THE MICROSTRUCTURAL EVOLUTION OF THE COEXISTENCE OF SPINODAL DECOMPOSITION AND ORDERING IN FE-23AL ALLOY DURING AGING

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Abstract:

The microstructural evolution of the coexistence of spinodal decomposition and ordering is characterized by metallographic microscopy and transmission electron microscopy in aged Fe-23Al (i.e. Fe-23at%Al) alloy. This paper discusses a phase transition mechanism of the microstructure evolution. The obtained results indicate that the as-quenched Fe-23Al alloys with equiaxed grain size of about 500μm comprise two kinds of the ordered phase in nano-scale, i.e., B2-FeAl and DO3-Fe_3Al phases. The average size of B2-FeAl ordering phases is about 15nm, while the size of DO3-Fe_3Al ordering phases is extreme fine in the as- quenched Fe-23Al alloys. The as-quenched Fe-23Al alloy presents characteristics of the coexistence of spinodal decomposition and ordering during the subsequent ageing at 565°C and 520°C. The domain size of B2-FeAl ordered phase rapidly increases while the one of DO3-Fe_3Al ordered phase slowly develops with the increase in aging time/with increased ageing time. A conclusion is reached that the coarsening process of both B2-FeAl and DO3-Fe_3Al ordered phase is controlled by the spinodal decomposition mechanism.

1 Introduction

It is well known that spinodal decomposition and ordering are mutually exclusive or opposite processes on the basis of the classic theory of the solid solution. The aggregation of the homogeneous atoms (the spinodal decomposition process) occurs when the interaction force among the homogeneous atoms is stronger than the one among the heterogeneous atoms; otherwise it produces the aggregation of heterogeneous atoms (the ordering process) [1-4]. According to the theory mentioned above, a conclusion was drawn that spinodal decomposition and ordering considered as the two decomposition modes of solid solution could not simultaneously occur. Since the 1970's, however, the coexistence phenomenon of spinodal decomposition and ordering has been discovered in many alloys [5-8], such as Cu-Ti， Fe-Be， Fe-Al, Cu-Zn， Ni-Al, which is opposite to the classic theory of the solid solution. Although many scholars have explicated the coexistence phenomenon of spinodal decomposition and ordering on the basis of thermodynamic theory [9, 10], few studies focus on the dynamic process and micro-mechanism of the coexistence phenomenon. In this paper, the microstructural evolution of the

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coexistence of spinodal decomposition and ordering during the ageing process in Fe-23Al alloy has been experimentally characterized and also the theory of phase transformation (has been) discussed.

2 Experimental investigations

The Fe-23Al binary alloy was prepared by vacuum arc melting using aluminum of 99.99% purity and electrolytic iron of 99.9% purity as raw materials. In order to minimize composition segregation, the synthesized Fe-23Al alloys were repeatedly melted by means of vacuum induction melting and vacuum arc-remelting. The uniform annealing was subsequently performed at 1100°C for 24h followed by furnace cooling (cooling rate=2°C/min) to further minimize composition segregation. After homogenization, the Fe-23Al specimens with dimensions of 30×30×5mm were solution-treated at 800°C (located in α single phase region) for 0.5h followed by water quenching at room temperature, and then the Fe-23Al specimens are aged at 565°C and 520°C, respectively. The microstructures of specimens were characterized by field emission transmission electron microscopy (FEI TACNAI-G^2 F30)

3 Results and Discussion

3.1 The microstructures of the solution-treated Fe-23Al alloy

Fig. 1 presents the metallographic photograph of the Fe-23Al alloy solution-treated at 800°C for

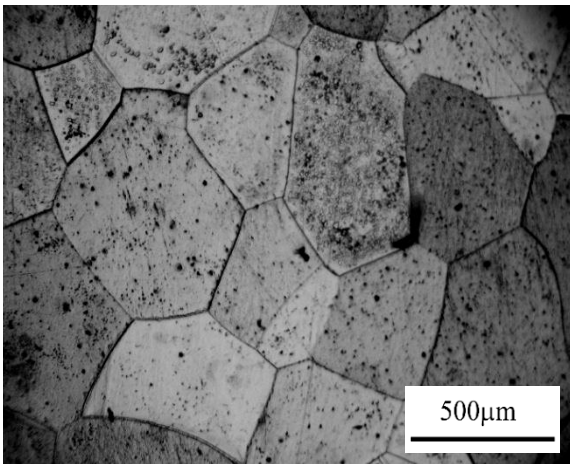


Figure 1. A metallographic photograph of the as - quenched Fe-23Al alloy at 800°C for 0.5h.

0.5h. It can be seen that mean value of the equiaxed grain size in diameter of the as-quenched Fe-23Al alloy is about 500 μm.

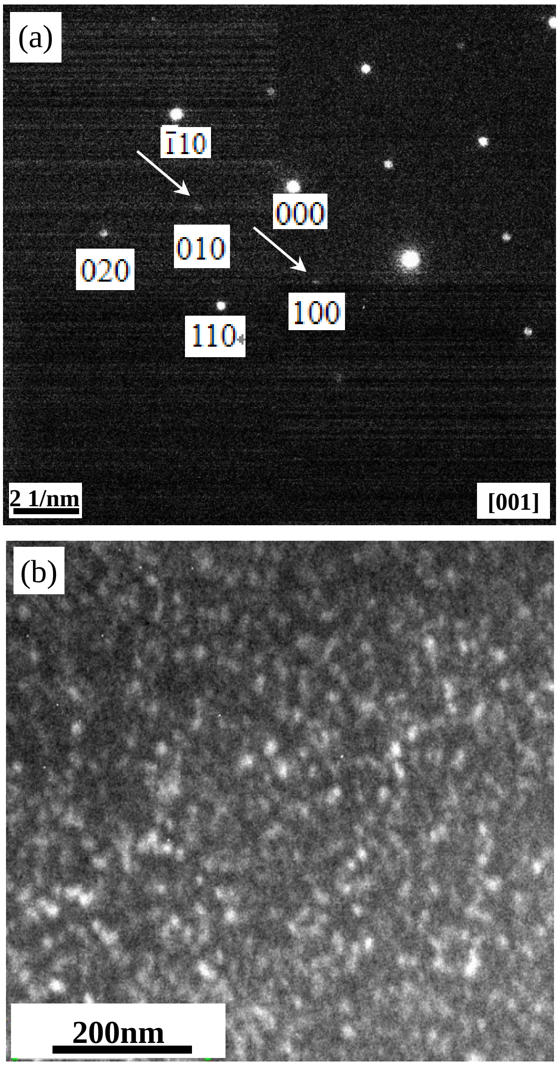


Figure 2. The microstructure of the Fe-23Al alloy solution-treated at 800°C for 0.5h by TEM (a) diffraction pattern for [001] zone axis of α-Fe, (b) dark image of B2-FeAl phase for (100) superlattice spots (equivalently, (200) for DO3-Fe_3Al phase).

Fig. 2 shows the microstructure of the as-quenched Fe-23Al alloy at 800°C for 0.5h using a transmission electron microscope (TEM). As shown in Fig. 2, the superlattice spots corresponding to B2-FeAl (marked in Fig. 2(a)) or DO3-Fe_3Al (marked in Fig. 2(c)) are found respectively, which shows that ordering occurs during the cooling process of the solution-treated Fe-23Al alloy. In fact, the DO3 structure is a superlattice with both the B2 ordering and α-Fe structure, the reciprocal lattice of the DO3 structure contains all the B2 and α-Fe reflections. Therefore, (100) superlattice spot for B2-FeAl phase is equivalent to (200) one for DO3-Fe_3Al phase. The dark-field images corresponding

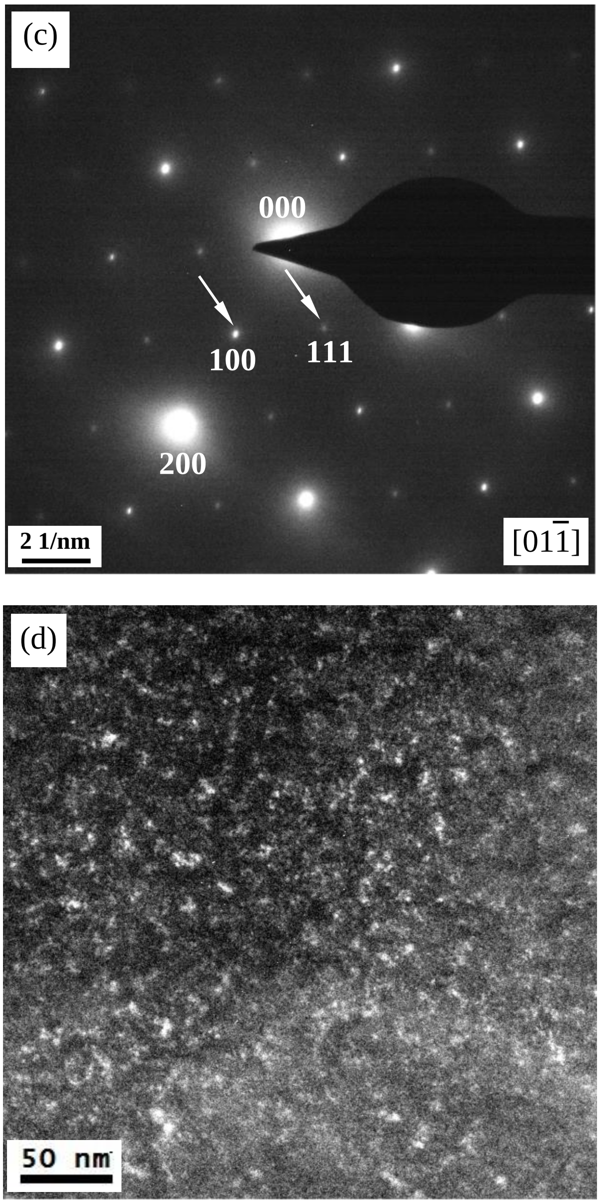


Figure 2. (continuited) (c) selected-area diffraction patterns for [011] zone axis (hkl=DO3 phase), (d) dark image for (111) superlattice spots of DO3-Fe_3Al phase

to the superlattice spots for B2-FeAl or DO3-Fe3Al are displayed in Fig. 2(b) and Fig. 2(d), respectively. The average size of B2-FeAl ordering phases is about 15nm, while the size of DO3-Fe_3Al ordered phases is extremely fine. The different domain size distribution, as shown in Fig. 2(b) and 2(d), reveals the presence of both B2-FeAl and DO3-Fe_3Al ordering phase in the as-quenching Fe-23Al alloy.

3.2 The microstructural evolution of Fe-23Al alloy during aging

Fig. 3 shows the dark-field electron micrographs of the aged Fe-23Al alloy at 565°C (located in the two-phase region of α+B2-type) for variation/varying time. It can be seen that by increasing aging time, the average size of B2-FeAl phase is rapidly increased. By 60 minute aging, the average size of B2-FeAl phase is increased to 100nm. Moreover, the spinodal-like characteristic becomes more obvious with the increase in aging time (Fig. 3). The phenomenon mentioned above seems to suggest that

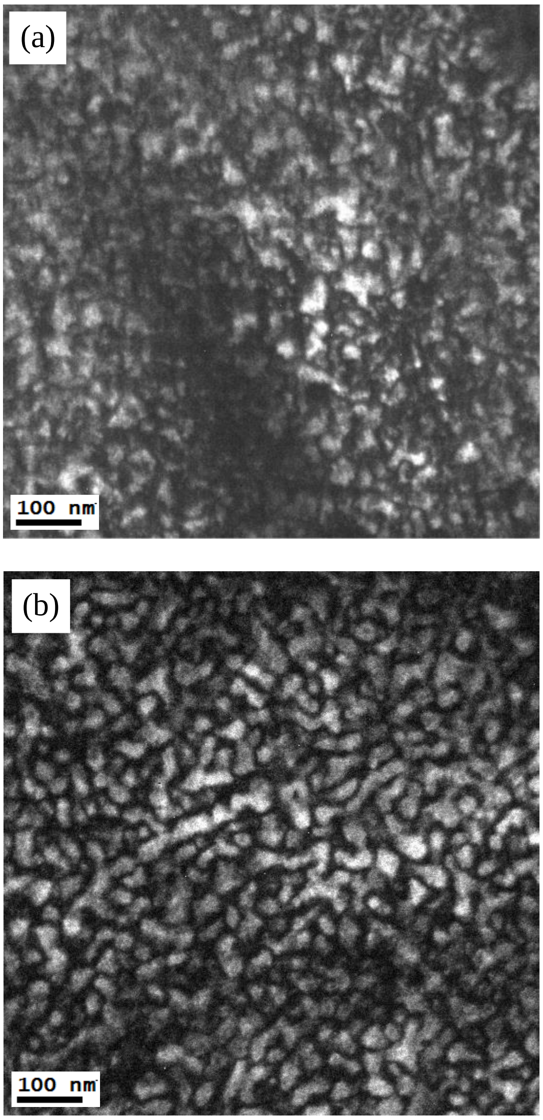


Figure 3. Dark-field electron microstructures for (100) superlattice spots of B2-FeAl phase aged at 565°C for variation/varying time (a) 1min；(b) 3min.

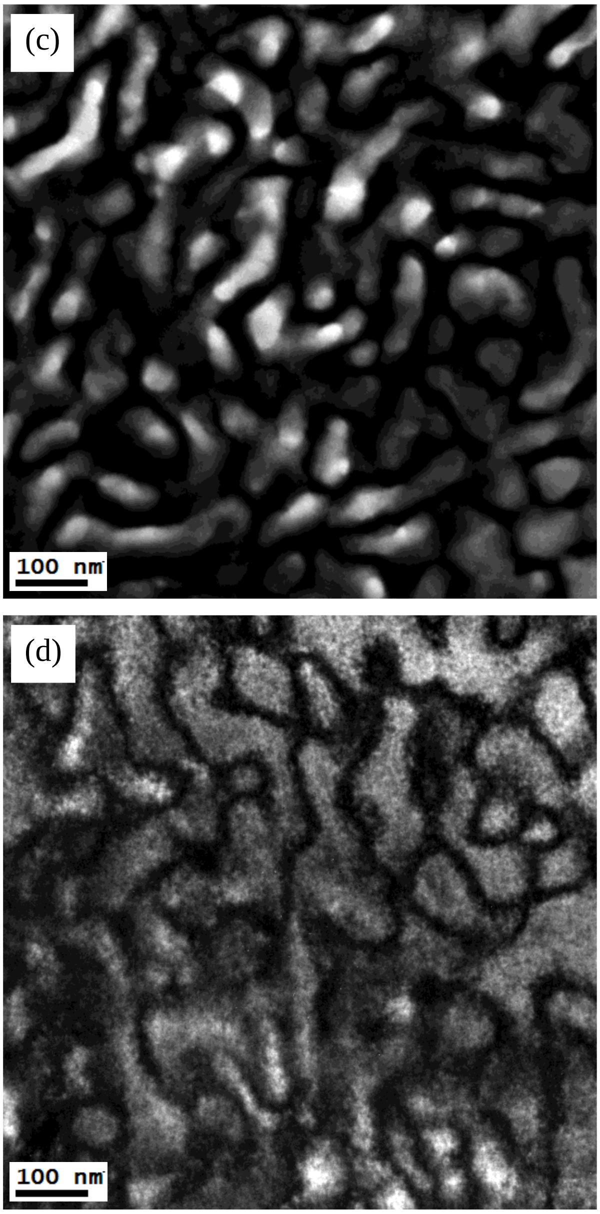


Figure 3. (continued) … (c) 30min；(d) 60min.

the growth of B2-FeAl phase refers to the occurrence of spinodal decomposition, which is to say, the coexistence of spinodal decomposition and ordering occur in the Fe-23Al alloy. It is noteworthy to mention that DO3-Fe_3Al ordered phase always keeps the extreme fine morphology in the aging process at 565°C (Fig. 4).

Fig. 5 shows the dark-field electron micrographs of Fe-23Al aged at 520°C (located in the two-phase region of α+DO3-type) for variation/ varying time. It can be seen that by aging time, the average size of DO3-Fe_3Al ordered phase is slowly increased and is about 50nm for 120min, which attributes to the stable foam structure [11]. The modulated morphology is also found during the coarsening process of DO3-Fe_3Al ordered phase aged at 520°C.

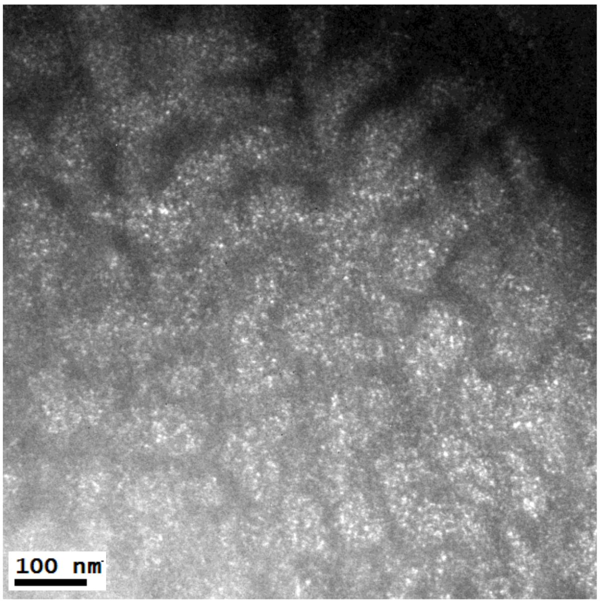


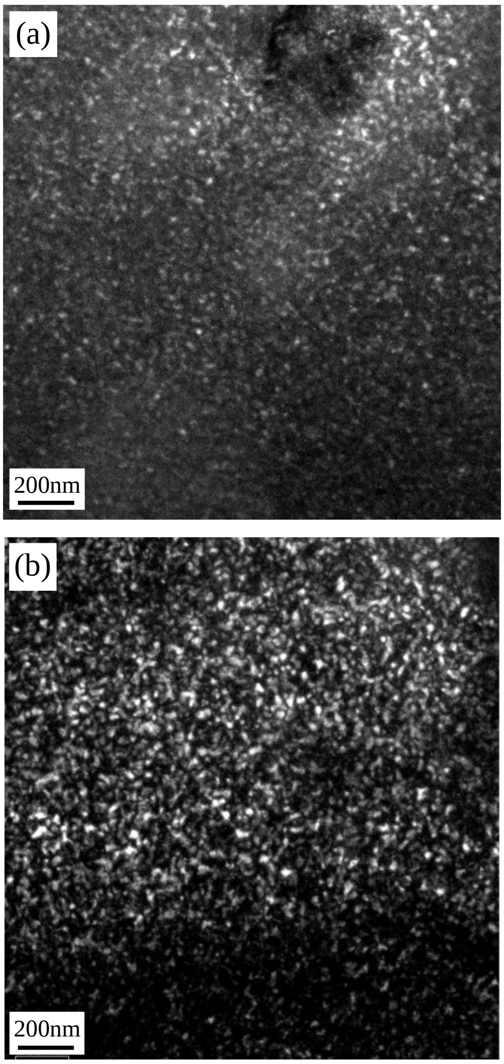
Figure 4. Dark-field electron microstructures for (111) superlattice spots of DO3-Fe_3Al phase aged at 565°C for 60min

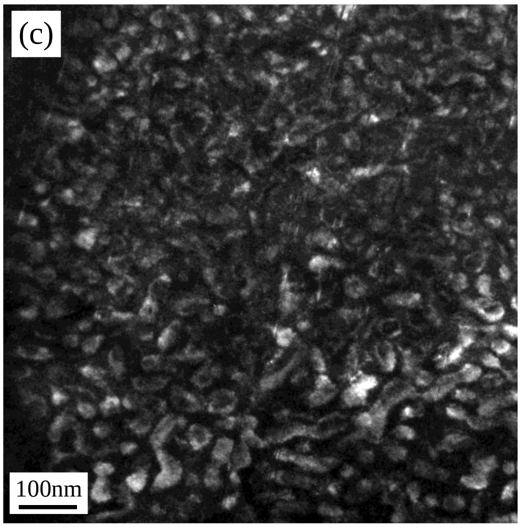
3.3 Discussion

It is worth noting that the microstructures present the modulated characteristics in the coarsening process of both B2-FeAl or DO3-Fe_3Al ordered phase of Fe-23Al aged at 565°C (α+B2 phase region) and 520°C (α+DO3 phase region), respectively. Furthermore, the hardness of Fe-23Al alloy increases continuously in the early stage of aging process at both 565°C and 520°C (Fig. 6). However, the hardness of the aged Fe-23Al alloy is decreased by coarsening B2-FeAl or DO3-Fe_3Al ordered phase, because the ordering domain boundary is continuously reduced in this process when the energy is higher. In fact, the spinodal decomposition process should result in the increase in the strength and hardness, which also confirms the occurrence of spinodal decomposition in the coarsening process of the ordered phases. So, a conclusion is reached that the composition modulation in the process of spinodal decomposition benefits element redistribution in the coarsening process of the ordered phases. It follows that there is the coexistence of spinodal decomposition and ordering *during coarsening of the ordered phases performed by spinodal decomposition mechanism in Fe-23Al alloy during aging. Fe-23Al alloy undergoes coarsening of the ordered phases performed by spinodal decomposition mechanism.

4 Conclusion

(1) The Fe-23Al alloys of solution heat-treated at 800°C with equiaxed grain size of about 500 μm comprises two ordered phase in nanoscale, i.e., B2-FeAl and DO3-Fe_3Al.
(2) Fe-23Al alloy presents the coexistence characteristics of spinodal decomposition and ordering during aging at 565°C and 520°C. The domain size of B2-FeAl ordered phase rapidly increases, while the one of DO3-Fe_3Al ordering phase slowly develops with the aging time.
(3) The coarsening process of both B2-FeAl and DO3-Fe_3Al ordered phase is performed by the spinodal decomposition mechanism.





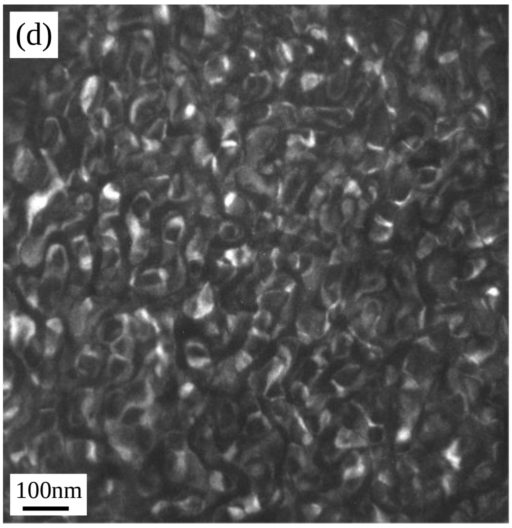


Figure 5. Dark-field electron microstructures for (111) superlattice spots of DO3-Fe_3Al phase aged at 520°C for variation time (a) 5min, (b) 10min, (c) 60min, (d) 120min.

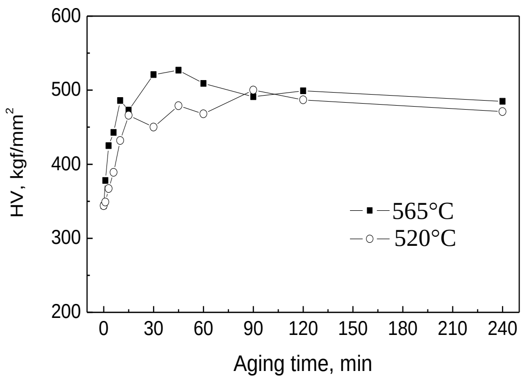


Figure 6. Aged behaviors of Fe-23Al alloy at different temperature.

Acknowledgement

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