INFLUENCE OF TEXTURE ON THE EFFECTIVE RESPONSE OF MULTIPHASE STEELS

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Summary The thermomechanical response of low-alloyed multiphase steels assisted by transformation-induced plasticity (TRIP steels) is analyzed taking into account the coupling between the thermal and mechanical fields. The internal generation of heat associated with the martensitic phase transformation and the plastic deformation are modeled explicitly in the balance of energy. The momentum and energy equations are solved using a coupled, fully-implicit numerical scheme. The simulations are conducted using a micromechanical formulation for single crystals of austenite and ferrite. The macroscopic response is obtained through numerical homogenization of polycrystalline samples that allow for the explicit incorporation of the spatial distribution of phases, crystalline orientations and grain size and shape. The influence of texture on the overall response of multiphase steels is analyzed through a parametric study using samples with distinct microstructural characteristics.

INTRODUCTION

The design of new multiphase steels with enhanced thermo-mechanical properties requires establishing a relevant connection between the macroscopic response behavior and the microscale characteristics of the material (see Fig.1). A typical microstructure of multiphase steels consists of grains of metastable retained austenite embedded in a ferrite-based matrix. Upon thermal and/or mechanical loading, the austenite may transform into martensite, generating the so-called transformation-induced plasticity effect (TRIP-effect). A link between the macro and micro scales may be established using advanced numerical models that accurately account for complex microstructural characteristics (texture).

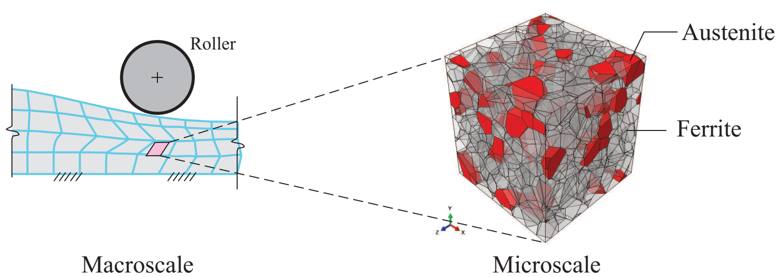

Figure 1. Schematic representation of length scales for a multiphase steel.

COUPLED THERMOMECHANICAL MODEL

The response of the austenitic grains is computed by means of an elastoplastic-transformation model that accounts for the martensitic transformation and plasticity on an FCC lattice whereas a crystal-plasticity model for BCC lattices is used to simulate the elasto-plastic deformations in the ferritic grains [1-3]. For the present simulations, these models have been refined to incorporate thermal effects on the internal energy and the kinetic relations for plasticity and transformation [4]. The kinematics of transformation and plasticity are described within a geometrically-nonlinear framework. The deformation of a single-crystal grain of austenite that may partially or totally transform into martensite, the total deformation gradient $\mathbf{F}$ is multiplicatively decomposed as

$$\mathbf{F} = \mathbf{F}_{\mathrm{e}}\mathbf{F}_{\mathrm{th}}\mathbf{F}_{\mathrm{p}}\mathbf{F}_{\mathrm{tr}}, \tag{1}$$

where $\mathbf{F}_{\mathrm{e}}$, $\mathbf{F}_{\mathrm{th}}$, $\mathbf{F}_{\mathrm{p}}$ and $\mathbf{F}_{\mathrm{tr}}$ are the elastic, thermal, plastic and transformation contributions to the total deformation gradient, respectively. Moreover, in order to develop a thermodynamically-consistent formulation, the total entropy density per unit mass η is additively decomposed as

$$\eta = \eta_{\mathrm{e}} + \eta_{\mathrm{m}} + \eta_{\mathrm{p}} + \eta_{\mathrm{tr}}, \tag{2}$$

where η_{e} is referred to as the purely thermal reversible entropy density (analogous to the elastic deformation gradient), η_{m} is the mechanical reversible entropy density that accounts for the coupling between the mechanical and thermal fields (analogous to the thermal deformation gradient) and η_{p} and η_{tr} are, respectively, the plastic and transformational entropy densities related to plastic and transformation processes. The thermomechanical coupling is particularly relevant since in TRIP steels the phase transformation that occurs during mechanical loading is accompanied by the release of a

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considerable amount of energy (latent heat) that, in turn, affects the mechanical response of the material. The internal generation of heat associated with the martensitic phase transformation and the plastic deformation are modeled explicitly in the balance of energy. The momentum and energy equations are solved simultaneously by using a fully-implicit numerical scheme.

MULTISCALE SIMULATIONS

The overall response of the material at macroscale is assessed by homogenizing the results obtained from microstructural simulations. These simulations are performed on a set of polycrystalline samples of increasing size (Fig.2) used to identify a representative volume element (RVE) for the numerical homogenization procedure (Fig.3). In order to have a proper scale transition, periodic boundary conditions are prescribed at the boundaries of the microstructure and the average microscopic temperature is compared to the macroscopic temperature for consistency. The influence of texture on the

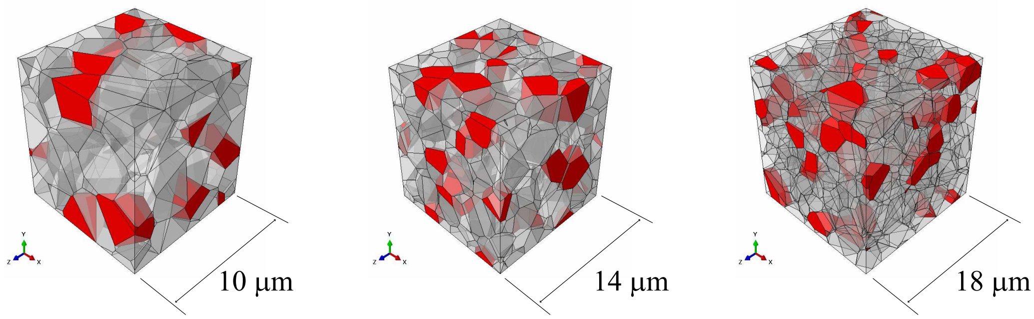

Figure 2. Typical volume elements used in RVE convergence analysis.

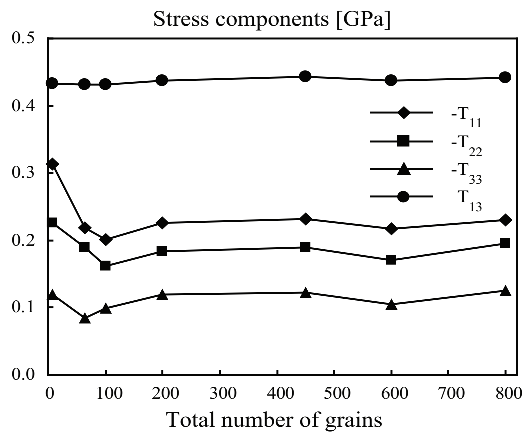

Figure 3. Convergence analysis: Stress components under macroscopic simple shear as a function of number of grains in volume elements.

overall response of multiphase steels is analyzed through a parametric study using samples with distinct microstructural characteristics. The samples, generated with a multi-level Voronoi-type algorithm, allow for the explicit incorporation of the spatial distribution of phases, crystalline orientations and grain size and shape.

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