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Effects of electric pulse modification on liquid structure of Al−5%Cu alloy

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Abstract: The electric pulse modification (EP, EPM) of liquid metal is a novel method for grain refinement. The structure of EP-modified Al−5%Cu melt was characterized by high-temperature X-ray diffractometry. The results show that the Cu-containing Al clusters remarkably increase in the EP-modified melt, furthermore, these clusters in that case tend to contract due to the decrease of relevant atomic radius and the co-ordination number. This kind of liquid-phase structure leads to a more homogeneous Cu-rich phase distribution in the final solidification structure. Differential scanning calorimetry (DSC) tests indicate that the solidification super-cooling degree of the EP-modified liquid phase is 2.36 times that of the unmodified. These facts suggest that the atom cluster changes in EP-modified Al−5%Cu melt would disagree with that by EPM model previously proposed in liquid pure metal.

Key words: electric pulse modification; Al−Cu melt; atomic cluster; liquid structure

1 Introduction

With the rapid development of solidification technology and cluster physics, the effects of melt structure on the final solidification structure attract more attention [1,2]. Recently, researchers have found that the imposed electric pulse (EP) on metal melt could refine grains, reduce segregation of solute elements and improve mechanical properties of the alloys [3−5]. It is generally considered that the interesting results stem from a certain structural change in liquid metal [6,7]. However, due to the difficulty of liquid structure tests requiring elevated temperature combined with pulse electric field, the past investigations on the above EP-modified melt were mostly carried out using so-called post-mortem examination methods such as metallographic examination [8], performance test [9]. As a result, the mechanism of EP treatment is still a hypothetical theory and far from being understood. Fortunately, the outstanding structure heredity of the EP-modified liquid aluminum has been reported [10,11]. It is indicated that for the EP-modified aluminum casting, its liquid structure after once remelting could roughly substitute for that in the EP-modified duration. Based on the significant heredity characteristics, previous researches were done for investigations of the structure transformation in EP-modified liquid aluminum [12,13]. However, the responses for EP should have some discrepancies between the binary alloy melt and pure metal melt [14]. The present work will examine the changes of EP-modified Al−5%Cu melt according to the method in Ref. [12], in order to illuminate the EP treatment mechanism for binary alloy system.

2 Experimental

The Al−5%Cu alloy was smelted from pure aluminum (99.99%) and pure copper (99.99% in mass fraction) raw materials in an electric resistance furnace, then appreciable amount of the prepared Al−5%Cu alloy was heated to 750 °C and melted. After holding at this temperature for 5 min and the subsequent refining procedure (C_2Cl_6 was here adopted as refining agent), two columnar graphite electrodes with dimensions of *d*5 mm × 200 mm were vertically inserted 50 mm into liquid alloy and EP treatment was performed. The EP parameters were optimized as follows: 500 V peak

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voltage, 3 Hz frequency and 30 s treating time. Then the molten alloy was poured into a metal mold by a manipulator at room temperature. The unmodified specimen used for comparison was also prepared under the same cooling conditions. The tested cuboid specimens with dimensions of 20 mm × 16 mm × 12 mm for high temperature X-ray diffraction were wire-cut at the same central section of the castings. The EP treatment experimental setup is schematically shown in Fig. 1.

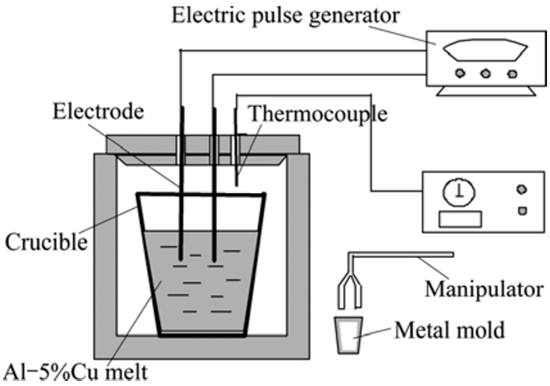

Fig. 1 Schematic pattern of EP treatment setup

The melt structure tests were carried out using a high temperature X-ray diffractometer with Mo K_α radiation (wavelength λ=0.071 nm). A graphite single crystal was used for monochromatisation of X-ray scattered by the specimens. The accuracy of the angle was 0.001°, and the scattering angle 2θ ranged from 5° to 90°. The magnitude of wave vector Q (Q=4πsinθ/λ) was then from about 0.2 to 120 nm^{-1}. The scanning step was 0.02º within the region of principal peak and 0.5° at rest values of wave vectors. During heating, diffraction measurements were made at 700, 750, 800 and 1000 °C, and at each temperature, the liquid Al−5%Cu alloy was held for 30 min before test. Differential scanning calorimetry (DSC) was performed respectively on specimens without EPM and with EPM using a SETARAM thermal analysis tester.

3 Results and discussion

Figure 2(a) shows the structure factor (SF) curve of liquid Al−5%Cu alloy as a function of wave vector Q at different elevated temperatures and the SF curve shown in Fig. 2(b) relates to the EP modification.

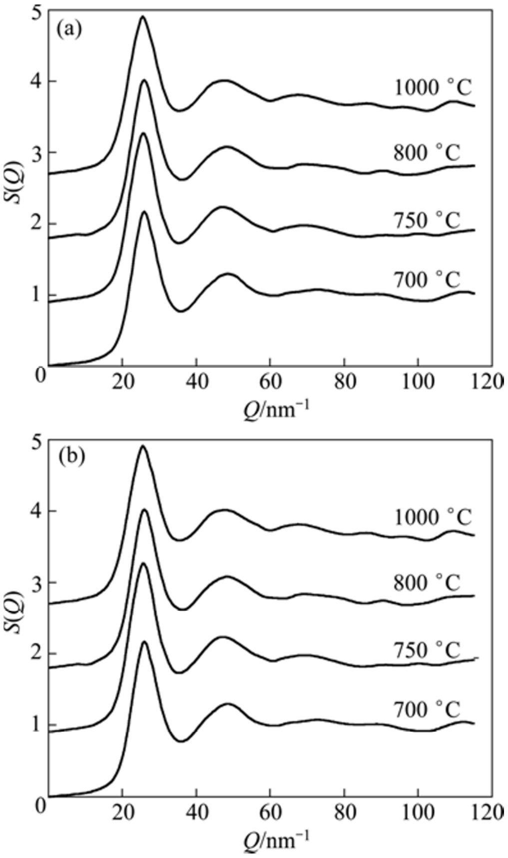

Fig. 2 Structure factor curves of liquid Al−5%Cu alloy at different temperatures: (a) Unmodified; (b) EP-modified

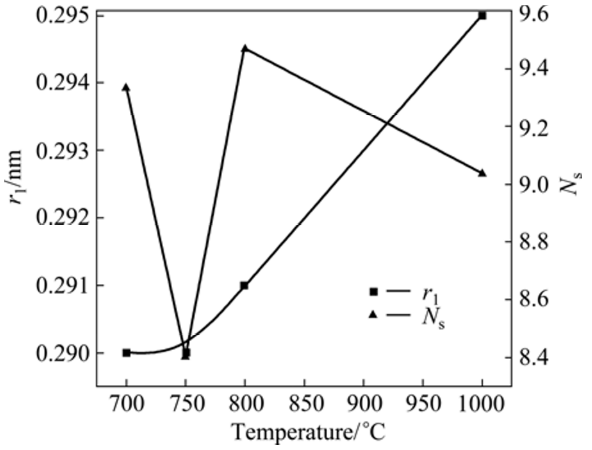

Fig. 3 Changes of r_1 and N_s in liquid Al−5%Cu alloy at various temperatures

One can see that their common features are a symmetrical principal peak and a similar broadened and blunted trend with increasing temperature. As for the unmodified one, it is noted in Fig. 3 that the neighbor distance r_1 changes from 0.290 nm to 0.295 nm during the 700−1000 °C temperature zone, which is dissimilar with the thermal contraction phenomenon of atomic cluster in liquid pure aluminum. On the other hand, the value of coordinating number N_s exhibits a fluctuant variation tendency; furthermore, the minimum value of N_s appears at the EP treatment temperature of 750 °C, which could be ascribed to the abnormal changes of short range order (SRO) at this temperature. At 800 °C, N_s reaches its maximum value of 9.469, then N_s declines, indicating the leading role of thermal motion at an