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Microstructural evolution of a 304-type austenitic stainless steel during rolling at temperatures of 773–1273 K

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Abstract—The structural changes leading to grain refinement in a 304-type austenitic stainless steel subjected to warm caliber rolling over a wide temperature range of 773–1273 K were studied. The development of a new ultrafine-grained structure during rolling primarily resulted from continuous dynamic recrystallization. Two deformation domains were recognized that exhibit different recrystallization processes. In the high-temperature deformation domain, the majority of new strain-induced grain boundaries developed homogeneously through largely uniform formation of a network of deformation sub-boundaries, the misorientations of which attained values of high-angle grain boundaries during deformation. In this case, the kinetics of the microstructural evolution depended on dynamic recovery, which accelerated with increasing deformation temperature. In contrast, the development of new strain-induced grain boundaries was primarily associated with deformation microbanding in the low-temperature deformation domain. The development of deformation microbands resulted from strain localization and was promoted by a decrease in the deformation temperature. Therefore, the opposite temperature effect on the contribution of different structural mechanisms to new grain development led to temperature-independent kinetics of grain refinement for a wide range of warm working.

Keywords: Austenitic stainless steel; Multiple rolling; Grain refinement; Continuous dynamic recrystallization

1. Introduction

Dynamic recrystallization (DRX) has been successfully utilized for microstructure control in various structural steels and alloys [1–5]. DRX enables the desired microstructure to be obtained directly during metal working under appropriate conditions [6–10]. The patterns of dynamic recrystallization that occur in metals and alloys with low to medium stacking fault energies during hot working have been clarified [1,4–9]. The mechanism for DRX involves a local migration (bulging) of grain boundaries leading to the formation of DRX nuclei, which grow out, consuming work-hardened surroundings during deformation at elevated temperatures. The process of nucleation and grain growth exhibits a cyclic behavior, and therefore this process is referred to as discontinuous DRX (dDRX) [1,5,7]. In particular, grain boundary bulging occurs repeatedly in previously grown and work-hardened grains during deformation. The cyclic nucleation and growth of new grains results in a dynamically constant average grain size, which depends on deformation conditions that can be expressed by power law functions of temperature-compensated strain rate or flow stress [5,7]. Because DRX involves diffusion-controlled grain boundary migration, an increase in the deformation temperature accelerates the recrystallization kinetics.

DRX holds great promise for processing of advanced ultrafine-grained metallic materials. Structural steels and alloys with a grain size well below 1 μm possess a beneficial combination of mechanical properties including high strength and sufficient ductility [11–13]. The mean grain size evolved by DRX can be substantially decreased by decreasing the deformation temperature [5,8,14,15]. Therefore, deformation under conditions of warm working is a very effective method for processing of ultrafine-grained metals and alloys [4,5,13–19]. However, in contrast to hot working, the mechanisms and regularities of microstructure evolution and DRX during warm deformation are still unclear. It is generally accepted that the new ultrafine grains result from a type of continuous reaction [5,16–19]. In particular, the structural changes are characterized by a gradual transformation of strain-induced sub-boundaries into grain boundaries when the sub-boundary misorientations increase to the values typical of conventional grain boundaries during deformation. This process is sometimes referred to as continuous DRX (cDRX) [4,5,20–22]. The deformation banding that rapidly introduces large misorientations in deformation substructures plays an important role in the development of strain-induced high-angle grain boundaries and new ultrafine-grained structures at low temperatures [5,23–26]. The new ultrafine grains readily appear within the deformation bands and their

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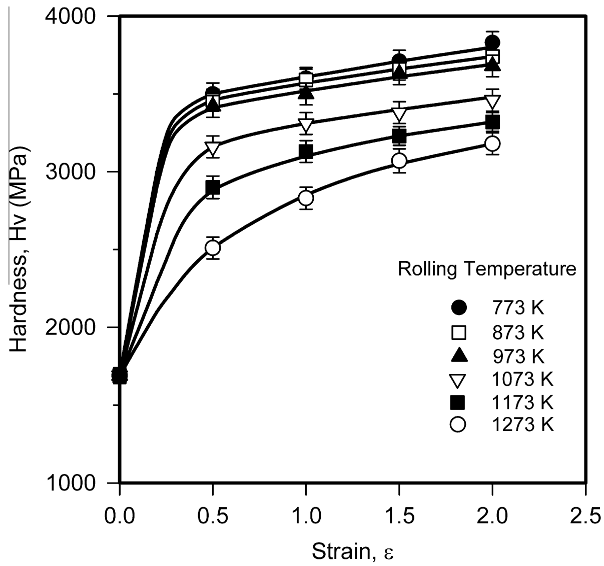

Fig. 1. Strain hardening of an S304H-type austenitic stainless steel subjected to rolling at temperatures of 773–1273 K.

intersections. The density of the deformation bands continuously increases with straining, which leads to progress in cDRX. The kinetics of cDRX remains unclear and has attracted much interested. Apparent retardation of the new grain evolution due to decreasing the deformation temperature may be due to stunted dynamic recovery [15,25]. On the other hand, a model of grain fragmentation based on lattice curvature, which has been recently proposed by Toth et al. [27], suggests an acceleration of the development of high-angle strain-induced grain boundaries as the deformation temperature decreases. This ambiguity in the kinetics of cDRX is associated with a lack of experimental data and different approaches to their interpretation.

The aim of the current study is to clarify the temperature effect on the development of high-angle strain-induced grain boundaries under conditions of warm deformation. An austenitic stainless steel was selected as representative of pseudo-single-phase metallic materials, which have a large number of various commercial applications and are frequently used in basic research of structure–property relationships, such as DRX simulations.

2. Experimental

An S304H-type austenitic stainless steel (Fe–0.1C–0.12N–0.1Si–0.95Mn–18.4Cr–7.85Ni–2.24Cu–0.5Nb–0.01P–0.006S, all in mass%) was hot forged at 1423–1473 K and solution treated at 1373 K, which resulted in the formation of a uniform microstructure with a mean grain size of 7 μm [28]. The rod samples were heated in a muffle furnace to the desired temperature in the range of 773–1273 K. Then,

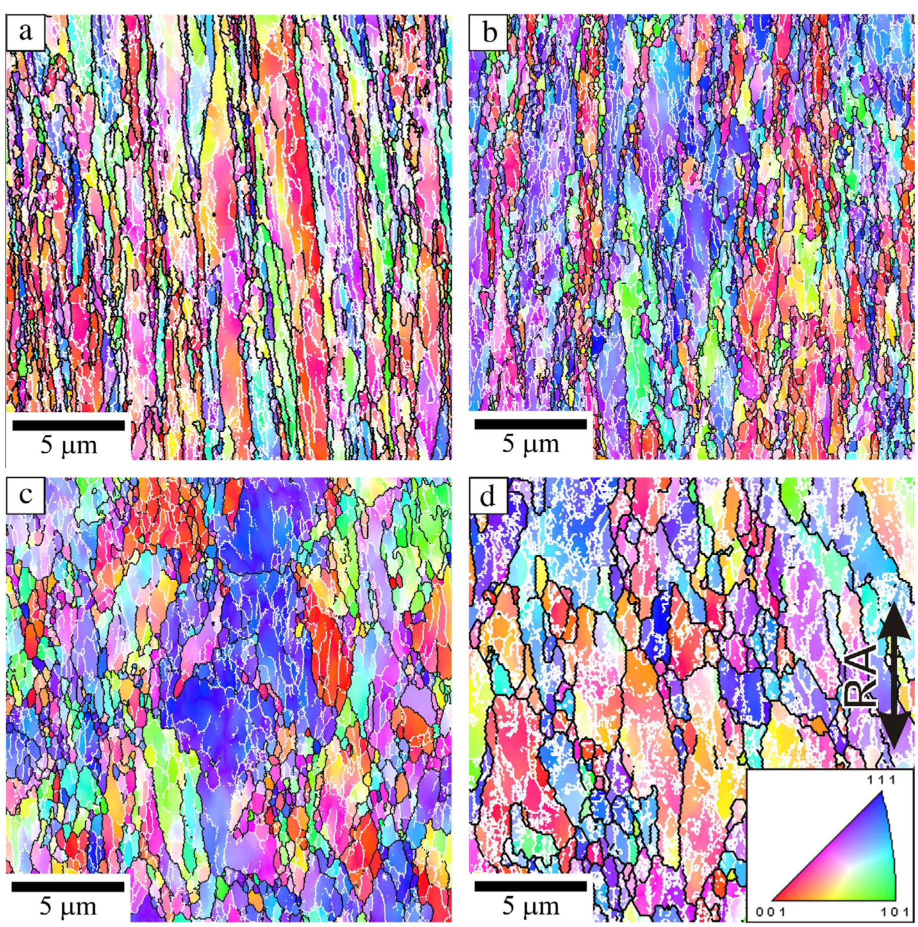

Fig. 2. Deformation microstructures developed in an S304H-type austenitic stainless steel through multiple rolling to a total strain of 2 at temperatures of 773 K (a), 873 K (b), 1173 K (c) and 1273 K (d). The inverse pole figures are shown for the rolling axis (RA). The black and white lines indicate high-angle boundaries (θ > 15°) and low-angle sub-boundaries (2° ⩽ θ < 15°), respectively.