A MICROMECHANICAL STUDY ON STRAIN-INDUCED TRANSFORMATION PLASTICITY IN LOW-ALLOY TRIP-STEELS

F. MARKETZ*
Christian Doppler Laboratory
Micromechanics of Materials
Franz-Josef-Straße 18
A-8700 Leoben, Austria

AND

G. REISNER AND F.D. FISCHER
Institute of Mechanics
University for Mining and Metallurgy
A-8700 Leoben, Austria

1. Introduction

Integrating concepts for computational modelling and experiencing under the combined viewpoint of thermomechanics and material science will provide for new alloy design capabilities to exploit mechanical properties in terms of strength, ductility, toughness or enhanced energy absorption capability. Recently, a new type of high strength dual-phase steels associated with transformation-induced plasticity (TRIP) due to a strain-induced martensitic transformation (SIMT) has been developed [1], [2]. These low-alloy TRIP-steels show a good combination of total elongation and tensile strength at room temperature. The enhanced deformation capability comes from the mechanical properties of the martensitic transformation itself. It is attributed to the TRIP-phenomenon associated with the SIMT of the retained metastable austenitic phase under the effect of mechanical loading at constant temperature. The overall hardening is increased due to the mechanical properties of the emerging martensitic phase.

*F. Marketz is on leave for Shell Research BV, Koninklijke/Shell Exploratie en Produktie Laboratorium, Volmerlaan 8, NL-2280 AB Rijswijk ZH, The Netherlands.

A. Pineau and A. Zaoui (eds.),
Low-alloy TRIP-steels have been developed to reduce the weights of various automotive structural components and to promote for higher safety by the enhanced energy absorption capability caused by dissipative processes during the SIMT (nucleation, motion of interphase boundaries and twin boundaries). The mechanical properties of this material depends to a large extent on the mechanical stability of the retained austenitic phase depending on the parameters of retained austenite. The properties of retained austenite also affect the mechanism of the SIMT itself. It has been experimentally observed that the martensitic phase appears plate-like with an internally twinned domain structure. On the other hand, thin transformation twins are observed, especially in very small retained austenitic islands [1].

The objective of the present study is to unify micromechanics with energy aspects of the SIMT of retained austenitic particles embedded in a ferritic matrix. The numerical results provide a quantitative understanding of the effect of austenite properties on its mechanical stability against SIMT which will support the development of alternative alloy design concepts in the viewpoint of designing microstructures for desired properties.

2. Modelling Framework for SIMT in Low-alloy TRIP-steels

The microstructure of low-alloy TRIP-steels is composed of a ferritic matrix and 20-40 vol% second phase particles (bainite plus 5-20 vol% retained austenite dependent on the heat treatment process). The retained austenite appears isolated as particles within the ductile matrix. Therefore, an inclusion-matrix-type microstructure is taken into account. Furthermore, retained austenite films as boundary layers between ferrite and bainite are experimentally observed. For the micromechanical model a constitutive element with volume $V$ with a spherical metastable austenitic inclusion (volume $V_I$) is considered. The volume fraction of retained austenite is, therefore, $\xi_I = V_I/V$. The periodic microfield approach is performed by an axisymmetric finite element analysis applying the unit-cell technique. The unit-cell is discretized into 384 axisymmetric elements. Suitable boundary conditions allow for the periodicity of the arrangement. The first step of the micromechanical analysis is the simulation of the cooling process from $400^\circ\text{C}$ to room temperature. In this stage the source of internal stresses is due to the mismatch of the coefficients of thermal expansion of ferrite and austenite. For each of the phases isotropic elastic behavior is assumed and $J_2$-flow theory is used. Large deformation analyses are carried out. For details on the modelling procedure see ref. [3]. At room temperature $T_R$ the material is loaded in uniaxial tension. The elastic constants of austenite, martensite and ferrite are taken to be identical (Young modulus $E = 211.4\,[\text{GPa}]$, Poisson ratio $\nu = 0.293$). The flow curve of the phases is described by $\sigma(\varphi) = \sigma_Y + K \varphi^n$.