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ZCu10Sn2ZnFe1.5Co1 SOLUTION TREATMENT PROCESS AND ORGANIZATIONAL PERFORMANCE RESEARCH

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ARTICLE DETAILS

ABSTRACT

Article History:

Received 26 June 2018 Accepted 2 July 2018 Available online 1 August 2018 The In-situ iron nanoparticle reinforced ZCu10Sn2ZnFe1.5Co1 alloy was fabricated by centrifugal casting in vacuum chamber with a medium frequency electrical furnace. The processes of solid solution of ZCu10Sn2ZnFe1.5Co1 alloy are investigated and the process optimization conditions are confirmed by microstructure observation and the tensile test measures. The results show that proper solid solution can improved the microstructure and the mechanical property. By 700°C×120min solid-solution treatment, brittle δ phase is almost entirely dissolved into the matrix, the tensile strength and the break elongation of ZCuSn10Zn2Fe1.5Co1 reach 485.8 MPa、51.84% respectively after, increased by 15.74% and 230.62% than the original alloy.

KEYWORDS

ZCu10Sn2ZnFe1.5Co1 alloy, solid solution, process optimization.

1. INTRODUCTION

The development of modern technology needs to develop higher performance and more comprehensive metal materials [1-3]. Therefore, how to obtain homogenous materials without segregation is critical [4,5]. Tin bronze is a non-ferrous alloy with the lowest casting shrinkage and can be used to produce castings with complex shapes and clear outlines. In addition, tin bronze is very corrosion-resistant in the atmosphere, sea water, fresh water and steam. It is widely used in steam boilers, sea vessels and other related parts. However, the segregation of tin elements in the solidification process of tin bronze is very serious, and the coarse dendrites occur in the microstructure of castings. Therefore, it is of great technical and economic significance to study and develop the reinforcement technology of tin bronze. Solid solution treatment is a key process in the preparation of the alloy, and its main role is to fully dissolve the alloy element Sn into the copper matrix [6-8]. In this paper, the effect of solution temperature on mechanical properties of ZCuSn10Zn2Fe1.5Co alloy is studied. Combining with SEM and in situ tensile test, it is proved that δ phase is the nucleation and propagation path of crack. And the "absorption" of Sn atoms by nanoclusters in as-cast ZCuSn10Zn2Fe1.5Co alloys has also been illustrated by a three-dimensional atomic probe.

2. EXPERIMENTS

Cu alloys were prepared, and includes 10wt% Sn (purity of 99.99), 2wt% Zn with a purity of 99.9% and 88wt% Cu(purity of 99.99%), The equipment used to prepare the samples is an induction furnace with an ultimate vacuum level 6.0×10^{-2} Pa. The main processing steps are as follows. Cu and Sn metals are first introduced into a graphite crucible located in the vacuum chamber. After being evacuated to 5 Pa, the chamber

temperature is increased from room value to 1350°C , and maintained at this value for 30 min. Next, argon is allowed into the chamber to increase the chamber pressure to 0.07MPa. Zinc are then added to the melt. After homogenizing, the furnace temperature is reduced to 1200°C and held for 10 min. Then the melt is poured into the mold on a centrifugal dish, which is rotated at 200 rpm. Then the ZCuSn10Zn2Fe1.5Co1 alloy prepared by centrifugal casting was treated by water quenching and solution after holding at 600 °C, 650 °C, 700 °C, 750 °C and 800 °C for 2 hours. The mechanical properties of the samples were tested by means of mechanical properties test, SEM and in situ SEM tensile experiment. At last the "absorption" of Sn atoms by nanoclusters in as-cast ZCuSn10Zn2Fe1.5Co alloys has also been illustrated by a three-dimensional atomic probe.

3. RESULTS AND ANALYSIS

3.1 Mechanical properties

The tensile properties at room temperature were tested on CMT4105 universal mechanical testing machine, and the drawing method was carried out according to GB/T228-2002 standard. Table. 1 shows the tensile stress-strain curves of ZCuSn10Zn2Fe1.5Co alloy and alloy at different solution temperatures at room temperature. It can be seen from figure 1 that the tensile strength and shape of the alloy have been improved after 2 hours of solid state at 600 °C, 650 °C, 700 °C and 750 °C. In particular, the tensile strength and elongation of D alloy at 700 °C for two hours reached 485.8 Mpa and 51.84%, which were 15.74% and 230.62% higher than that of as-cast alloy, respectively, and the tensile strength and elongation of F alloy were lower than that of as-cast alloy at 800 °C for two hours.

Table 1: The effect of the change of solid solution temperature on tensile strength and elongation

Samples	Heat treating processes	Rm (Mpa)	Rp (Mpa)	A(%)
A	as-cast	419.75	233.5	15.68
В	600°C×120min	424.32	219.03	27.84
С	650°C×120min	436.06	207.78	34
D	700°C×120min	485.8	217.02	51.84
E	750°C×120min	425.27	185.33	44
F	800°C×120min	413.27	244.19	12.8

3.2 Mechanical properties

BSE was used to investigate the microstructure. Microstructure of sample A contains the typical coarse dendrites in several hundred-micron size, with a large number of white tin-rich phase (which chemical formula is Cu31Sn8 identified by X-ray diffraction combined with EDS data) distributed on the grain boundaries (Figure 1a). With the increase of solution temperature, δ phase gradually decreases and then disappears (Figures 1b,c,d,e and f). From the binary phase diagram of Cu-Sn alloy, it can be seen that the solubilization degree of Sn in Cu can reach 15.8% in theory between 300°C and 800°C, but in practice, under the influence of the diffusion rate of Sn atom, the δ phase cannot disappear at lower solution temperature. Hard brittle tin-rich phase contributes to the low strength and low ductility of sample A, B and C.

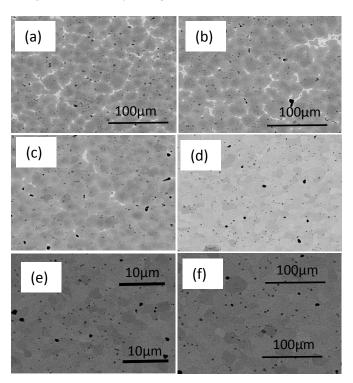


Figure 1: The BSE morphology of ZCuSn10Zn2FeCo1 alloy in different solid solution states; (a) as-cast; (b) 600°C×120min; (c) 650°C×120min; (d) 700°C×120min; (e) 750°C×120min; (f) 800°C×120min

3.3 Fracture Analysis

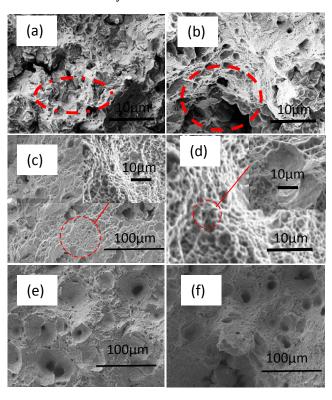
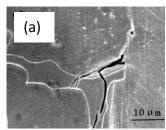


Figure 2: The fracture analysis of ZCuSn10Zn2FeCo1; (a) as-cast; (b) 600°C×120min; (c) 650°C×120min; (d) 700°C×120min; (e) 750°C ×120min; (f) 800°C×120min

The fracture surfaces of SA、SB、SC、SD、SE and SF were characterized by SEM as shown in Figure 2a、2b、2c、2d、2e and 2f, respectively. The large holes could be observed in the as-cast specimens and the samples after solution at 600°C for 120 min. Compared with Fig1, it is clear that the failure in ZCu10Sn2ZnFe1.5Co1 alloy is believed to be due to hard and brittle δ phases. It seems that the δ phases in samples acts as a fracture initiation point and the fracture path preferentially goes through the regions containing δ phases (Figure 3). As shown in Figure 2c up to 2d, dimples are observed in the fracture surfaces. Top right corner of Figure 2c and 2d are the enlarged image of the circular area marked with a red arrow, where dimple-like patterns can be found. The size of each dimple is less than $10\mu\text{m}$. Further investigations reveal that dimple-like patterns

were uniformly distributed all over the fracture surface of Figure 2d, indicative of high ductility. With an increase in solution temperature, as shown in Figure 2e and 2f, The size of dimple starts to get bigger, maybe due to the agglomerated of iron-rich nanoparticles.

4. DISCUSSION



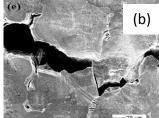


Figure 3: The in situ tension analysis of ZCuSn10Zn2FeCo1; (a)The crack nucleation; (b) The crack growth

Figure 3 shows the in-situ SEM micrograph of crack initiated at tin-rich δ phase between grains for SA alloy, as shown in the Figure 3a, broken δ phases are observed on the surface of specimen. During in-situ SEM tensile test, micro cracks first nucleates at the tin-rich δ phases as a result of stress concentration (Figure 3a), as the stress increases, the crack propagation will throughout the whole of tin-rich phases connected each other (Figure 3b). So, how to eliminate the negative effect of tin-rich phase on mechanical properties is deserved our close attention.

The microstructure of ZCuSn10Zn2 contains the typical coarse dendrites in several hundred-micron size, with a large number of white tin-rich phase distributed on the grain boundaries, famously. With the addition of Fe, Co element, there were little white tin-rich phase randomly distributed on the grain boundaries, we think that large number of nanoparticles in the molten metal is main reason of the reduction of δ phase. During the solidification of ZCuSn10Zn2FeCo1 alloy, large number of Fe nanoparticles will precipitate in priority, homogeneously distribute in the melt and do irregular Brownian motion, with the growth of matrix grain, solid-liquid interface advances to liquid phase at the speed of VS-L [9,10]. The coherent structure between the nanoparticles and the copper matrix manifests that Fe nanoparticles are surrounded by a transition layer of Cu atoms. With the advance of interface, due to the redistribution of solute, Sn atoms pushed from the solid-liquid interface also do irregular Brownian motion in the melt. As Sn atoms move away from the interface forefront, due to the presence of large number of Fe nanoparticles with considerable specific surface area and more uniform distribution, most of Sn atoms will meet with Fe nanoparticles. Now part of Sn atoms will attach to vacancy of nanoparticles surface, with the growth of nanoparticles, they will be engulfed; the other part of Sn atoms will be reflected back by nanoparticles and can't diffuse forward. Therefore, with the advance of solid-liquid interface, finally most of Sn atoms are engulfed by Solidifying Interfaces. Consequently, large number of existence of nanoparticles makes Sn atoms have more uniform distribution, which leads to great reduction of Sn atoms aggregation at the border of final solidification.

The distribution of Fe, Cu, Zn, Sn and Co in ZCuSn10Zn2FeCo1 alloys have been characterized by the three-dimensional atom probe (3DAP) technique. Figure 4(a) shows 3DAP elemental-maps of needle-like FIM specimens prepared from ZCuSn10Zn2FeCo1. A small volume of $38 \text{nm} \times 37 \text{ nm} \times 29 \text{ nm}$ was extracted for the compositional analysis, and the 3D spatial distribution of different elements was reconstructed by PoSAP software. It can be seen that the distribution density of the cluster is relatively high, and the cluster size is within 10nm. The averaged composition of Fe, Cu, Zn, Sn and Co were plotted as functions of the approximate distance from the surface of iron cluster (Figure 4b). In the matrix which is far from interface, Fe and Co are of lower concentrations

and are uniformly distributed. The concentrations of Fe and Co are $\sim\!2$ at% and $\sim\!1.2$ at%, respectively. The average composition of Fe and Co are increased significantly in the interface of Fe nanoclusters, both concentrations can up to 20 at%. In the matrix which is far from interface, Sn and Zn are uniformly distributed. However, when entering the interface of Fe nanoclusters, concentrations of Sn and Zn fluctuated, i.e., both concentrations are increased slightly. Which means nanoclusters can adsorb Sn atoms.

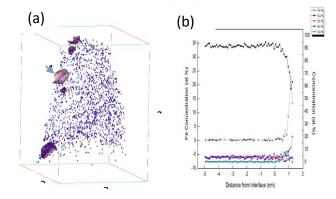


Figure 4: (a) The iron nanostructured clusters; (b) The concentration distribution curve of iron nanostructured cluster 1.

5. CONCLUSIONS

By $700^{\circ}\text{C}\times120\text{min}$ solid-solution treatment, the tensile strength and the break elongation of ZCuSn10Zn2Fe1.5Co1 reach 485.8 MPa、51.84% respectively after, increased by 15.74% and 230.62% than the oringine alloy. The δ phases in samples acts as a fracture initiation point and the fracture path. The distributed of nanoparticles in the matrix can also reduce the segregation of Sn element at some extent.

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