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Precipitation behavior of plastically deformed CuAgZr alloy

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Abstract

CuAgZr alloy is well known for good compromise between high strength and high conductivity. The strengthening is mainly contributed by the self-aligned nanosize Ag precipitate on {111} planes in the Cu matrix. In this study, the nature of Ag precipitate in Cu–7wt%Ag–0.05wt%Zr during thermal processing is characterized to understand the alloy microstructures and thus improve its mechanical strength and electrical conductivity. The solution treated CuAgZr alloy samples were cold rolled with logarithmic strain of 2.3 and subsequently aged at various times. The complementary small angle X-ray scattering (SAXS) and X-ray diffraction (XRD) techniques indicate the evolution of precipitate size during different thermal routines. The radius of gyration of precipitate estimated from SAXS measurement agrees with the measured size from TEM investigation. This paper discusses the effect of plastic deformation on the Radius of gyration size of nanoscale Ag precipitate.

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Keywords: copper alloy; precipitation; small angle X-ray scattering; deformation

1. **Introduction**

CuAgZr alloy has been recognized as a high strength and high conductivity copper alloy (Gaganov et al., 2006; Sakai et al., 2009). This alloy can be strengthened along with increasing electrical conductivity through a precipitation hardening process (Lin and Meng, 2008; Xu et al., 2012). Therefore, it is important to understand the precipitation sequences and hardening mechanism during the aging process to successfully gain a good compromise between its strength and electrical conductivity. Precipitation mechanism in Cu–7wt%Ag–0.05wt%Zr has been characterized by High resolution TEM in our previous study (Piyawit et al., 2014). It suggested that Ag precipitates were formed by clustering of Ag atoms on {111} planes of Cu matrix and maintained cube-on-cube orientatation relationship with the matrix. Precipitate formation on particular {111} planes can be explained by the minimal disruption of lattice fit. The previous work suggests that the thickening of nanoscale Ag precipitates appears to be by

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the ledge growth mechanism. This is resulted by misfit dislocation networks on the Ag-Cu interface (Piyawit, 2014). Small-angle scattering technique using X-rays is a powerful tool to quantitatively characterize the nanoscale and mesoscale materials (Garrido et al., 1999; Fisk et al., 2014; Gilles et al., 2014; Rashkova et al., 2008; Rosalie and Pauw, 2014). The investigation of the nanoparticle evolution in a bulk sample by small angle X-ray scattering (SAXS) is very powerful compared to the transmission electron microscopy (TEM) in terms of the observation volume. Moreover, the SAXS study of the CuAgZr alloy has not been reported. The complementary small angle X-ray scattering (SAXS) and X-ray diffraction (XRD) techniques would indicate the evolution of precipitation during different thermal routines and the effect of deformation on precipitation behavior might be clarified.

In this study, the evolution of Ag precipitates in a plastically deformed Cu–7wt%Ag–0.05wt%Zr alloy with logarithmic strain of 2.3 will be characterized in order to clarify the Ag precipitate formation and growth.

2. Experimental Procedures

A 15 mm diameter cylindrical ingot of 92.95 wt% Cu, 7 wt% Ag and 0.05 wt% Zr was melted in an induction furnace and cast in a graphite mold. The ingot were homogenized at 850 °C for 5 h followed by water quenching. An ingot was sliced into disk samples with the thickness of 3 mm. Samples were subsequently deformed at room temperature by rolling with logarithmic strain of 2.3. The final thickness after cold rolling was approximately at 300 μm. The rolled samples were successively aged at 430 °C with various times in tube furnace with controlled argon atmosphere. The X-Ray diffraction (XRD) measurement was performed using a conventional X-ray diffractometer (D8 ADCANCE, Bruker AXS). Diffraction profiles were measured in Bragg-Brentano geometry (2θ-θ) utilizing Cu Kα radiation. The SAXS measurement was carried out using the beamline 1.3W at Synchrotron Light Research Institute (SLRI), Thailand. The beamline delivers a photon flux of $3x10^9$ photons/second. All the SAXS data were normalized to scattering cross section per unit sample volume I(Q) and corrected for the background scattering using the SLRI in-house developing software SAXSIT. The wave vector transfer or the scattering vector (Q) can be defined by the scattering angle (θ) and X-rays wavelength (λ)

$$Q = \frac{4\pi \sin\left(\theta/_2\right)}{\lambda} \quad (1)$$

The SAXS measurement using the CCD detector offers the scattering vector, Q, ranged from 0.05 to 40 nm^{-1}. SAXS specimens cut from rolled samples were prepared into 5 mm x 10 mm plate. Samples were mechanically thinning to the thickness of 70 μm using 1200 grit SiC abrasive paper. All the measurements were performed with the x-ray energy of 8 keV, the exposure time of 100 s and the Q range from 0.07 to 0.83 nm^{-1}. Specimen for transmission electron microscope (TEM) was prepared by GATAN PIPS ion milling using 3keV. TEM characterizations were carried out using JEOL JEM-2000FX. The microscope were operated at 200 kV.

3. Results and Discussion

3.1 X-ray diffraction analysis

X-ray diffraction (XRD) patterns of the deformed samples to examine the composition and structural evolution during different thermal routines are shown in Fig. 1. The reference patterns used in the analysis were PDF# 85-1326 for copper, 87-0720 for silver, 03-0884 for CuO and 05-0667 for Cu_2O, respectively. The rolled sample without thermal treatment, 0h sample, has a face-centered cubic (fcc) crystal structure with the lattice constant of 0.3644 nm, which is larger than the calculated lattice parameter using Vegard's law (a=0.3636), assuming all Ag was in solid solution, by 0.22%. After two hours of aging, the Ag(111) peak appeared at 38.147^o which was not in a good agreement with pure Ag (2θ at 38.318^o). However, the slightly different lattice parameter of Ag precipitate and pure Ag could be affected by the variation of size and shape of Ag nanoparticles (Qi and Wang, 2005). The small