Structure-property modeling of low-alloyed TRIP steels

Structure-property modeling of low-alloyed TRIP steels

S.P. Chen, V. Kouznetsova, M.G.D. Geers
Netherlands Institute for Metals Research
Eindhoven University of Technology
Faculty of Mechanical Engineering

Introduction

TRansformation Induced Plasticity (TRIP) is a phenomenon which occurs during solid phase transformation triggered by an applied mechanical load, and which causes irreversible strains at stress levels that are below the current yield stress of the softer phase. Low alloyed multi-component TRIP steels present a unique combination of high ductility and strength, which comes from both TRIP and the synergy between the properties of multicomponents. The aim is to develop a physically-based, multi-scale model to predict the structure-property relations in the TRIP steels (Fig.1).

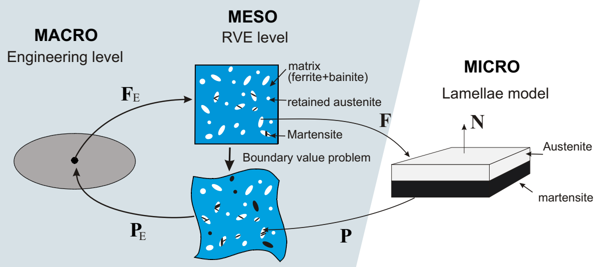

Figure 1. *A general scheme of the multi-scale model for multi-component low alloyed TRIP steel.*

Methods

- Develop a model for martensitic transformation in TRIP steel in a thermodynamically based continuum mechanics framework at large strains.
- Incorporate the model in a hierarchical micro-macro computational homogenization strategy [1].

Miromechanical model

The transforming microstructure is considered as a rank-one laminate composed of a martensite plate and an austenite layer. The total deformation gradient tensor $\mathbf{F}$ at a transforming region is assumed to be known. The evolution of martensitic volume fraction and the constitutive behavior of the transforming region can be obtained by solving the following equation system:

$$\mathbf{F_{tr}} = \mathbf{I} + \vec{M} \otimes \vec{N} \tag{1}$$

$$\mathbf{F_A} \cdot (\mathbf{I} - \vec{N} \otimes \vec{N}) = \mathbf{F_M} \cdot (\mathbf{I} - \vec{N} \otimes \vec{N}) \tag{2}$$

$$(\mathbf{P_A} - \mathbf{P_M}) \cdot \vec{N} = 0 \tag{3}$$

$$\mathbf{F} = (1-\xi)\mathbf{F_A} + \xi\mathbf{F_M} \qquad \mathbf{P} = (1-\xi)\mathbf{P_A} + \xi\mathbf{P_M} \tag{4}$$

$$\boldsymbol{\tau}_i = f(\mathbf{C}_i, \ln \mathbf{B^e}_i, \triangle\gamma_i) \tag{5}$$

$$G = \rho_0[\Phi] - \langle\mathbf{P}\rangle^{\mathbf{T}} : [\mathbf{F}] \geq G_c \tag{6}$$

where $\mathbf{F_{tr}}$ is the transformation deformation tensor, $\vec{N}$ and $\vec{M}$ the habit plane normal and shape deformation vector, ξ the martensitic volume fraction, $i = A, M$ austenite or martensite, $\mathbf{F}_i$ the deformation gradient tensor, $\mathbf{P}_i$ the first Piola-Kirchhoff stress tensor, $\mathbf{B^e}_i$ the elastic left Cauchy-Green deformation tensor, $\boldsymbol{\tau}_i$ the Kirchhoff stress tensor, $\mathbf{C}_i$ a fourth-order tensor of material constant, $\triangle\gamma_i$ the increment of the plastic flow, G the thermodynamic driving force, $\langle\mathbf{P}\rangle = (\mathbf{P_A} + \mathbf{P_M})/2$, $[\mathbf{F}] = \mathbf{F_A} - \mathbf{F_M}$, $[\Phi]$ the jump of Helmholtz free energy at the interface, G_c a critical barrier.

Results

The model is applied to a single crystal austenite colony to characterize the TRIP effect. Evolution of the martensitic volume fraction under different shear deformation modes is shown in fig. 2.

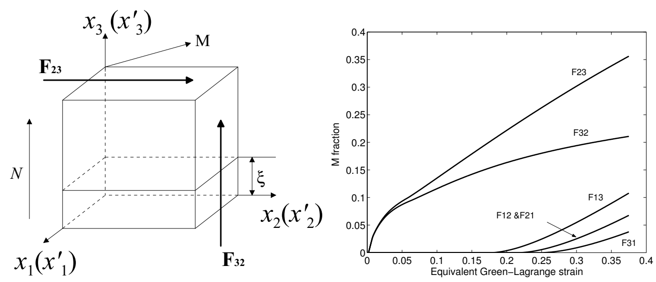

Figure 2. *Evolution of the martensitic volume fraction under different prescribed shear deformation modes.*

The equivalent stress vs the equivalent strain of the laminate subjected to a simple shear F_{23} or F_{32} is shown in fig. 3, in which τ_A is the stress in the austenite layer and τ_M the stress in the martensite layer of the laminate, τ_{meso} the total stress of the transforming colony, τ_{A0} the flow stress in single austenite without martensitic transformation. The model captures the basic features of the TRIP behavior.

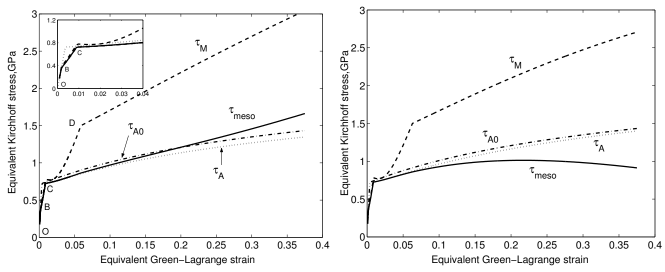

Figure 3. *The equivalent stress vs. the equivalent strain of the laminate subjected to a simple shear F_{23} (left) or F_{32} (right).*

Future work

Multi-variant martenstic transformation in a meso level will be considered. The model will be incorporated in a hierarchical micro-macro computational homogenization strategy.

References:

[1] V. Kouznetsova. PhD thesis, Eindhoven University of Technology, The Netherlands, 2002.

PO Box 513, 5600 MB Eindhoven, the Netherlands