JOURNAL OF MATERIALS PROCESSING TECHNOLOGY 201 (2008) 226–231

ELSEVIER

journal homepage: www.elsevier.com/locate/jmatprotec

Micromechanics model of martensitic transformation-induced plasticity

C.Y. Sun, G. Fang, L.P. Lei, P. Zeng*

Key Laboratory of Advanced Materials Processing Technology, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Keywords:
Martensitic transformation
Micromechanics model
Transformation-induced plasticity

ABSTRACT

A micromechanics model was introduced to predict macroscopic deformation behavior of a material undergoing non-thermoelastic martensitic phase transformation. Considering the characteristics of ferrous alloys, the elliptic martensitic variants inclusion within a representative volume element of an austenite parent phase was built, where the transformation strain was determined by Wechsler–Lieberman and Read theory (WLR) accounting to dilatation and shear components of the transformation strain. Undergoing a macroscopic shear, the effects of interaction parameters between the different internal variables and the geometrical characteristics parameters of martensitic inclusion such as sizes, shapes and orientations on both the mechanical response and martensitic volume fraction were discussed. The result of this study provides a guideline for development of realistic stress-dependent transformation evolution laws for steels.

1. Introduction

The plasticity induced by the martensitic phase transformation, has a favorable influence on the overall mechanical characteristics of carbon steels due to the two involved mechanisms, i.e., plastic flow and martensitic transformation. It is important to understand how the microstructure evolution influences the overall stress–strain response of the material during the martensitic transformation. In order to understand the transformation-induced plasticity (TRIP) effect of phase transformation materials, scientists are nowadays challenged with finding reliable constitutive laws describing the responses to the arbitrary thermo-mechanical loading. Over the past 20 years, a variety of models have been proposed to describe the behavior of transformation-induced plasticity due to the microstructure evolution (Suiker and Turteltaub, 2005; Cherkaoui et al., 2000, 1998; Reisner et al., 1998; Fischer et al., 1998; Levitas, 2004; Leblond, 1989a; Greenwood and Johnson, 1965; Leblond, 1989b). Some of these models have a strongly phenomenological nature (Greenwood and Johnson, 1965; Leblond, 1989b), whereas other models incorporate microstructure information through the use of averaging techniques (Cherkaoui et al., 1998; Reisner et al., 1998; Cherkaoui and Berveiller, 2000). In the latter category, the micromechanical model presented by Cherkaoui et al. is attractive (Cherkaoui et al., 2000, 1998; Cherkaoui and Berveiller, 2000; Cherkaoui, 2002; Auricchio et al., 2007). Based on the theory of internal variable constitutive and the crystallographic theory of martensitic transformation, the volume fractions of each possible martensitic variant as well as the plastic flow in austenite and martensite are taken as internal variables of the system to lead to the constitutive equation. The ellipsoidal growing assumption of martensitic microdomains was adopted in the intrinsic dissipation. The mechanical driving force or accommodation energy results from the externally applied stress as well as the internal stress generated

* *Corresponding author*. Tel.: +86 10 62782694.
E-mail addresses: suncy04@mail.tsinghua.edu.cn (C.Y. Sun), zengp@mail.tsinghua.edu.cn (P. Zeng).
0924-0136/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.jmatprotec.2007.11.136

by transformation strain of martensitic variants. The interaction parameters between the different internal variables and martensitic variants geometrical configuration are important to control the occurrence of the phase transformation and select the most favorable martensitic variants; further, it has an influence on the macroscopic irreversible deformation behavior. The purpose of the present research is to obtain the effect of various parameters on the macroscale stress–strain behavior and the evolution of martensitic volume fraction of alloys undergoing martensitic phase transformation.

2. Transformation strain and kinetic description of martensitic transformation

2.1. *Transformation strain*

In steels, due to its composition, the austenite is unstable and transforms into a martensitic phase under a thermo-mechanical loading. This transformation generates a transformation strain, which results from a lattice variant strain and a lattice invariant strain (Cherkaoui et al., 1998). The transformation strain is assimilated to a shear along an invariant plane and a dilatation component. The kinematics representation of a transformation process is the development of an eigen-strain tensor ε_{ij}^{tr}. In the case of a displacive phase transformation, it is referred to the Wechsler–Lieberman–Read tensor. Due to the high symmetry of the austenite lattice, 24 possible martensitic variants may occur. According to this theory, the transformation strain imposed by the creation of a new martensitic variant *I* is respectively given by

$$\varepsilon^{\mathrm{tr}_I} = \frac{1}{2} g (M_i^I N_j^I + M_j^I N_i^I) \tag{1}$$

where *N*, *M* are the habit plane normal (Cherkaoui, 2002) and the direction of 24 possible variants, and *g* is the amplitude of the transformation strain which is a material constant (appropriate 0.2).

2.2. *Kinetic description of martensitic transformation*

Due to the small strain hypothesis used, as seen from Fig. 1, several strain mechanisms contribute to the overall response of TRIP steels. For the representative volume element (REV), the austenitic single crystal with the volume *V* subjected to its external boundary and thermo-mechanical loading, and then the total macroscopic inelastic strain can be written as

$$\begin{aligned} E^{\mathrm{tp}} &= \frac{1}{V} \int_V \varepsilon^{\mathrm{p}}(r)\,\mathrm{d}V + \frac{1}{V} \int_V \varepsilon^{\mathrm{tr}}(r)\,\mathrm{d}V \\ &= \frac{1}{V^{\mathrm{A}}} \int_{V^{\mathrm{A}}} \varepsilon^{\mathrm{p}}(r)\,\mathrm{d}V + \frac{1}{V^{\mathrm{M}}} \int_{V^{\mathrm{M}}} \varepsilon^{\mathrm{p}}(r)\,\mathrm{d}V + \sum_{I=1}^{N} f^I \varepsilon^{\mathrm{tr}_I} \end{aligned} \tag{2}$$

where the plasticity strain ε^{p} arises from both austensitic phase and martensitic domain at microscopic level. The transformation strain $\varepsilon^{\mathrm{tr}_I}$ has been given at above. Eq. (2) can also be written as

$$E^{\mathrm{tp}} = (1-f)\bar{\varepsilon}^{\mathrm{p_A}} + \sum_{I=1}^{N} f^I \bar{\varepsilon}^{\mathrm{p}_{\mathrm{M}_I}} + \sum_{I=1}^{N} \varepsilon^{\mathrm{tr}_I} f^I \tag{3}$$

where *N* is the total number of active martensitic variants at the current configuration of RVE and f^I is the corresponding volume fractions; *f* is the total volume fraction of all possible martensitic variants.

In the case of TRIP steel, the inelastic strain of the single crystal E^{tp} corresponds to the macroscopic inelastic strain arising from the phase transformation and the plastic flow at microscopic level. $\varepsilon^{\mathrm{p}}(r)$ includes the plastic strain at austenitic domain and martensitic domain of an element volume. For the TRIP steels and the general carbon steels, the reorientation and inverse transformation are insignificant mechanisms during the transformation and the progression of the transformation can be described by the instantaneous growth of martensitic domains in the austenitic phase. Therefore, one obtains the expression

$$\dot{E}^{\mathrm{tp}} = (1-f)\dot{\bar{\varepsilon}}^{\mathrm{p_A}} + \sum_{I=1}^{N} f^I \dot{\bar{\varepsilon}}^{\mathrm{p}_{\mathrm{M}_I}} + \sum_{I=1}^{N} \varepsilon^{\mathrm{tr}_I} \dot{f}^I \tag{4}$$

where $(1-f)\dot{\bar{\varepsilon}}^{\mathrm{p_A}}$ describes the average plastic flow in the residual austenitic phase, $\sum_{I=1}^{N} f^I \dot{\bar{\varepsilon}}^{\mathrm{p}_{\mathrm{M}_I}}$ corresponds to the plastic flow in the pre-existing martensitic phase, $\sum_{I=1}^{K} \varepsilon^{\mathrm{tr}_I} \dot{f}^I$ can express the formation of new plates or laths.

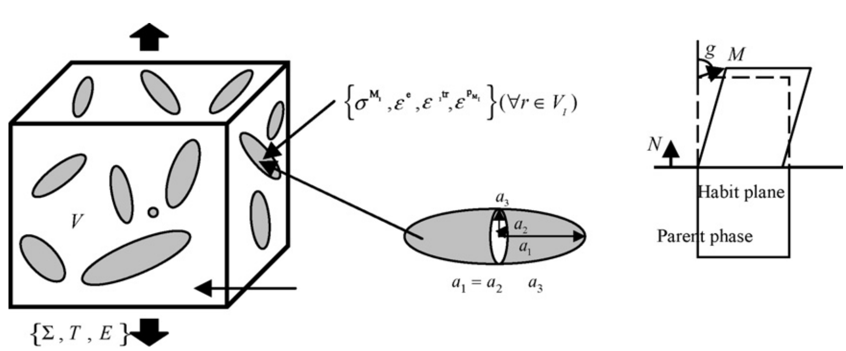

Fig. 1 – Illustration of a constitutive element with a number of martensitic variant.