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AS-QUENCHED MICROSTRUCTURES OF Cu-14.2Al-xNi ALLOYS

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Introduction

The as-quenched microstructure of the Cu-Al-Ni alloy has been studied by other workers [1–4]. Several investigators reported that when an alloy with a chemical composition in the range of Cu-(14–15.1) wt% Al-(3.1–4.3) wt% Ni was solution heat-treated at a point in the single β phase (disordered body-centered cubic) region and then quenched into room-temperature water, the microstructure was single $D0_3$ phase [1–3]. However, Otsuka et al. [4] reported that a high density of extremely fine particles with a mottled structure could be observed within the $D0_3$ matrix in a Cu-14.2 wt% Al-4.3 wt% Ni alloy. By using electron diffraction, the crystal structure of the extremely fine particles was determined to be of the 2H-type [4].

In order to clarify the discrepancy between these observations, a transmission electron microscopy study was performed to investigate the as-quenched microstructure of the Cu-14.2Al-4.3Ni alloy. To date, most examinations were focused on Cu-Al-Ni alloys with Ni \leq 4.3 wt%, another purpose of this work is thus to investigate the as-quenched microstructure of Cu-Al-Ni alloys with a higher nickel content.

Experimental Procedure

Three alloys, Cu-14.2 wt% Al-4.3 wt% Ni (Alloy A), Cu-14.2 wt% Al-6.0 wt% Ni (Alloy B) and Cu-14.2 wt% Al-10.0 wt% Ni (Alloy C), were prepared by using 99.99% copper, 99.99% aluminum and 99.9% nickel. The melts were chill cast into $30 \times 50 \times 200$ -mm-copper molds. After being homogenized at 1000°C for 72 hours, the ingots were sectioned into 2-mm-thick slices. These slices were subsequently heat-treated at 1000°C (in the single β -phase state) for 1 hour and then quenched into room-temperature water.

Electron microscopy specimens were prepared by means of a double-jet electropolisher with an electrolyte of 67% methanol and 33% nitric acid. The polishing temperature was kept in the range from -20°C to -10°C and the current density was kept in the range from 3.0×10^4 to 4.0×10^4 A/m². Electron microscopy was performed on a JEOL 2000FX scanning transmission electron microscope operating at 200 kV.

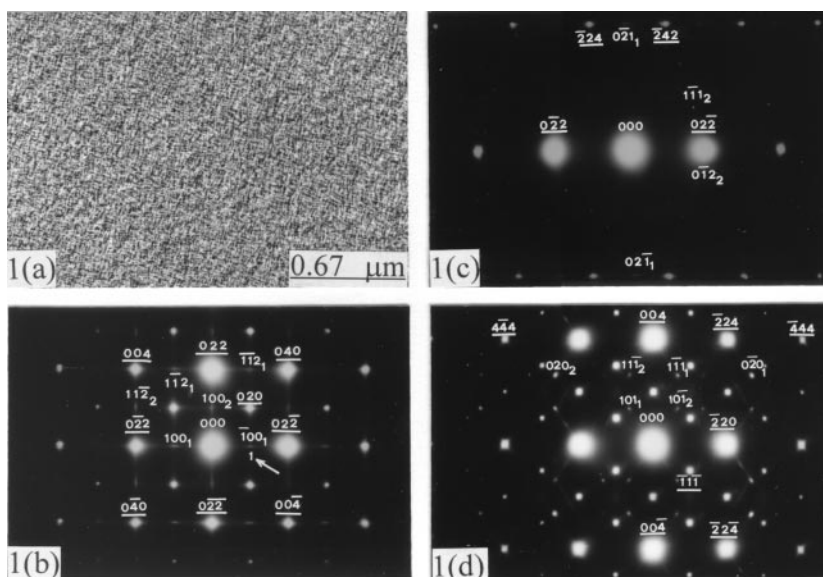


Figure 1. Electron micrographs of the as-quenched alloy A. (a) BF, and (b) through (i) eight SADPs. The zone axes of the $D0_3$ phase are (b) [100], (c) [311], (d) [211], (e) [110], (f) [331], (g) [111], (h) [321] and (i) [331], respectively ($hkl = D0_3$ phase, $hkl_{1, \text{ or } 2} = \text{L-J phase, 1: variant 1; 2: variant 2}$). (j)-(k) $g = [200]$ and $g = [111]$ DF micrographs. (l) DF micrograph, which was taken with the reflection spot marked as 1 in (b).

Results and Discussion

Figure 1(a) is a bright-field (BF) electron micrograph of the alloy A in the as-quenched condition, exhibiting that a high density of extremely fine particles with a mottled structure was formed within the matrix. Figures 1(b) through (i) show eight different selected-area diffraction patterns (SADPs) of the as-quenched alloy. In these SADPs, it is seen that in addition to the reflection spots corresponding to the $D0_3$ phase [4–7], the diffraction patterns also consist of extra spots caused by the presence of the extremely fine particles. Compared to our previous study in a $\text{Cu}_{2.2}\text{Mn}_{0.8}\text{Al}$ alloy [8], it is found that the positions and streak behaviors of the extra spots are the same as those of the L-J phase with two variants. The L-J phase has an orthorhombic structure with lattice parameters $a = 0.413$ nm, $b = 0.254$ nm and $c = 0.728$ nm. Figure 1(j) is a $g = [200]$ dark-field (DF) electron micrograph of the as-quenched alloy, indicating that no $a/4\langle 111 \rangle$ anti-phase boundaries (APBs) could be observed. This feature is similar to that observed by other workers in an as-quenched Cu-14Al-4Ni alloy [2]. Figure 1(k), a $g = [111]$ DF electron micrograph of the same area as Figure 1(j), reveals the presence of the $D0_3$ domains with $a/2\langle 100 \rangle$ APBs. In this figure, it is also seen that a high density of the extremely fine L-J particles (dark contrast) was present within the $D0_3$ domains. Figure 1(l), a DF electron micrograph taken with the reflection spot marked as 1 in Figure 1(b), exhibits the presence of the extremely fine L-J particles. Accordingly, it is concluded that the microstructure of the alloy A in the as-quenched condition was $D0_3$ phase containing extremely fine L-J particles.

Transmission electron microscopy examinations of thin foils indicated that the as-quenched microstructure of the both alloy B and alloy C was also $D0_3$ phase containing extremely fine L-J particles, which is similar to that observed in the alloy A. The examples are shown in Figures 2 and 3, respectively. By comparing Figures 1 through 3, three important experimental results are given below. (I) The amount of the extremely fine L-J particles was increased with increasing the nickel content. Correspondingly, the intensity of the reflection spots and streaks of the L-J particles was also increased

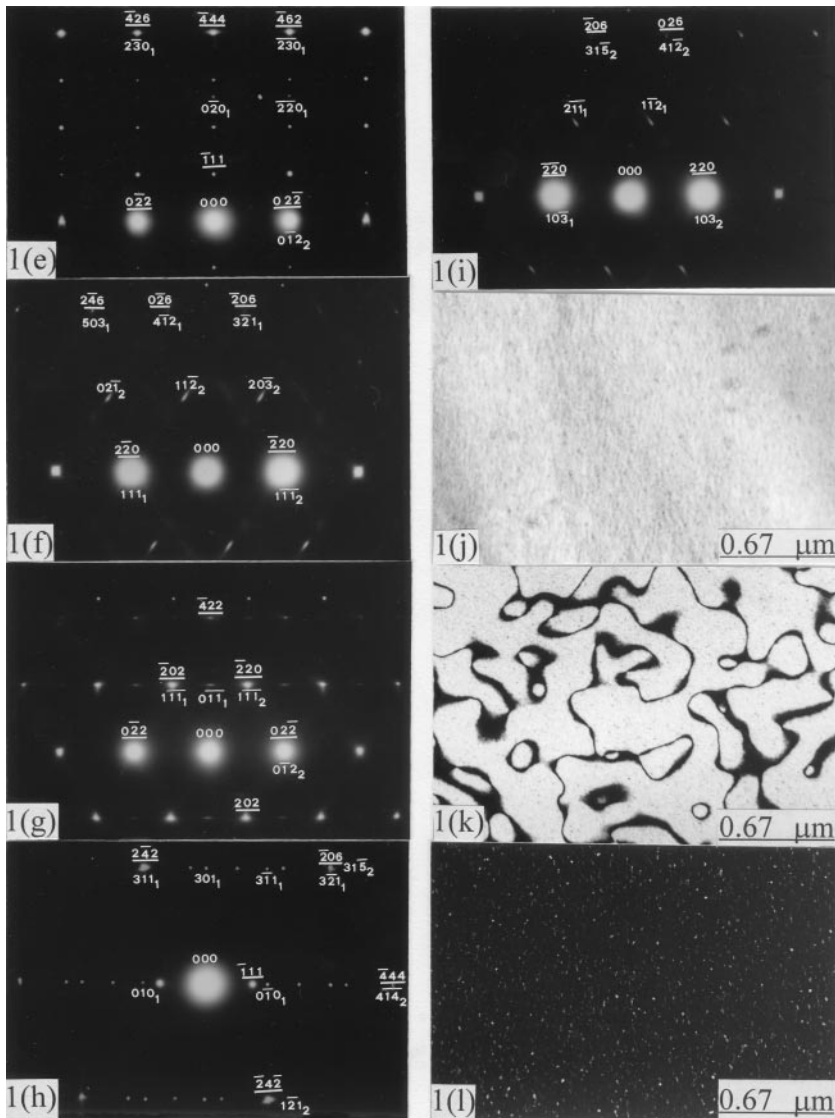


Figure 1. (Continued)

with increasing the nickel content. (II) The size of the $D0_3$ domains was decreased with increasing the nickel content. (III) In the $g = [200]$ DF electron micrographs, it is seen that no evidence of the $a/4\langle 111 \rangle$ APBs could be detected in the both alloy A and alloy B. However, the $a/4\langle 111 \rangle$ APBs were clearly present in the alloy C.

On the basis of the preceding results, some discussion is appropriate. In the previous study [4], it was reported that the as-quenched microstructure of the Cu-14.2Al-4.3Ni alloy was $D0_3$ phase containing extremely fine particles. The crystal structure of the extremely fine particles was determined to be of the 2H-type, which was analyzed by using four different SADPs. The 2H phase has an orthorhombic structure with lattice parameters $a = 0.4274$ nm, $b = 0.5393$ nm and $c = 0.4127$ nm. Compared the previous study and the present work, it is seen that the positions and streak behaviors of the extra spots

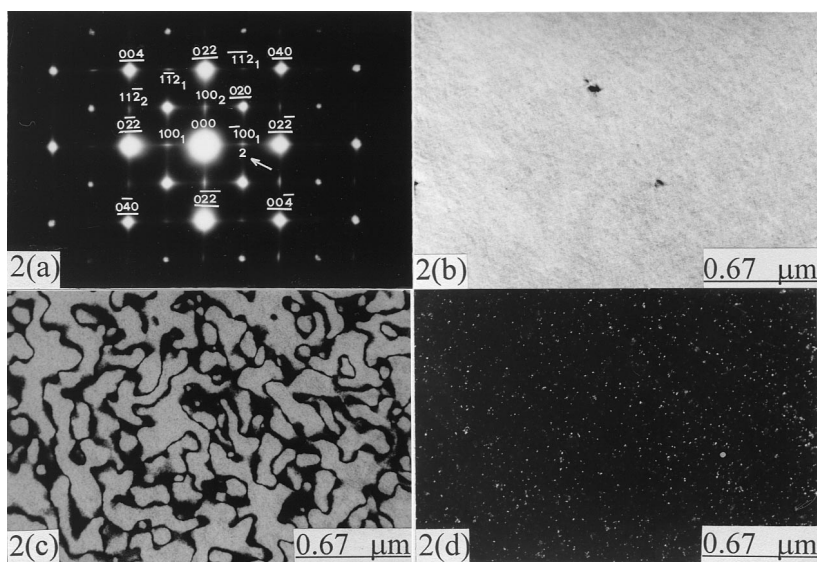


Figure 2. Electron micrographs of the as-quenched alloy B. (a) an SADP. The zone axis of the $D0_3$ phase is $[100]$. (b)-(c) $g = [200]$ and $g = [111]$ DF micrographs. (d) DF micrograph, which was taken with the reflection spot marked as 2 in (a).

in their four SADPs are the same as those in Figures 1(b) through (e), respectively. However, a further analysis indicated that the extra spots in Figures 1(f) through (i) could not be indexed completely in terms of the lattice parameters of the 2H phase; whereas, compared to our previous study in the $\text{Cu}_{2.2}\text{Mn}_{0.8}\text{Al}$ alloy [8], it is found that all of the positions and the streak behaviors of the extra spots in Figures 1(b) through (i) are the same as those of the L-J phase. Therefore, it is proposed that the

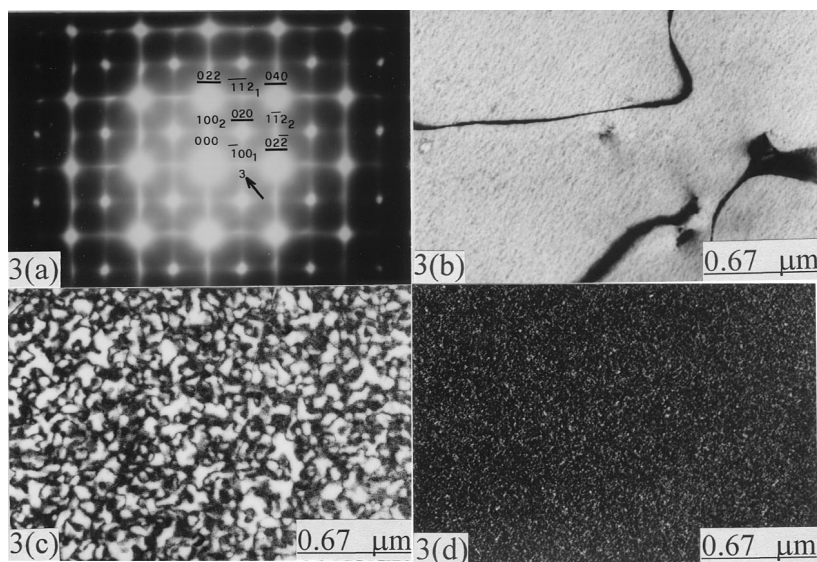


Figure 3. Electron micrographs of the as-quenched alloy C. (a) an SADP. The zone axis of the $D0_3$ phase is $[100]$. (b)-(c) $g = [200]$ and $g = [111]$ DF micrographs. (d) DF micrograph, which was taken with the reflection spot marked as 3 in (a).

extremely fine particles formed in the present alloys should belong to the L-J phase, rather than 2H phase.

In the Cu-Al, Cu-Al-Mn, Fe-Al and Fe-Al-Mn alloys [9–14], it is well-known that if the $D0_3$ phase was formed by continuous ordering transition during quenching, it was always occurred through an $A2$ (disordered bcc) $\rightarrow B2 \rightarrow D0_3$ transition. The $A2 \rightarrow B2$ transition produced $a/4\langle 111 \rangle$ APBs and the $B2 \rightarrow D0_3$ transition produced $a/2\langle 100 \rangle$ APBs [9–10]. However, to date, no $a/4\langle 111 \rangle$ APBs could be observed by other workers in the Cu-Al-Ni alloys [2]. In the present study, it is indeed found that no evidence of the $a/4\langle 111 \rangle$ APBs could be observed in the both alloy A and alloy B, which contain 4.3 wt% and 6.0 wt% nickel, respectively. However, when the nickel content was increased to 10.0 wt% (alloy C), the $a/4\langle 111 \rangle$ APBs could clearly be observed. This result seems to imply that in the Cu-Al-Ni alloys with $Ni \leq 6.0$ wt%, the size of the B2 domains could be equivalent to the grain size. However, the increase of the nickel content could decrease the B2 domain size significantly. Therefore, the $a/4\langle 111 \rangle$ APBs became visible, as observed in Figure 3(b).

Finally, it is worthwhile to point out that although the effects of nickel addition on the microstructure of the Cu-Al binary alloy have been extensively studied by many workers [1–4,15–17], no information concerning this addition on the ordering transition temperature of the Cu-Al binary alloy has been provided. In the present study, it is obviously seen that the size of the $D0_3$ domains was decreased with increasing the nickel content. The result implies that the increase of the nickel content would lower the $B2 \rightarrow D0_3$ ordering transition temperature. This feature is similar to that found by the present workers in an Fe-23.2Al-4.1Ni alloy [18]. In the previous study, we have shown that the addition of nickel to the Fe-Al alloy could lower the $B2 \rightarrow D0_3$ ordering transition temperature.

Conclusions

1. In the as-quenched condition, the microstructure of the alloys A, B and C was $D0_3$ phase containing extremely fine particles. The extremely fine particles should belong to the L-J phase, rather than 2H phase. The amount of the L-J particles was increased with increasing the nickel content. On the contrary, the size of the $D0_3$ domains was decreased with increasing the nickel content.
2. No evidence of the $a/4\langle 111 \rangle$ APBs could be detected in the both alloy A and alloy B. However, the $a/4\langle 111 \rangle$ APBs were clearly observed in the alloy C. This result seems to imply that the increase of the nickel content in the Cu-Al-Ni alloys could decrease the B2 domain size.

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