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Computational prediction of deformation behavior of TRIP steels under cyclic loading

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Abstract

A constitutive equation accounting for strain rate, temperature and applied stress system dependencies of strain-induced martensitic transformation is given. A series of computational prediction of monotonic and cyclic deformation behavior including tension, compression and shearing of typical 304 austenitic stainless steel, have been performed under different environmental temperatures from 77 to 353 K. The effect of stress range, pre-strain, temperature and applied stress system on such responses of TRIP steels as the evolution of martensitic phase, the accumulated plastic strain, and the asymptotic nature of the stress–strain relation with an increase in the number of cycles is clarified. The predictability of the present constitutive model is checked against the experimental results. Furthermore, simulation of the cyclic deformation behavior of TRIP steel bars with ringed notch is performed. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: TRIP steels; Consititutive equation; Monotonic deformation; Cyclic deformation; Computational simulation; Ringed notch specimen; Effect of pre-strain

1. Introduction

Martensitic transformation of transformation-induced plasticity (TRIP) steel is observed during large deformation in the low-temperature range. A TRIP steel possesses advantageous mechanical properties including high strength, ductility and toughness due to the effect of strain-induced martensitic transformation which strongly depends on temperature, stress, strain and strain rate.

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Therefore, computational simulations using an appropriate constitutive equation are indispensable for predicting the deformation process as well as the final strength of the products. To date, the constitutive equation accounting for the temperature and strain effect on the martensitic transformation [1] and its generalization to account for the effect of stress state [2], strain rate [3] and stress state for stacking fault energy [4] have been proposed and computational simulations have been conducted to exemplify the transformation behavior and the mechanisms in order to improve the mechanical properties through the forming processes. However, the problems associated with the predictability of the constitutive equation for the cyclic deformation process are still unclear.

In order to clarify the validity of the constitutive equations, a series of computational simulation are carried out for cyclic loading under such different stress systems as tension, compression and shearing. Subsequently, computationally predicted results are compared with results [5,6] obtained from carefully performed experiments which include the effect of stress range, number of cycles and pre-strains on the subsequent response of TRIP steels. A simple equation is proposed to reproduce the numerically predicted cyclic deformation behavior. Furthermore, the computational method thus established is applied to the prediction of the deformation behavior of ringed-notched bars deformed under cyclic loading.

2. Constitutive equation

Olson and Cohen [1] established a model for strain-induced martensitic transformation kinetics, which can express the temperature dependence of the transformation phenomena. This phenomenological model was constructed under the assumption that the transformation occurred at the intersection of the shear band in the austenite mother phase with a certain probability. Stringfellow et al. [2] generalized the Olson and Cohen model so as to include the stress state and the contribution of the martensite phase to the strength. Tomita and Iwamoto [3] modified the two models to account for the experimental finding that the mode of the deformation behavior is controlled by the shear band mode as the strain rate increases [7]. The rate of increase of the volume fraction of martensite, $\dot{f}^{\alpha'}$, is given by

$$\begin{aligned} \dot{f}^{\alpha'} &= (1 - f^{\alpha'})(A\dot{\bar{\varepsilon}}_{\gamma}^{pslip} + B\dot{g}), \\ A &= \alpha p n \eta (f^{sb})^{n-1}(1 - f^{sb}), \quad B = \eta \frac{\mathrm{d}p}{\mathrm{d}g}(f^{sb})^{n} H(\dot{g}), \end{aligned} \tag{1}$$

where $\dot{\bar{\varepsilon}}_{\gamma}^{pslip}$ is the equivalent strain rate of slip deformation in austenite, f^{sb} is the volume fraction of the shear band, p is the probability that an intersection forms a martensitic embryo [2,3], g is the driving force for martensitic transformation, $H(\dot{g})$ is the Heaviside step function with respect to $\dot{g}$ which describes the irreversible process of martensitic transformation, and n and η are geometric constants. α is a parameter related to the stacking fault energy and is a function of temperature T [1], strain rate $\dot{\bar{\varepsilon}}_{\gamma}^{pslip}$ [3] and the stress triaxiality parameter