Journal of Iron and Steel Research, International 24 (2017) 1231—1237

Contents lists available at ScienceDirect

Journal of Iron and Steel Research, International

journal homepage: www.chinamet.cn

Effect of martensitic transformation on nano/ultrafine-grained structure in 304 austenitic stainless steel

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ARTICLE INFO

Key words:
304 austenitic stainless steel
Nano/ultrafine-grained structure
Reversion mechanism
Lath-type martensite
Dislocation-cell type martensite
Martensitic transformation

ABSTRACT

304 austenitic stainless steel was cold rolled in the range of 20%—80% reductions and then annealed at 700—900 ℃ for 60 s to obtain nano/ultrafine-grained (NG/UFG) structure. Transmission electron microscopy, electron backscatter diffraction and X-ray diffraction were used to characterize the resulting microstructures. The results showed that with the increase of cold reduction, the content of martensite was increased. The steel performed work hardening during cold-working owing to the occurrence of strain induced martensite which nucleated in single shear bands. Further rolling broke up the lath-type martensite into dislocation-cell type martensite because of the formation of slip bands. Samples annealed at 800—960 ℃ for 60 s were of NG/UFG structure with different percentage of nanocrystalline (60—100 nm) and ultrafine (100—500 nm) grains, submicron size (500—1000 nm) grains and micron size (>1000 nm) grains. The value of the Gibbs free energy exhibited that the reversion mechanism of the reversion process was shear controlled by the annealing temperature. For a certain annealing time during the reversion process, austenite nucleated first on dislocation-cell type martensite and the grains grew up subsequently and eventually to be micrometer/submicrometer grains, while the nucleation of austenite on lath-type martensite occurred later resulting in nanocrystalline/ultrafine grains. The existence of the NG/UFG structure led to a higher strength and toughness during tensile test.

1. Introduction

Austenitic stainless steel (SS) is quite suitable for structural applications due to its excellent corrosion characteristic, but because of the lack of high strength, it is hard to apply in construction fields widely[1]. Grain refinement is supposed to be a potential method in developing the strength of the materials[2,3]. Thermomechanical controlled processing (TMCP) is considered to be one of the primary methods to realize the exact grain refinement. It was reported that TMCP together with microalloying elements such as element Nb got the grain size of ferrite down to 4—5 μm in body-centered cubic (bcc) ferrous alloys[4-6]. However, generally TMCP results in coarse grain size to 20—40 μm based on the processing condition in austenitic stainless steel. Besides, it is not effective. Olson and Cohen[7] proposed a model to account for strain induced martensite (SIM) formation because of cold deformation. However, many studies proved that the martensitic morphology comprised dislocation forests, walls and tangles, and incidental dislocation boundaries, and was severely deformed lath-type martensite and dislocation cell-type martensite in cold deformed low-carbon steel, specialty steels and Fe-Cr-Ni alloys[8-13].

Recently, several kinds of austenitic stainless steels such as 304, 304L, and 316L were subjected to heavy cold deformation and reversion transformation to develop nano/ultrafine-grained (NG/UFG) structure[14-16]. Regarding this matter, a method which is gaining wide acceptance for improving the strength of austenitic stainless steel without degrading ductility is to anneal a heavily cold deformed metastable austenitic stainless steel to produce NG/UFG structure[10,17-19]. And thermomechanical reversion treatment on the basis of SIM transforma-

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Received 12 November 2016; Received in revised form 26 April 2017; Accepted 9 May 2017
Available online 15 December 2017

tion has been regarded as a quite significant approach to obtain NG/UFG structure in austenitic SS[20-25]. It is shown that the structure of NG/UFG can add a lot in toughness while just very small dip in strength[2,3,26]. Severe cold rolling of austenite makes austenite (fcc γ) grain transform to martensite (bcc α′) under the condition of room temperature. It was reported that SIM reverted to austenite either by shear controlled or diffusion controlled mechanism during reversion treatment[14,19,26,27]. Based on different fractions of cold rolling and annealing temperature-time arrangement, different good combination of good strength and toughness can be obtained[14]. In this research, emphasis was laid on the effect of martensitic transformation on NG/UFG structure in 304 SS. Meanwhile, a grain size distribution statistic was done to quantitatively describe the nano/ultrafine grains.

2. Material and Methods

A commercial 304 SS in the form of a sheet with thickness of 7.9 mm was used as the initial material. The composition of the 304 SS is Fe-0.04C-0.16Si-1.52Mn-17.8Cr-8.1Ni-0.005P-0.005S. The samples were heated to 1050 ℃ and held for 12 min to solution treatment. The initial austenite grain size was in the range of 20－40 μm with single-phase of austenite as shown in Fig. 1. Several specimens with dimensions of 600 mm×80 mm were prepared for cold rolling (CR). CR was set at reductions of 20%－80% at room temperature. Simulated annealing experiment was carried out on CCT-AV-II simulated annealing experiment machine. The specimens were heated at a heating rate of 30 ℃/s and then annealed at 700－900 ℃ for 60 s with a cooling rate of 50 ℃/s.

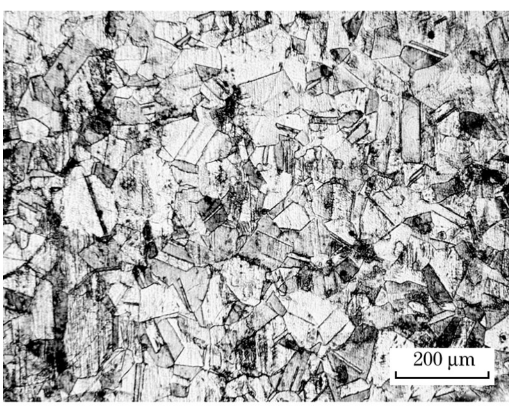

Fig. 1. Initial grain structure after solution treatment of 304 SS.

The microstructural evolutions were analyzed using the optical microscope (Zeiss Axiovert 40MAT), and transmission electron microscope (TEM, Tecnai G2 F30 S-TWIN). X-ray diffraction (XRD) measurements (Rigaku DMAX-RB with CuKα radiation) were employed to identify the phases. The electron backscatter diffraction (EBSD) was applied to determine the microscopic characterization. Before XRD and EBSD, the specimens were prepared by electropolishing at a voltage of 15 V for 30 s, and the electrolyte contained 20 vol. % of perchloric acid and 80 vol. % of ethanol. The tensile tests were carried out at room temperature using the CMT5605 tensile machine. And Vickers micro-hardness values were measured on HV-1000 micro-Vickers durometer.

3. Results and Discussion

Fig. 2 shows XRD patterns of the different cold deformed specimens from the initial specimen (0% CR) to 80% reduction. The initial sample consists of single-phase of austenite with $(211)_γ$, $(110)_γ$ and $(200)_γ$ peaks with the austenite content of 100%, as shown in Fig. 2. It can be seen that with the increase of cold reduction, the content of martensite is increased, while the content of austenite is decreased, observed from the peak intensities in X-ray diffraction. The volume fractions of the martensite phases were calculated using MDI Jade 5.0 based on the XRD results. It is worth noting that after 80% CR, there are two peaks of α′ martensite, namely $(200)_M$ and $(211)_M$ peaks with the high content of SIM 83.2%.

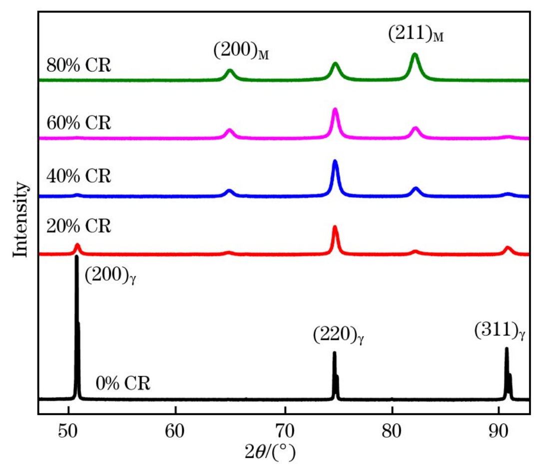

Fig. 2. X-ray diffraction patterns of the cold rolled 304 SS.

The stress-strain results of specimens with different cool rolling reductions are shown in Fig. 3. It clearly demonstrates the effect of rolling on the shape of the stress-strain curves of 304 SS. With the increase of cold rolling, the plastic deformation of the steel is known. The mechanical properties with different reductions of CR are shown in Table 1. With the increase of cold rolling, the strength and hardness of the steel are increased, while the elongation to failure is decreased. Furthermore, it is known that the initial specimen exhibits a low yield strength (YS) of (253±22) MPa, the ultimate tensile strength (UTS) of (733±25) MPa and great elongation (EL) of 69.8%±2%. With 20% CR, the hardness