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The growth behavior of austenite grain in the heating process of 300M steel

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ABSTRACT

The 300M steel was heated in an electric furnace at the temperatures of 850, 900, 950, 1000, 1050 °C, and holding time of 5, 10, 30, 60, 90, 120 min. The grain size of austenite was measured by using the linear intercept method on Olympus PMG3 metallographic microscope. The experimental results show that grain size of austenite increases with the increasing of heating temperature and holding time, and the grain growth model of austenite in 300M steel is in the following: $d = 4.04 \times 10^6 t^{0.17} \exp(-(1.32 \times 10^5/RT))$.

1. Introduction

The grain growth of austenite in heating process of steel has been focused by many researchers for many years. Sha and Sun [1] investigated the grain growth behavior of austenite in Nb–V–Ti microalloyed steel, and found that the grains of austenite grow up with the increasing of heating temperature; the Ti-rich carbonitrides assembling in the grain boundaries of austenite restrain the grain growth of austenite at the temperature below 1250 °C. Yu and Sun [2] pointed out that the critical growth temperature of austenite grains in 0.015% Nb steel is 1240 °C; the grains of austenite in 0.015% Nb steel are finer than that in Nb free steel in the range of 1150–1230 °C. The austenite grain size in $16MnNi_4$ HSLA steel increases rapidly by heating at 1200 °C for 5–30 min or 1150 °C for 60 min, which was obtained by Fernández et al. [3]. Therefore, the major factors affecting the grain size of austenite are the heating temperature, holding time and alloying elements.

The commercial ultrahigh-strength low alloying steel 300M ($40CrNi_2Si_2MoV$), has been modified by adding the alloying elements of silicon and vanadium in 4340 steel. Because of the high strength, good fracture toughness and fatigue behavior, 300M steel is widely used to manufacture the central spindle, wheel gear, aerofoil fastener and so on. It becomes one of the best steels for manufacturing the aircraft landing system. Much more investigation was carried out for the microstructure and mechanical properties of 300M steel [4–8]. As the coarse grains are generally observed in the manufacturing process of 300M steel forging, many researchers have paid attention to investigate the mechanism of low plasticity and ductility caused by the coarse grains. Zhang et al. [9] pointed out that the 300M steel being fabricated by vacuum induction melting and vacuum arc remelting has higher purity and stronger overheating sensitivity, in which the growth tendency of austenite grain increased and it would result in the occurrence of coarse grains as adopting unsuitable forging method. In terms of the experimental results, two heat treatment processes of 300M steel were suggested so as to eliminate the coarse grains as follows [10]: (1) high temperature normalizing in the temperature range of 970–980 °C, and (2) heated to 700 °C for 60 min and air-cooling, then heated to 930 °C rapidly with holding time of 60 min, and finally cooled in air. However, the growth behavior of austenite grain in the heating process of 300M steel was reported in a few literatures. In this article, the effect of the heating temperature and holding time on the morphology and grain size of austenite in as received 300M steel is investigated. Based on the experimental results, the growth model of austenite grain in 300M steel is presented.

2. Experimental procedures

The chemical composition of as received 300M steel is shown in Table 1, and the morphology of austenite grains is shown in Fig. 1. The as received 300M steel bar is of 22.0 mm in diameter, its A_{c1} temperature and A_{c3} temperature are 748 °C and 802 °C, respectively. The dimensions of experimental specimens machined from as received 300M steel are 10.0 mm × 8.0 mm × 5.0 mm. The heating treatment was carried out in a type SX-5-12 electric furnace

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Table 1
The chemical composition of as received 300M steel (wt.%).

C	Si	Ni	Mn	Cr	Mo	V	Cu	S	P
0.39	1.61	1.82	0.69	0.91	0.42	0.07	0.06	0.0012	0.0089

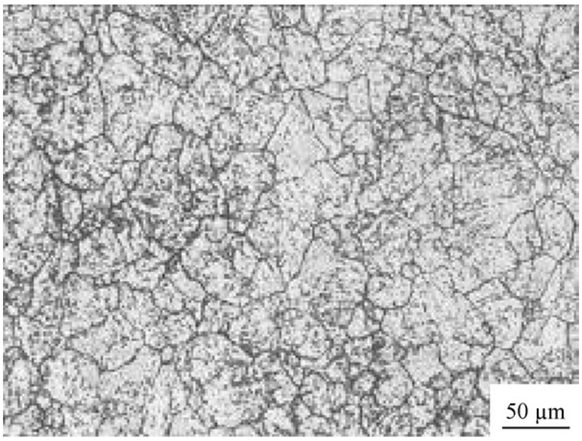

Fig. 1. Morphology of austenite grains in as received 300M steel.

at the heating temperatures of 850, 900, 950, 1000, 1050 °C and holding time of 5, 10, 30, 60, 90, 120 min. After heating treatment, the 300M steel specimens were quenched in water immediately. Those quenched specimens were prepared using standard metallographic techniques. The saturated aqueous picric acid solution with a few drops of detergent was used to reveal the prior austenite grain boundaries, and polished surfaces were etched in that aqueous solution for about 30 min at room temperature. The austenite grains choosing 8 visual fields in every specimen were observed on Olympus PMG3 microscope. The grain size of austenite was measured by using the linear intercept method through SISC IAS V8.0 image software [11], counting more than 400 grains for each specimen so as to ensure the measurement accuracy, and choosing the mean chord length of austenite grain as a measure of austenite grain size.

3. Results and analysis

3.1. Effect of heating temperature on the morphology and grain size of austenite

Fig. 2 shows the morphology of austenite grain in 300M steel at different heating temperatures and a holding time of 5 min. As seen from Fig. 2, the fine austenite grains distribute inhomogeneously as new austenite grains contact with each other, the grain boundary is bend, and the undissolved particles (carbides) occur as shown in Fig. 2a. Adding Cr, Mo and V as alloying elements in 300M steel, the carbides having high melting point and stability occur in 300M steel. Those carbide particles that separate toward grain boundaries affect the diffusion of iron and carbon atoms, and finally prevent the growth of austenite grain in the heating process of 300M steel [12,13]. The grain boundaries reduce and become flat with the increasing of heating temperature being close to an angle of 120°. Grain shapes have a slight change, in which some of the austenite grains grow up and the others shrink or disappear. As the carbides dissolved, the pinning effect of carbides reduces and the austenite grains grow up quickly, meanwhile the austenite grains coarsen as seen from Fig. 2b and c.

Fig. 3 indicates the distribution of austenite grain in 300M steel at different heating temperatures. As seen from Fig. 3, the grain size distribution of austenite is close to lognormal distribution being consistent with the results presented by Han et al. [14] and Kurtz and Carpay [15]. At a temperature of 850 °C, the grain size of austenite is less than 20 μm and mostly in the range of 6–10 μm as shown in Fig. 3a; at a temperature of 950 °C, the number of austenite grains with grain size above 20 μm increases, and that of austenite grains

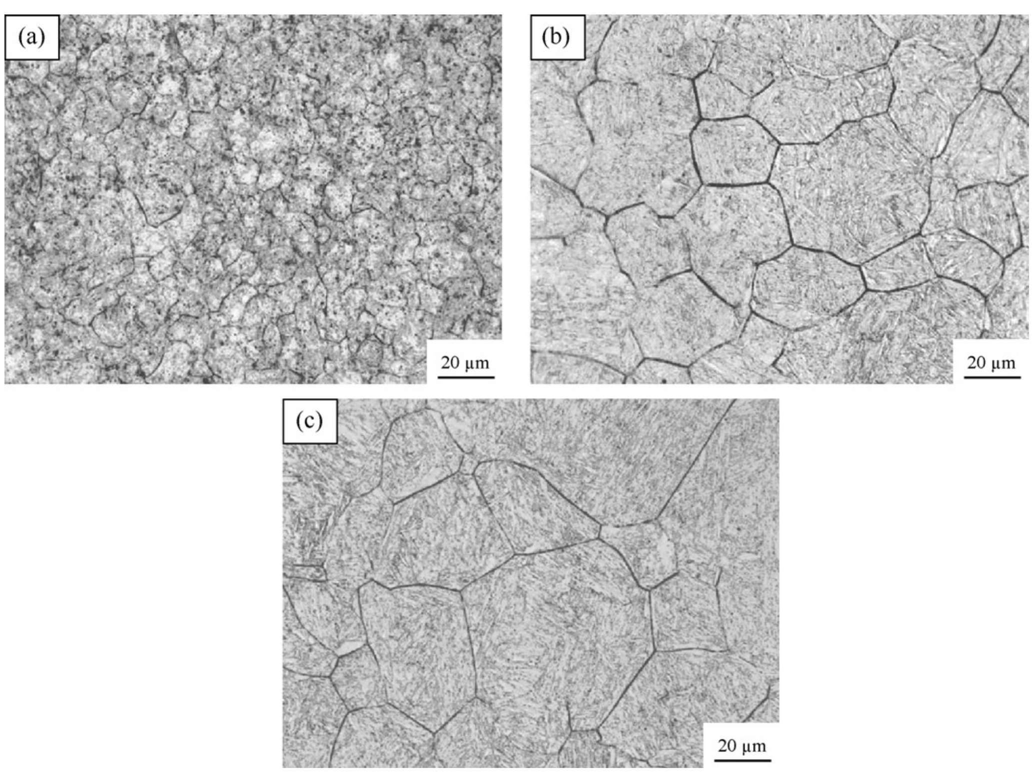

Fig. 2. Effect of the heating temperature on the morphology of austenite grain with holding time of 5 min: (a) 850 °C, (b) 950 °C, and (c) 1050 °C.