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Characterization of precipitation behaviors in a non-stoichiometric Cu-24.5at.%Al-19.4at.%Mn alloy

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ABSTRACT

Scanning and transmission electron microscopy examinations of Cu-24.5at.% Al-19.4at.% Mn (similar to $Cu_{2.2}Mn_{0.8}Al$) alloy were performed after aging at temperatures ranging from 350 °C to 700 °C for various durations. It was observed that only γ-brass type and L-J phases were formed after aging at or below 400 °C. On the other hand, the β-Mn phase was formed after aging at temperatures ranging from 500 °C to 650 °C. It is noteworthy that the precipitation behaviors of the γ-brass type and β-Mn phases are different at different aging temperatures. This remarkable result differs from those reported in previous studies on the $Cu_{3-X}Mn_XAl$ alloys with $X \leqq 1$.

1. Introduction

Many studies have focused on phase decomposition in Cu-Al-Mn ternary alloy systems [1–12]. These studies have revealed that when $Cu_{3-X}Mn_XAl$ alloys are quenched from a high-temperature β-phase (disordered b.c.c.) region, they undergo either a $\beta \rightarrow B2 \rightarrow (D0_3+L2_1)$ phase transition sequence with $0.4 \le X \le 0.8$ or a $\beta \rightarrow B2 \rightarrow L2_1$ two-stage ordering transition with $X=1$ [2,6–8]. In addition, many studies have focused on phase precipitation in $Cu_{3-X}Mn_XAl$ alloys, particularly that in the Cu_2MnAl alloy, through X-ray diffraction, electron microprobe, resistometry, and magnetometry analyses [4,5,9–12]. These studies have revealed that γ-brass type, T-Cu_3Mn_2Al, and β-Mn phases are formed at grain boundaries or on other structural defects in the Cu-Al-Mn alloy systems after aging at temperatures ranging from 360 °C to 700 °C [5,9,10].

However, a previous study [13] reported that an L-J phase with two variants existed within the $(D0_3+L2_1)$ matrix in an as-quenched and aged $Cu_{2.2}Mn_{0.8}Al$ alloy. The L-J phase has an orthorhombic structure with lattice parameters $a=0.413$ nm, $b=0.254$ nm, and $c=0.728$ nm. And the orientation relationship between the L-J phase and $(D0_3+L2_1)$ matrix was also determined to be $(100)L-J//(0\bar{1}1)m, (010)L-J//(1\bar{1}\bar{1})m$, and $(001)L-J//(211)m$. Meanwhile, the rotation axis and angle pairs between two variants of the L-J phase were $[021]_{L\text{-}J}$ and 90°. Furthermore, when the as-quenched $Cu_{2.2}Mn_{0.8}Al$ alloy was aged at 350 °C for a moderate duration, it was found that the matrix exhibited a well-developed $(D0_3+L2_1)$ modulated microstructure and that the γ-brass type phase precipitated at the $a/2<100>$anti-phase boundaries (APBs) in the early stage. Subsequently, after aging at 350 °C, the γ-brass type precipitates preferentially grew further with aggregations along the $<100>$crystallographic direction. Here, it is important to note that other studies on $Cu_{3-X}Mn_XAl$ alloys with $X<1$ have not yet reported the precipitation behavior and coexistence of $(D0_3+L2_1+\text{L-J}+\gamma\text{-brass type})$ phases within the miscibility gap [14]. Although many studies have clarified the phase decomposition of the Cu_2MnAl Heusler alloy [5,10–12], few have clarified the precipitation behaviors and microstruc-

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tural changes in $Cu_{3-X}Mn_XAl$ alloys with $X<1$ [4,8]. Therefore, this study investigates the precipitation behavior and the corresponding microstructural change in $Cu_{2.2}Mn_{0.8}Al$ alloy at temperatures ranging from 350 °C to 700 °C by means of scanning and transmission electron microscopy. Consequently, some unique precipitation behaviors are reported, and these differ from those reported in other studies through X-ray diffraction electron microprobe, resistometry, and magnetometry analyses of $Cu_{3-X}Mn_XAl$ alloys with $X<1$.

2. Experimental Procedures

The Cu-24.5at.%Al-19.4at.%Mn alloy (similar to $Cu_{2.2}Mn_{0.8}Al$) was prepared in an induction furnace under a protective argon atmosphere by using 99.9% copper, 99.9% manganese, and 99.97% aluminum. The melt was chill cast into a copper mold. After being homogenized at 850 °C for 72 h, 2-mm-thick ingots were cut from the alloy. These ingots were subsequently heat-treated at 850 °C for 1 h and then rapidly quenched in iced brine. Aging treatment was carried out at temperatures ranging from 350 °C to 700 °C for various durations in a vacuum heat-treated furnace, following which rapid quenching was carried out.

The scanning and transmission electron microscopy specimens were prepared by means of a double-jet electropolisher with a mixture of 70% methanol and 30% nitric acid as the electrolyte. The polishing temperature was maintained in the range from −40 °C to −30 °C, and the current density was maintained in the range from 3.0×10^4 to 4.0×10^4 A/m^2. Scanning electron microscopy was performed using a JEOL 6500 F operating at 15 kV and transmission electron micros-

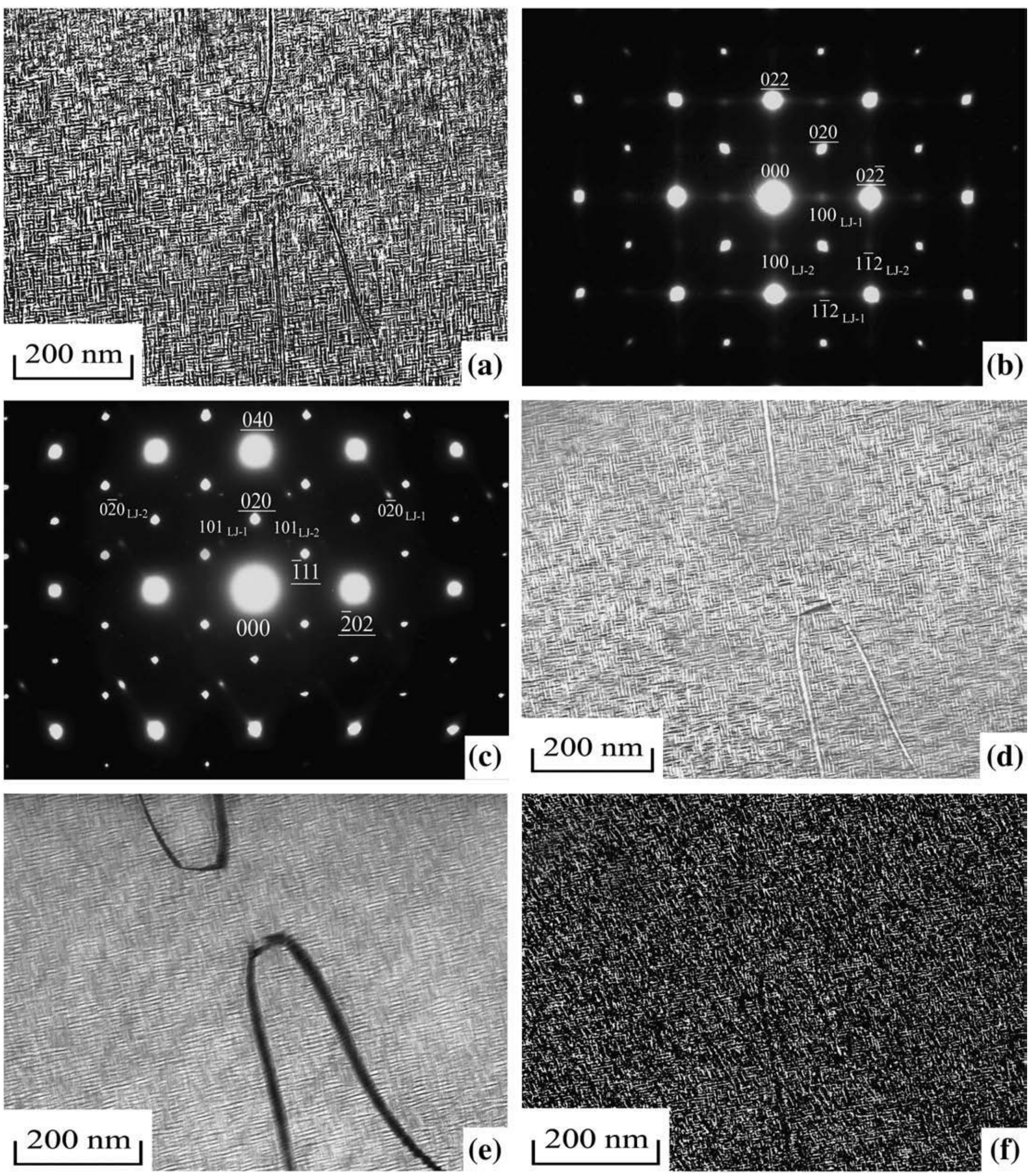

Fig. 1 – Electron micrographs of the as-quenched alloy. (a) BF, (b) and (c) two SADPs. The zone axes of the ($D0_3+L2_1$) matrix are [100] and [101], respectively (hkl: ($D0_3+L2_1$), $hkl_{LJ-1,\ LJ-2}$: corresponding to the variant 1 or 2 of the L-J phase), (d) and (e) are the (020) and ($\bar{1}11$) ($D0_3+L2_1$) DF images, respectively. (f) the (100_{LJ-1}) L-J DF image.