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A new insight into manufacturing fine-grained heavy retaining rings

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ABSTRACT

Heavy retaining rings in electric generators are manufactured from high nitrogen Cr—Mn austenitic steels. It is difficult to product fine-grained heavy retaining rings because of their large size and the stable austenitic matrix. Cold expansion is necessary for the production of heavy retaining rings. In this study, the feasibility of cold expansion followed by annealing for manufacturing fine-grained heavy retaining rings was investigated. 18Mn18Cr0.6N steel was cold tensioned to 10–40% and then annealed at 900–1000 °C. Microstructures were observed using electron backscatter diffraction and mechanical properties were measured using tensile test and hardness test. The preferred nucleation sites of static recrystallization were triple junctions and grain and twin boundaries. After two cycles of 40% cold tension and annealing at 1000 °C, the grain size number changed from 1.5 to 8.5. Cold tensioned texture was completely eliminated through static recrystallization. Through the two-cycle process, the yield and ultimate strength, the linear strain hardening rate, and the hardness were enhanced significantly. Cold expansion followed by annealing is a suitable method for manufacturing fine-grained heavy retaining rings. In addition, detailed nucleation mechanisms of static recrystallization at triple junctions, at the recrystallization front, and between two strained grains were discussed, respectively.

1. Introduction

Heavy retaining rings, i.e., rings that tighten coils in electric generator rotors, have to be non-magnetic and have high strength and excellent corrosion resistance. Heavy retaining rings are manufactured from high nitrogen Cr—Mn austenitic steel which has an excellent combination of mechanical, chemical and physical properties because of the beneficial effect of nitrogen [1,2]. The grain size refinement can increase the strength of high nitrogen Cr—Mn austenitic steels via the Hall-Petch mechanism [3,4]. However, coarse-grained structure usually appears during the hot forging process of heavy retaining rings [5].

Wang et al. [6] and Moon et al. [7] suggested optimum hot forging parameters to obtain fine-grained microstructures in high nitrogen Cr—Mn austenitic steels. These data are useful for understanding the forming practice of small and medium components manufactured from high nitrogen Cr—Mn austenitic steels. For heavy retaining rings, the deformation process is long and complex [8]. It is difficult to achieve a fine-grained microstructure by controlling only the hot forging parameters. As-forged grains would further coarsen in the following solution treatment process (at about 1050–1100 °C for 3–10 h). To satisfy the increasing capacity of power plants and withstand the larger centrifugal force, steels with higher nitrogen concentration have to be used [2]. However, these steels are very difficult to melt and costly to produce.

In production, retaining rings require cold expansion to enhance their strength. If expanded rings are subjected to further annealing, the grain structure may be refined by static recrystallization. Previous studies have focused on the hot working [6,7,9], cold working [2, 10–12], and precipitation [13–15] behaviors of high nitrogen Cr—Mn austenitic steels. There is limited information available in the literature relating to the static recrystallization behavior of high nitrogen Cr—Mn austenitic steels. In this study, the cold worked microstructure and its evolution behaviors during annealing were observed for 18Mn18Cr0.6N steel. The mechanical properties of annealed material were examined. The feasibility of cold expansion followed by annealing for manufacturing fine-grained heavy retaining rings is discussed.

2. Experimental procedure

18Mn18Cr0.6N steel was melted in a vacuum electric furnace and then electroslag remelted; its chemical composition is shown in Table 1. Small slabs were cut from the ingot and then passed through several hot rolling processes at 1100 °C. The total true strain during rolling was ~2. The rolled slabs were heat treated at 1200 °C for 1 h and subsequently quenched in water. The average grain size is

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Table 1
Chemical composition of 18Mn18Cr0.6N steel.

Elements	C	Cr	Mn	N	Si	Ni	P	S	Fe
wt.%	0.084	18.06	17.9	0.62	0.46	0.2	0.009	0.002	Bal.

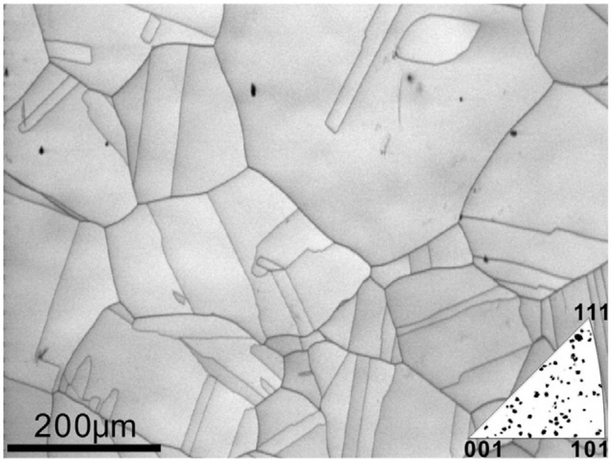

Fig. 1. Band contrast image of specimen annealed at 1200 °C for 1 h.

approximately 210 μm (Fig. 1). No texture exists in this state, as shown in the corresponding inverse pole figure (IPF).

Tensile test was selected to simulate the cold expansion process of heavy retaining rings. Cylindrical tensile specimens 10 mm in diameter and 100 mm in the gauge-length section were machined from the quenched slabs. Specimens were tensioned at a constant speed of 1 mm/min to engineering strains of 10%, 20%, 30%, and 40%, respectively. No necking or cracking appeared on the tensioned specimens. Tensioned specimens were preheated at a rate of 20 °C/s to different temperatures (900 °C, 950 °C, and 1000 °C) and annealed for 1–5 min. Additional bending tests were conducted to examine the applicability of the tensile test results in real situation. Sheet specimens (10 mm in thickness, 20 mm in width, and 100 mm in length) were bent to 120° using Φ10 mm and 20 mm plungers to achieve 40% and 30% bending elongations, respectively [16]. Bent specimens were preheated at a rate of 20 °C/s to 1000 °C and annealed for 5 min.

Annealed specimens were sectioned parallel to initial tensile direction (or bending elongation direction) and then ground. The ground specimens were electro-polished with a solution of 1:15:3 $HClO_4$–CH_3CH_2OH–H_2O at 30 V for 1 min. Electron backscatter diffraction (EBSD) analysis was performed using the TSL-OIM-Analysis software and specimens were studied with a step size of 1 μm and a misorientation detection limit of 1°. High-angle grain boundaries (HAGBs) are defined as those boundaries having a misorientation ≥15°. Low-angle grain boundaries (LAGBs) are defined as those boundaries having a misorientation within 2°–15°. The crystal orientation maps (Figs. 3 and 5–8) showed HAGBs by black lines, LAGBs by grey lines, and twin boundaries by white lines.

Additional tensile tests were performed to examine the strength of annealed specimens. The fracture surfaces were observed using scanning electron microscopy. Hardness measurements were carried out using a Vickers hardness testing machine FM-ARS9000 with a load of 300 g.

3. Results and discussion

3.1. Deformed microstructures

Fig. 2 shows the microstructures obtained from the cold tensioned specimens. In Fig. 2 and all subsequent figures, the horizontal direction is the tensile direction. In the 10% elongation specimen (Fig. 2a), slip traces with different directions appear in several grains. Dark shading indicates that the defects, including dislocations and stacking faults [2], are mainly concentrated in the vicinity of the triple junctions. In the 20% elongation specimen, slip traces appeared in most of the grains (Fig. 2b). The arrow indicates curved slip traces in a distorted grain. When the tensile strain reached 30% (Fig. 2c), the density of slip traces

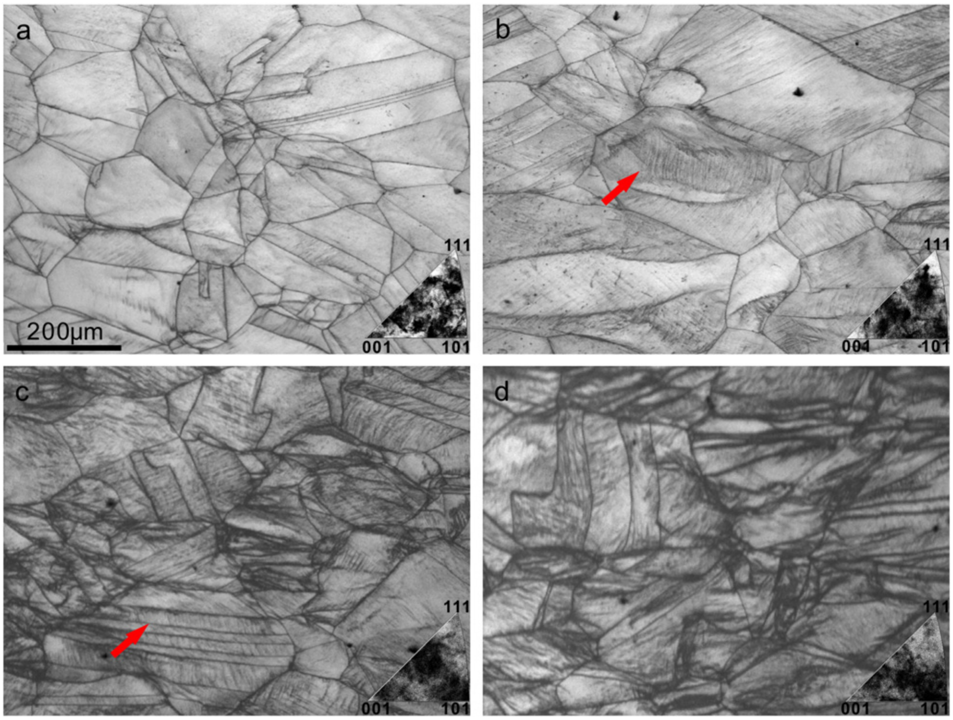

Fig. 2. Band contrast images showing the deformation microstructures obtained from the cold tensioned specimens with: (a) 10%; (b) 20%; (c) 30%; and (d) 40% strain.