Materials Science & Engineering A 649 (2016) 174–183

Contents lists available at ScienceDirect

Materials Science & Engineering A

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

Effect of martensitic phase transformation on the behavior of 304 austenitic stainless steel under tension

H. Wang [a,*], Y. Jeong [b], B. Clausen [a], Y. Liu [a], R.J. McCabe [a], F. Barlat [c], C.N. Tomé [a]

[a] Materials Science and Technology, Los Alamos National Laboratory, Los Alamos, NM, USA
[b] Materials Science and Engineering Division, National Institute of Standards and Technology, Gaithersburg, MD, USA
[c] Graduate Institute of Ferrous Technology, POSTECH, Republic of Korea

ARTICLE INFO

Article history:
Received 22 July 2015
Received in revised form
19 September 2015
Accepted 27 September 2015
Available online 30 September 2015

Keywords:
Transformation induced plasticity (TRIP) steel
Crystal plasticity
In-situ neutron diffraction
EBSD

ABSTRACT

The present work integrates in-situ neutron diffraction, electron backscatter diffraction and crystal plasticity modeling to investigate the effect of martensitic phase transformation on the behavior of 304 stainless steel under uniaxial tension. The macroscopic stress strain response, evolution of the martensitic phase fraction, texture evolution of each individual phase, and internal elastic strains were measured at room temperature and at 75 °C. Because no martensitic transformation was observed at 75 °C, the experimental results at 75 °C were used as a reference to quantify the effect of formed martensitic phase on the behavior of 304 stainless steel at room temperature. A crystallographic phase transformation model was implemented into an elastic–viscoplastic self-consistent framework. The phase transformation model captured the macroscopic stress strain response, plus the texture and volume fraction evolution of austenite and martensite. The model also predicts the internal elastic strain evolution with loading in the austenite, but not in the martensite. The results of this work highlight the mechanisms that control phase transformation and the sensitivity of modeling results to them, and point out to critical elements that still need to be incorporated into crystallographic phase transformation models to accurately describe the internal strain evolution during phase transformation.

Published by Elsevier B.V.

1. Introduction

Transformation induced plasticity (TRIP) steels are characterized by their excellent combination of strength, ductility and response to high-speed deformation and are thus extensively used in the automobile industry [1–3]. In addition to common strengthening mechanisms, such as grain refinement, precipitation or composite strengthening both, strength and ductility, can be improved by the contribution of martensitic phase transformation [4,5]. A lot of works have investigated the microscopic plastic behavior of TRIP steels using techniques of Transmission Electron Microscopy, Electron Backscatter Diffraction (EBSD), and Neutron Diffraction, etc. [3,6,7]. Among the measuring techniques, neutron diffraction is well adapted for the characterization of the microscopic plastic behavior of TRIP steels because of its selectivity based on the crystal lattices and the large size of gauge volume. Moreover, in-situ neutron diffraction measurement provides separate information about the evolution of internal elastic strains (or internal stress) for each phase of the TRIP steel under deformation. The transformed martensitic phase results from the combination of shear and dilatational volume expansion, which in return induces additional plasticity in the surrounding matrix by imposing locally concentrated stress field [8–10]. The precise measurement of the lattice strains under such a circumstance will lead us to a better understanding of the TRIP effect. Several studies have demonstrated the possibility of monitoring the stress partitioning between the austenitic and martensitic phases using in-situ neutron diffraction during mechanical straining [6,7,11].

Most of the in-situ neutron measurements on TRIP effect have been performed to relatively small plastic strains. In addition, the data in those measurements were collected through periodically interrupting the loading while holding either the stress or the strain constant. In such a case, the holding times could be as long as 45 min [12]. As a consequence, either stress or strain relaxation takes place during data collection, with the inconvenience that the internal strains evolve during the measurement. An alternative testing technique, which consists in performing in-situ measurements on specimens deformed uninterruptedly at very low strain rates (10^{-6}–10^{-5} s^{-1}), was recently applied to austenitic steel by An et al. [13] and Wang et al. [14]. This technique has the advantage over the conventional measuring techniques that it avoids

* Corresponding author.
E-mail address: wanghm@lanl.gov (H. Wang).

http://dx.doi.org/10.1016/j.msea.2015.09.108
0921-5093/Published by Elsevier B.V.

the stress or strain relaxation associated with the interrupts during lattice strain measurements.

An accurate constitutive model is demanded to interpret shifts of diffraction peaks in terms of internal strain pertaining to a specific subset of grains. Various constitutive models for martensitic phase transformation have been proposed in the literature [9,10,15–21]. These models fall into two categories: phenomenological and crystallographic mechanisms-based models. None of them, however, addresses the probabilistic relations between the microstructural/stress variability and phase transformation variant selection. Modeling the evolution of internal elastic strain under loading becomes even more challenging when phase transformation is present, and requires incorporating explicitly lattice scale mechanisms.

We pursue experimental and modeling goals in the present work. The first goal is to apply the uninterrupted in-situ neutron diffraction measuring technique to study the influence of martensitic phase transformation on the large deformation behavior of TRIP steel. Two tension tests of 304 austenitic stainless steel at 25 and 75 °C are performed. Since phase transformation takes place at room temperature, but does not at 75 °C for the steel tested here, the test at 75 °C is then used as a baseline to evaluate the influence of martensitic transformation on the behavior of 304 austenitic stainless steel both qualitatively and quantitatively. The second goal is to develop a crystallographic mechanisms-based model for martensitic phase transformation with mechanical predictive capabilities. Such a model should account for various modeling elements that include: (a) a nucleation and variant selection criterion; (b) the introduction of martensitic grains in the aggregate; (c) the orientation relationship between the martensitic grain and its parent austenitic phase; (d) the evolution of the martensitic grain and the implementation of the martensitic phase transformation strain. In this work, those modeling elements are incorporated into the elastic viscoplastic self-consistent (EVPSC) model [14,22–26]. The EVPSC model has been successfully applied to study the evolution of internal elastic strain of stainless steel not exhibiting transformation [14,27], magnesium alloys [28–30] and zirconium alloys [31]. The polycrystal model is applied to interpret the hardening, texture and phase evolution during the in-situ neutron diffraction measurement on the 304 stainless steel. And the model is applied to interpret for the first time the evolution of diffraction peak intensity and internal elastic strain in both austenitic and martensitic phases as they evolve. Section 2 of this paper presents a description of the experimental procedure. Section 3 presents a detailed description of the specific elements added to the EVPSC model. The experimental and simulated results are compared and discussed in Section 4.

Table 1
Chemical composition of the stainless steel in weight percent.

Element	C	Cr	Ni	Si	Mn	Mo
Fraction	0.08	19.0	9.25	0.75	2.0	0

2. Experimental procedure

A 304 austenitic stainless steel sheet with average grain size of 25 μm was investigated. The chemical composition is listed in Table 1. The microstructures were characterized by Electron Backscatter Diffraction (EBSD) analysis. A pure austenitic phase was observed in the EBSD orientation map of the undeformed sample (Fig. 1a). Dog-bone tension specimes were machined such that the loading axis aligns with the rolling direction (RD) of the stainless steel sheet. The EBSD orientation map at 30% tensile strain is presented in Fig. 1b, where it can be seen that mainly one martensite variant was activated in most of the grains. The latter observation is relevant to the modeling assumptions done in this work. The spectrometer for high intensity pressure and preferred orientation (HIPPO) at LANSCE (Los Alamos Neutron Science Center) was used to measure the textures. Fig. 2 shows the {111}, {200} and {220} pole figures of the initial austenitic phase. The pole figures indicate that the as-received stainless steel has a very weak rolling texture. The textures at tensile strains of 10%, 20%, 30% and 40% were also measured and will be reported in Section 4.

In-situ neutron diffraction measurements were performed during tensile deformation using the Spectrometer for Materials Research at Temperature and Stress (SMARTS), also at LANSCE (details of the instrument can be found in Bourke et al. [32]). Uniaxial tension tests at a strain rate of 10^{-5}/s were performed at two different temperatures, i.e., room temperature (RT) and 75 °C. An induction coil was used to heat the sample to the specified temperature. This low strain rate avoids a temperature increase induced by deformation. Within such a narrow temperature interval, the properties of austenitic phase are not subject to change significantly. Martensitic phase is transformed from austenitic phase under tension at RT, while it is not observed at 75 °C. Therefore the effect of martensitic phase transformation is investigated through comparing the two deformation behaviors of stainless steel at RT and at 75 °C. The load frame is oriented at a 45° angle to the incident beam and thus the two detector banks at $\pm 90°$ to the incident beam allow for simultaneous measurement of diffraction patterns with scattering vectors parallel and transverse to the loading axis, respectively. The neutron data are collected continuously throughout all the testing time using the uninterrupted

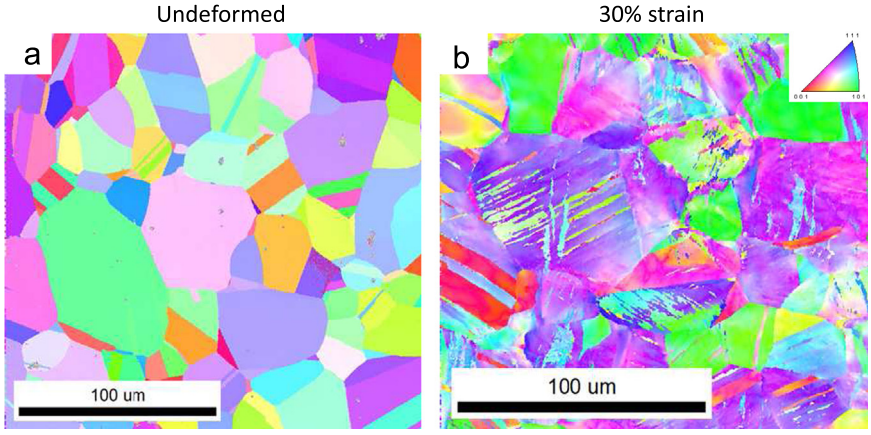

Fig. 1. EBSD orientation map of 304 stainless steel sheet at tensile strains of (a) 0% (undeformed) and (b) 30%.

Download English Version:

https://daneshyari.com/en/article/7976491

Download Persian Version:

https://daneshyari.com/article/7976491

Daneshyari.com