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Correlation between mechanism of ordering transformation and microstructure of interfaces in Ni-Cr-W superalloys

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ABSTRACT

It is found that the microstructure of interfaces between superlattices and matrix correlates perfectly with the mechanism of ordering transformation. The mechanism of continuous ordering makes the ordering degree from the center of the superlattice to interface to surrounding disordered matrix become increasingly weaker, leading to an obscure interface which can be regarded as a transition region. In contrast, the mechanism of nucleation and growth makes the whole region of the superlattice completely ordered superstructure, resulting in a sharp interface between superlattice and matrix. The mechanism of ordering transformation can be identified by the microstructure of interface.

1. Introduction

Order hardening as a mechanism to enhance strength of the superstructure alloys for possible use as engineering materials has been studied extensively recently [1–3]. Superstructural ordering, prevalent in several Ni-based superalloys, has been the subject of vigorous studies. The Ni-Cr-Mo/W system, by virtue of it possessing a number of intermetallic compounds containing $C11_b$ (Pt_2Mo-type), DO_{22} and D1a superlattices, has been the prime candidate for such investigations. The center of interest mainly focuses on the nature of short range order (SRO) phase [4–6], the occurrence of metastable or stable long range order (LRO) ordered superlattices [7–11], the effect of LRO superlattices on the mechanical properties of Ni-based superalloys [1–3,12–14]. It has been found that the microstructure of interface between superlattice and matrix correlates with the mode of ordering transformation in this study, but the theme has never been focused on among researchers.

In this letter, Ni-20Cr-18W (wt%) and Ni-35.8W-3.4Cr (wt%) were investigated as our model materials. The microstructure of interfaces between matrix and superlattices was studied by using high resolution transmission electron microscopy (HRTEM). We hope to provide a fundamental understanding and identification method on the mechanism of ordering transformation occurring in Ni-based superalloys.

2. Experimental procedures

The experimental alloys with the composition Ni-20Cr-18W (wt%) and Ni-35.8W-3.4Cr (wt%) were prepared in an arc melting furnace in an argon atmosphere and were melted for six times in order to obtain a homogeneous composition. The ingot was then homogenized at 1200 °C for 24 h in a vacuum environment and furnace cooled to room temperature. The specimens were cut from the homogenized ingot and annealed at 1200 °C for 0.5 h followed by water quenching. Subsequently, the Ni-20Cr-18W specimens were aged at 550 °C for 2 and 200 h then air cooled, and aged at 700 °C for 2 and 200 h then air cooled. The Ni-35.8W-3.4Cr specimens were aged at 800 °C for 0.5 and 20 h then air cooled.

For transmission electron microscopy (TEM), disks of 3 mm diameter were punched out from thin foils of 65 μm thickness. Electron transparent samples for TEM investigation were prepared by electrolytic jet polishing in a solution of 10 vol% perchloric acid in 90 vol% ethanol at −30 °C. TEM experiments were carried out using an FEI Tecnai G^2 F30 microscope operating at 300 kV. Standard TEM techniques such as dark-field (DF) imaging and selected area electron diffraction (SAED) were used to characterize the microstructure. The interfaces between the precipitates and the Ni-based matrix were studied by HRTEM.

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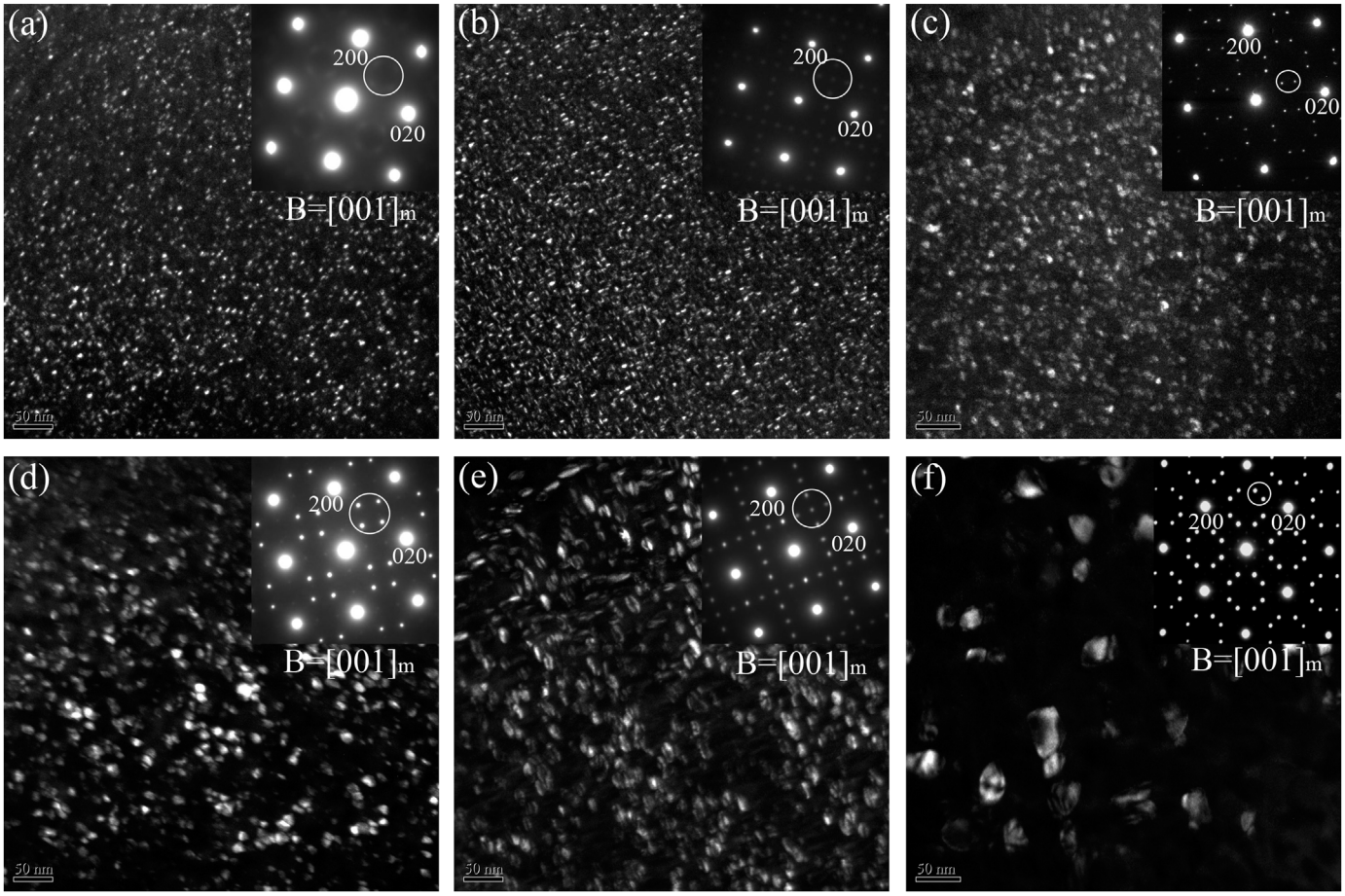

Fig. 1. DF images and corresponding SAED patterns oriented to $[001]_m$ zone axis. (a) and (d) showing the DF images of $C11_b$ phase taken from Ni-20Cr-18W aged at 550 °C for 2 and 200 h, respectively; (b) and (e) showing the DF images of DO_{22} phase taken from Ni-20Cr-18W aged at 700 °C for 2 and 200 h, respectively; (c) and (f) showing the DF images of D1a phase taken from Ni-35.8W-3.4Cr aged at 800 °C for 0.5 and 20 h, respectively. Subscript m represents matrix.

3. Results and discussion

All of the DF images in Fig. 1 was obtained by using the superlattice diffraction spots marked by white circles in the insets in Fig. 1 (including all of the variants of superlattices). On the basis of tilting experiments, it could be concluded that the $C11_b$ and D1a precipitates are shaped in the form of sphere, while the DO_{22} precipitates are shaped in the form of ellipsoidal sticks. As aging time extending from 2 h to 200 h, it could be observed that the particle size of the $C11_b$ phase increased from 3 to 5 nm to 8–10 nm and that of the DO_{22} phase increased from 3 to 5 nm to 17–20 nm along the major axis and 8–11 nm along the minor axis, as shown in Fig. 1(a), (b), (d) and (e). It illustrates that the $C11_b$ and DO_{22} phase grow extremely slowly and have a high thermal stability. Nevertheless, upon aging for 20 h, large D1a precipitates with an average size of 40–55 nm were present in matrix, increasing from 5 to 7 nm at 0.5 h, as shown in Fig. 1(c) and (f). The size of the D1a precipitates and the distance between the particles increased rapidly with the increase of aging time, though the volume fraction seems to remain fairly constant (Fig. 1(c) and (f)), indicating that the D1a superlattice had coarsened. From the ordering transformation kinetics and thermal stability of the superlattice, it can be roughly deduced that the $C11_b$ and DO_{22} phases form by the mechanism of continuous ordering and the D1a precipitates form by the mechanism of nucleation and growth [9,16]. In order to further investigate the microstructure of interface between superlattices and matrix to understand the mechanism of ordering transformation deeply, HRTEM experiments were carried out. One unique aspect observed in the lattice images from Ni-Cr-W alloys in this study was the presence of two completely different types of interfaces, which just correspond to two different mechanisms of ordering transformation.

The lattice images of different kinds of superlattices in the Ni-based matrix are presented in Fig. 2. The crystal structure were identified by the fast Fourier transformed (FFT) diffractogram, as shown in Fig. 2(d), (e) and (f). From the FFT diffractogram oriented to the $[001]_p$ zone axis in Fig. 2(d), the precipitate in Fig. 2(a) were determined to be D1a superlattice. According to the FFT diffractogram oriented to $[100]_p$ zone axis in Fig. 2(e), the precipitate marked by blue square in Fig. 2(c) were identified to be DO_{22} superlattice. From the FFT diffractogram oriented to the $[001]_p$ zone axis in Fig. 2(f), the precipitate marked by brown square in Fig. 2(c) were determined to be $C11_b$ superlattice. By using an inverse fast Fourier transformation (IFFT) for only the examined areas as indicated by the marked square in Fig. 2(b) and (c), the microstructure of interface between DO_{22} or $C11_b$ superlattice and matrix can be clearly observed, as shown in Fig. 3(c) and (d).

The sharp interface between superlattice precipitates and matrix can be observed clearly in Fig. 3(b), while the obscure interface is seen in Fig. 3(c) and (d). The two different types of interface