Thermo-mechanical forming analysis and mapping of material properties in hot stamped component with tailored material properties

Greger Bergman, **Daniel Berglund** and Kenneth Isaksson

2014-08-21

AGENDA

- Background
- Introduction
- Tailored material properties
- Simulation methodology
- Discussion and Conclusions

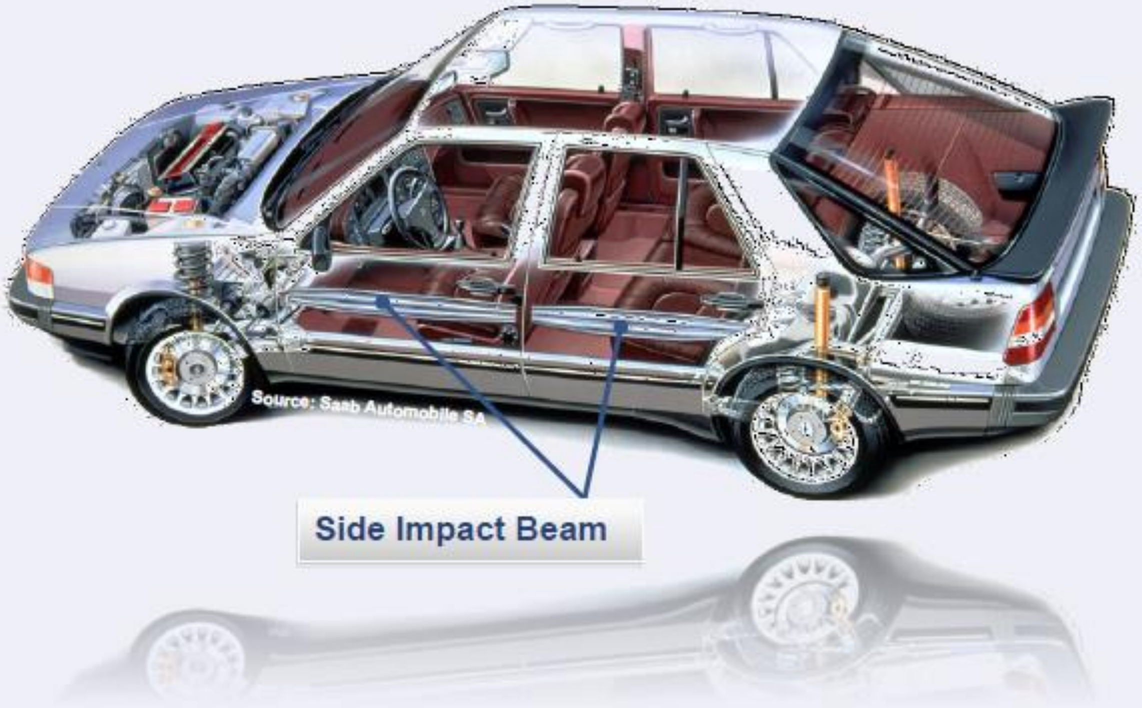
***BACKGROUND**-PRESSHARDENING EVOLUTION 1984-2016*

HISTORICAL PROJECTS DEVELOPED IN COOPERATION WITH HARDTECH GESTAMP

1986: First automotive series applicaton of press hardened UHSS components

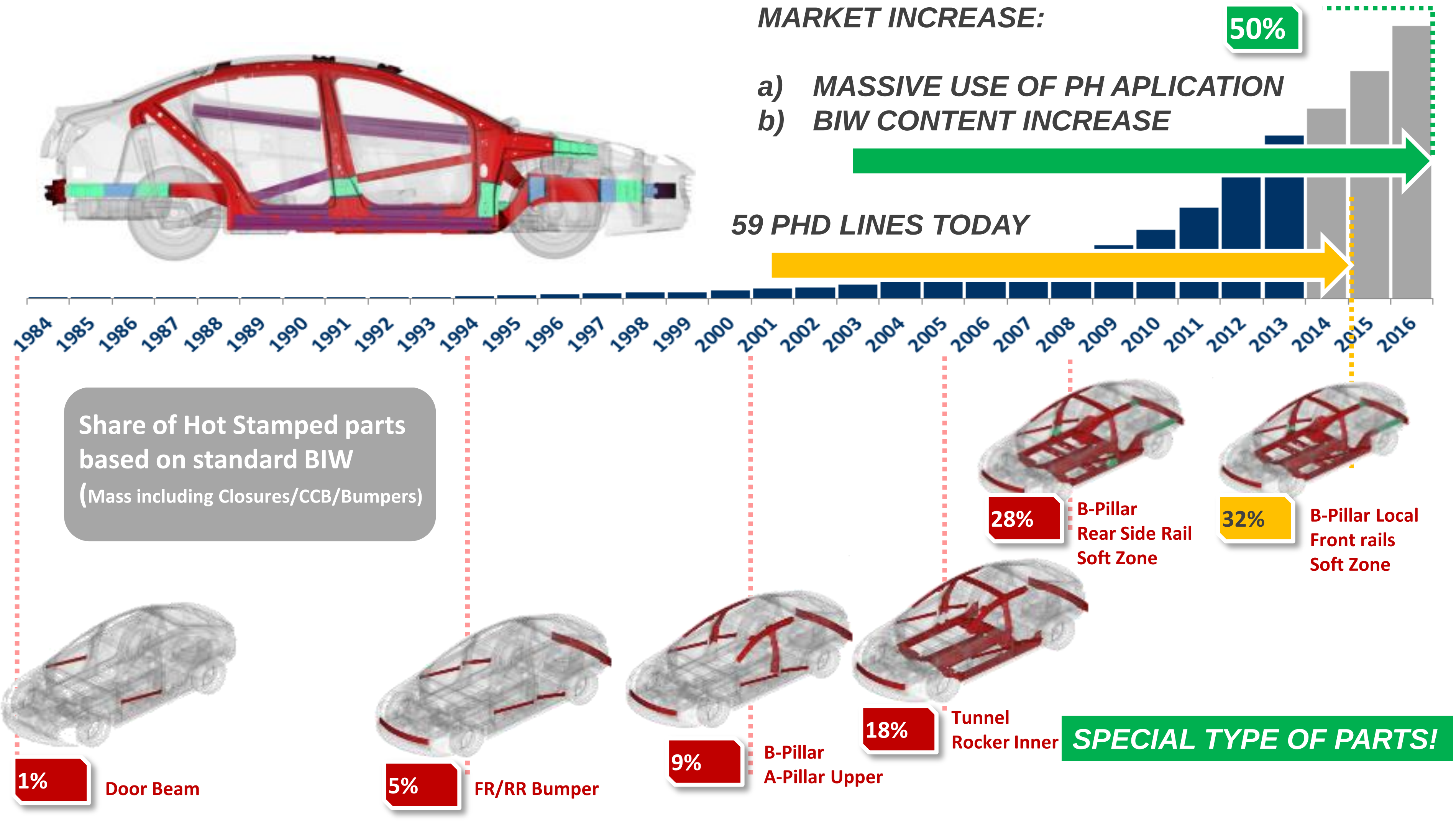
-

Side Impact Beam Saab 9000




Source: Saab Automobile SA

***BACKGROUND**-PRESSHARDENING EVOLUTION 1984-2016 ON PRODUCT*



MARKET INCREASE:

50%

a) *MASSIVE USE OF PH APLICATION*
b) *BIW CONTENT INCREASE*

59 PHD LINES TODAY

Share of Hot Stamped parts based on standard BIW
(Mass including Closures/CCB/Bumpers)

1%	Door Beam
5%	FR/RR Bumper
9%	B-Pillar A-Pillar Upper
18%	Tunnel Rocker Inner
28%	B-Pillar Rear Side Rail Soft Zone
32%	B-Pillar Local Front rails Soft Zone

SPECIAL TYPE OF PARTS!

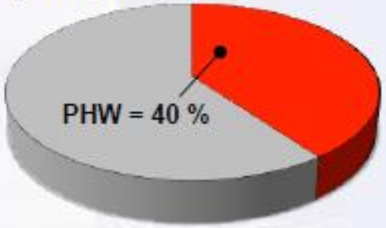
50% BIW MASS WILL BE PHD and ¼ SOFT ZONE TECHNOLOGY

***BACKGROUND**-PRESSHARDENING EVOLUTION 1984-2016*

HISTORICAL PROJECTS DEVELOPED IN COOPERATION WITH GESTAMP

Volvo SPA (Scalable Product Architecture)

Dec 2013 Preview on next generation XC90 (2015)




Source: Volvo Car

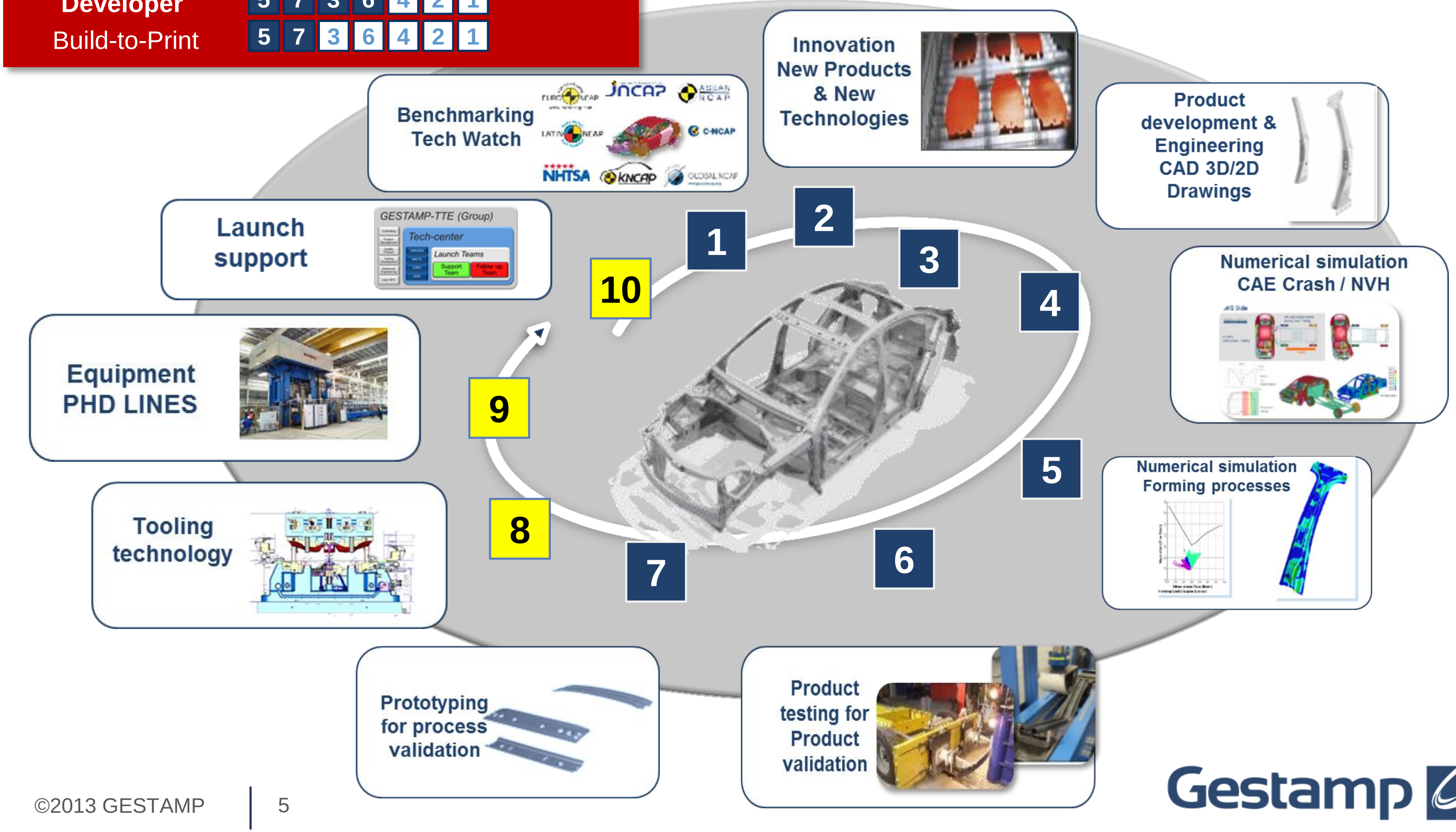

Source: Volvo Car

BACKGROUND-GESTAMP

SUPPLIER LEVEL

FULL PROCESS	5	7	3	6	4	1	2	8	9	10
Strategic	5	7	3	6	4	1	2			
Developer	5	7	3	6	4	2	1			
Build-to-Print	5	7	3	6	4	2	1			

GESTAMP IS FULLY INVOLVED WITHIN THE COMPLETE VEHICLE DEV. VALUE CHAIN FROM BTP TO STRATEGIC SUPPLIER



Benchmarking Tech Watch

Innovation New Products & New Technologies

Product development & Engineering CAD 3D/2D Drawings

Numerical simulation CAE Crash / NVH

Numerical simulation Forming processes

Product testing for Product validation

Prototyping for process validation

Tooling technology

Equipment PHD LINES

Launch support

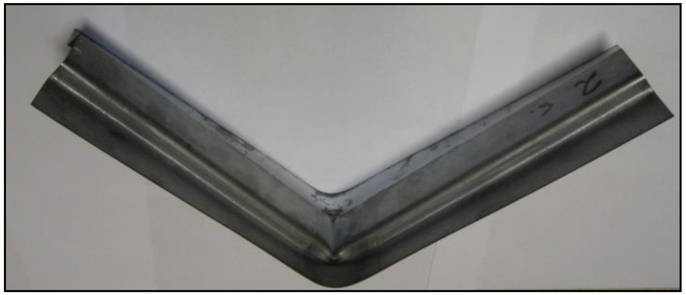
AGENDA

- ✓ Background
- **Introduction**
- Tailored material properties
- Simulation methodology
- Discussion and Conclusions

INTRODUCTION-CHALLANGES

What is the challenges for suppliers of hot stamped components facing today?

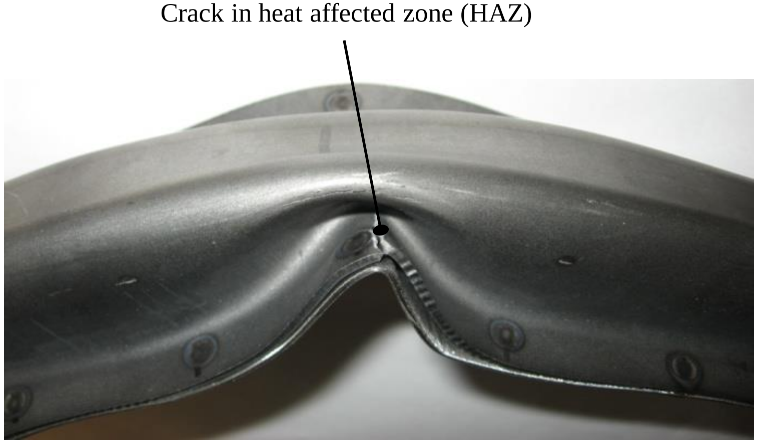
- *Reduced weight without compromising with the BIW stiffness (OEM)*
- New coated blank materials with catodic protection for use in the *direct hot stamping process.*
- **Increased failure strain in critical areas**



- Prediction of tool wear in the hot stamping tools with adequate accuracy.

What is the challenges for suppliers of hot stamped components facing today?

- **Redistribution of plastic strains around welds in crash applications.**



Crack in heat affected zone (HAZ)

•Fracture in the heat affected zone.

•Ductile fracture but in a narrow area.

•Low elongation if the specimen is fully hardened

AGENDA

✓ Background

✓ Introduction

- **Tailored material properties**
- Simulation methodology
- Discussion and Conclusions

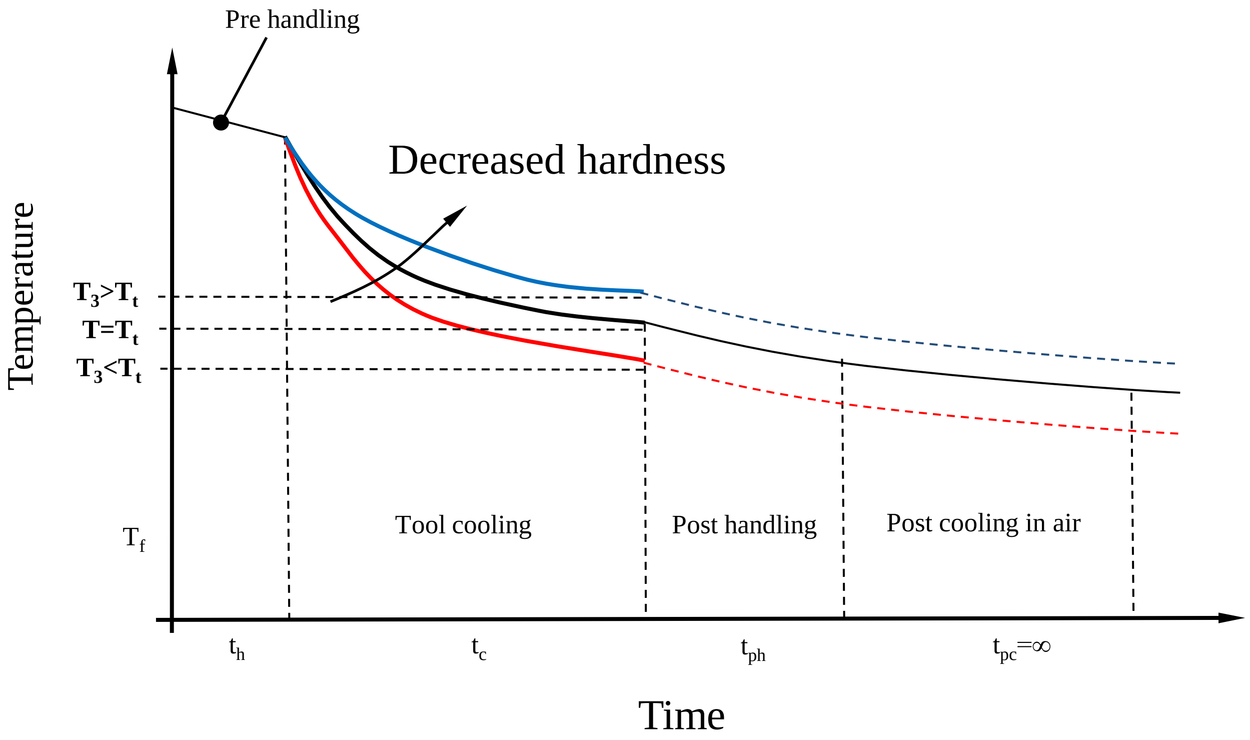
TAILORED MATERIAL PROPERTIES

Components with ”Soft zones”- A predefined area of the components with a lower hardness and lower mechanical properties then for fully hardened material.

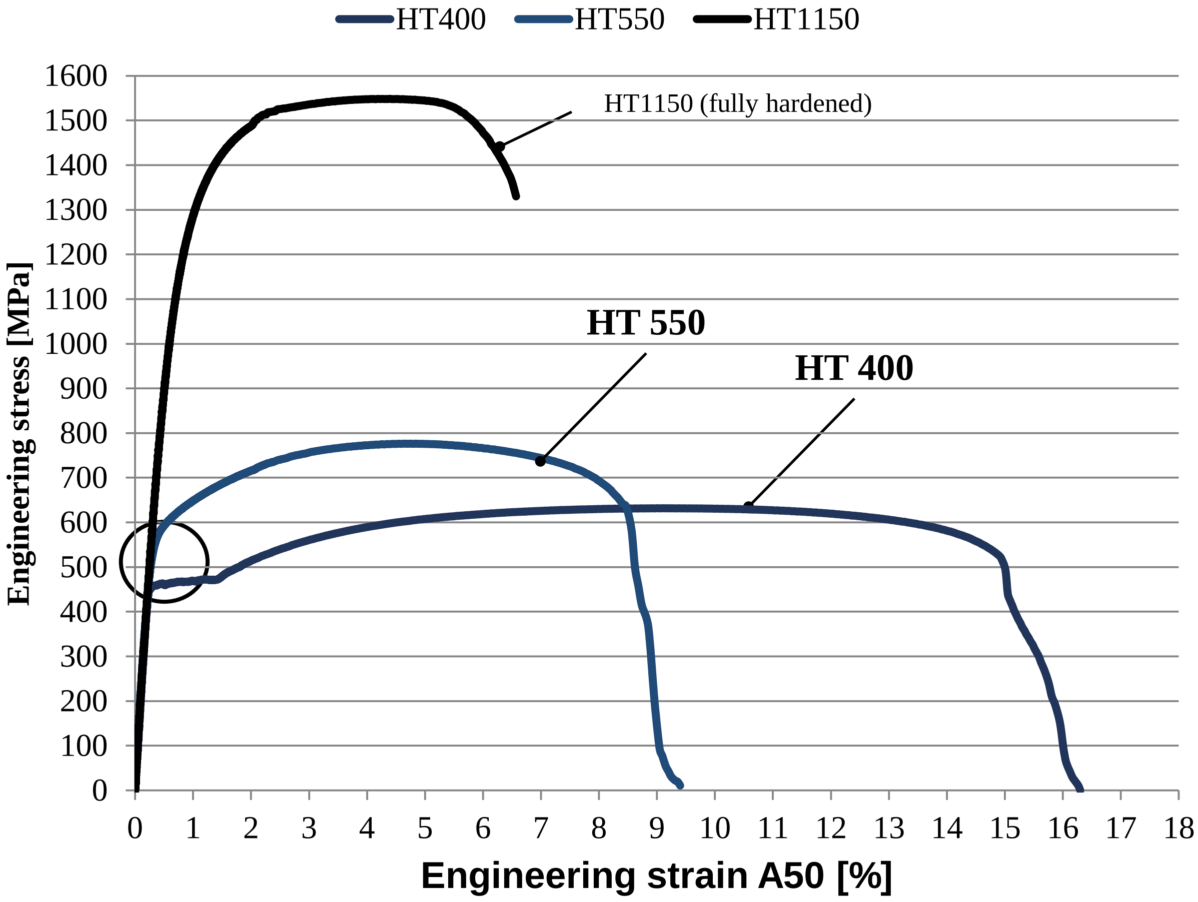
Components with ”Tailored” properties- Extension of the ”soft zone” concept. Components with tailored properties have a predefined distribution of material properties and/or thickness to obtain optimum component properties.

TAILORED MATERIAL PROPERTIES

- Different material grades can be achieved by changing the temperature in the tool
- An **increased tool temperature gives a decreased hardness**

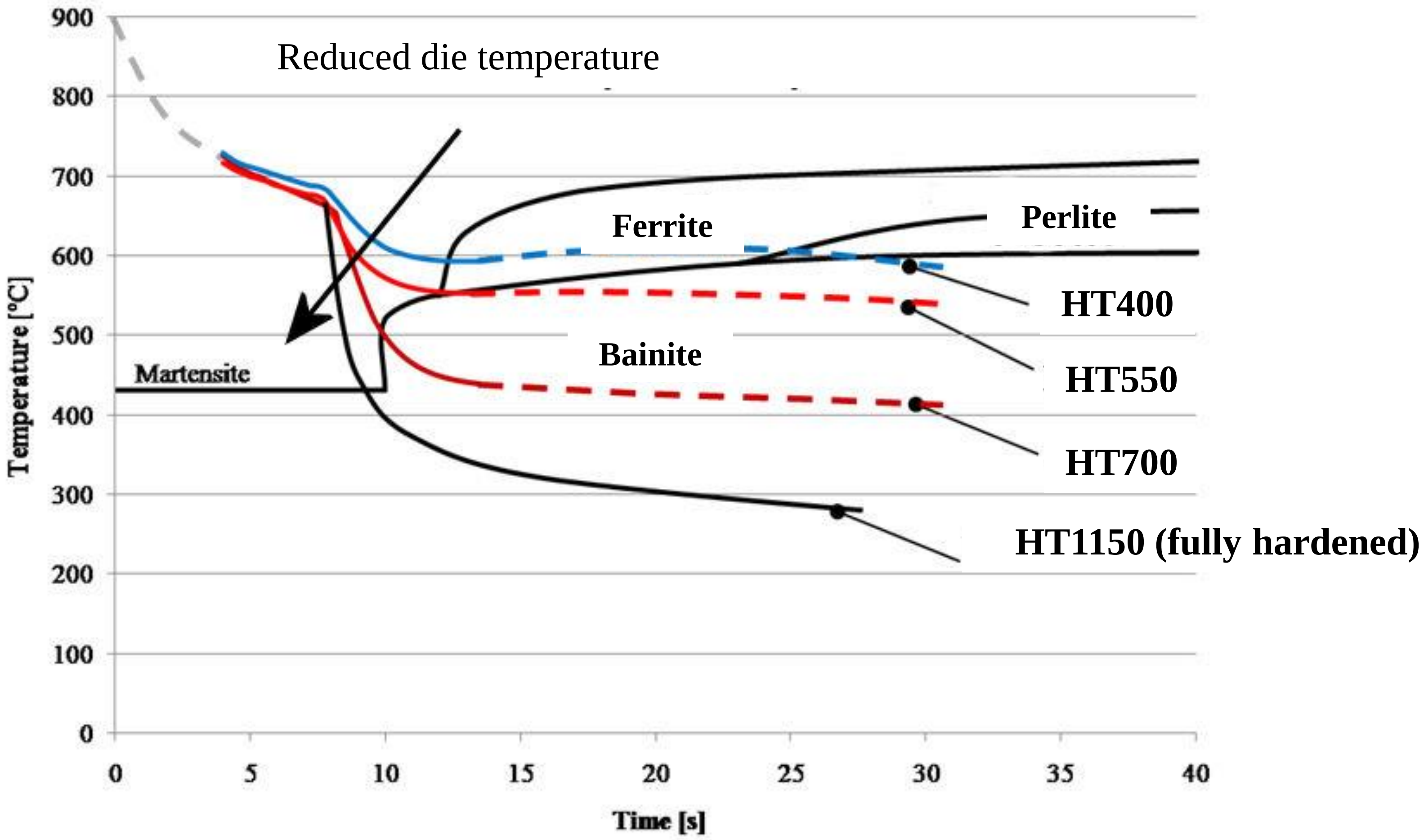


***TAILORED MATERIAL PROPERTIES**-MATERIAL GRADES ON THE MARKET*

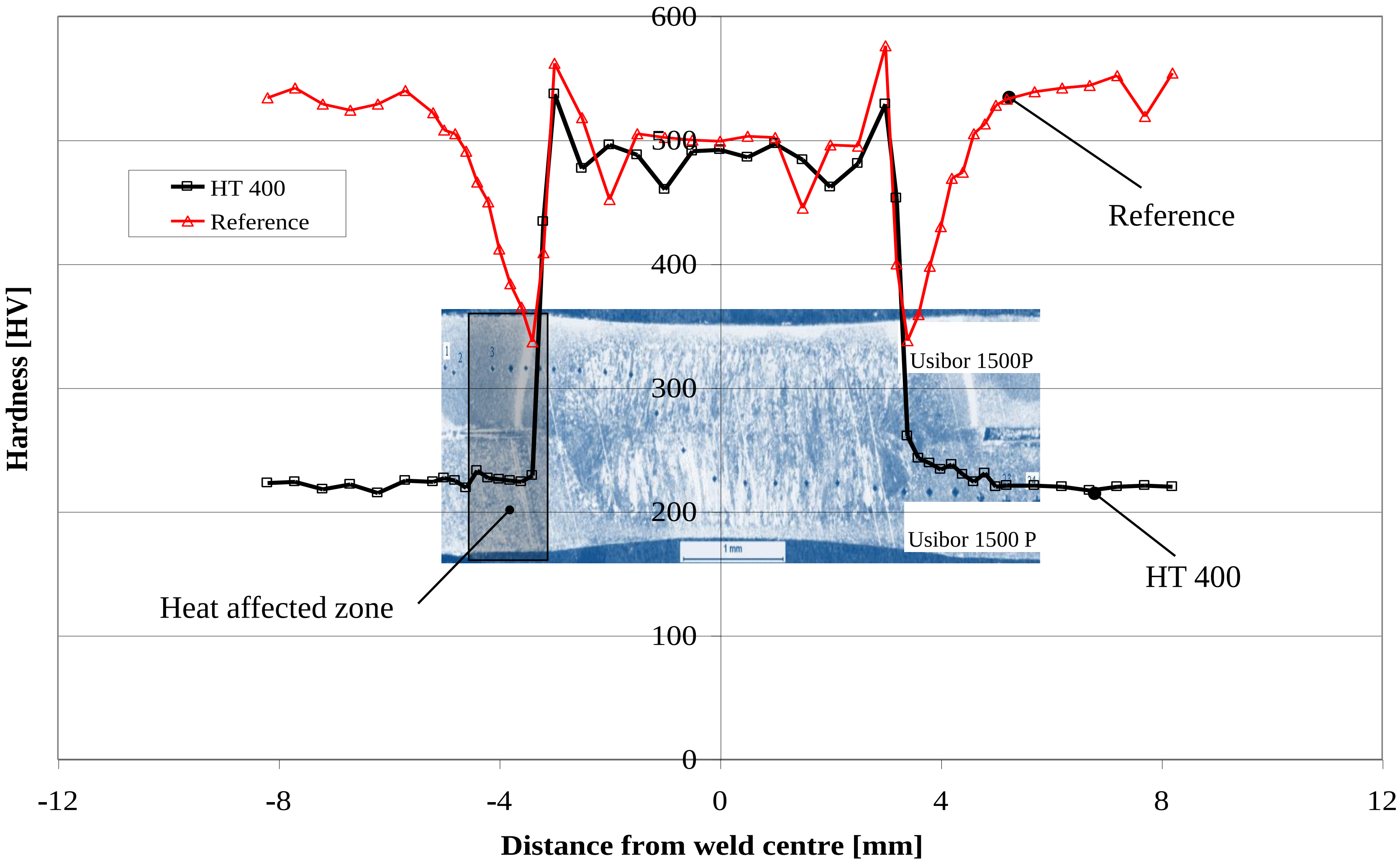


- HT-**H**ard**T**ech
- The grades are numbered depending on yield limit.
- HT400: yield limit of 400±50 MPa
- HT400: Ultimate tensile stress (UTS) of 600±50 Mpa.
- A minimum failure strain (A50) of 13% for HT400
- HT400 is on the market in two different B-pillars

***TAILORED MATERIAL PROPERTIES**-MATERIAL GRADES ON THE MARKET*

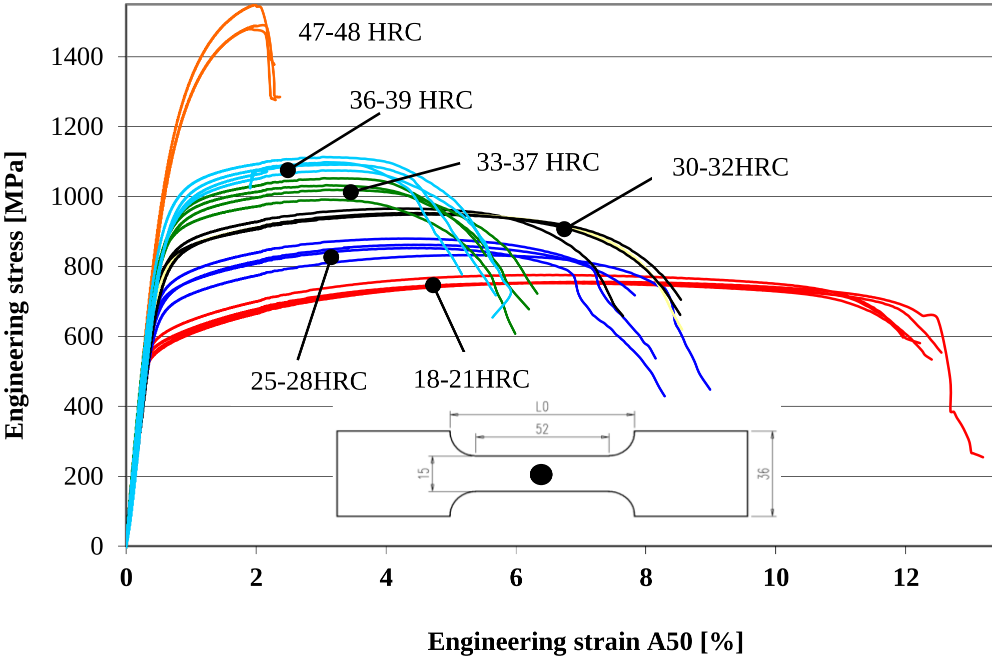


TAILORED MATERIAL PROPERTIES

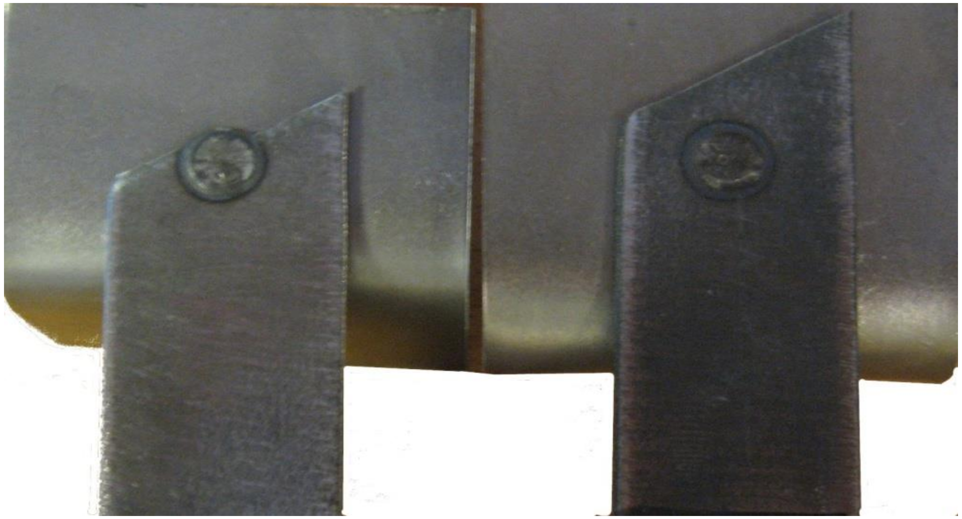


TAILORED MATERIAL PROPERTIES

- Spot weld positioned in the centre of a tensile specimen.
- A failure strain of approximately 2 % for fully hardened material (47-48 HRC)
- A significant increase in failure strain for material with a hardness of 30-32 HRC.



TAILORED MATERIAL PROPERTIES



Hardness: 47-48HRC

Hardness 30-32 HRC

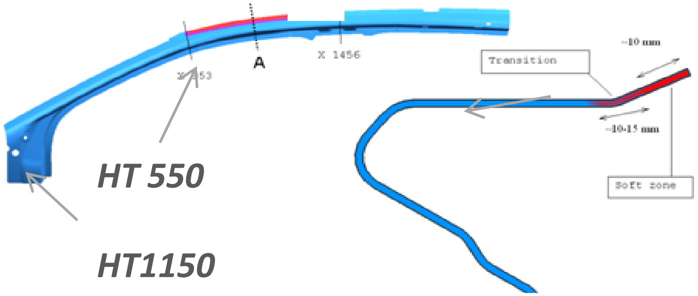
Hardness interval [HRC]	No. specimens with failure along HAZ	No. specimens with failure outside HAZ
47 – 48	3	0
36 – 39	3	2
33 – 37	1	4
30 – 32	0	5
25 – 28	0	5
18 – 21	0	5

- Failure occurs in the HAZ for the fully hardened material (47-48 HRC).

- Failure occurs outside the spot weld and HAZ when the hardness of the base material is below 30-32 HRC.

SOFT FLANGE APPLICATION

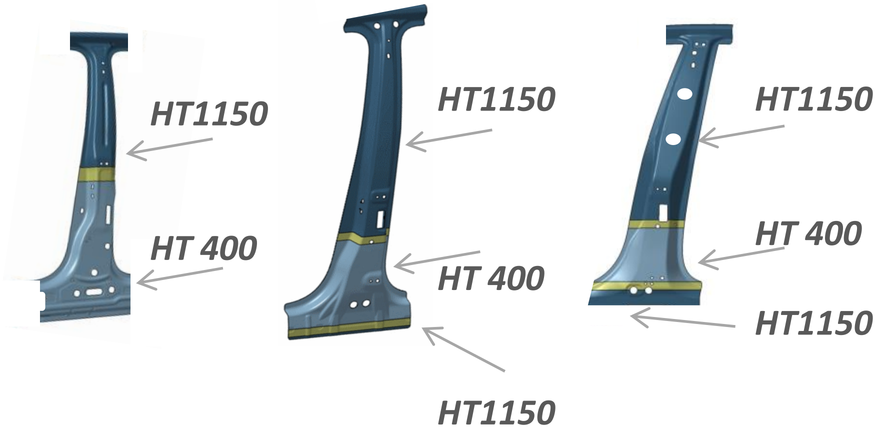
(one or more zones possible)



TAILORED MATERIAL PROPERTIES

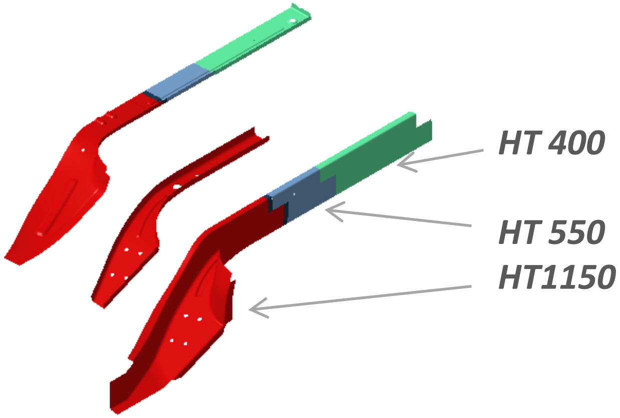
SOFT ZONE B PILLAR APPLICATION

(free area to define)



SOFT ZONE RAIL APPLICATION

(one or more zones possible)



SOFT ZONE IN DIE TECHNOLOGY BY GESTAMP CREATE NEW PRODUCTS

The state of the art SOFT ZONE offers new, until today not possibilities solutions in crash management.

Possibility to create all required material grades within one part and at any required position!

AGENDA

- ✓ Background
- ✓ Introduction
- ✓ Tailored material properties
- **Simulation methodology**
- Discussion and Conclusions

SIMULATION METHODOLOGY-CHALLANGES

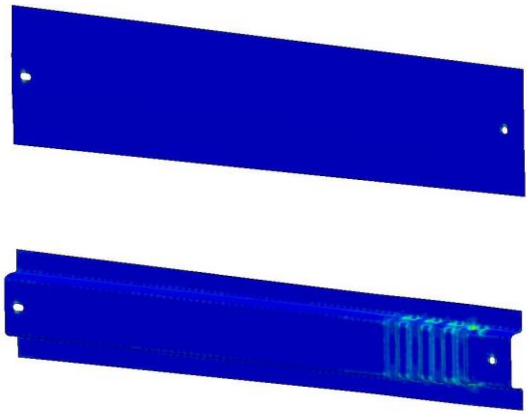
Which are the main simulation challenges for feasibility and crash analysis of components with tailored material properties?

- Correct representation of contact condition between the die parts and the blank/formed component
- Accurate microstructural calculation
- **Model for global mechanical and failure properties based on phase composition and single phase material data**
- Correct prediction of deformation modes and failure independent of element size.
- **Transfer of information from the internal forming analysis to the customers crash model**

SIMULATION METHODOLOGY

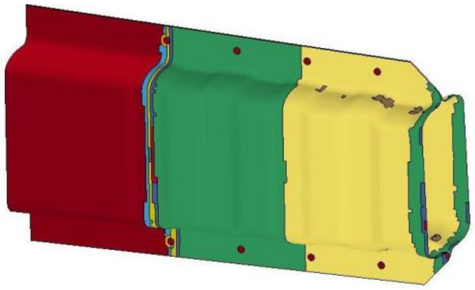
Thermo-mechanical forming analysis

- Air cooling during transfer
- Forming and quenching
- Post cooling to obtain final shape, thickness and microstructure



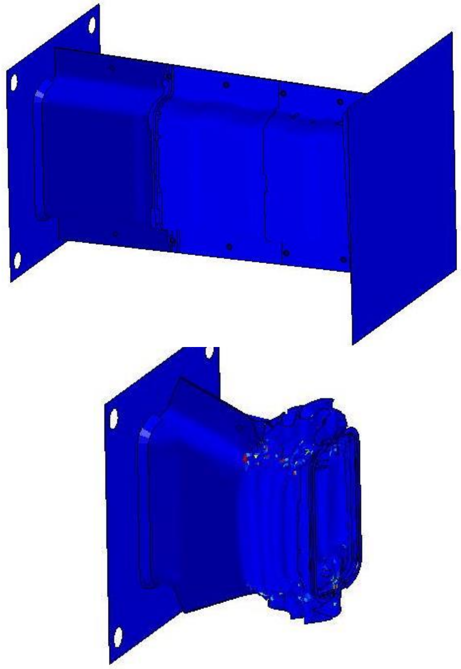
Mapping

- In-house mapping software
- Phase composition and single phase material data gives
  - ○ Global stress-strain curves
  - ○ Failure parameters
  - ○ Thickness



Crash analysis

- Force-displacement response
- Deformed geometry
- Area with failure



SIMULATION METHODOLOGY-THERMO-MECHANICAL FORMING

Thermo-mechanical forming analysis → Mapping → Crash analysis

- Microstructural calculation
  - Ferrite, pearlite and bainite formation is modelled using Kirkaldy's equation with enhancements according to Li et al.

$$\frac{dX_i}{dt} = F_G F_C F_T F_X$$

  - Martensite formation is modelled using Koistinen-Marburger's equation
- Carbon segregation
  - Occurs during ferrite and pearlite formation
  - The carbon content in the remaining austenite will be different than the bulk value
  - The major effect is in changing the critical temperatures A_{e3}, B_s and M_s

SIMULATION METHODOLOGY-THERMO-MECHANICAL FORMING

Thermo-mechanical forming analysis | **Mapping** | **Crash analysis**

- User-defined thermo-elastic-plastic material model
  - Implemented 2006 in LS-DYNA: Åkerström, P; Bergman, G; Oldenburg, M: Numerical implementation of a constitutive model for simulation of hot stamping. In: Modelling and simulation in materials science and engineering 15 (2007), pp. 105-119
  - Transformation plasticity model according to Leblond et al.
  - Strain rate dependency during global yielding

SIMULATION METHODOLOGY-MAPPING

Thermo-mechanical forming analysis

Mapping

Crash analysis

Mapping-*Translate calculate phase composition to a set of hardening- and failure parameters for a specific element size and thickness*

- A homogenization scheme is used to calculate the hardening, softening and fracture parameters based on the calculated microstructure.
- Two different homogenization methods have been investigated, the double inclusion (DI) model proposed by Nemat-Nasser and Hori [9] and the iso-strain model.
- The original part is subdivided into ten property zones (sub parts) depending on level of the stress-strain curve.

[9] M. Hori och S. Nemat-Nasser, Micromechanics: Overall Properties of Heterogeneous Materials, Amsterdam: Elsevier Science Publishers, 1999.

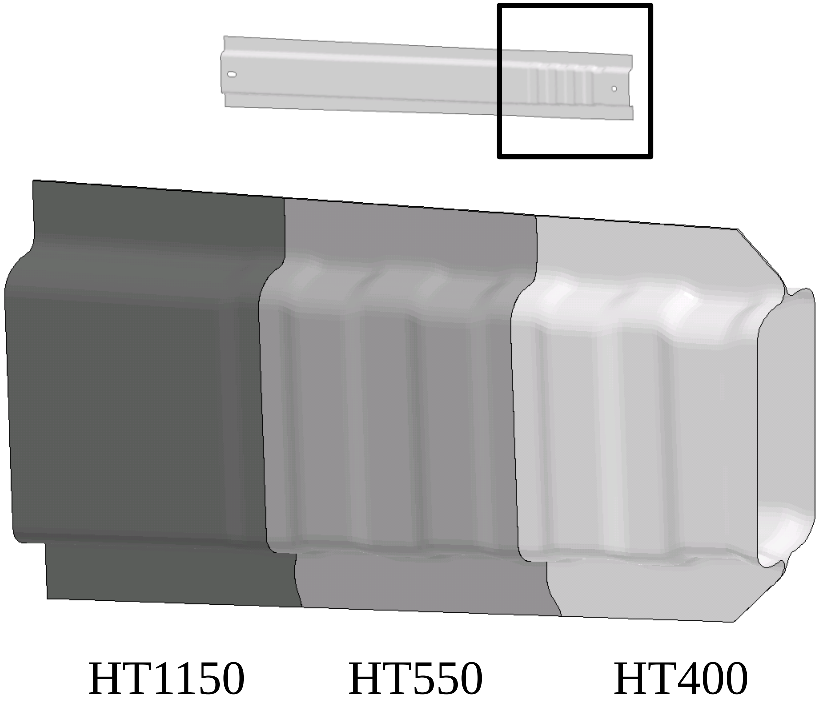
SIMULATION METHODOLOGY-MAPPING

Thermo-mechanical forming analysis

Mapping

Crash analysis

- Two hat profiles which are spot welded together
- Consists of three major material zones
- Manufactured from Usibor 1500P AS150 (nominal thickness 1.25 mm)



Grade	$R_{p0.2}$ (MPa)	R_m (MPa)
HT1150	1150±150	1550±150
HT550	490-600	750±50
HT400	400±50	600±50

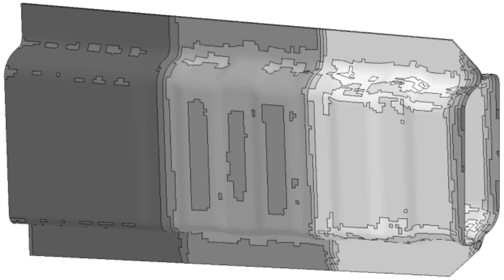
SIMULATION METHODOLOGY-MAPPING

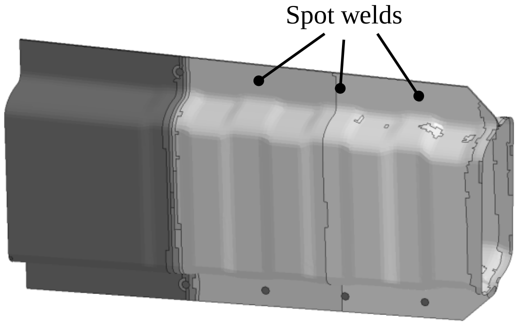

Thermo-mechanical forming analysis

Mapping

Crash analysis

- The original part is subdivided into ten property zones (sub parts)
- The distributions of the property zones are shown the left figure for the DI-model and in the right figure for the iso-strain model
- In the iso-strain model, the material properties are also modified in the fusion- and heat zone of the spot welds.

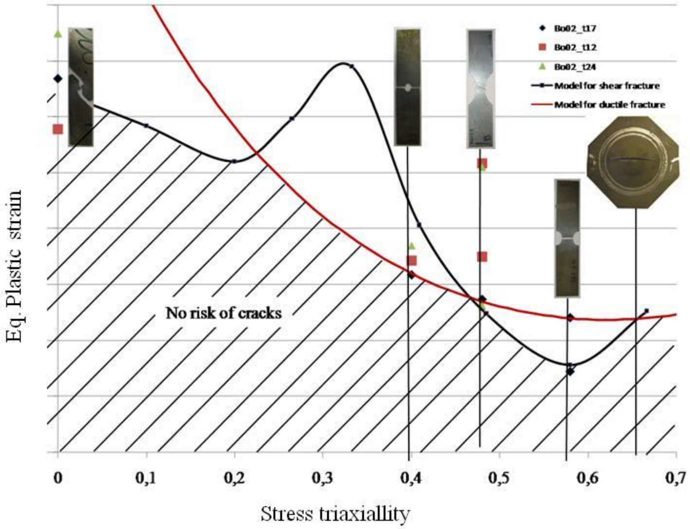


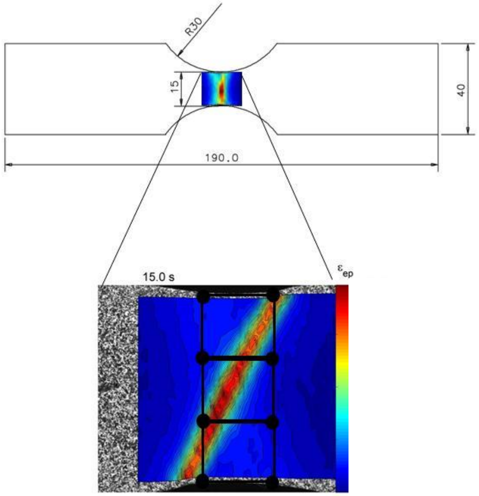


SIMULATION METHODOLOGY-CRASH

Thermo-mechanical forming analysis → **Mapping** → **Crash analysis**

- A user-defined elastic-visco-plastic material model is used in the crash analysis.
- The model includes mesh size dependent damage and predict crack initiation [11] using a ductile and shear fracture model [12]. The damage model activates after strain localization.





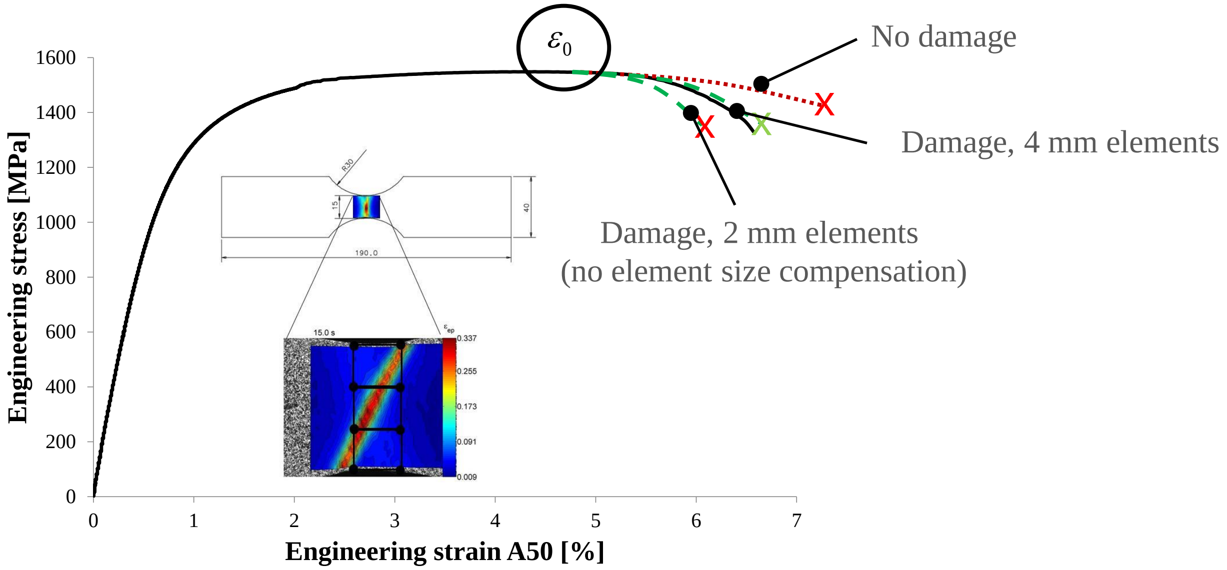
[11] H. H, D. Berglund, S. K och M. Oldenburg, ”Formulation of a finite element model for localisation and crack initiation in components of ultra high strength steels,” i *2nd International conference on Hot sheet metal forming of high-performance steel*, Luleå, Sweden, 2009.

[12] H. Hooputra, G. H, D. H och H. Werner, ”A comprehensive failure model for crashworthiness simulation of aluminium extrusions,” *International journal of crashworthiness*, vol. 5, pp. 449-463, 2004.

SIMULATION METHODOLOGY-CRASH

Thermo-mechanical forming analysis → Mapping → **Crash analysis**

Why include damage (localization function)?



$$\bar{\sigma}_{ij} = \frac{\sigma_{ij}}{1 - d_{crit.}h(\sigma^m)D}$$

Element size

$$\dot{D} = A_0 \left(\frac{l}{t}\right)^2 Be^{B(\varepsilon_p - \varepsilon_0)} \dot{\varepsilon}_p$$

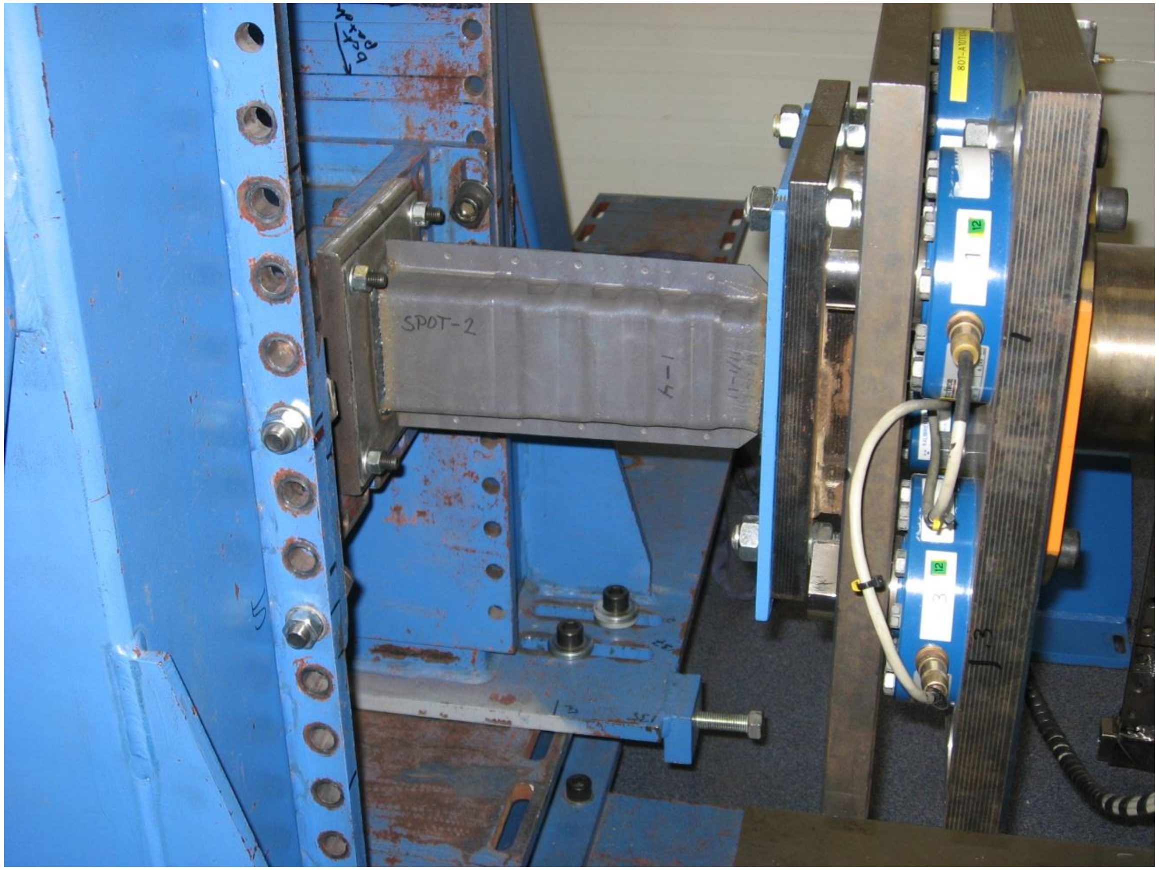
Thickness

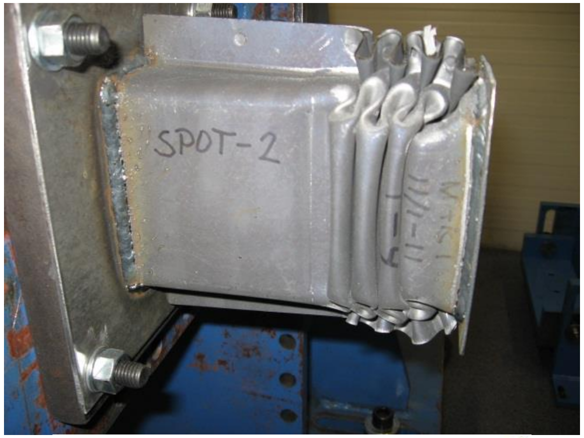
Threshold value

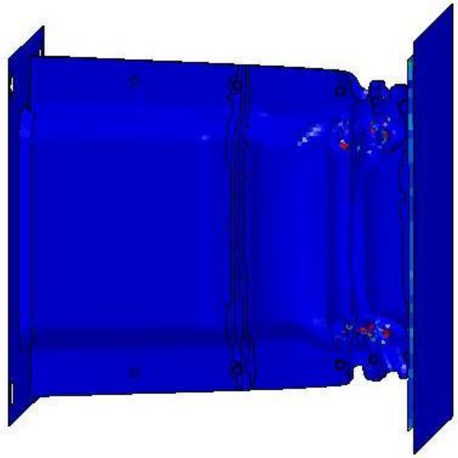
- A localization criterion is used to calculate the threshold strain value when damage starts to occur. The criterion is dependent on stress triaxiality

SIMULATION METHODOLOGY-VALIDATION

Quasi-static axial compression test at 12.5 mm/s



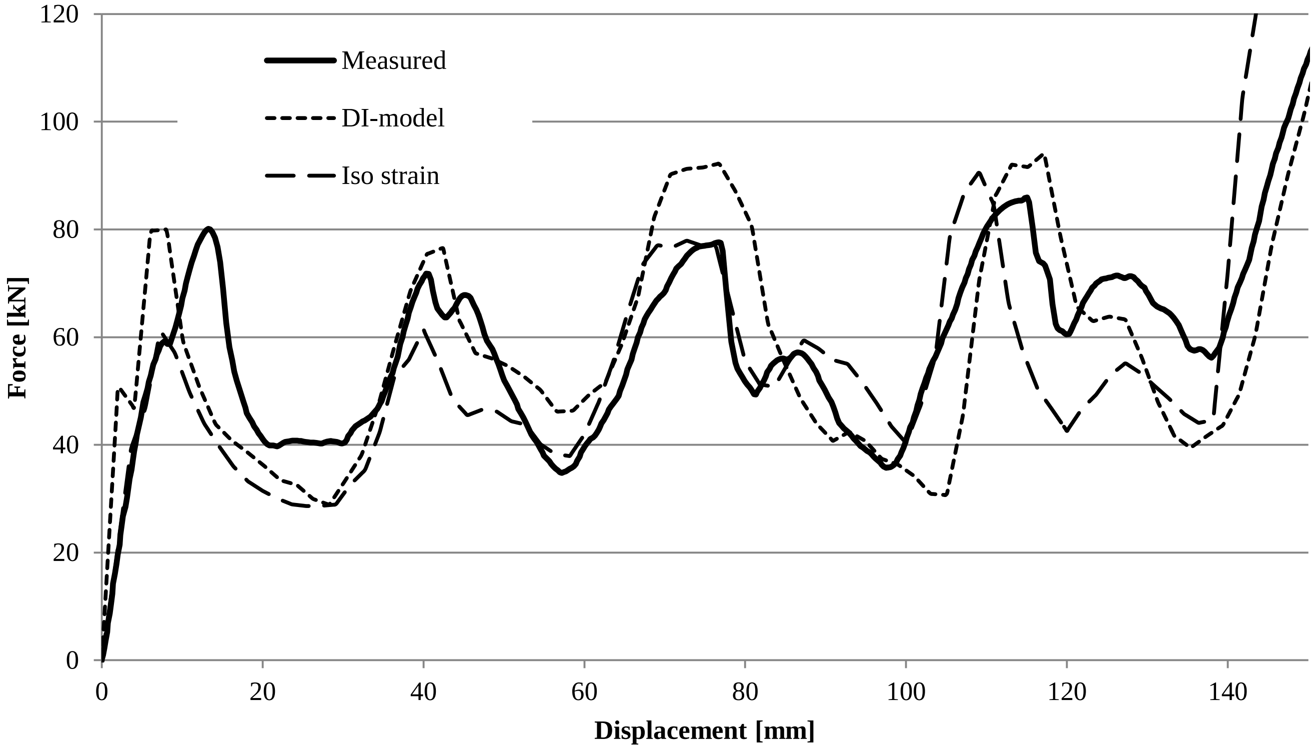




SIMULATION METHODOLOGY-VALIDATION

- The initial peak load of 60 kN is significant lower for the iso-strain model in comparison with the test (80 kN) but the stiffness up to 7 mm shows good agreement with the test.

- Except for initial deviation in the force response, acceptable agreement is found after 20 mm displacement for the DI-model.

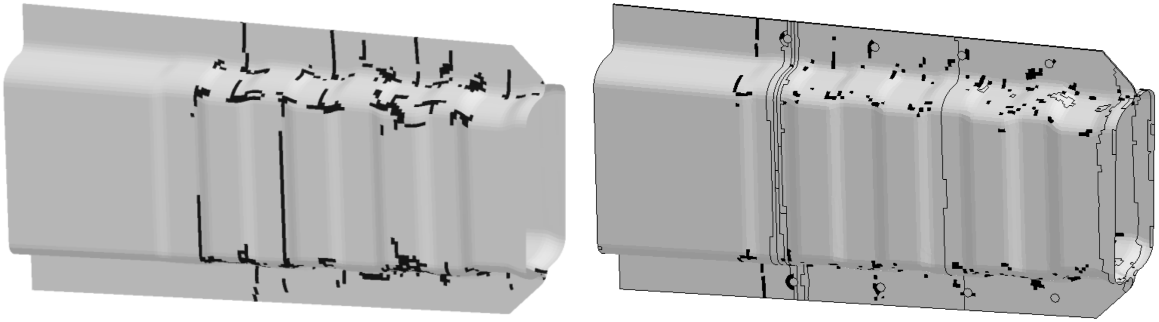


SIMULATION METHODOLOGY-VALIDATION

- Predicted ductile damage displayed on undeformed geometry is shown in the Figure below.

- The simulation indicates high risk of crack initiation (dark elements with a damage value equal to 1.0) at multiple positions when using the DI-model and constant threshold value , Fig. 4a).

- The number of critical positions is less when including the localization based threshold value, Fig. 4b). Visual inspection of the physical test only showed cracks in the vicinity of some spot welds.


a) b)

AGENDA

- ✓ Background
- ✓ Introduction
- ✓ Tailored material properties
- ✓ Simulation methodology
- **Discussion and Conclusions**

DISCUSSION AND CONCLUSIONS

- A finite element model for failure prediction has been used for axial compression simulation of a front side member beam with tailored material properties.
- Acceptable agreement between measured and computed force response was found with the DI-model but the Iso-strain model shows a too low initial peak force.
- The model for localization and crack initiation is found to be too conservative for cases where buckling is involved also when using the localization based threshold value.
- The DI-model is “good enough” for using in product development of hot stamped components with tailored material properties