VIRTUAL MANUFACTURING AND PRODUCT ENGINEERING OF LASER-TREATED CRASH-RELEVANT CAR BODY STRUCTURES

VirtualCarBody 2018
Simulation in car body related product and manufacturing engineering

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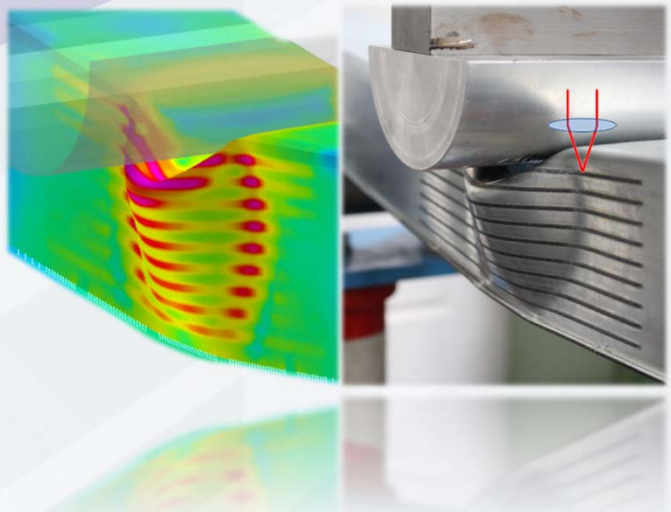

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Agenda

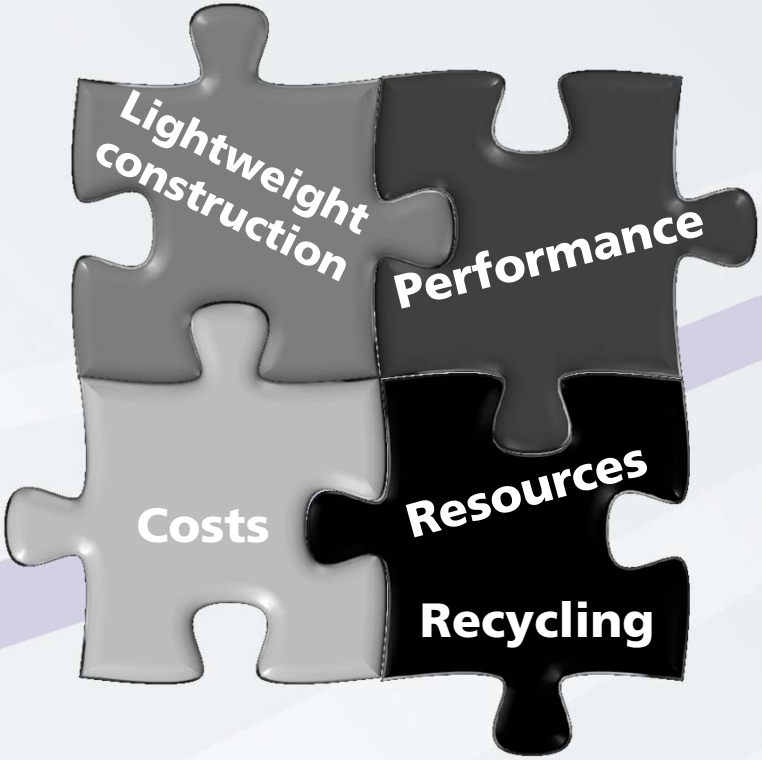
1. Motivation and virtual design approach
2. Laser-strengthening
3. Virtual material data
4. Virtual component design
5. Automotive applications
6. Conclusions

Motivation

Conflict of goals in automotive car body manufacturing

EDAG Light Cocoon

Car body manufacturing Opel AG



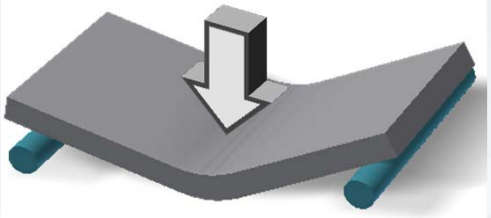
Frontal crash test Audi AG

Load-adapted car body structures made of steel!

Motivation

Load-adapted car body structures

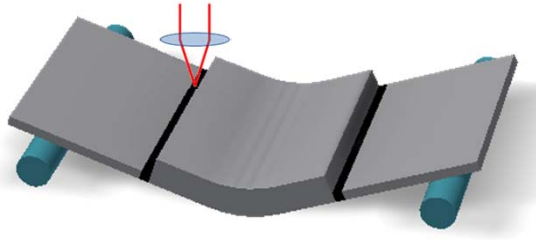
Conventional (uniform) design



Uniform steel grade and sheet thickness

Oversized!

Large-scaled property modifications

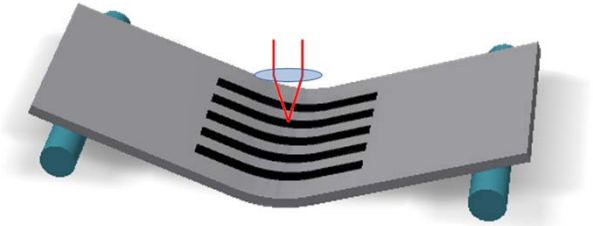


Laser-welded structures

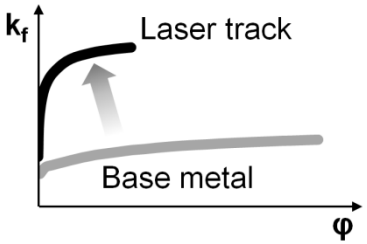
- Tailored Components
- Patchwork Structures

„Strength Tailoring“ by

Local laser-strengthening



Flow curves



Individualized mechanical properties!

Virtual car body design

- Laser-welding
- Laser-strengthening
- Laser-hardening
- Laser-structuring

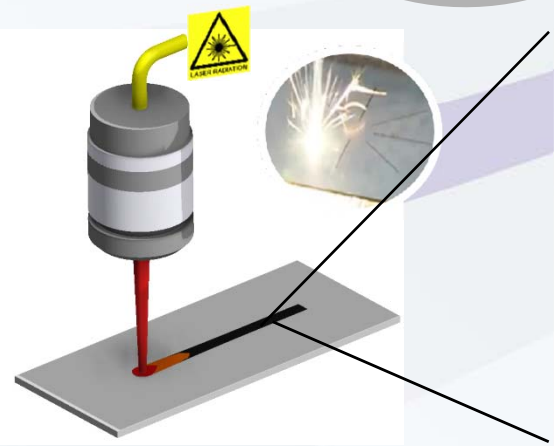
Laser-treatment

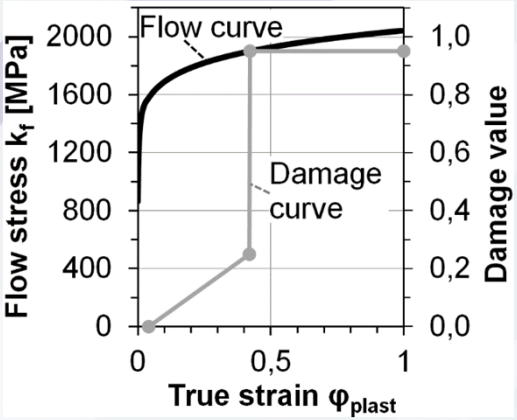
Virtual material data

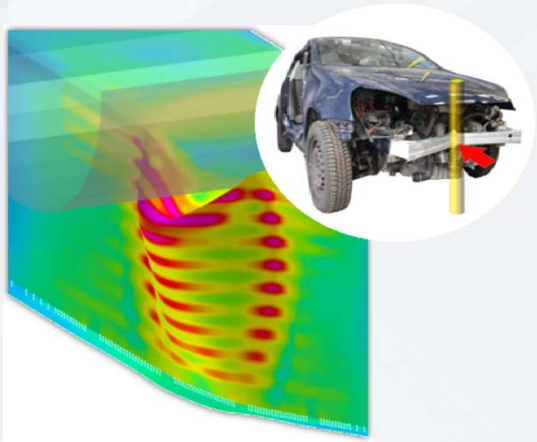
- Dimensions of laser-treated zones
- Flow curves and damage behavior

- FE-based part design
- Crash / forming simulations

Virtual part design







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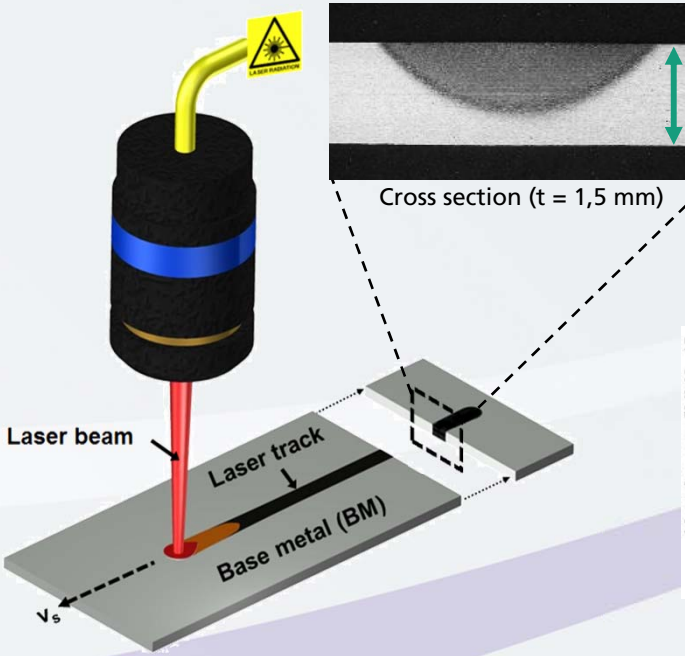
Laser-strengthening

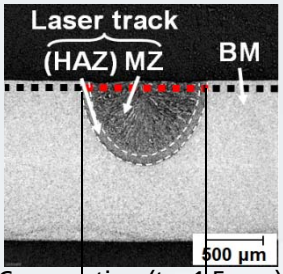
Process



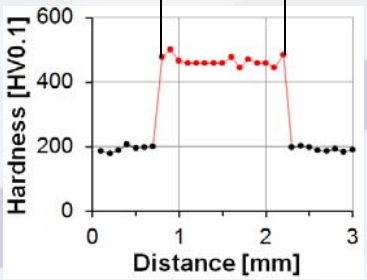
Solid phase process

Cross section (t = 1,5 mm)

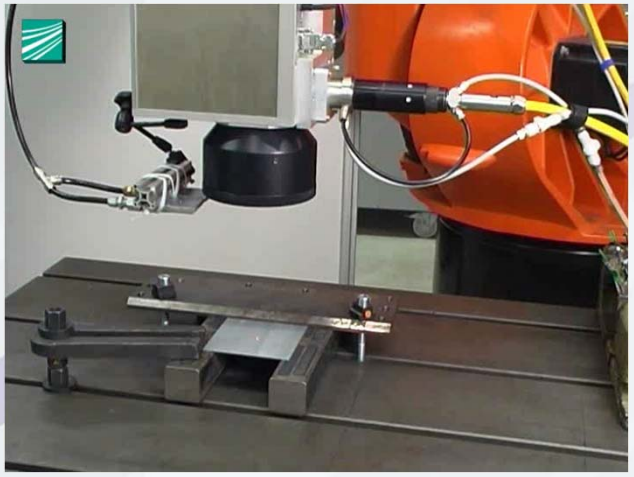
Remelting process



Cross section (t = 1,5 mm)



Process video: exemplary laser track designs



BM…base metal
HAZ…heat affected zone
MZ…molten zone

Process flow

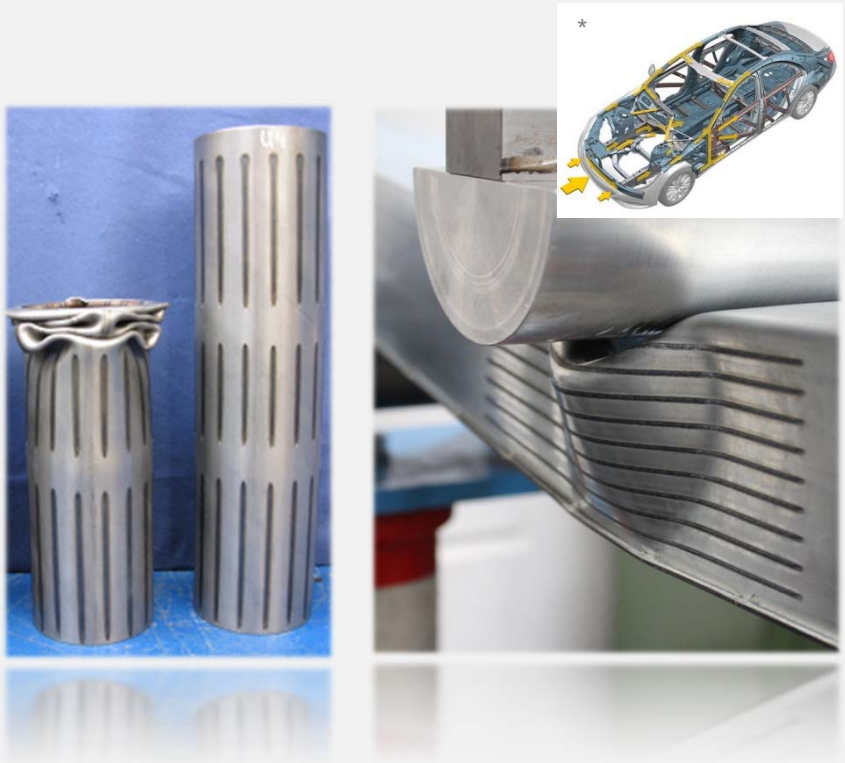
1) Short-time local laser-heating/ -melting
2) Rapid cooling (self-quenching)
3) (Martensitic) phase transformation → significant increase of hardness / strength!

Hardenable steel grades!

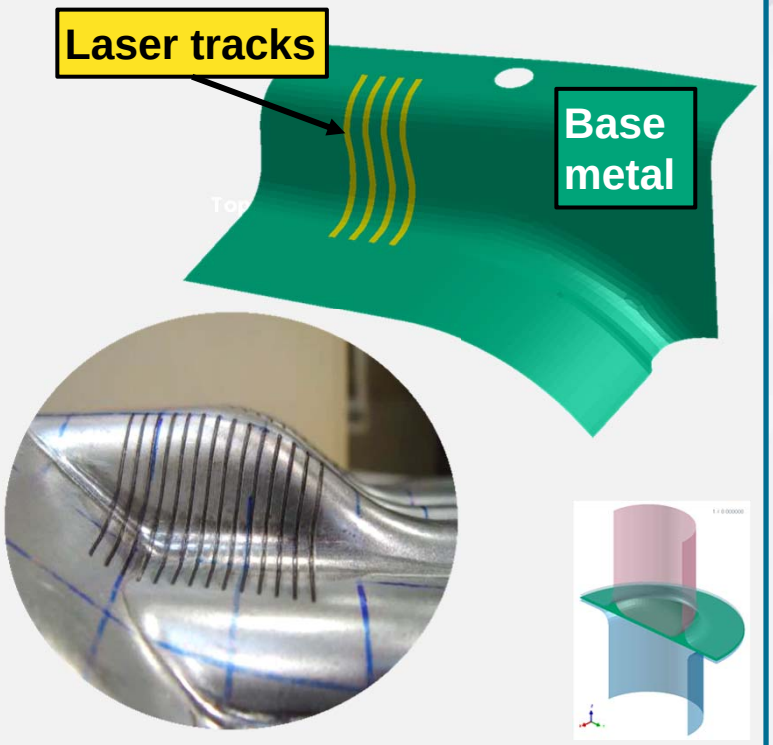
Laser-strengthening

Application purposes

Crash structures



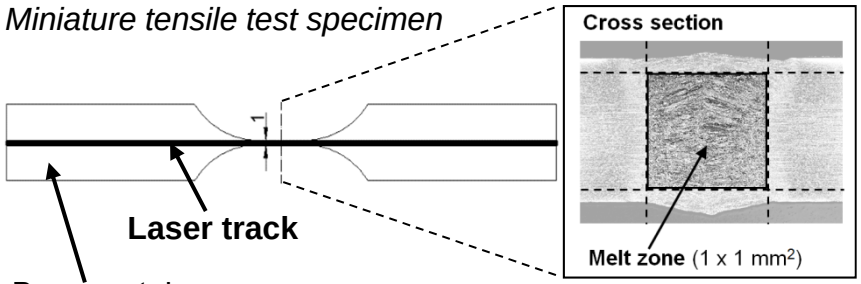
Deep drawing applications



* Mercedes Benz: Crash load paths

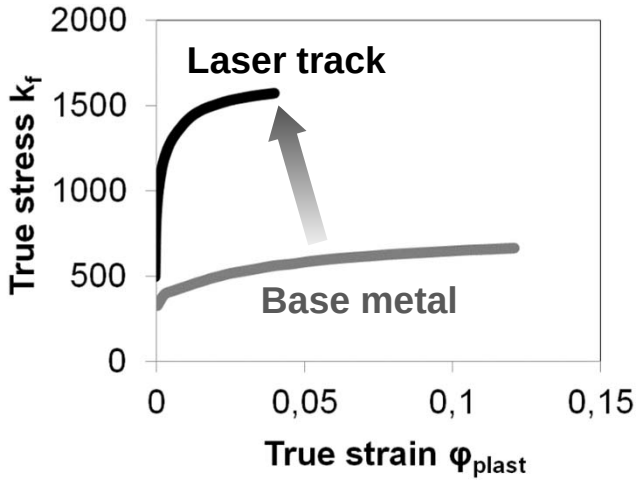
Laser-strengthening

Experimental determination of laser track flow curves



Very small dimensions of the laser-treatment zone!

Flow curve
(low alloyed car body steel)



Laser track

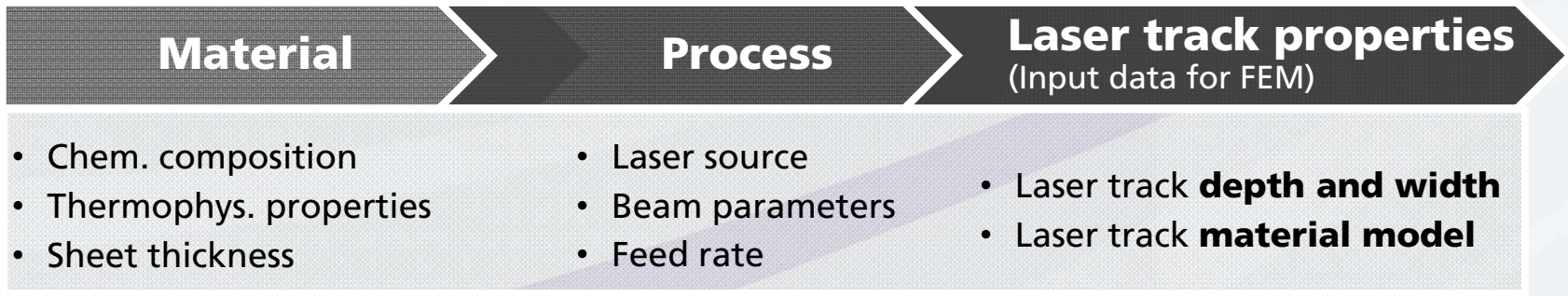
- Significant increase of flow stress (strengthening effect) for typical car body steel grades (LSS, HSS, AHSS), but loss of ductility!
- Experimental examination of local flow curves for crash simulations is very cost- and time-consuming!

Virtual material data

Objective

Calculation of relevant laser track properties for crash simulations

Approach

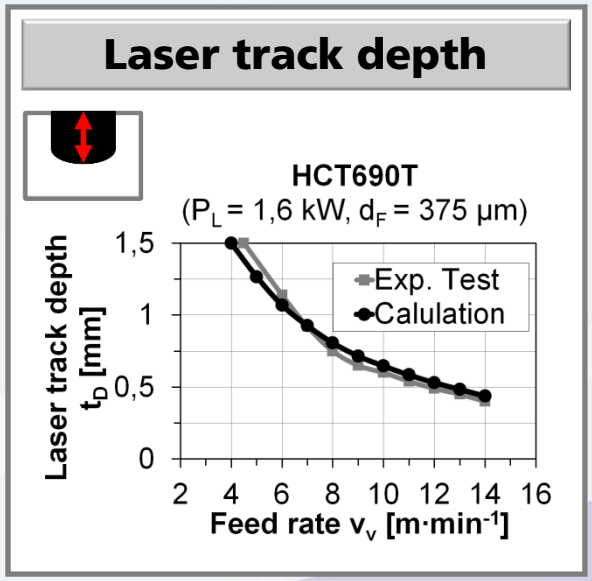


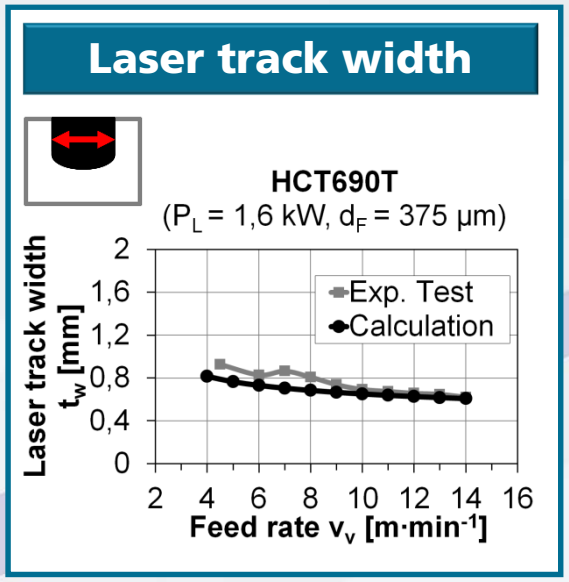
Application area

- Optimized selection of material
- Development of load-adapted car body structures
- Component optimization

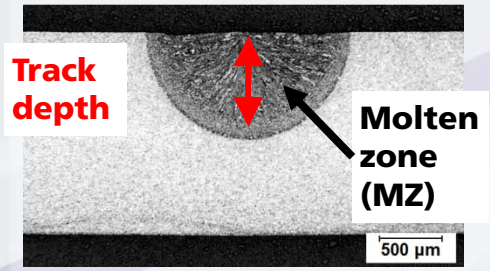
Virtual material data

Virtual process development

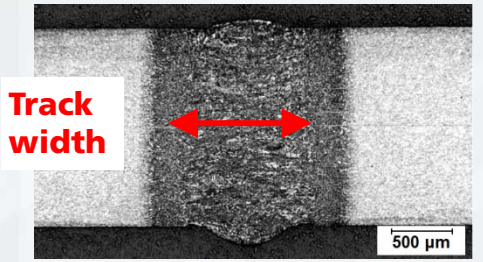




Partial penetration



Full penetration



Cross section

Calculation model

- 2D heat conduction model for deep welding* + model for coupling efficiency**
- Complex analytical correlations between technological laser process variables and the resulting contour of the melt pool can be established!

* Beyer, E.: Schweißen mit Laser: Grundlagen, Springer, 1995, ISBN 3-540-52674-9

** Gouffé, A.: Correction d'ouverture des corps-noirs artificiels compte tenu des diffusions multiples internes. Revue d'Optique 24, 1945.

Virtual material data

Virtual flow curve description

Assumptions

- Nadai/Reihle description of the flow curve : $k_f = R_m \cdot \left(\frac{e}{n}\right)^n \varphi^n$
- Multiple linear regression: Correlation between relevant alloy elements and resulting hardness of molten zone (laser-strengthening process!)

Developed description of the flow curve (molten zone)

$$k_f = 2{,}9 \cdot \underbrace{\left(224 + 696 \cdot C + 255 \cdot Si - 82 \cdot Cr + 52 \cdot Mn + 6 \cdot Mo\right)}_{R_m} \cdot \left(\frac{e}{0{,}085}\right)^{0{,}085} \cdot \varphi^{0{,}085}$$

Alloy content in mass-%

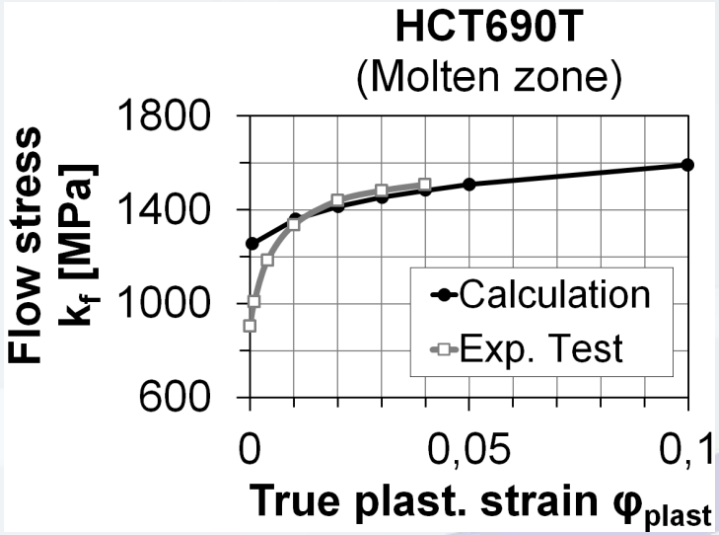
Limitations (Alloy content)

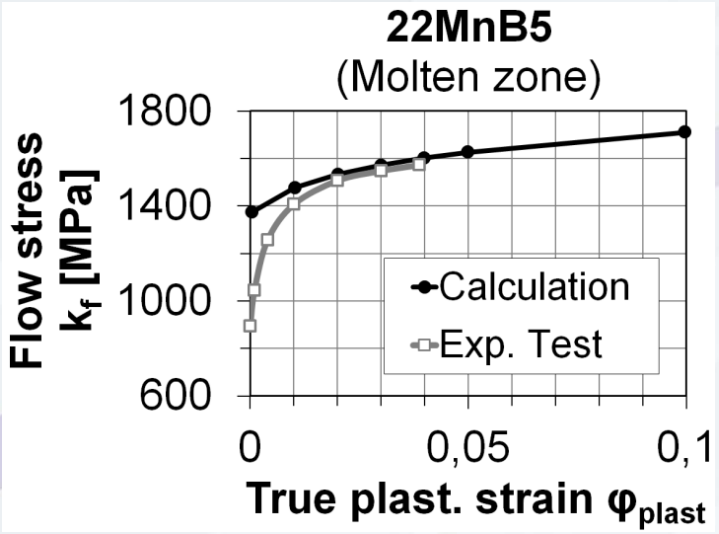
Alloy element	C	Si	Cr	Mn	Mo
Min. alloy content [mass-%]	0,031	0,006	0,010	0,078	0,004
Max. alloy content [mass-%]	0,252	0,271	0,540	1,880	0,234

φ	True strain
e	Euler number
k_f	Flow stress
n	Strain hardening coeff.
R_m	Tensile strength

Virtual material data

Virtual flow curve description





Results

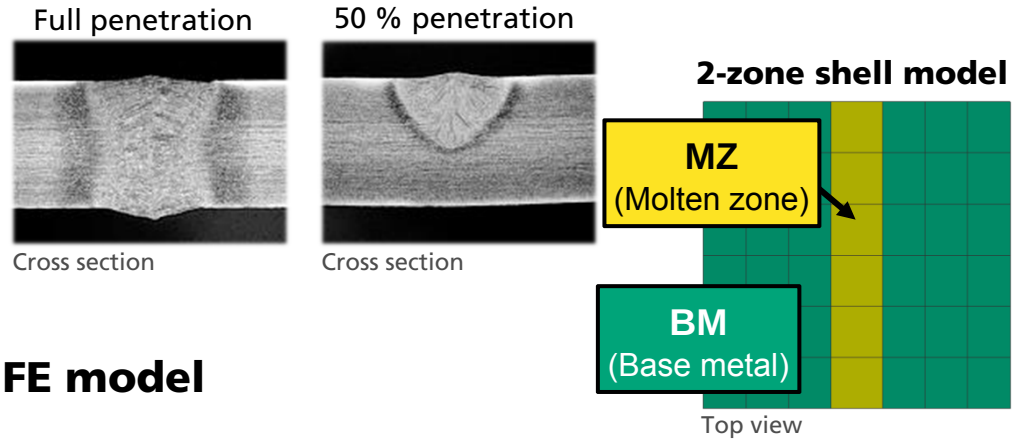
- **Virtual determination of all** necessary geometrical and **mechanical properties** of the laser track for crash simulations!

⇨ **Time- and cost-efficient car body design!**

Virtual component design

Application-oriented FE modeling approach

Macroscopic model

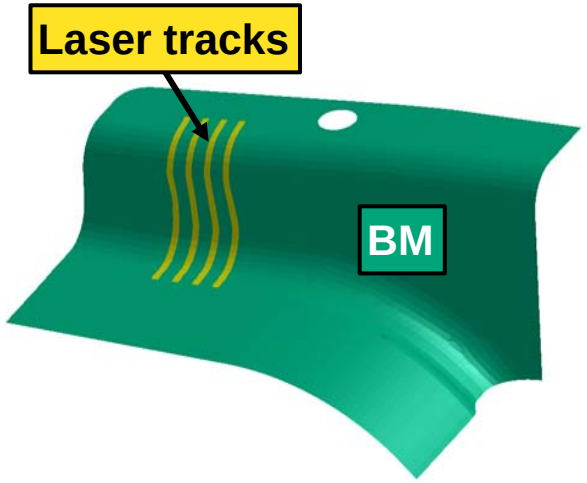


FE model

- Material models for MZ and BM (flow curve and damage behavior)
- The (small) heat affected zone can be considered by adapting the width of the MZ
- Partial melt penetrations: Multi-Layer shells

FE model (Formed car body structure)

Load-adapted laser track design?

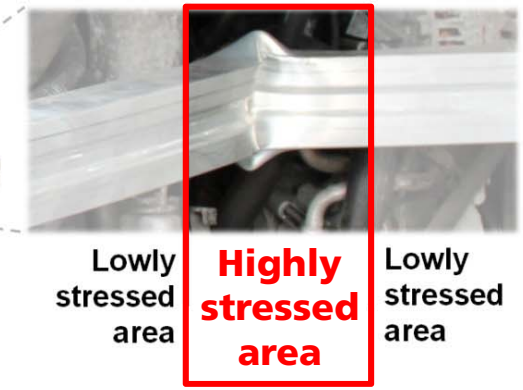


Virtual component design

Stress situation of crash structures

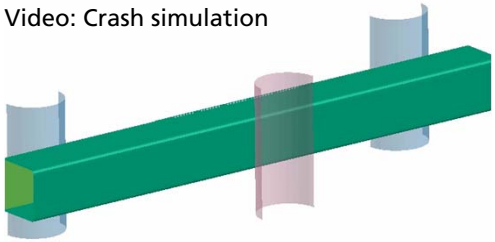
Crash test (Pole test): TU Bergakademie Freiberg

Inhomogeneous stress distribution!



Lightweight cross beam

Video: Crash simulation



Approach

Increasing the resistance against plastic deformations at highly stressed part areas!

Design-objective

- Crash deformation ↓
- Crash energy absorption ↑

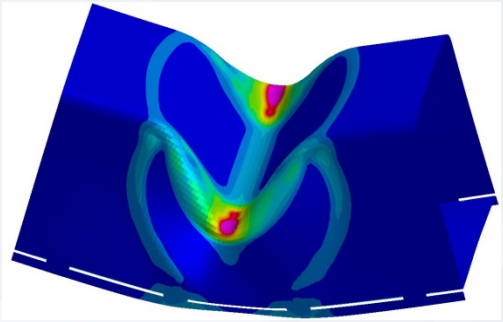
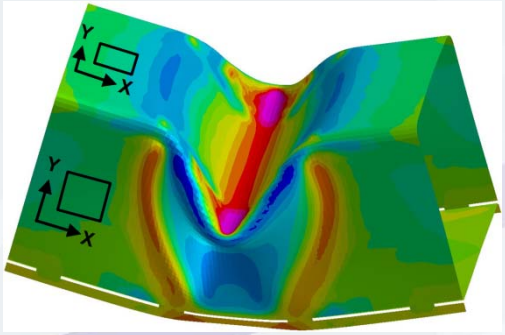
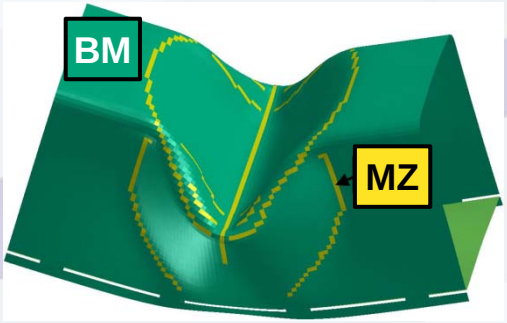
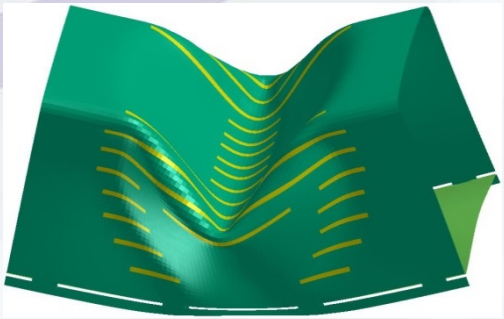
Car body structures

- Crash performance and lightweight ↑
- Flexibility in car body manufacturing ↑ (e.g. Derivatives, Redesigns, …)

Virtual component design

Load-adapted laser track design

3-point bending crash

	Max. plastic strain	Normal stress in X-direction (Element coordinate system)
Analysis model (untreated)		
Modified model (Laser-strengthened)		

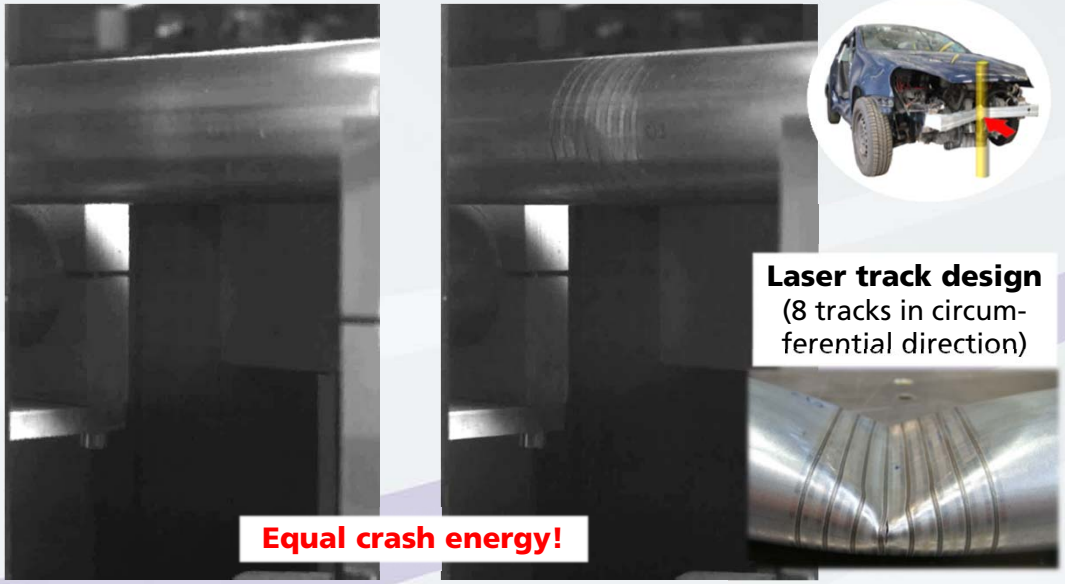
Effectivity of the laser track design!

1) Laser tracks at areas with high plastic strains
2) Laser tracks along high tension stresses (directional properties!)

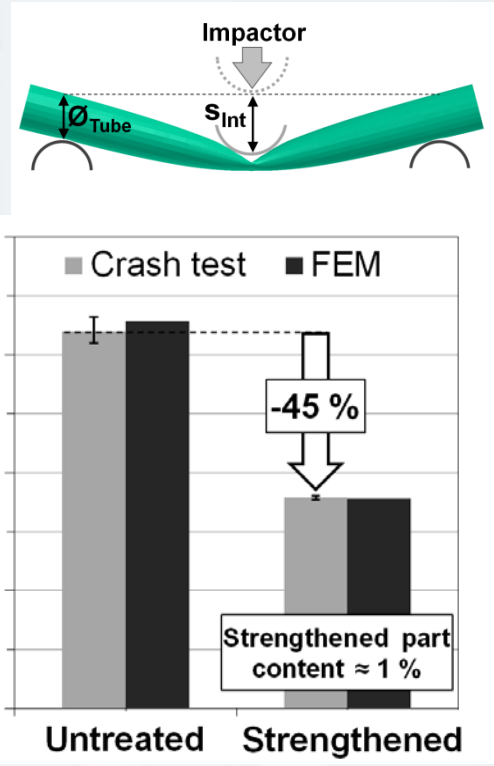
Automotive applications

Laser-strengthened crash structures

Untreated **Laser-strengthened**



Laser track design
(8 tracks in circum-ferential direction)



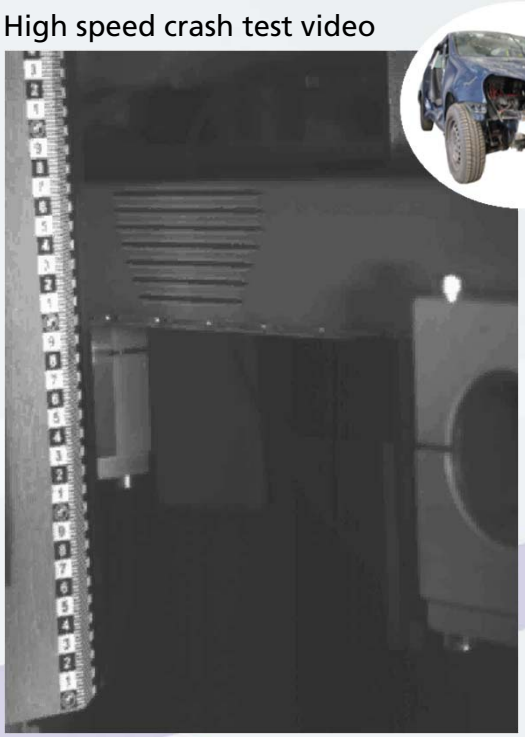
Crash profile	Ø = 64 mm; L = 1360 mm
Steel grade	HCT690T; t = 0,9 mm
Impactor	m = 60 kg; v = 3,4 m·s^{-1}

- Tubular structures (bending crash load)
  - Laser-strengthened part content: **1 %**
  - ⇨ **Reduced part intrusion: 45 %!**

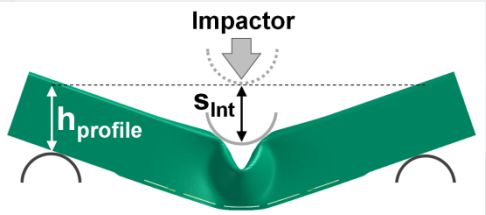
Automotive applications

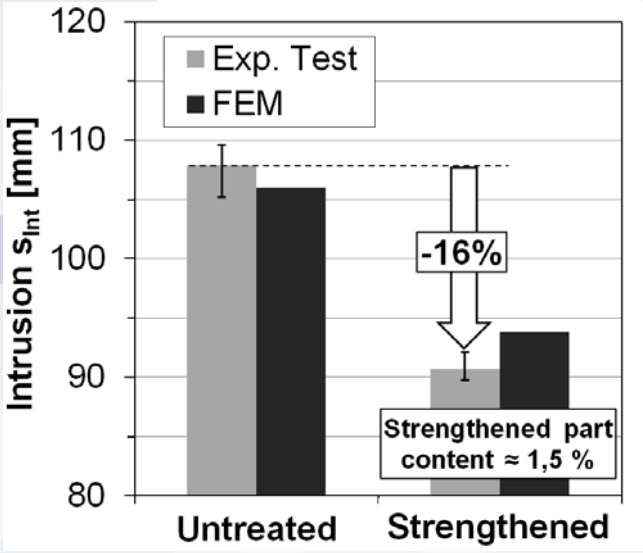
Laser-strengthened crash structures

High speed crash test video



Laser track design
(2 x 7 longitudinal tracks)





Crash profile	900 x 80 x 80 (LxBxH in mm)
Steel	HCT690T; t = 1,5 mm
Impactor	m = 57 kg; v = 6,7 m·s^{-1}

☐ Rectangular structures (bending crash load)

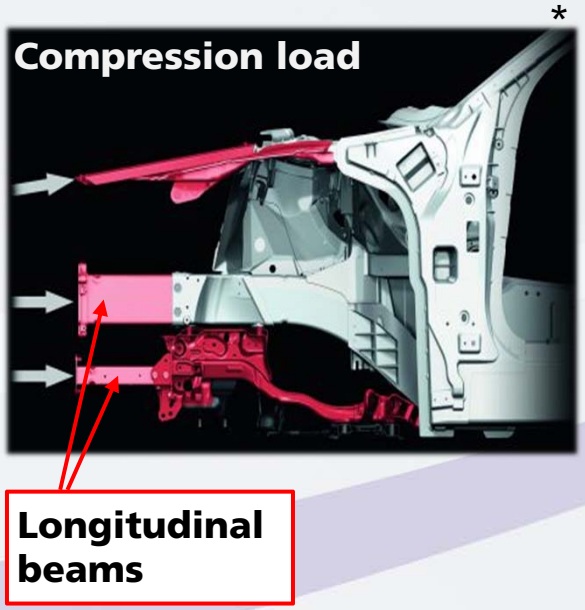
- Laser-strengthened part content: **1,5 %**

⇨ **Reduced part intrusion: 16 %!**

Automotive applications

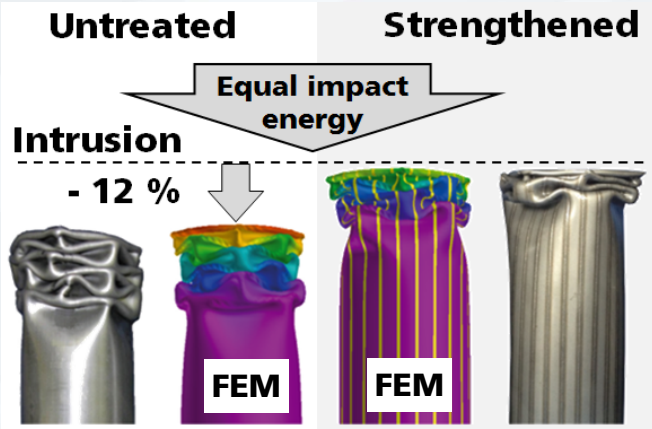
Laser-strengthened crash structures

Frontal crash



Longitudinal beams

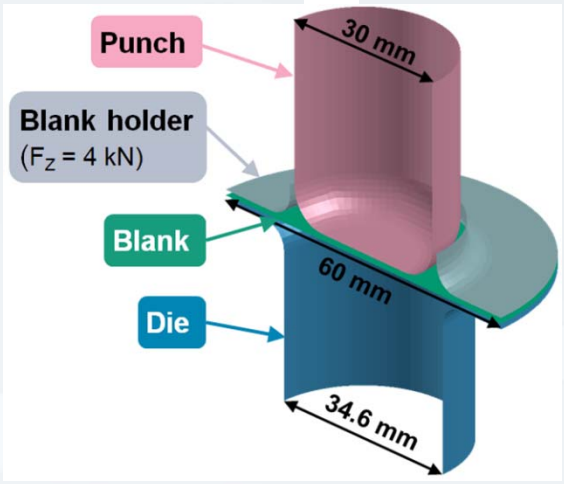
- Individualized deformation behavior
- Avoiding / Forcing of plastic deformation zones
- Reduced crash intrusion: 12 %



* Crash safety Audi AG

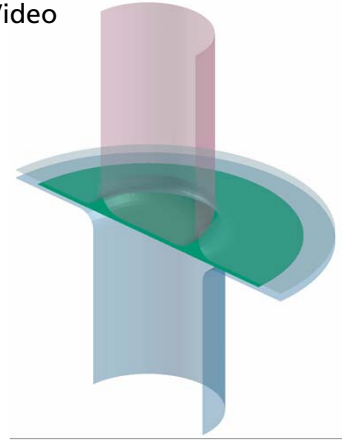
Further automotive applications

Customizing the forming behavior deep-drawn parts



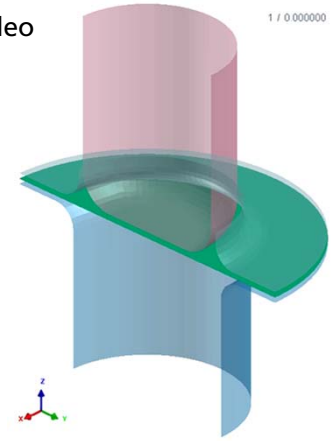
Cup bottom fracture

Video



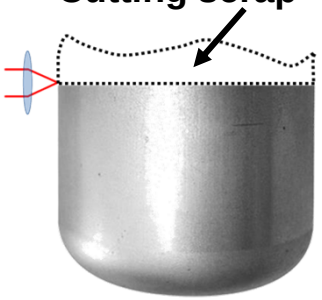
Earing

Video



Earing

Cutting scrap



Approaches

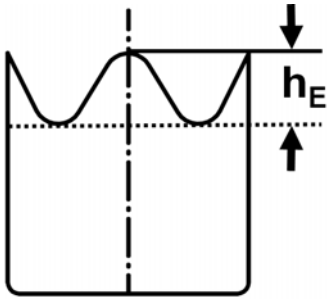
- Introducing load-adapted local laser-strengthened zones in planar condition

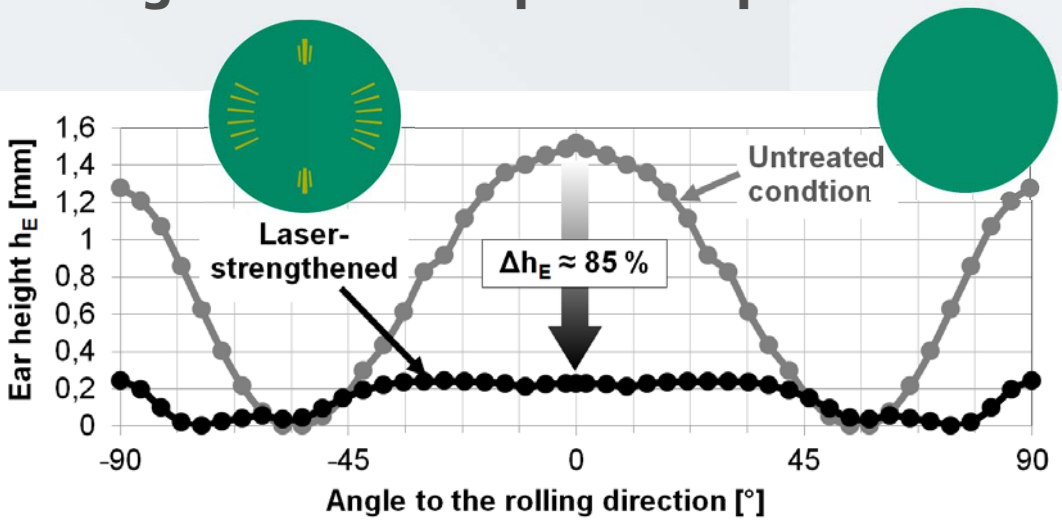
1) **Reduction of earing** during deep drawing
2) **Increase of** the **forming capacity** (e.g. max. drawing depth)

Further automotive applications

Customizing the forming behavior deep-drawn parts

Earing





Earing

- **Reduction of** the maximum **ear height** by about **85 %**
- Laser-strengthened content: ≈ 3.7 %

Forming capacity

- **Increase of** the maximum **drawing depth** by approximately **22 %** is possible!

Further automotive applications

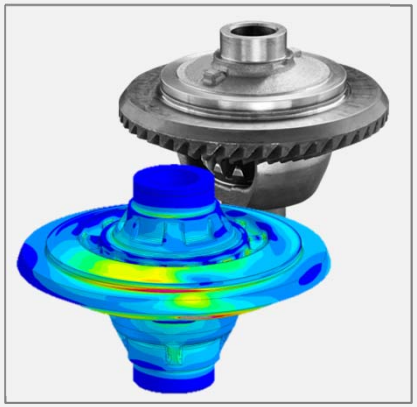
Laser-welded components

The results can be translated from laser-strengthening to laser-welding!

Patchwork structures

Tailored components

Tailor welded blanks / tubes*



Tailored powertrain parts

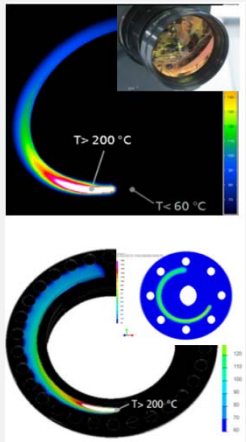
- Virtual manufacturing and product engineering of laser-welded structures is possible!
- Load-adapted positioning and designing of laser weld seams
- Avoidance of failure critical weld seam designs

* Jahn, A.: Umformbarkeit laserinduktionsgeschweißter Strukturen aus höherfesten Stahlfeinblechen. Dissertation, Fraunhofer Verlag, 2011.

Further automotive applications

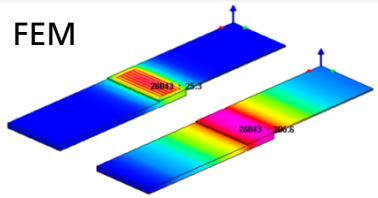
Component design of laser-treated / additively manufactured structures

Laser-hardening / -structuring



Additive manufacturing

Additively manufactured aircraft engine structure



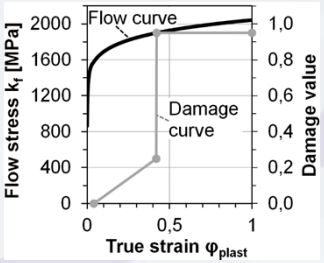
Micro-generated clamping structures for multi-material joints

- Virtual manufacturing and product engineering
- Load-adapted material selection and component design

Conclusions

Virtual process and material data for laser-treatment processes

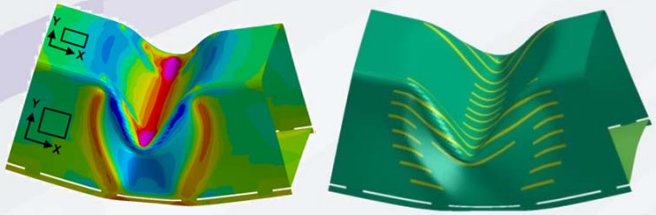
- Correlations between laser process variables and the resulting geometry of laser-treated zones
- Calculation of all necessary local mechanical properties for performing crash simulations



Virtual component design

- Analyzing local plastic strain and stress distributions

⇨ Load-adapted designs of car body components



Automotive applications

- Significant increase of the crash performance
- Improved forming properties
- Improved flexibility in car body manufacturing

⇨ Time- and cost-efficient car body design!

Thank you for your kind attention!

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