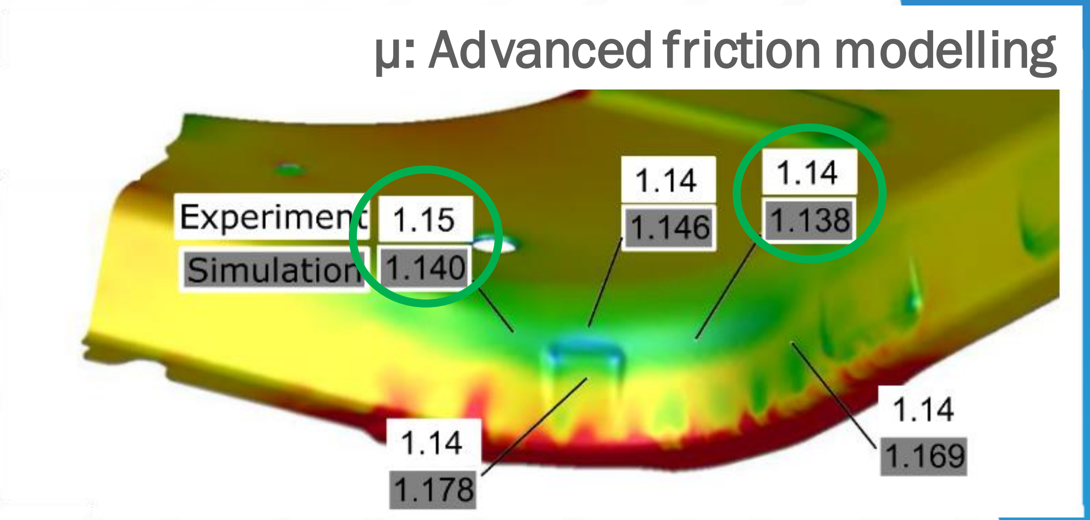
- Temperature dependent r-Values
- Modeling of cooling channels with 3D heat conduction



Constant Coulomb vs. TriboForm

Thickness distribution





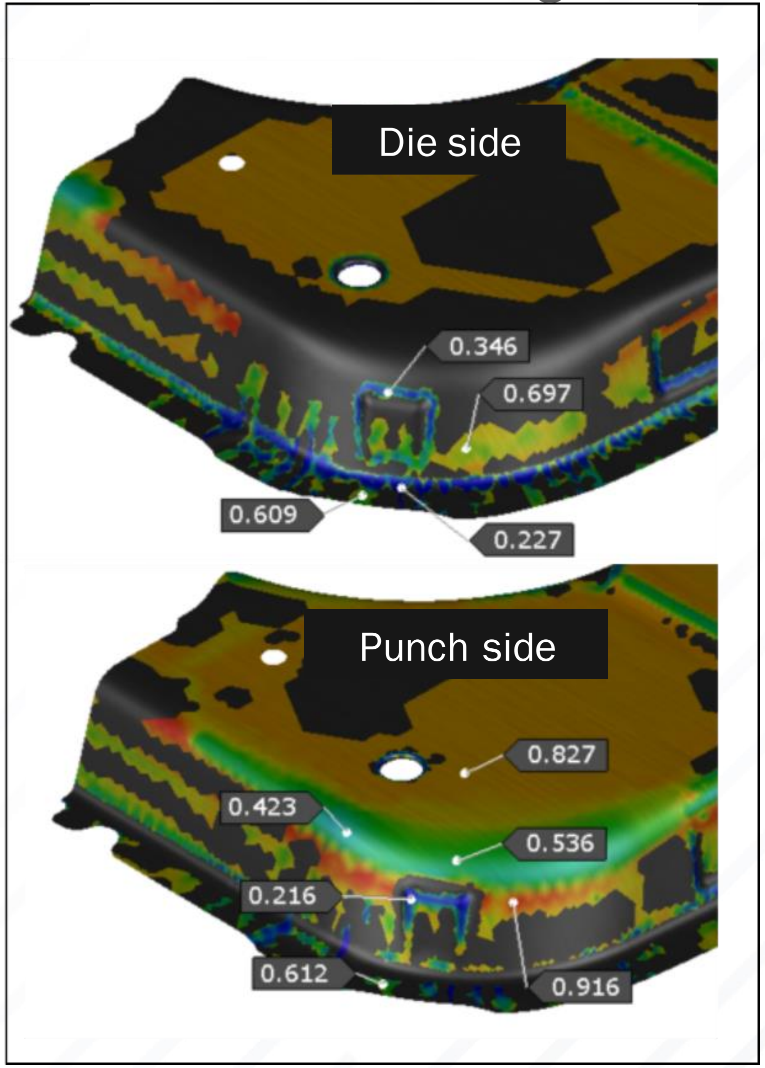
Distribution of Friction Coefficients

Friction coefficient changes through the process...

Considered dependencies:

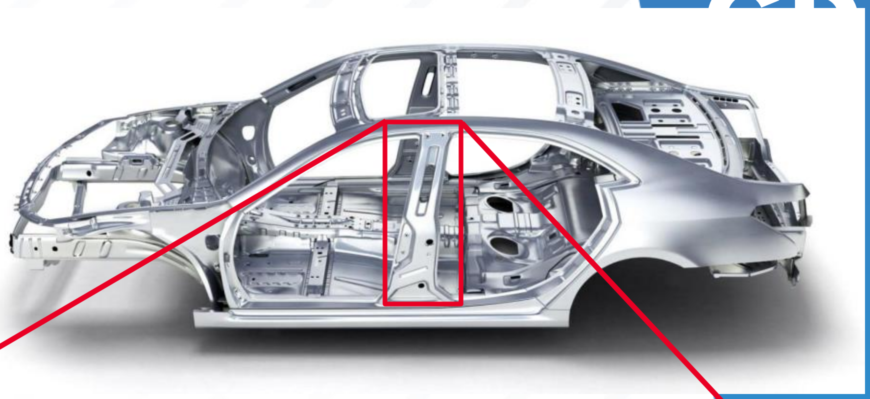
- Surface topography
- Contact pressure
- Temperature
- Strain
- Sliding velocity

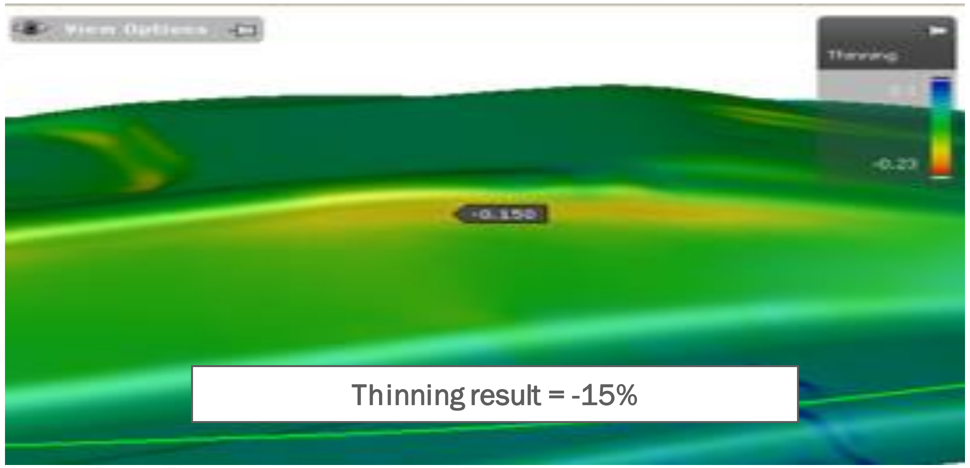
End of drawing



B-Pillar

Material: 22MnB5, t=1.60 mm





Simulation + constant (Coulomb) friction: *Not critical*

First press trial: *Necking*

B-Pillar

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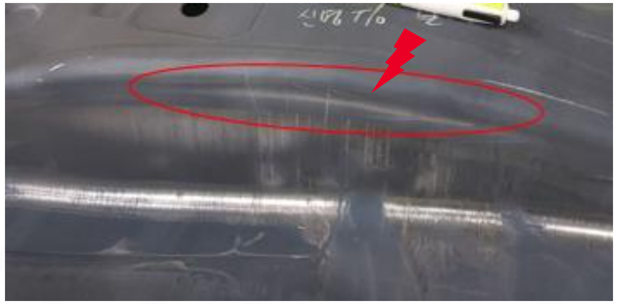
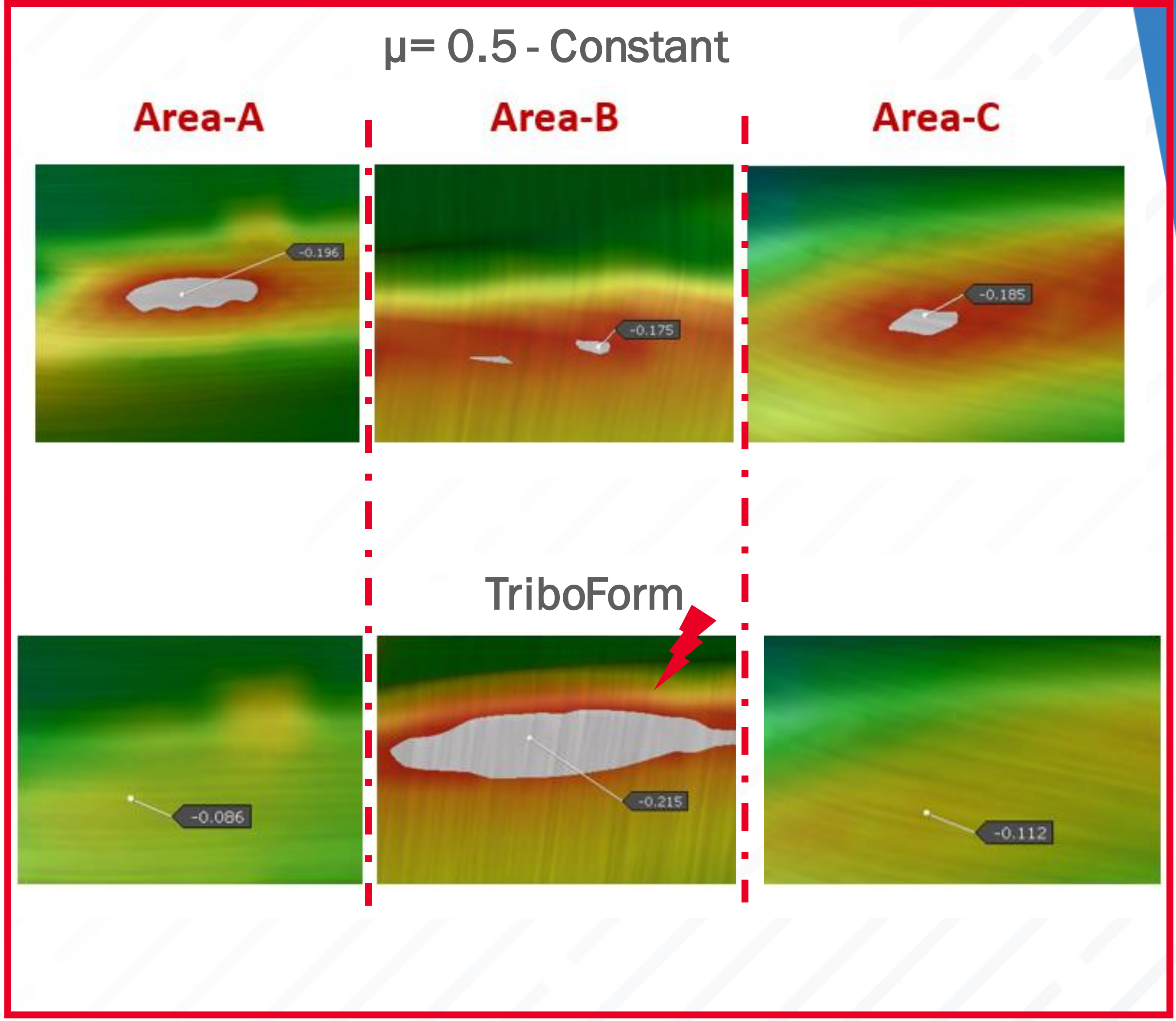


Thickness comparison



State of the Art

Phase Dependent Flow Curves

Heat transfer

Phase transformation

r-Values (T)

FLD (T)

Patchwork and Tailor Welded Blanks

Property Tailoring

Modeling of cooling channels & thermal cycling

Interface Sheet-Tool:

- *Advanced friction modeling*
- *Heat transfer coefficient*
- *Galling and wear*

Galling and Wear – some early results…

- *Advanced Friction Model was extended to include galling initiation and lump growth*
- *Model calibrated using experimental data from hot strip draw tests*
- *Model capable of predicting galling location and amount*
- *Validated so far against observations on galling location on tools*

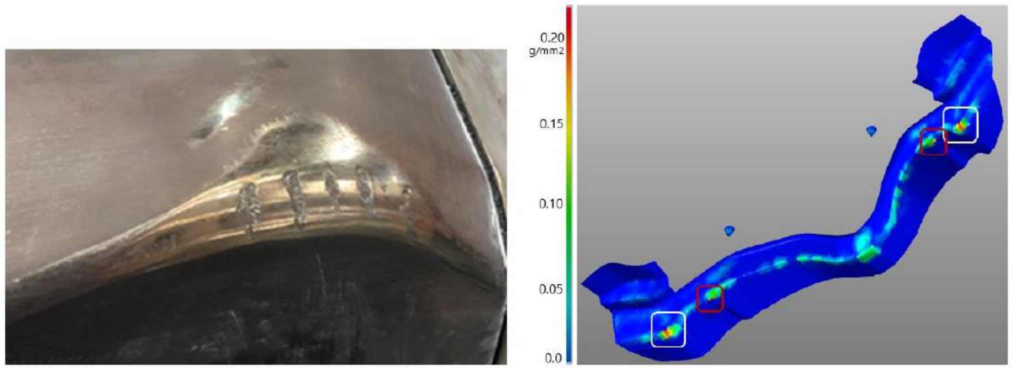


Figure 7. (Left) The observed galling at the tooling surface of side member which corresponds to (right) the distribution of predicted galling (g/mm^2) in the white boxes. Red boxes show the second location with high galling.

An industrial application case to predict galling in hot stamping processes
S Berahmani *et al* 2022 *IOP Conf. Ser.: Mater. Sci. Eng.*

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Looking forward...

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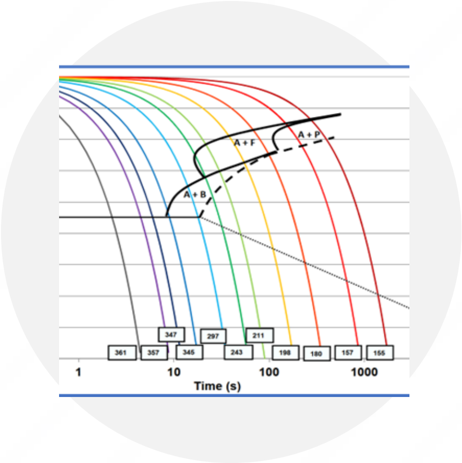
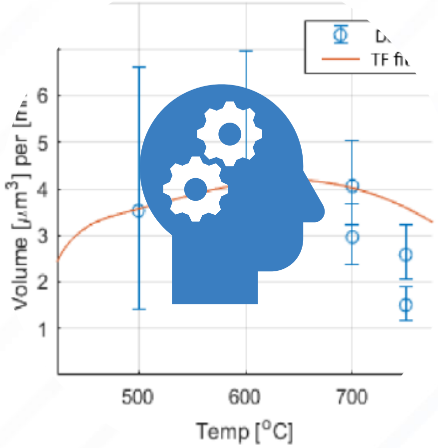
Experimental and numerical investigations on tailored product properties of BIW parts using MBW®1200+AS and MBW®1900+AS Pro

GEDIA, thyssenKrupp Steel, AutoForm

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

Volvo Cars Sweden, TriboForm, Blekinge Institute





NEW PHASE-DEPENDENT MATERIAL MODELS

ADVANCES IN WEAR AND TOOL LIFE PREDICTION

Join us at CHS², Nashville TN, May 27-29, 2024

GDIS

For More Information

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AUTOFORM
Forming Reality

Dr. Johan Hol, TriboForm Engineering B.V. and Dr. Alper Guener, AutoForm Engineering GmBH are gratefully acknowledged for their ongoing work on these topics, and for their permission to present this state of the art at Great Designs in Steel, 2024

The cooperation and contributions of our project partners – Volvo Cars Sweden, Tata Steel Research and Development, and the Institute of Forming Technology and Lightweight Components of the TU Dortmund Germany - is also acknowledged