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Production of nano/submicron grained AISI 304L stainless steel through the martensite reversion process

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ABSTRACT

Production of nano/submicron grained AISI 304L austenitic stainless steel through formation of strain-induced martensite and its reversion to austenite are studied in this paper. The effects of annealing parameters on the microstructural development and mechanical properties are also investigated. Heavily cold rolling at 0 °C is employed to induce the formation of martensite in the metastable austenitic material, followed by reversion treatment at the temperature range of 700–900 °C for 0.5–300 min. Microstructural evolutions are analyzed using Feritscope, X-ray diffraction, and scanning electron microscopy, whereas the mechanical properties are determined by hardness and tensile tests. The smallest grain size (about 135 nm) is obtained in the specimen annealed at 700 °C for 20 min. The resultant nano/submicron grained steel not only exhibits a high strength level (about 1010 MPa) but also a desirable elongation of about 40%. Moreover, an annealing map is developed which indicates the appropriate range of annealing parameters for grain refinement of AISI 304L stainless steel through the martensite reversion process.

1. Introduction

Austenitic stainless steels (ASSs) generally exhibit superior corrosion resistance, high ductility, and excellent weldability. However, yield strength of these steels is relatively low in the annealed state [1,2]. Therefore, these steels are not suitable for structural applications. There are various strengthening mechanisms for ASSs including grain refinement, solid solution strengthening, and work hardening [3,4]. Among these mechanisms, grain refinement is the only method which improves both strength and toughness simultaneously. Grain refinement in ASSs can only be achieved by recrystallization after cold or hot deformation, because no phase transformation is possible at typical annealing temperatures. In ASSs, due to the high recrystallization temperature, strengthening by grain refinement is limited [4,5]. For instance, the smallest austenite grain size that can be obtained by hot deformation-recrystallization process is 10 μm [4]. Therefore, it is difficult to obtain nano/submicron grained ASSs by the conventional thermo-mechanical treatments. However, Takaki et al. [6,7] have suggested a new thermo-mechanical process consisting of heavy cold rolling to induce the formation of martensite and subsequent annealing to reverse the nano/submicron grained austenite from deformation induced martensite, as schematically shown in Fig. 1. To obtain this grain structure, four conditions must be satisfied in this new treatment [4,6–12]:

(1) Metastable austenite phase should be almost completely transformed to strain-induced α′-martensite phase by cold rolling.
(2) The strain-induced α′-martensite should be further heavily deformed during cold rolling so that any lath α′-martensite structure is destroyed prior to reversion treatment. This means that a higher reduction after α′-martensite saturation could result in a higher capability for getting finer austenite grains.
(3) The strain-induced, deformed α′-martensite should be reverted to austenite at temperatures or times as low as possible to suppress grain growth of the reversed austenite.
(4) The martensite start temperature (M_S) of reversed austenite should be below room temperature to obtain completely austenitic structure. Tomimura et al. [8,9] have developed a thermo-mechanical treatment to obtain austenitic structure with a grain size of about 200 nm in a non-commercial metastable ASS with the yield strength of about 0.8 GPa (which is four to five times as large as that of commercial ASSs). Di Schino et al. [5,13], Johanssen et al. [14], Rajasekhara et al. [15], Somani et al. [16], Eskandari et al. [17,18], and Misra et al. [19] have also obtained nano/ultrafine grained structure in some commercial ASSs by using thermo-mechanical treatment. For the first time, Ma et al. [20] have suggested a repetitive thermo-mechanical treatment consisting of a double cold rolling-annealing cycle to produce nanocrystalline austenitic steel. The purpose of this work was to optimize the annealing

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Table 1
Chemical composition of 304L austenitic stainless steel (weight percent).

Type	C	Si	Mn	Cr	Ni	Cu	Mo	Nb	Fe
304L	0.0269	0.427	1.58	18.2	8.22	0.58	0.348	0.0020	Base

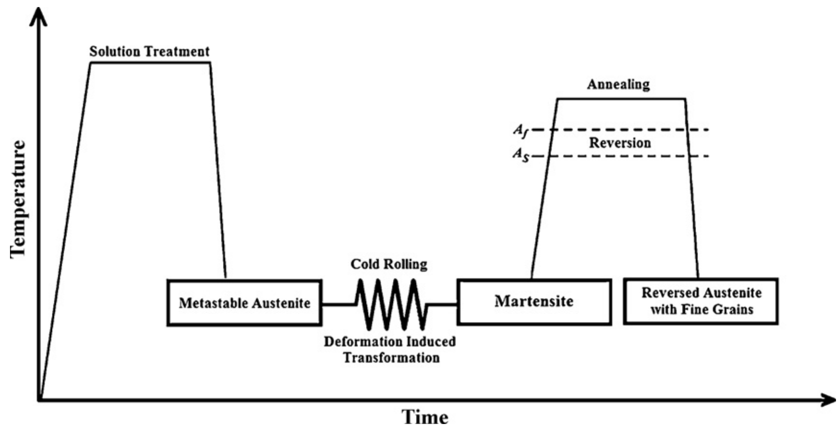

Fig. 1. Thermo-mechanical treatment to achieve ultrafine grains in metastable austenitic stainless steels. A_s and A_f are the reversion start and finish temperatures, respectively.

parameters in the martensitic thermo-mechanical process to produce nano/submicron grained structure in AISI 304L ASS. Besides the importance of this steel in industry, no previous work is reported for production of nano/submicron grained austenite in this steel through the martensite reversion process.

2. Materials and methods

The chemical composition of AISI 304L metastable ASS used in this investigation is shown in Table 1. The steel was received in sheet form with 10 mm thickness in annealed condition. The calculated M_S [21] and M_{d30} (the temperature at which 50% martensite will form at 30% true strain) [22,23], stacking fault energy (SFE) [24], and ASTM grain size of the test material are shown in Table 2. Several specimens with the size of 15 cm × 3 cm were cut from the sheets for cold rolling. The multi-pass unidirectional cold rolling was carried out in a two-high rolling mill under oil lubrication. Different thickness reductions from 10 to 90% at 0 °C using ice and water were applied on the specimens with inter-pass cooling. Cold rolled samples with 90% thickness reduction were then annealed at different temperatures in the range of 700–900 °C. All specimens were then electropolished at 30 V for 30 s by using electrolyte (200 ml perchloric acid and 800 ml ethanol) for microscopic char-

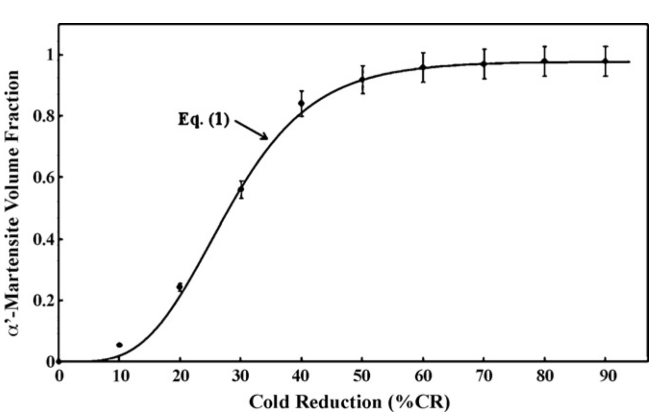

Fig. 2. Volume fraction of α′-martensite as a function of cold reduction in AISI 304L stainless steel at 0 °C and Eq. (1) fitted to this data (the solid line).

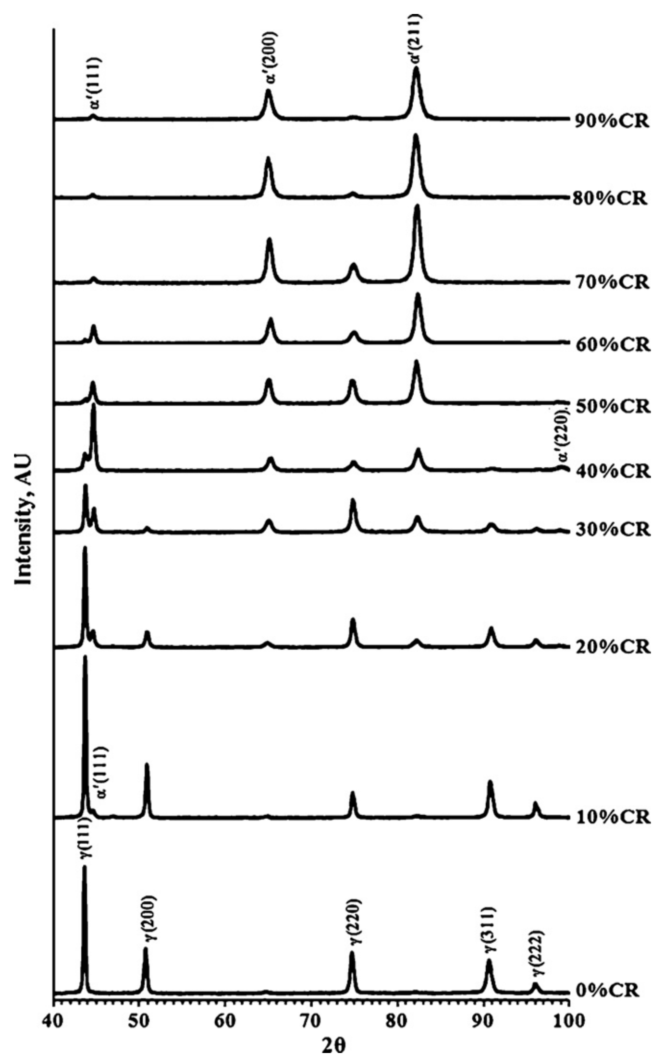

Fig. 3. X-ray diffraction patterns of the cold rolled (0 °C) AISI 304L stainless steel.