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Effect of in-situ nanoparticle wall on inhibiting segregation of tin bronze alloy

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ABSTRACT

Scanning electron microscopy (SEM), transmission electron microscopy (TEM), small-angle X-ray scatter (SAXS) and atom probe tomography (APT) were combined to characterize the change of δ phase microstructure under the effect of in-situ iron-rich nanoparticles. In-situ nanoparticle wall model was proposed to elucidate the effect of high density of iron-rich nanoparticles on inhibiting tin segregation which causes δ phase formation. This work sheds light on a potential pathway for fabricating bulk homogenous materials during casting process.

1. Introduction

Segregation is inevitable in alloys during common casting process caused by non-equilibrium solidification [1,2]. Segregation always has harmful impact on properties of the alloys. Taking tin bronzes for example, brittle tin-rich δ phase forms at grain boundaries caused by tin segregation during casting greatly deteriorate the overall properties of the finished product such as impact toughness and ductility decline and corrosion resistance decreases [3–7]. Besides, tin bronzes are always used in the as-cast condition with no subsequent heat treatment, so their properties can only be controlled by the casting process [8]. Thus it is imperative to inhibit or reduce tin segregation in such materials. Numerous investigations including modifying pouring temperature and cooling rate, applying centrifugal casting and electromagnetic field, and adding with alloy elements, etc. have been made to overcome the segregation in tin bronze, but the problems are still not well solved [9–12]. Rapid solidification under the condition of high cooling velocity (10^4–10^9 K/s) or high undercooling (tens to hundreds of K), in such instance that the atomic motions responsible for solid/liquid (S/L) interface advancement are much more rapid than those necessary for the solute element to escape at the interface, has been investigated to eliminate segregation and obtain homogenous materials in the past several decades [2,13–17]. Nevertheless, rapid solidification under the extreme conditions provides only limited success and, in particular, is limited in the sizes/volumes of parts, which make them difficult for practical applications that demand by bulk materials in the fabrication industry.

Recently, δ phase segregated at the grain boundary was greatly reduced in cast Cu–10Sn–2Zn–1.5Fe alloy in contrast to virgin Cu–10Sn–2Zn tin bronze alloy [3]. Understanding the mechanism of δ phase reduction in cast Cu–10Sn–2Zn–1.5Fe alloy may shed light on a new way to eliminate or inhibit segregation. In this work, cast Cu-10Sn-2Zn-1.5Fe-0.5Co (wt%) and Cu-10Sn-2Zn (wt%) alloys were fabricated to investigate the mechanism of δ phase reduction. In the former alloy, high density of iron-rich nanoparticles were uniformly distributed in copper matrix, and δ phase was reduced consistent with the previous research [3]. Coupled with in-situ nanoparticle wall model, iron-rich nanoparticles were described to have a dominant effect on δ phase reduction. A potential pathway was presented to eliminate inhomogeneity of solute at a large extent and greatly reduce the fraction of segregation phase in bulk materials.

2. Experimental

Virgin Cu-10Sn-2Zn (wt%) and Cu-10Sn-2Zn-1.5Fe-0.5Co (wt%) alloys were melted and cast into rod samples (Φ20 × 140 mm), named as Sample A and Sample B, respectively. The samples were

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fabricated by centrifugal casting in the vacuum chamber with a medium frequency electrical furnace. The main processing steps has been described in [3]. Note that Fe and Co were added to the melt at 1350 °C and held for 30 min. Iron-rich nanoparticle was confirmed to precipitate in the melt before copper solidification [3,18,19]. The microstructures of the samples were examined with a LEO1450 SEM (scanning electron microscopy). Size distribution of the nanoparticles in SEM micrograph was statistically measured by Image-Pro Plus 6.0 software. The morphology and distribution of the nanoparticles were observed by using transmission electron microscope (TEM) technique on a JEM-2010 TEM. The average size and volume fraction of the nanoparticles were obtained by means of small-angle X-ray scattering (SAXS) measurement technology using a 1w2a small angle scattering station. The atomic level of nanoparticle characterization was performed by a Leap 3000 Hz atom probe tomography (APT), using a pulse repetition rate of 200 kHz and a 20% pulse fraction on the sample with temperature of 50 K. The atomic data sets from 3DAP measurements were analyzed using the IVAS software (Cameca, version 3.6.2).

3. Results and discussion

3.1. Microstructure of the samples

In the SEM micrographs of Sample A (Fig. 1a and b), white δ phase exists frequently and almost links together. δ phase is tin-rich phase identified by X-ray diffraction combined with EDS data

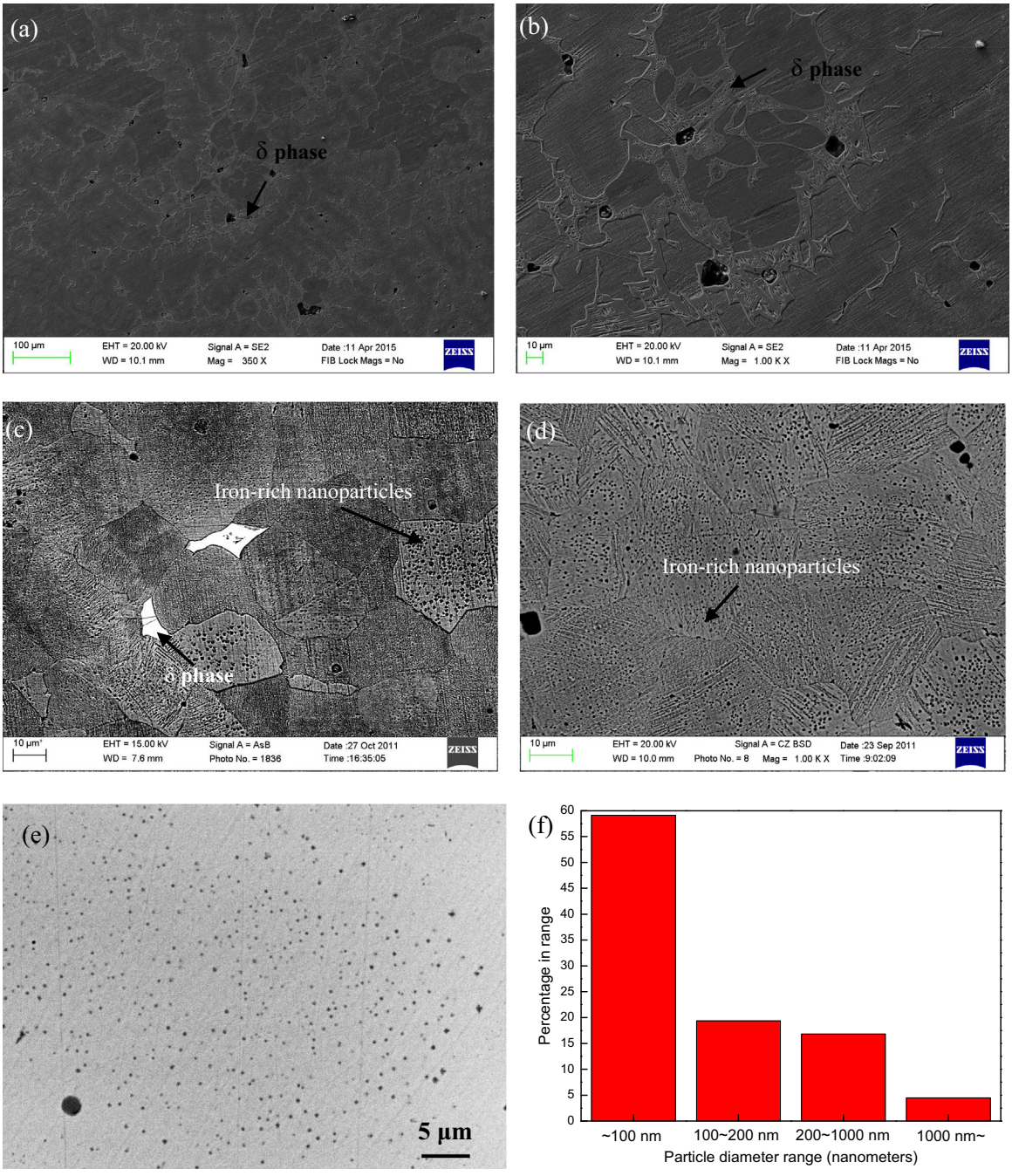

Fig. 1. SEM micrographs showing microstructure of the samples: (a)(b) Etched Sample A; (c)(d) Etched Sample B; (e) Enlarge SEM micrograph of uniformly distributed iron-rich nanoparticles in unetched Sample B; (f) The size distribution of iron-rich nanoparticles selected from the area in (e) of 719 black particles.