
OPEL

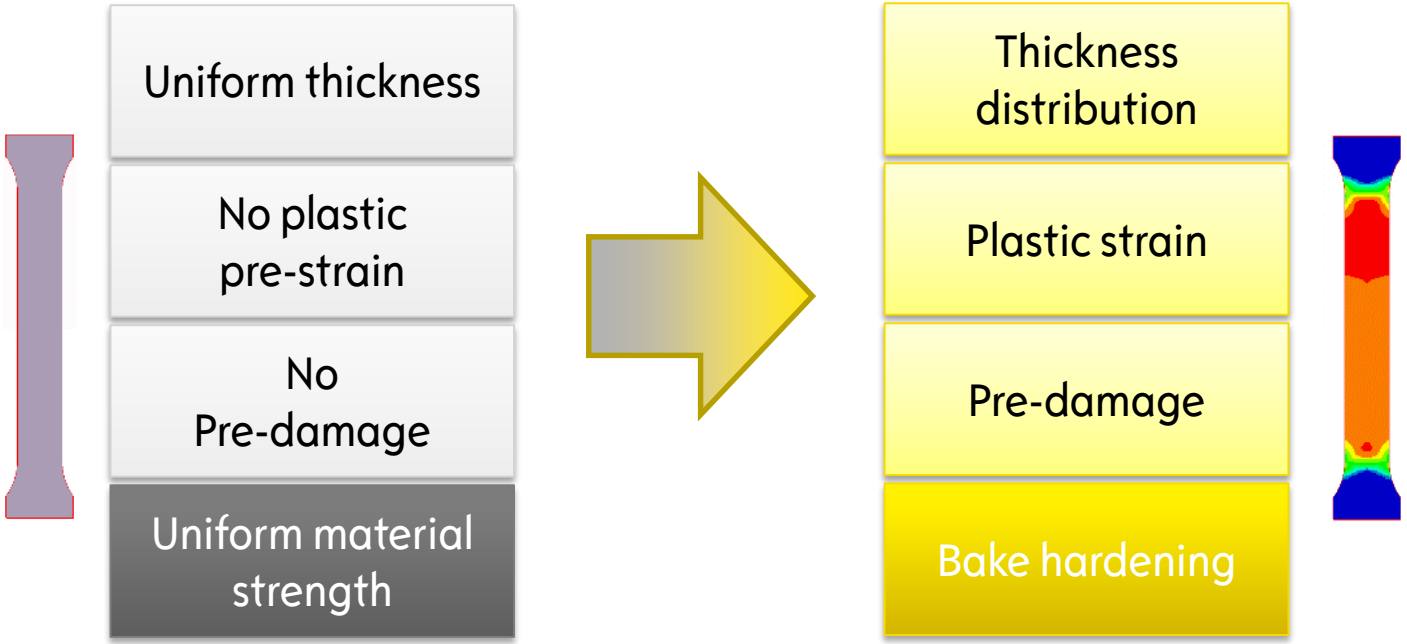
CONSIDERING BAKE HARDENING FOR DEFORMED SHEET STEEL

A phenomenological approach

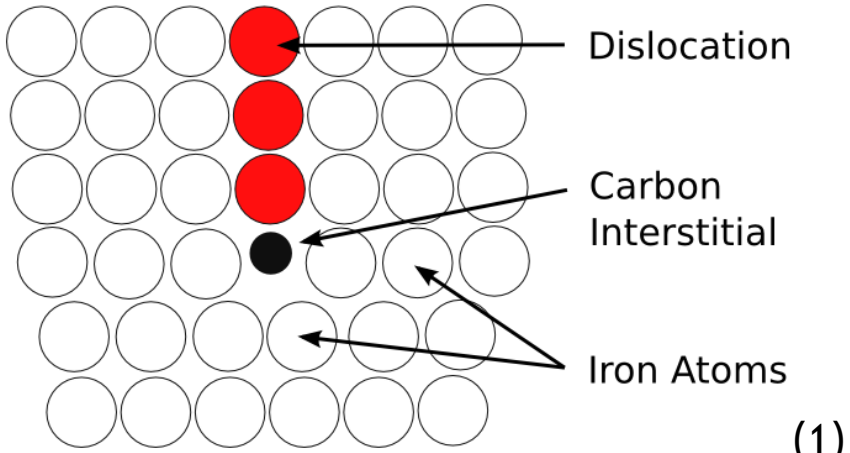
Daniel Riemensperger
Adam Opel AG

MOTIVATION

Capturing local property distribution



BAKE HARDENING(BH) EFFECT

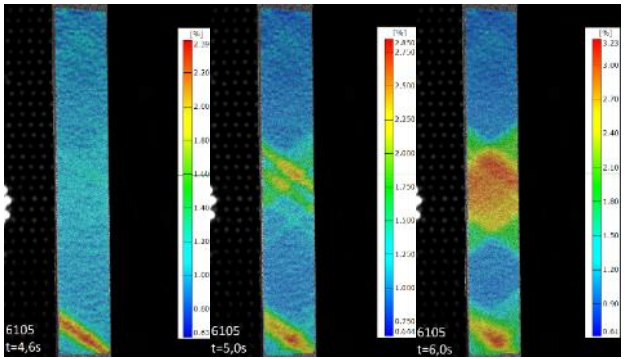


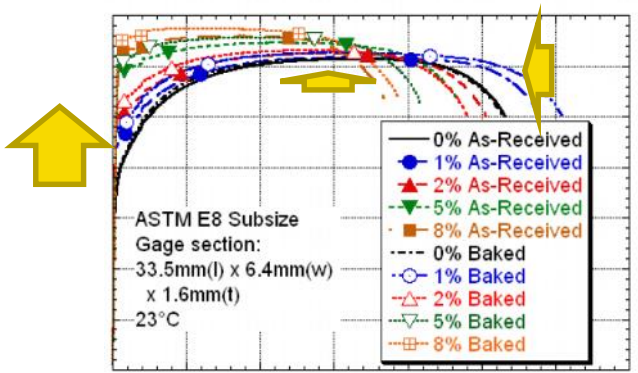
https://en.wikipedia.org/wiki/Cottrell_atmosphere (1)

- Accelerated ageing by movement of carbon atoms in solid solution during paint baking
- Carbon atoms attach to dislocations
- Movement of dislocation hindered
  → Increase of resistance to external load

MECHANICAL EFFECTS OF BH

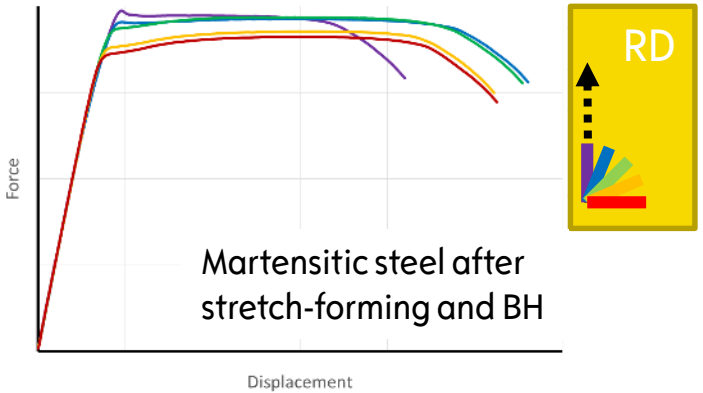
- Significant increase of yield strength
- Mild increase of tensile strength
- Reduction of A80 fracture strain
- Increase of upper yield strength
- Lueders bands
- Increase of anisotropy





Bake-Hardening Effect of Dual Phase Steels (SAE 2009)

(2)

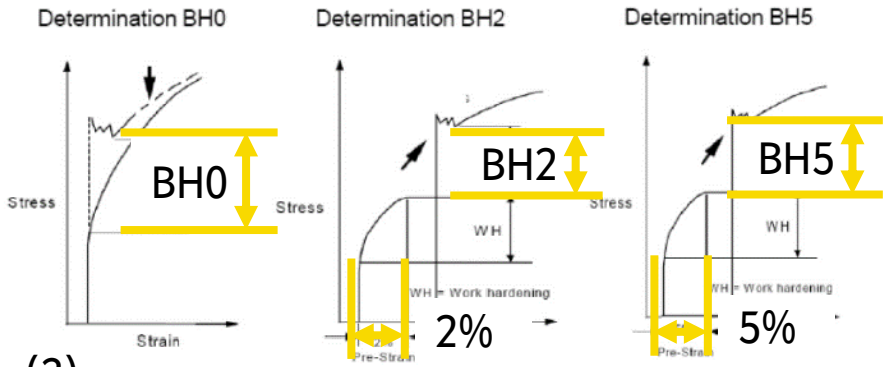


STANDARD MEASUREMENT OF BH

Determination of BH-values

acc. to EN 10325

- Difference in yield strength of unbaked and baked condition
  → BH-value
- Part of standard test matrix
- Values in engineering stress
  → transferred to true stress



(3) Bake Hardening Behavior of Advanced High Strength Steels under Manufacturing Conditions, Heike Kantereit (SAE 2011)

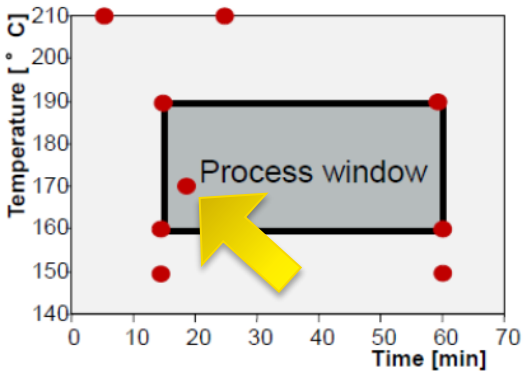
Prüfkarte OPEL

×	BH0	[N/mm²]	76	$R_{p0,2}$ [N/mm²] nach 170°/25'	771
×	BH2	[N/mm²]	153	$R_{2\%}$ [N/mm²]	932
				$R_{p0,2}$ [N/mm²] nach 2%/170°/25'	1085

	ENG	TRUE	
BH0	76	**77**	MPa
BH2	153	**142**	MPa

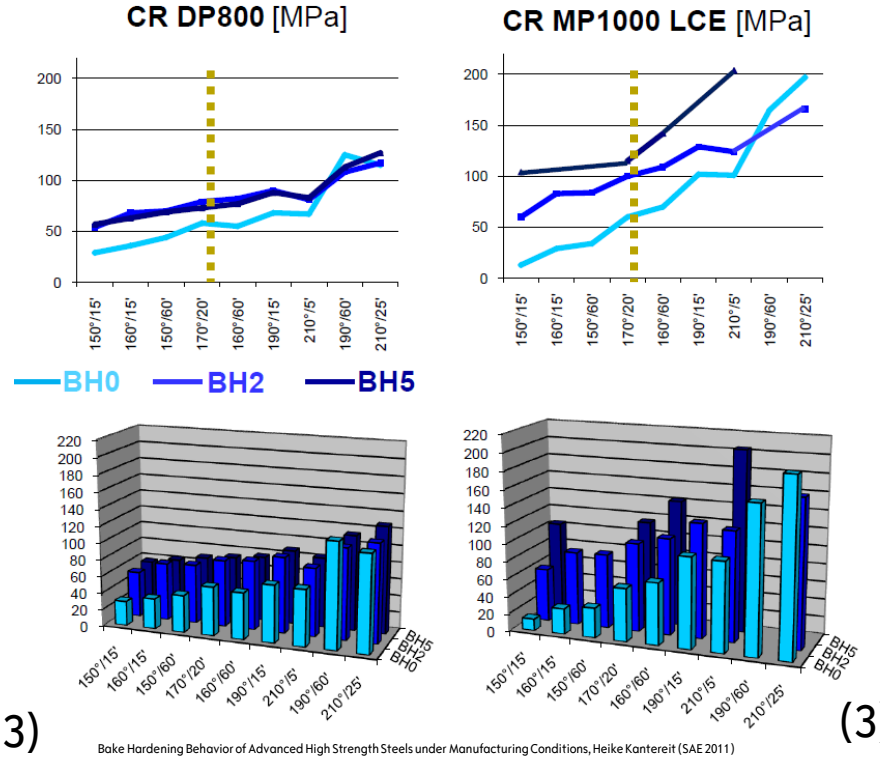
INFLUENCES ON BH

- Carbon concentration
- Deformation prior to heat treatment (pre-strain)
- Time and temperature of heat treatment



Bake Hardening Behavior of Advanced High Strength Steels under Manufacturing Conditions, Heike Kantereit (SAE 2011) (3)

Yield strength increase



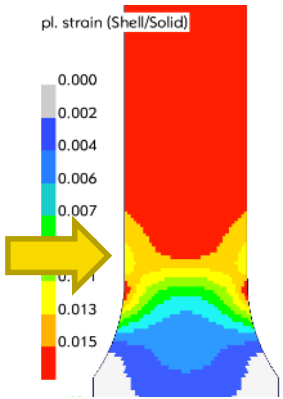
Bake Hardening Behavior of Advanced High Strength Steels under Manufacturing Conditions, Heike Kantereit (SAE 2011) (3)

IMPACT ON CRASH PERFORMANCE

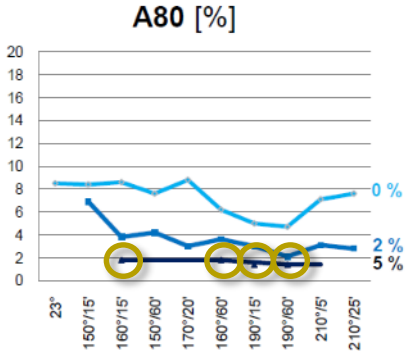
- Drastic reduction of ductility for some materials?
  - Uniaxial test with 5% pre-stretch
    → High tendency for preliminary fracture
- BH effect increases heterogeneity of the part
  - Local yield strength varies
    → Early necking

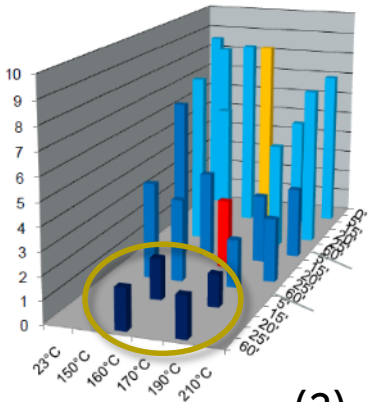
	CR MP1000 LCE		
	150°C/15’	170°C/20’	190°C/60’
BH0	19 MPa	60 MPa	165 MPa
BH2	60 MPa	100 MPa	166 MPa
BH5	100 MPa	114 MPa	204 MPa

(3)



Plastic strain





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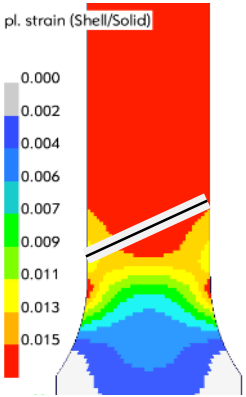

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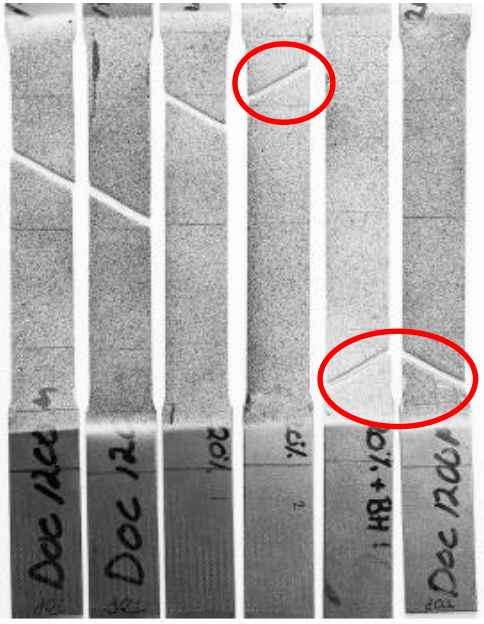


(b) Docol 1200M

(4)

Bake hardening effect in advanced high-strength steels , KARL LINDQVIST 2013

Bake Hardening Behavior of Advanced High Strength Steels under Manufacturing Conditions, Heike Kantereit (SAE 2011)

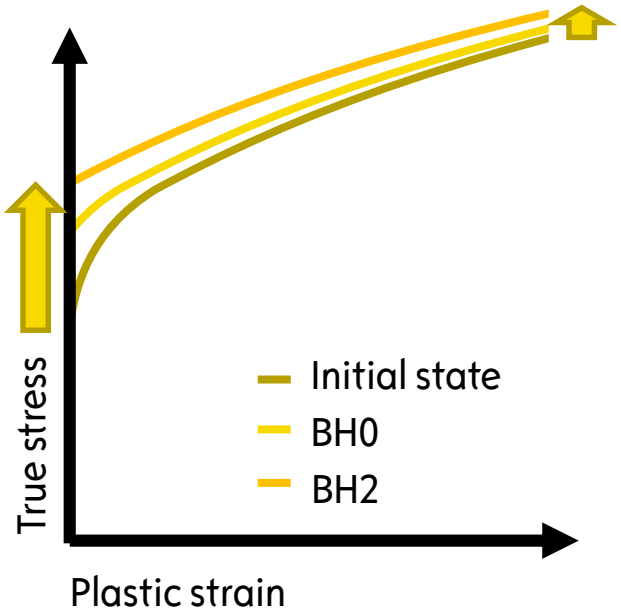
PHENOMENOLOGICAL APPROACH

Complex Problem

- Simple shift of curve not feasible
- Deformation of curve is pre-strain dependent
- Change has to be done element by element

Simple Approach

- Translate bake hardening into work hardening
- Map result to element



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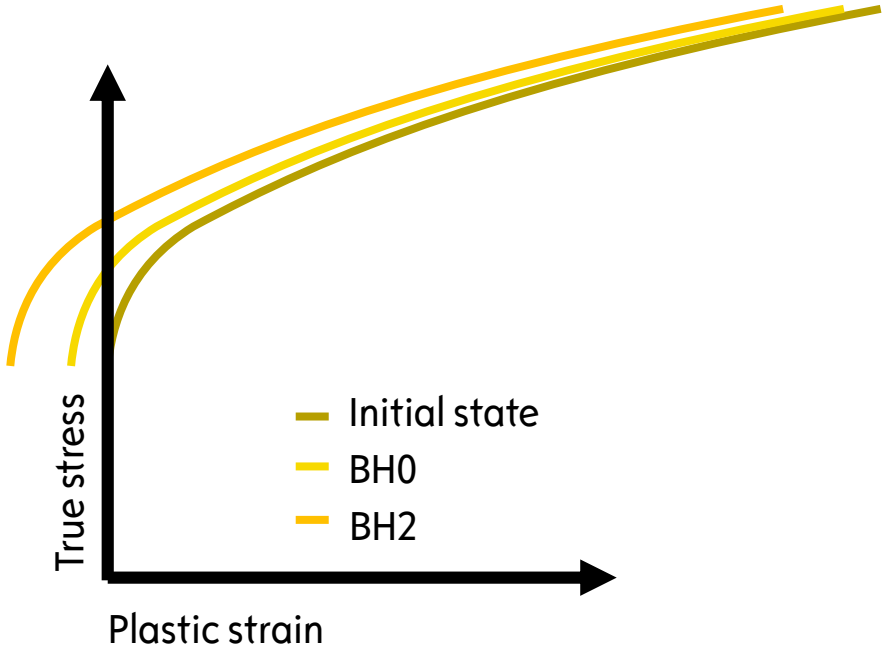


BAKE VS. WORK HARDENING

Work hardening

- Breakage of atomic bonds
- Dislocations start moving or slipping across crystal planes
  → Plastic deformation

- Dislocations interact among themselves and with grain boundaries / point defects
  →Pile-up
  →Increase of resistance to external load

Bake hardening

- Accelerated ageing by movement of dissolved carbon atoms during paint baking

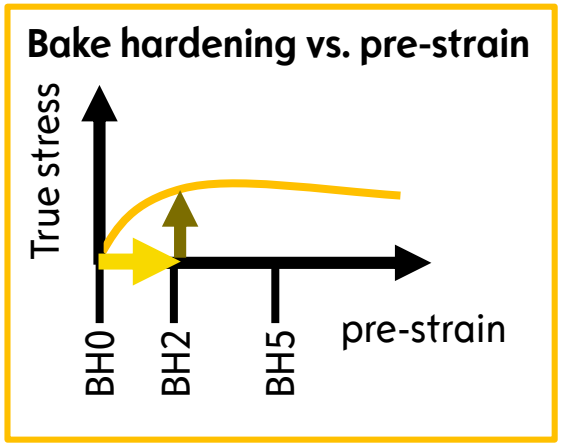
- Carbon atoms attach to dislocations
- Movement of dislocation hindered
  → Increase of resistance to external load

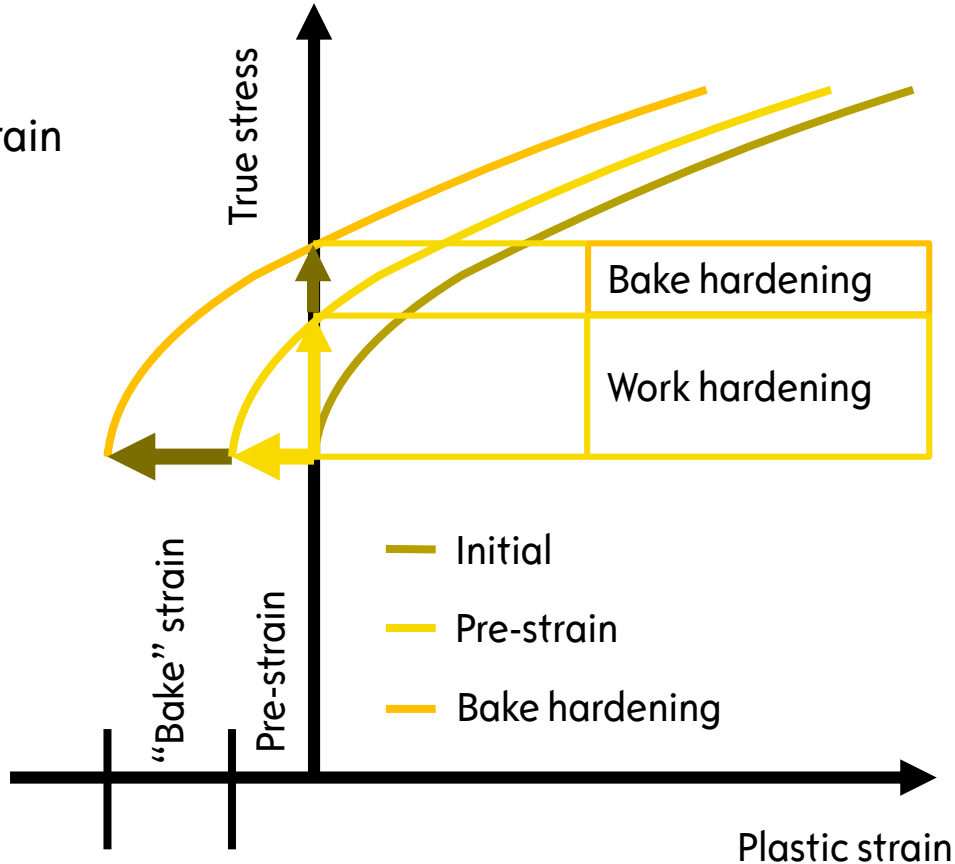
➔ Mechanical response quite similar

PHENOMENOLOGICAL APPROACH

Apply BH as per rule

- Look up yield strength shift per pre-strain
- Look up equivalent bake-strain
- Update value in mapping file

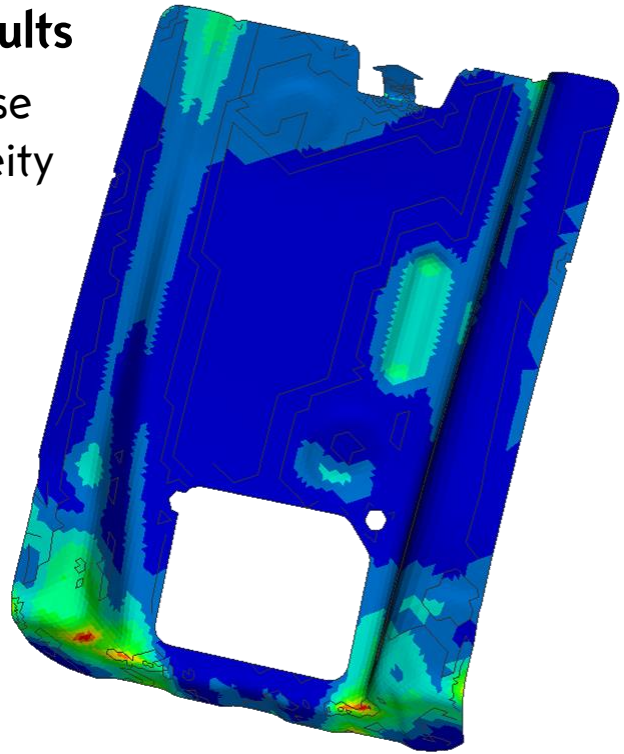




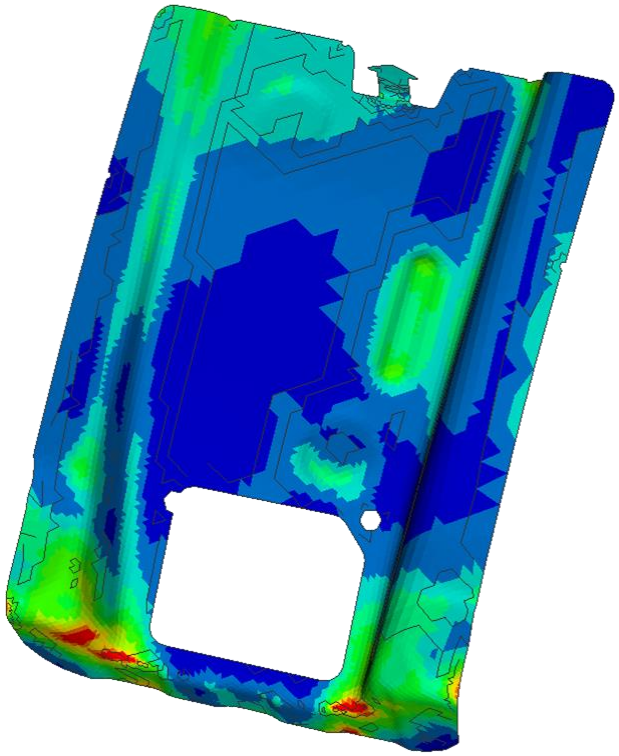
PHENOMENOLOGICAL APPROACH

Example results

Visible increase
of heterogeneity



initial



baked

PHENOMENOLOGICAL APPROACH

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Visible increase
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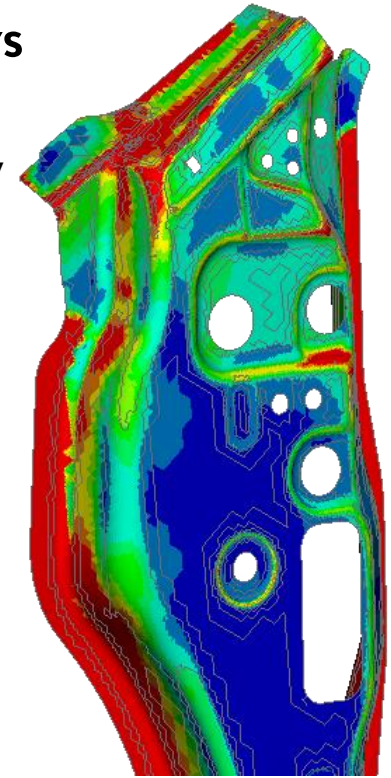

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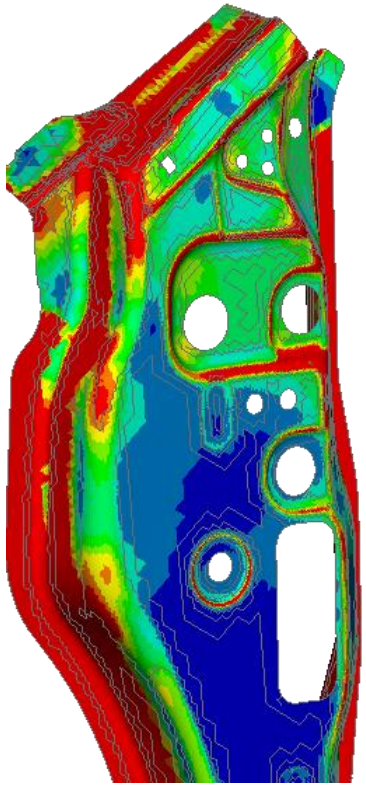


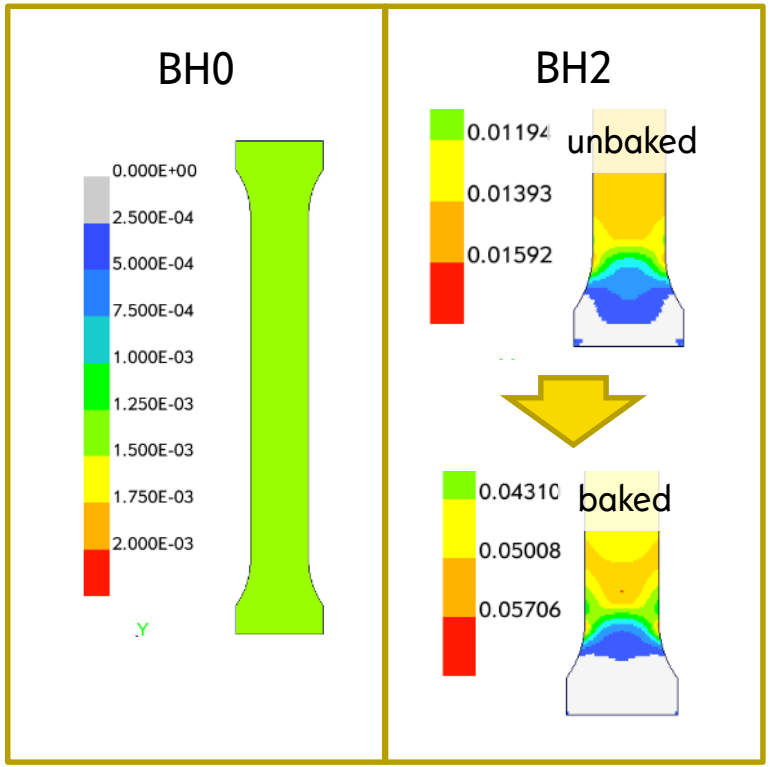
baked

PROOF OF CONCEPT

- True stress BH data from data sheet

	ENG	TRUE	
BH0	76	**77**	MPa
BH2	153	**142**	MPa

- ***MAT_024** for unbaked material with GISSMO
- BH0
  - Add plastic strain to anticipate WH
- BH2
  - Stretch UT specimen to 2% pre-strain
  - Map deformed specimen

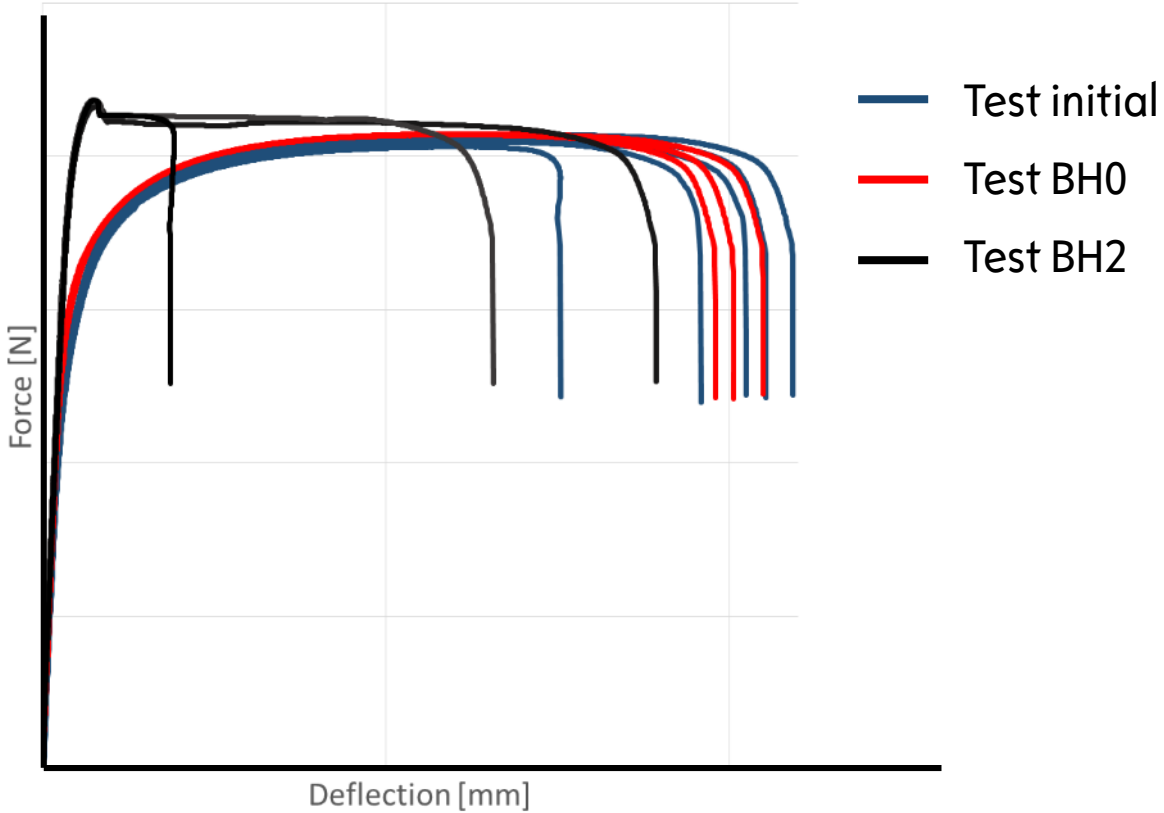


PROOF OF CONCEPT

0. Test data

- BH0 → Mild
- BH2 → Strong

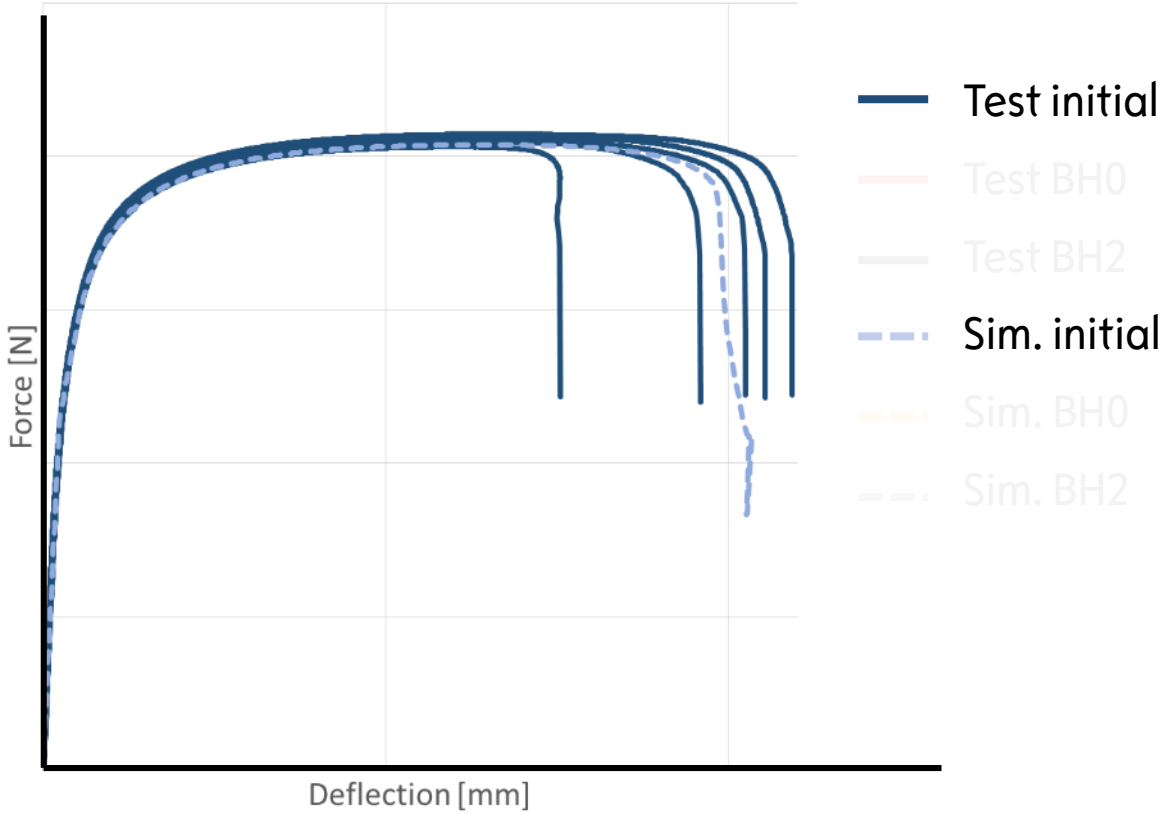
	ENG	TRUE	
BH0	76	**77**	MPa
BH2	153	**142**	MPa



PROOF OF CONCEPT

1. Unbaked condition

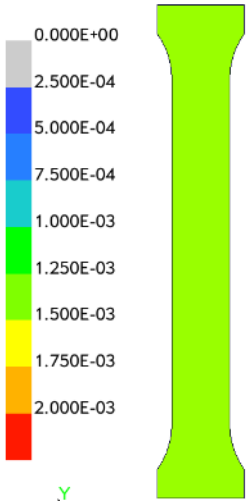
Yield curve calibrated to tests

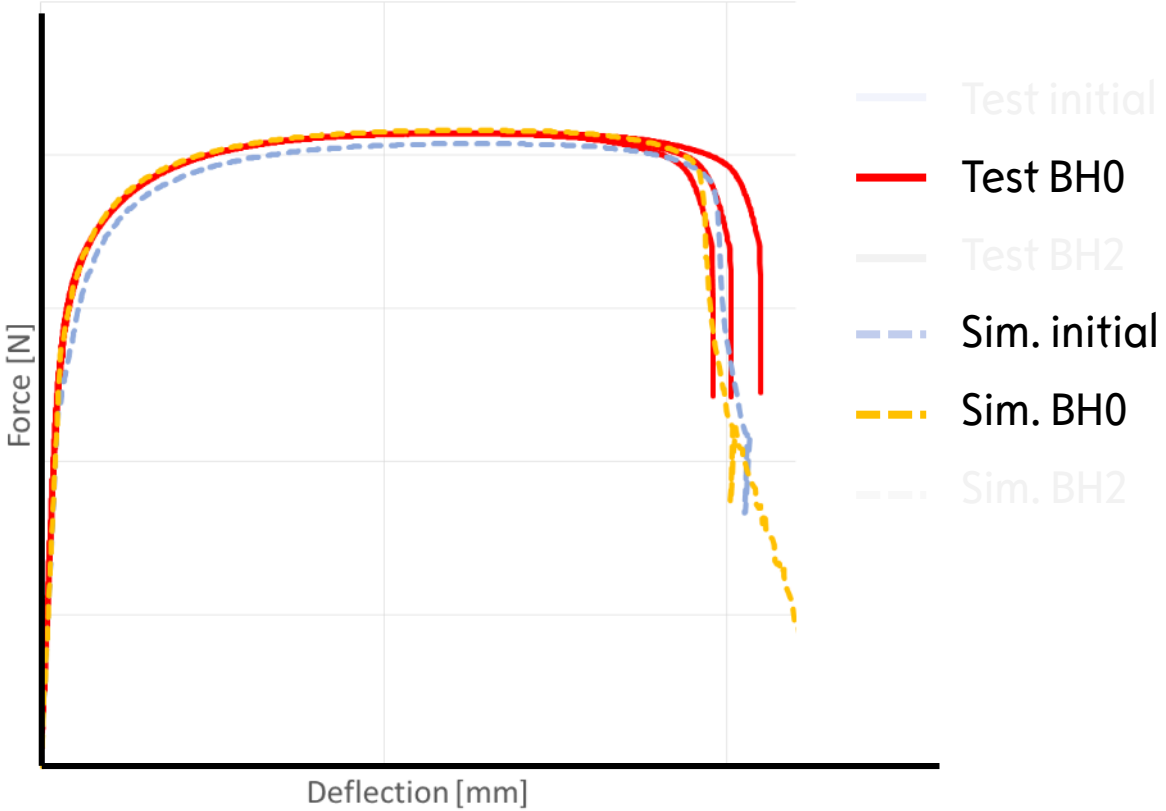


PROOF OF CONCEPT

2. Baked condition (BH0)

Addition of homogeneous pre-strain

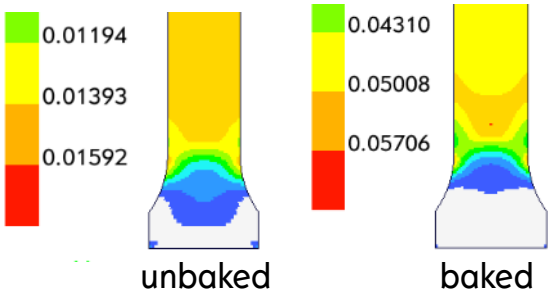


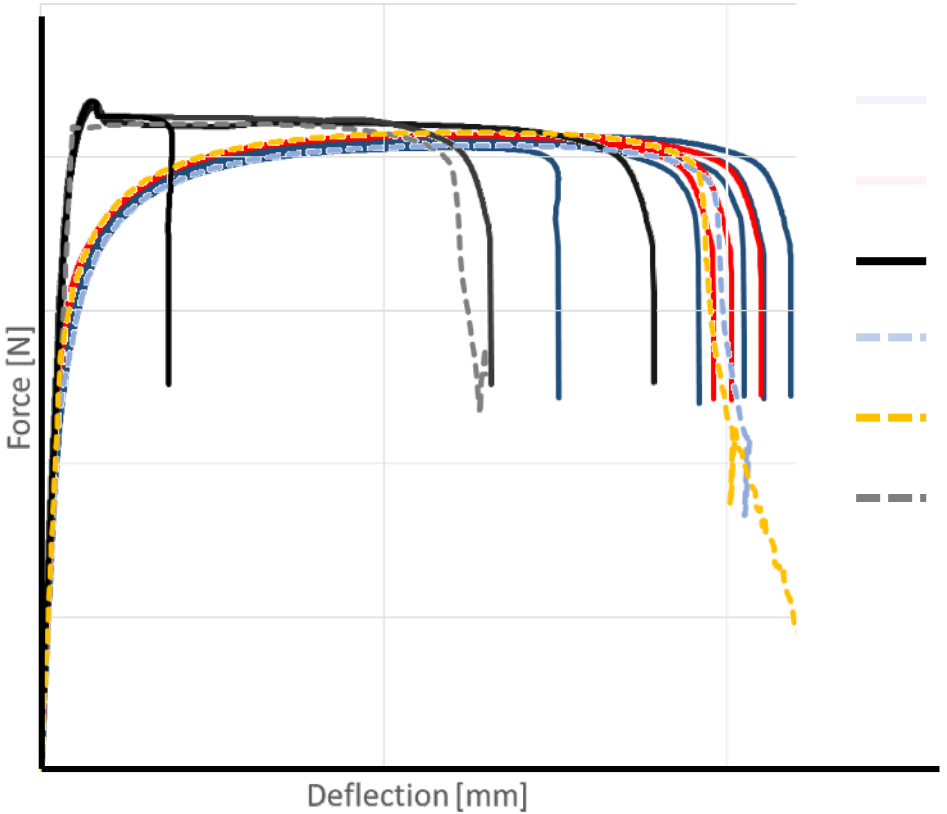


PROOF OF CONCEPT

3. Baked condition (BH2)

- Deformed specimen with pre-strain
- Increase of pre-strain
- Visible increase of heterogeneity

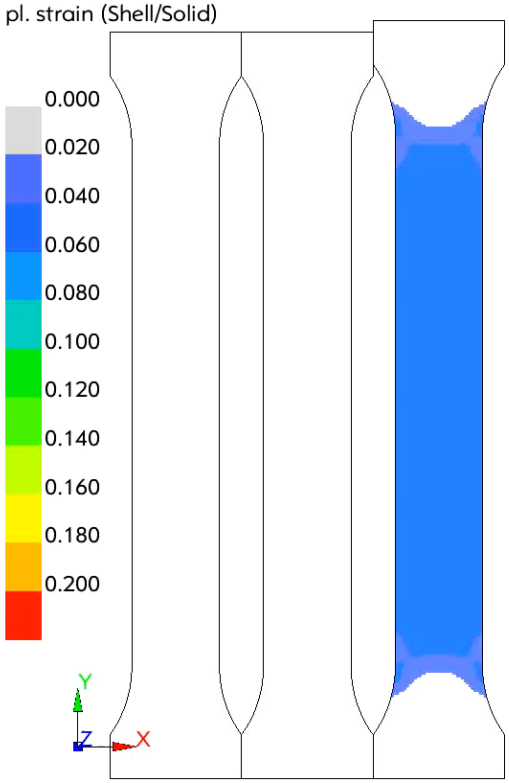


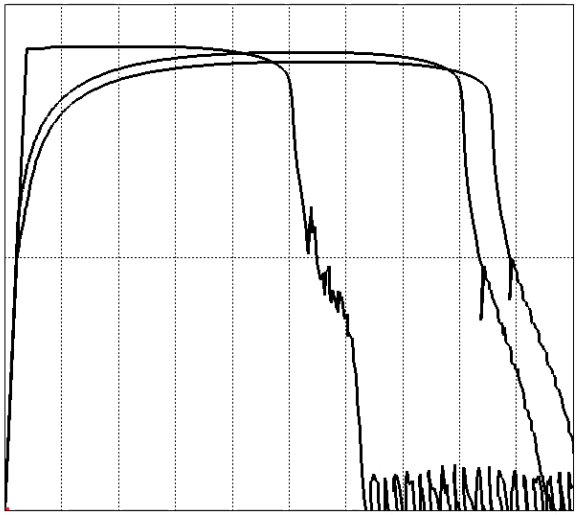


PROOF OF CONCEPT

Comparison

- No change of local fracture strain
- Change of fracture location for BH2

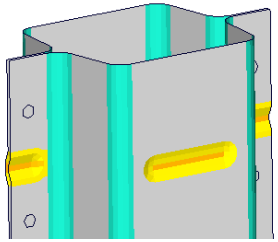




IMPACT ON GENERIC CRUSH TEST

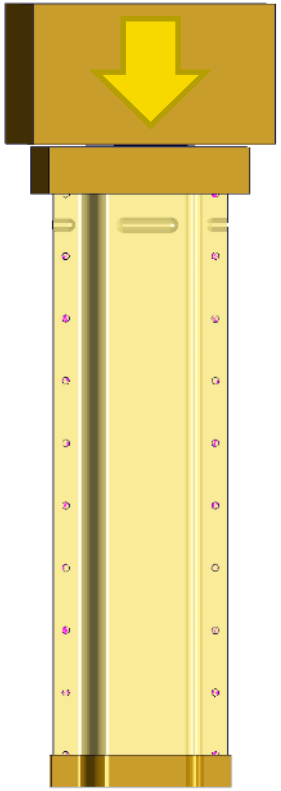
Bent component

Areas of deformation well defined



Comparison of 3 simulations

	WH	BH
	✔	
	✔	✔



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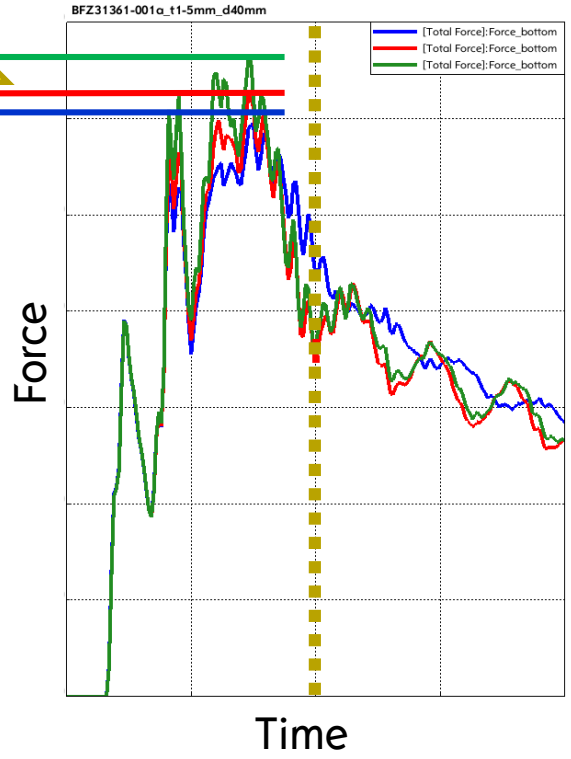
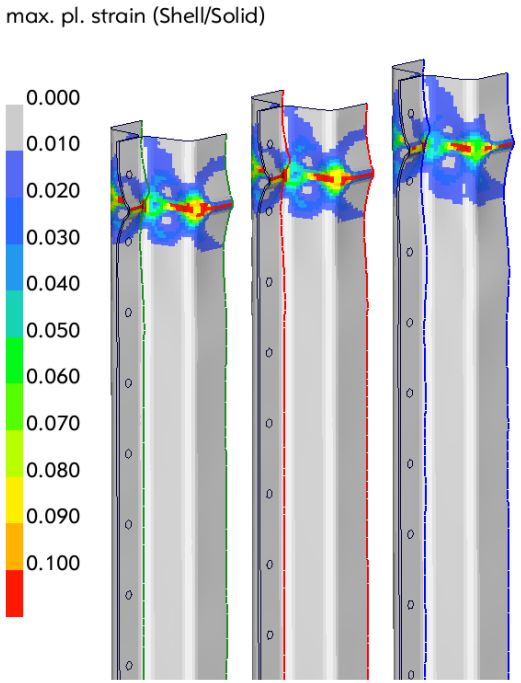
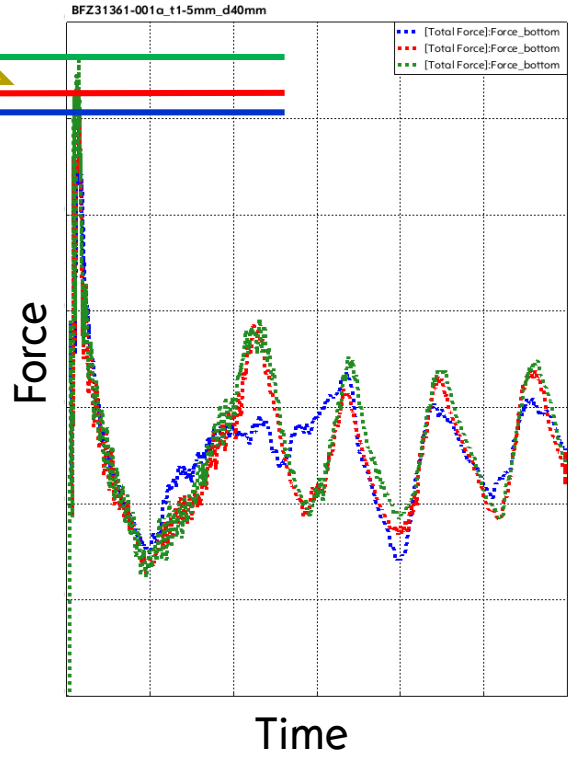
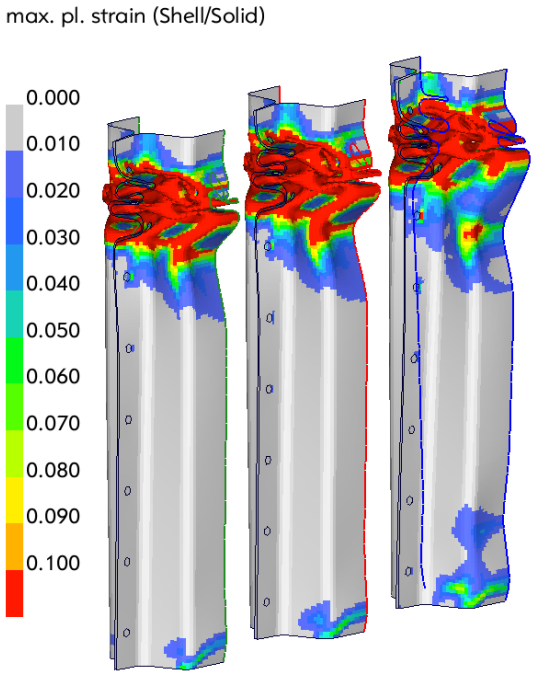




	WH	BH
	✔	
	✔	✔

IMPACT ON GENERIC CRUSH TEST





	WH	BH
	✔	
	✔	✔

CONCLUSION

- BH is relevant for AHSS and UHSS
- Approach feasible
- Process simulation results mandatory for method
- Increasing effort in material characterization
- No increase in simulation time

Daniel Riemensperger

THANK YOU

	Sources
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2	Bake-Hardening Effect of Dual Phase Steels (SAE 2009)
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