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Mechanical behavior and microstructure evolution during steady-state dynamic recrystallization in the austenitic steel 800H

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ABSTRACT

Investigations of steady-state dynamic recrystallization (DRX) were carried out on an austenitic steel alloy 800H. The influence of strain rate and temperature on the mechanical behavior, microstructure development and texture evolution were analyzed. Strain rate and temperature change experiments during steady-state deformation revealed characteristic interdependencies of flow stress, hardening rate, and grain size. The grain size sensitivity of the flow stress was found to scale with the characteristic length scale of the deformed structure. Based on these observations a new model is proposed that relates the process of DRX to an interaction of mobile grain boundaries with deformation-induced subboundaries.

1. Introduction

Despite extensive research during the past decades the physical mechanisms of dynamic recrystallization (DRX) are not yet fully understood. The subject is not only of academic interest but also of immense importance for industrial processing, e.g. hot rolling: DRX offers a powerful tool for microstructure control and, therefore, a useful way for the optimization of the sheet properties. Furthermore, advances in through-process computer simulation require precise experimental data and physics-based models of the material behavior for each step of the complex process chain (hot rolling, cold rolling, annealing, . . .) for reliable predictions of microstructure and texture evolution.

Early models of DRX were based on concepts assuming a simple superposition of deformation and (static) recrystallization [1–3]. While the essential features of microstructure and flow behavior could be reproduced, e.g. the development of grain size, the apparent differences to static recrystallization – like the nucleation mechanisms and the steady-state behavior – could not be accounted for.

The current study focused on the steady-state regime of the flow curve. Particular attention was paid to the microstructure and texture development as well as to the transient behavior during strain path changes.

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2. Experimental procedure

The material used in this investigation was the austenitic steel X10NiCrAlTi3220, also referred to as alloy 800H. Its exact chemical composition is given in Table 1. Cylindrical samples of 5 mm diameter and 7.7 mm height were machined from the statically recrystallized material using Rastegaev geometry [4] with BN as lubricant. Hot Compression tests were performed with true strain rates of $10^{-4}\,s^{-1} \leq \dot{\varepsilon} \leq 10^{-1}\,s^{-1}$ at temperatures of $1000\,°C \leq T \leq 1200\,°C$. For texture and microstructure analysis the samples were quenched with cold helium gas immediately after deformation. Details are given elsewhere [5].

The influence of the deformation parameters on the flow stress, dynamically recrystallized grain size, and texture evolution was investigated. Electron backscatter diffraction (EBSD) measurements using a field emission gun scanning electron microscope (FEGSEM) served for the analysis of the local orientation arrangement and for the reconstruction of the microstructural features. The main focus was on the examination of the grain size evolution and the texture development during steady-state DRX.

3. Results

3.1. Plastic flow behavior

The characteristic stress–strain curve of a material undergoing DRX exhibits either a single maximum (single-peak behavior) or an oscillating shape (multiple-peak behavior) depending on the deformation parameters, i.e. temperature and strain rate [6]. Fig. 1

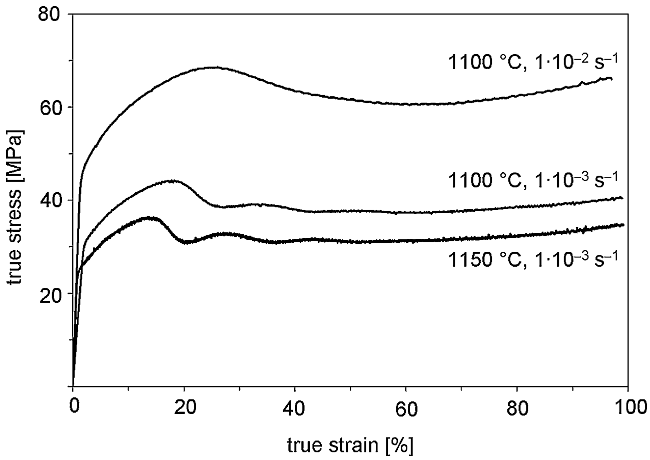

Fig. 1. Typical flow curves of the austenitic steel Alloy 800H during high temperature deformation at different strain rates and temperatures.

Table 1
Chemical composition of the austenitic steel Alloy 800H.

Cr	20.35
Ni	30.20
Mn	0.70
Si	0.42
Ti	0.34
Cu	0.12
S	0.002
P	0.013
Al	0.30
Co	0.05
C	0.071
Fe	bal.

shows the typical flow curves of the austenitic steel 800H in the temperature range 1000 °C ≤ T ≤ 1200 °C and at true strain rates of $10^{-4}\,s^{-1} \le \dot{\varepsilon} \le 10^{-1}\,s^{-1}$. With increasing temperature T or decreasing strain rate $\dot{\varepsilon}$ the flow curves are shifted to lower stress levels. Furthermore, a transition from single-peak to multiple-peak behavior is observed. The slight increase of the stress in the steady-state regime at higher strains (ε > 60%) which is discernible in Fig. 1 is the result of friction due to the increasing contact area between the sample and the compression platens.

3.2. Microstructure development

The microstructural features were determined from orientation maps measured by EBSD. The initial grain size of the statically recrystallized material (Fig. 2a) was 27.1 μm and contained a large fraction of recrystallization twins. During DRX at 1100 °C and strain rates of $1 \times 10^{-2}\,s^{-1}$ (Fig. 2b and c) and $1 \times 10^{-3}\,s^{-1}$ (Fig. 2d), grain refinement was observed. In Fig. 3 the microstructure evolution is shown for constant (triangular symbols) and transient deformation conditions. The full lines indicate the average dynamically recrystallized grain size in the steady-state regime at constant strain rates giving values of 14.9 μm (1100 °C; $1 \times 10^{-2}\,s^{-1}$) and 21.2 μm (1100 °C; $1 \times 10^{-3}\,s^{-1}$). Since the steady-state regime was attained at higher strains in case of higher strain rates (see Fig. 1), the grain size at $\varepsilon \cong 40\%$ and $\dot{\varepsilon} = 1 \times 10^{-2}\,s^{-1}$ was not considered for the calculation of the average grain size.

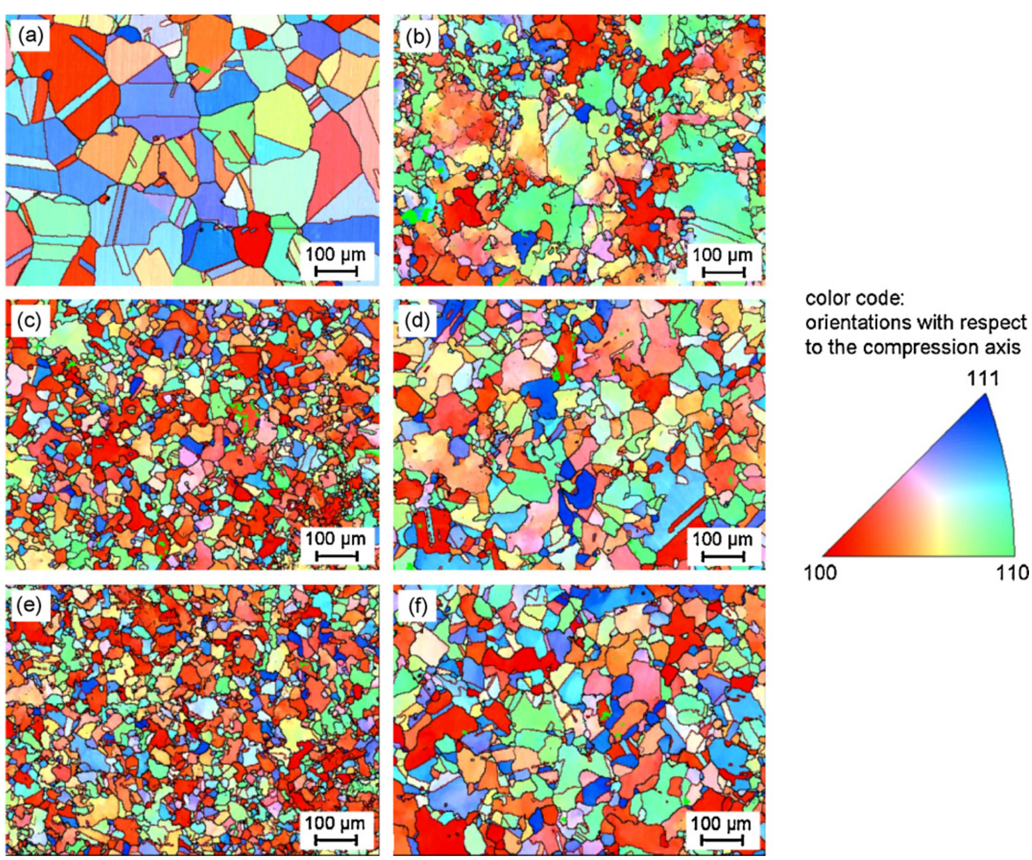

Fig. 2. Microstructure development at 1100 °C: (a) initial microstructure; (b) and (c) deformed at $1 \times 10^{-2}\,s^{-1}$ to true strains of 38% and 96%; (d) deformed at $1 \times 10^{-3}\,s^{-1}$ to 96%; (e) strain rate change from $1 \times 10^{-3}\,s^{-1}$ to $1 \times 10^{-2}\,s^{-1}$ at 56% and further deformation to a total strain of 96%; (f) strain rate change from $1 \times 10^{-2}\,s^{-1}$ to $1 \times 10^{-3}\,s^{-1}$ at 57%, total strain 96%; the compression axis is perpendicular to the sheet plane.