UNIVERSITÄT DUISBURG ESSEN
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Faculty of Engineering
Department of Civil Engineering
Institute of Mechanics
Prof. Dr.-Ing. habil. J. Schröder

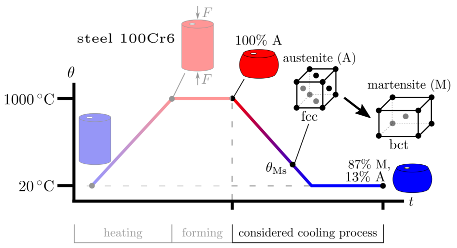
A multiscale approach to investigate residual stresses due to targeted cooling of hot bulk formed parts

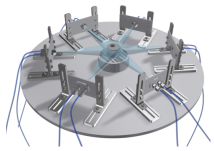
Motivation

Hot bulk forming enables the utilization of mechanical, thermal and metallurgical interaction to induce compressive residual stresses in regions near the outer surface of a component.
Multi-scale Finite Element simulations give an insight into microscopic processes and related macroscopic material behavior at the same time. Thus, it provides an appropriate approach for efficient stress analysis on different scales at low costs.

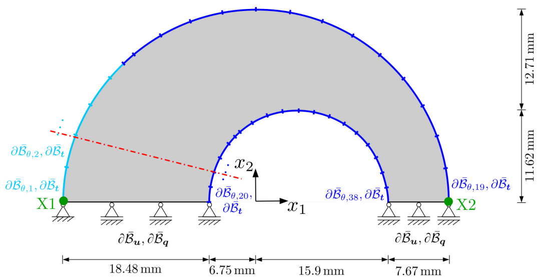
Experimental setup IFUM

Experimental investigations of the hot bulk forming of a cylindrical specimen are carried out, in which targeted cooling routes are applied. A spray cooling device offers temporal and spatial control of the cooling process, cf. [1]. Microstructural investigations give information regarding the final phase fractions.

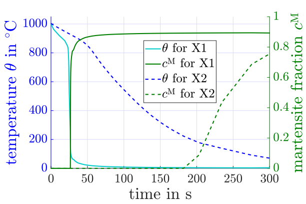




Boundary value problem



A reduction of the boundary value problem is inevitable for efficient numerical two-scale analysis. During single-scale computation, the u_2-displacement is stored along the red dashed line to provide an additional boundary condition.



Macroscopic balance laws, see [3]:

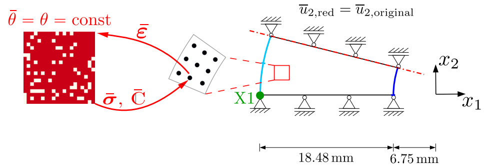
Balane of linear momentum	$\operatorname{div}\bar{\boldsymbol{\sigma}} = \mathbf{0}$
Balance of energy	$\bar{c}_\rho\,\dot{\bar{\theta}} + \bar{\theta}\,\bar{r} + \operatorname{div}\bar{\boldsymbol{q}} = 0$

Microscopic material model includes elastic, plastic, thermal, transformation volumetric and TRIP strains, see [2]:

$$\boldsymbol{\varepsilon} = \boldsymbol{\varepsilon}^{\mathrm{e}} + \boldsymbol{\varepsilon}^{\theta} + \boldsymbol{\varepsilon}^{\mathrm{p}} + \boldsymbol{\varepsilon}^{\mathrm{trip}} + \boldsymbol{\varepsilon}^{\mathrm{tv}}\,.$$

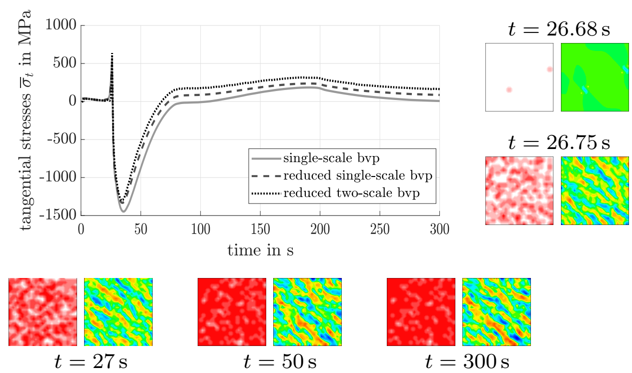
FE^2-Simulation

For microstructural stress analysis in terms of an FE^2 method, a structured RVE is defined, which describes austenite-to-martensite phase transformation as arbitrary elementwise switch.



Residual stress analysis

In measuring point X1, the tangential stresses are analyzed over cooling time of 300 seconds. First, thermal contraction leads to tensile stresses. With the onset of phase transformation, a superposition with compressive stresses due to volumetric expansion of the atomic lattice is observed. The final state shows compressive stresses, as aimed for. On microscale, stress peaks can be found, which are to be analyzed regarding microscopic failure, see [4].



Open questions

- more realistic microstructure
- profound microstructural stress interpretation
- influence of third dimension

Acknowledgment

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References

[1] B.-A. Behrens et al., FIIN, **85**, p. 757-771, 2021.
[2] R. Mahnken et al., IJP, **25**, p.183-204, 2009.
[3] S. Uebing et al., AOAM, **91**, p.3603-3625, 2021.
[4] S. Hellebrand et al., SEMC, 2022.

S. Hellebrand[1], L. Scheunemann[2]
D. Brands[1], J. Schröder[1]
[1]University of Duisburg-Essen, Institute of Mechanics
[2]TU Kaiserslautern, Chair of Applied Mechanics

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