OTTO VON GUERICKE UNIVERSITÄT MAGDEBURG

# Modeling the inelastic material behavior of advanced chromium steels

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Aim of this doctoral thesis is to describe material behavior of advanced chromium steels to predict deformation behavior, stress concentrations and damage accumulation in components. This complex and challenging task has to be overcome for the reason that components made of these steels are typically used in power plants and therefore they face complex mechanical loading and high temperatures. Moreover the failure of such highly-loaded components can have disastrous consequences. To describe deformation-, stress-field and damage evolution properly in this thesis a unified material model is used. To this end a continuum that consists of two phases is introduced. The idea for such a model is motivated by macroscopic behavior as a reason of micro structural changes. Deformation of the continuum is described by a constitutive equation and micro structural changes are taken into account by evolution equations, which enter the constitutive law as internal state variables.

## Problem Definition

Turbine components of power plants are subjected to high mechanical loading, due to large temperature gradients during start-up and shut-down processes of turbines. At typical operation mode components withstand moderate mechanical loads and high temperatures, up to 650 ◦C for these steels. So on one hand at start-ups and shut-downs the material behavior is treated to be plastic, whereas on the other hand operation mode is a characteristic creep load. So the material model has to valid for a broad stress and temperature range, as well as for high and low deformation rates.

## Objectives

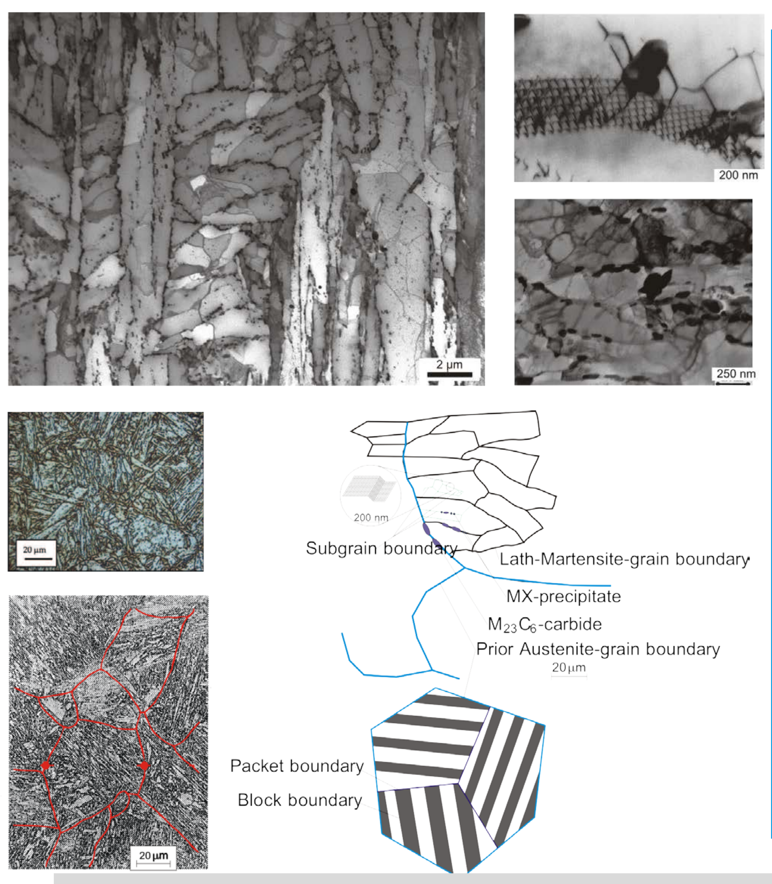
As it is a major aim of the graduate school to connect micro and macro scale the objectives of this work are:

- connect mechanism on the micro scale with the macroscopic material behavior
- the identification procedure of material model parameters should be assured from a statistical point of view
- the developed material model should pass various verification tests
- implement the material model in a finite element code to simulate components

## Cooperation

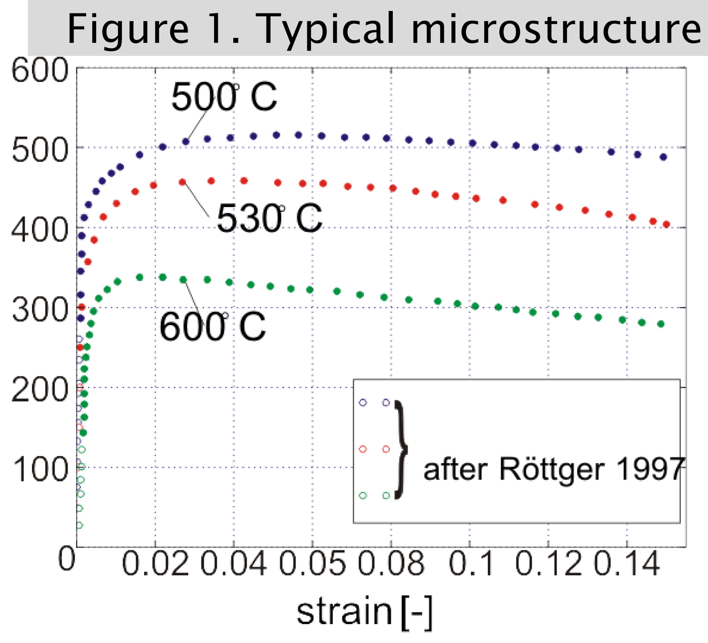
The general topic of deformation mechanism in materials and their proper description by material models were intensively discussed with: O. Ozhoga-Maslovskaja, M. Ievdokymov, I. Lvov, O. Prygorniev, A.Girchenko, M. Weber, S. Borsch and Dr.-Ing. R. Glüge, Prof. A. Bertram. The exchange of experience in discussions with other members of the GRK-school working in different fields of research, mathematics, thermodynamics etc, was also very beneficial and inspiring especially on workshops. Presentation skills were achieved during participation in conferences with financial support of the GRK-school.

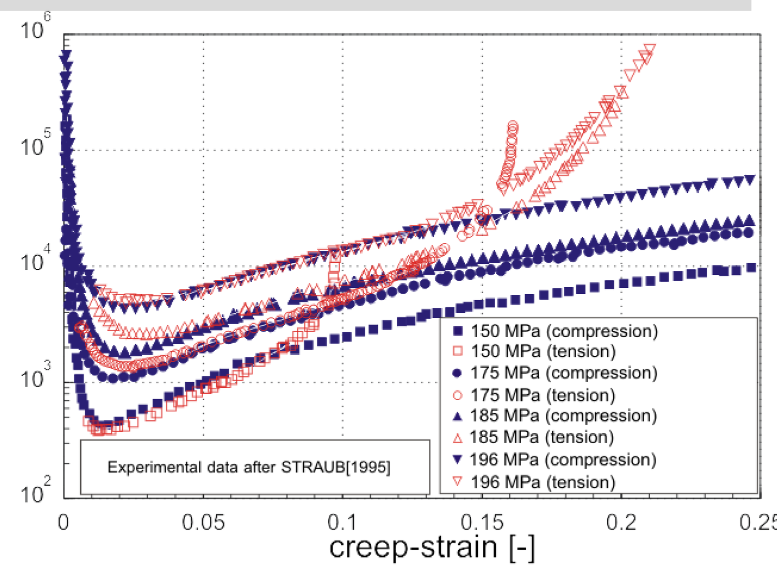
## Advanced Chromium Steels

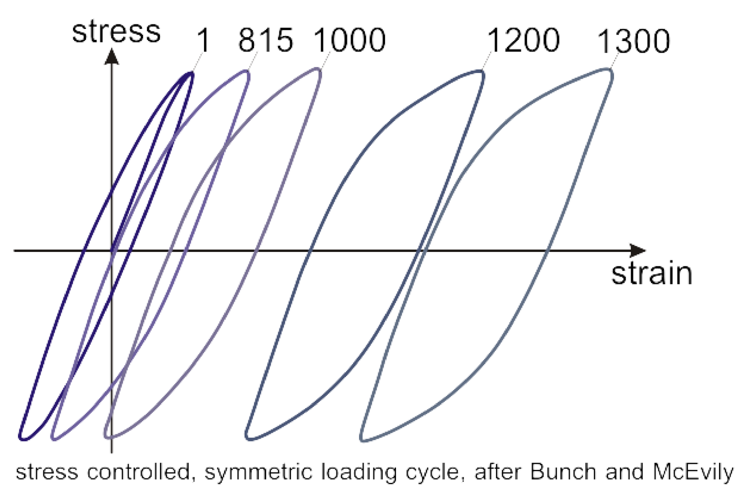



Advanced chromium steels posses a complex microstructure. Prior austenite grain boundaries are the first location for precipitates to grow, followed by lath martensite boundaries and finally precipitates start also growing at subgrain boundaries.
Precipitates and dislocation networks, i.e. subgrain boundaries, are obstacles for the motion of free dislocations. Some precipitates and distribution of subgrain networks are thermo-dynamical non stable, so the microstructure evolves with time, depending on load and temperature.

Figure 1. Typical microstructure of advanced chromium steels




As a result of the complex micro-structure the macroscopic material behavior is complex as well. For a constant strain rate loading a strong temperature dependence is observed. For a constant stress load only primary and tertiary creep is reported with an interesting tertiary creep behavior. For a cyclic stress controlled tests these steels show an anomalous ratcheting.

Figure 2. Complex macroscopic behavior of advanced chromium steels

## Mixture Based Material Model

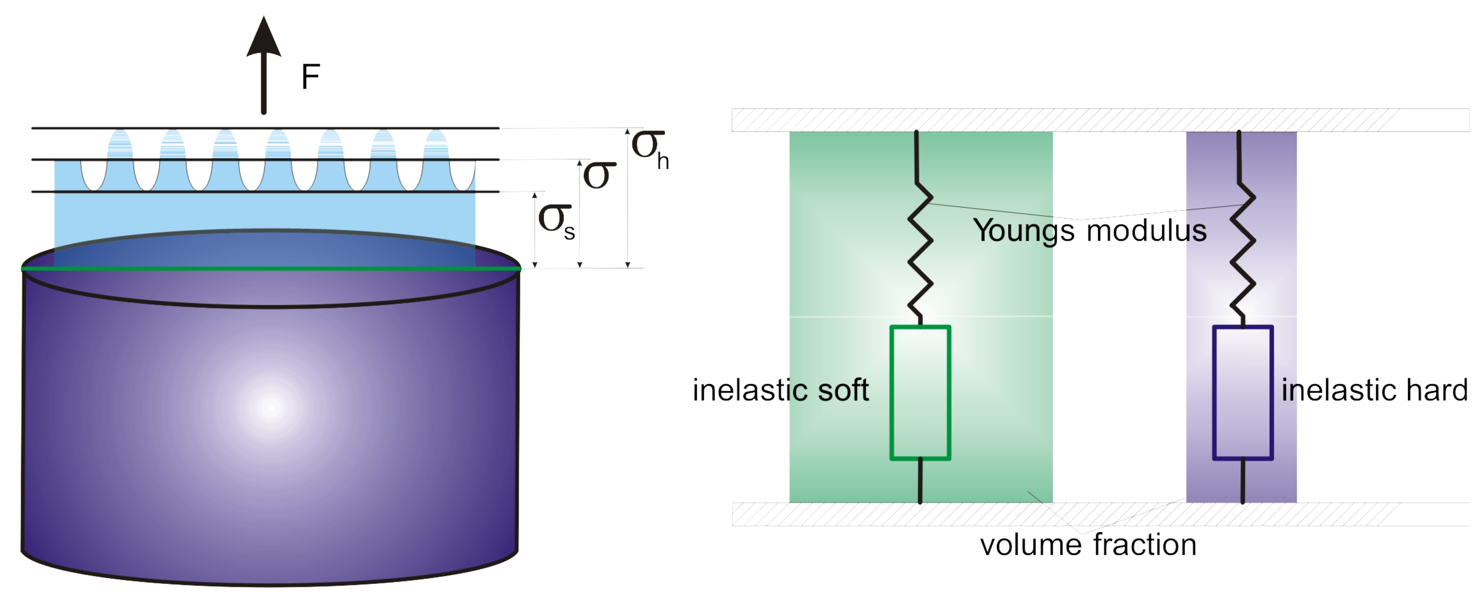



Figure 3. Basic idea of the mixture based material model

Motivated by microstructure, where inelastic soft regions can be easy crossed by dislocations and consequently inelastic hard regions are areas with obstacles for motion of dislocations. So with help of the mixture theory a continuum is introduced with inelastic hard and soft constituents, for the sake of simplicity they are connected by iso-strain condition. For the one dimensional case the mixture can be represented by a fraction model. The evolution with time of the original microstructure is in the artificial mixture represented by a decreasing volume fraction of the inelastic hard phase.

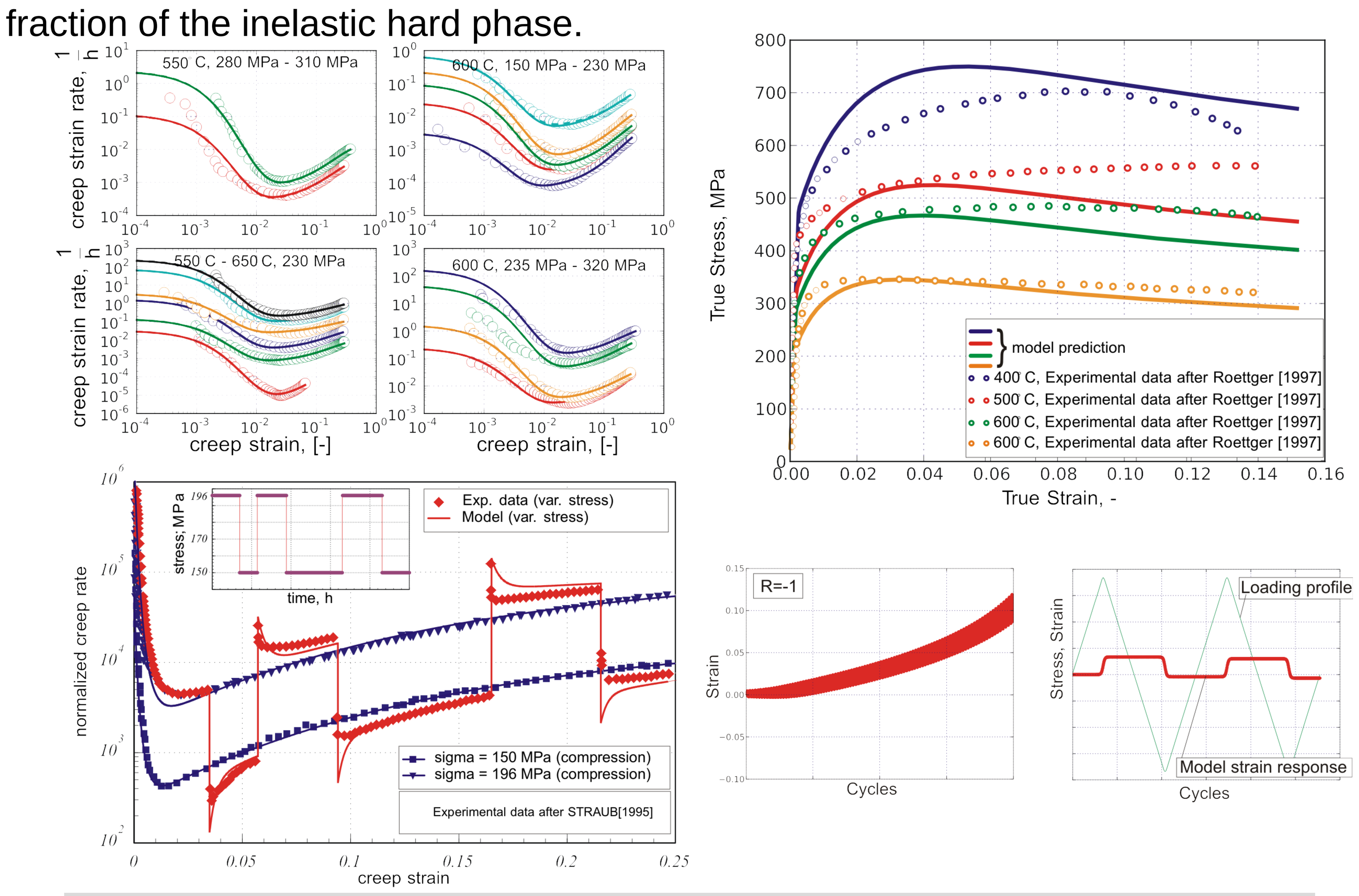



Figure 4. Results - model prediction and verification

## Summary and Outlook

With the proposed model, which is motivated by microstructure and evolution of microstructure, the complex macroscopic material model could be reflected. The idea to utilize a mixture of an inelastic hard and inelastic soft constituent seems suitable. Stress accumulation in the inelastic hard phase and the iso-strain condition lead to a Frederick-Armstrong like backstress law and the softening behavior is controlled by the volume fraction reduction of the inelastic hard phase. The results for creep load and for constant strain rate load are in good agreement to experimental results. The results for cyclic loading show qualitatively the correct tendency.
For the future response functions need to be modified, another constituent may be introduced to increase the accuracy of the material model.

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