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Rapid communication

Microstructure evolution in AISI201 austenitic stainless steel during the first compression cycle of multi-axial compression

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ABSTRACT

The microstructure of AISI201 stainless steel deformed in the first compression cycle of MAC at 973 K in air was investigated. It is suggested that the continuous dynamic recrystallization (cDRX) and dynamic recovery are responsible for the formation of strain-induced fine austenitic grains.

1. Introduction

Metals and alloys with ultrafine-grained microstructures exhibit a variety of attractive mechanical properties such as high strength combined with sufficient ductility, enhanced impact toughness, superplasticity at high strain rates and low temperature [1]. These materials are the subject of extensive research efforts worldwide. Recently, special attention has been paid to various ultrafine-grained metallic materials with traditional compositions processed by severe plastic deformation (SPD) process, such as equal channel angular pressing (ECAP) [2], high-pressure torsion (HPT) [3], multi-axial compression (MAC) [4] and accumulative roll-bonding (ARB) [5,6]. MAC is a unique process in which the material is deformed at a given temperature with a changing loading direction of 90° pass-by-pass (i.e., x–y–z–x…). MAC (frequently also denoted as multi-axial forging—MAF) is characterized by higher deformation rates which permit to produce larger samples. The periodic 90° variation in loading direction, i.e. x–y–z, will be denoted in the following as compression cycle.

Many studies analyzing the deformation mechanisms occurring during MAC have been carried out [6–12]. Depending on the materials and the processing temperatures employed, there are various mechanisms proposed for the evolution of ultrafine grains (UFGs) microstructure during MAC. One of the mechanisms of UFGs evolution during MAC which is explained by Sakai et al. [6] is similar to continuous dynamic recrystallization (cDRX) [6–9]. In their works, the strain-induced UFGs are the result of the deformed microbands, involving the transformation of low-angle grain boundaries into high angle boundaries, and the misorientation between subgrains increased gradually with increasing cumulative strains [10]. Cu–Zn alloy grain refinement during MAC was enhanced by grain subdivision through mechanical twinning [11]. The presence of the twin boundaries, beside the grain boundaries, was thought to significantly increase strength [12]. Ultrafine-grained materials fragmented by mechanical twinning exhibit special high strength [13]. Strain-induced phase transformation during large plastic deformation also contributed to grain refinement. Nakao and Miura [14] found that grain fragmentation took place after MAC of austenitic stainless steels as a result of the coordinated mechanisms of deformation twinning and martensitic transformation. Therefore, grain refinement in different materials during MAC may be enhanced by different mechanisms such as cDRX, dynamic recovery, mechanical twinning, and martensitic transformation.

The initial change of microstructure has great significance to understand the development of ultrafine-grained materials. Thus, a special attention has been paid to the first compression cycle during the MAC processing. The aims of this paper are: (1) to report the observations of the microstructure of AISI201 austenitic stainless steel during the first compression cycle of MAC process and (2) to discuss the mechanism of grain refinement.

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2. Experimental

The material used in this study is the AISI201 stainless steel with chemical composition (wt%) 12.62% Cr, 3.3% Ni, 7.46% Mn, 0.15% C, 0.82% Si, 0.2% N and balance iron. The dimensions of the compression specimen were 20 mm × 16.33 mm × 13.33 mm, i.e. the samples were designed to match the ratio 1.5:1.22:1 [15].

Successive uniaxial compression passes, with strain $\varepsilon = -0.4$, were applied to the longest side of samples. Assuming volume conservation and material isotropy, this procedure enables the initial dimensional ratio to be maintained at the end of each pass [14,16]. The compressions with the changing loading direction of 90° pass-by-pass (i.e., *x*–*y*–*z*) were carried out at 973 K in air at a strain rate of about $10^{-2}\,s^{-1}$. MoS_2 was used as lubrication during compression. The deformed samples were quenched in water quickly after each pass.

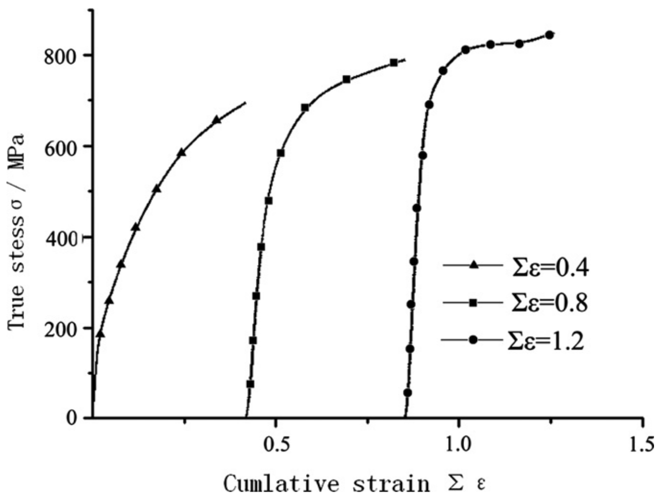

Fig. 1. True stress–cumulative strain curves.

Specimens for analyses, cut from the central portion of the samples in a plane parallel to the final compression axis (C.A.), were polished and etched by 5 g $FeCl_3$ + 50 mL HCl + 100 mL · H_2O. Optical microscope (OM) was performed with POLYVAR-MET. After hand-grinding, TEM samples were reduced to a thickness of about 0.10 mm, and then the foils were perforated upon the shear band by electropolishing in solution of 300 ml CH_3OH + 175 ml $C_4H_{10}O$ + 30 ml $HClO_4$ at 243 K. Transmission electron microscope (TEM) observations are carried out with a JEOL-2010 transmission electron microscope operated at 200 kV. Electron back Scattered diffraction (EBSD) measurement was carried out on a FEI Sirion200 scanning electron microscope. The samples for EBSD were twin jet-polished in a solution of 4% perchloric acid and 96% ethanol. The scanning areas focused on the core of the samples. EBSD data were analyzed using TSL-OIM software.

3. Results and discussion

3.1. Mechanical response

The stress–cumulative strain curves of the samples plotted for the first compression cycle during MAC are shown in Fig. 1. From *x*-pass through *z*-pass, difficulties of deformation increase with cumulative strain. The inflection points of the curve are encountered at the second pass (*y*-pass, $\Sigma\varepsilon = 0.8$) and the third pass (*z*-pass, $\Sigma\varepsilon = 1.2$), and the plateau of the curve is encountered at the third pass. The strain hardening is evident at strain below

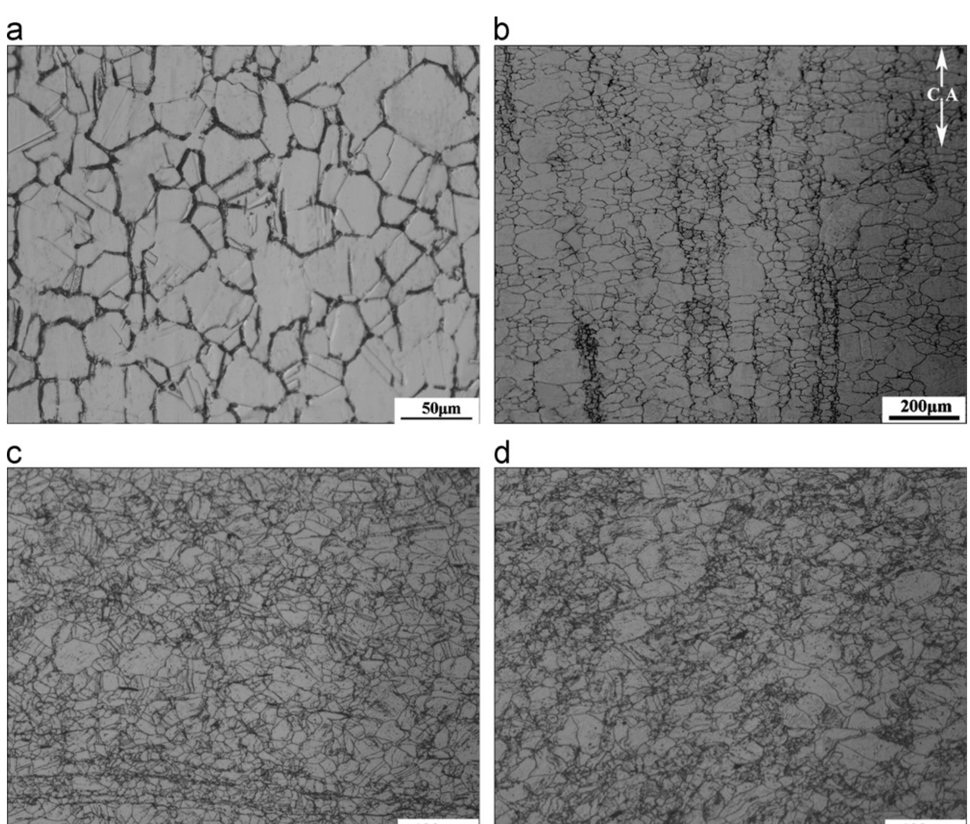

Fig. 2. Optical micrographs of grains during the first compression cycle: (a) original; (b) first pass; (c) second pass and (d) third pass.